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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Australian Government
Grape and Wine Research and Development Corporation

Molybdenum Foliar Sprays and Other Nutrient Strategies to Improve Fruit Set and Reduce Berry Asynchrony ('hen and chickens')



FINAL REPORT to

Project Number: **SAR 02/09b**

Principal Investigator: **Dr Christopher Williams**

Research Organisation: **South Australian Research and Development Institute, Adelaide**

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Cover photo caption:

(Left) A Merlot bunch deficient in molybdenum (Mo) showing the disorders; ‘hen and chickens’ and green ‘shot berry’ formation (seedless berries or berry asynchrony) at harvest; (centre) a grower spraying Mo to both trial plots and a commercial vineyard at site1; and (right) a normal Merlot bunch from grapevines sprayed with Mo at pre-flowering to overcome Mo deficiency.

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Authors

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION
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Molybdenum foliar sprays and other nutrient strategies to improve fruit set and reduce berry asynchrony ('hen and chickens')

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Dedication:

We dedicate this work to the memory of Norbert Maier, our valued work mate and co-author who suddenly passed away in April, 2007. Norbert, an expert in plant nutrition, had a keen analytical mind that was strongly focused on delivering practical solutions to industry for SARDI. Norbert was always willing and happy to help colleagues and he will be sorely missed.

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Abstract

This project addressed industry concerns about unpredictable, poor fruit set and bunch yield losses in grapevines associated with the deficiency of the micronutrient molybdenum (Mo) and other factors. This project involved a nutrient survey of commercial vineyards, field experiments and workshops with the aim of developing strategies to manage Mo in vineyards. Improved industry information, based on these findings, included the development of a corrective foliar spray strategy of Mo applied pre-flowering to overcome Mo deficiency during reproduction in grapevines. Responses of different rootstocks, use of plant tests to indicate Mo deficiency, effects after 3 to 5 years of Mo spray regimes, and assessment of potential accumulation of Mo in soils and potential leaching from vineyards were evaluated. Finally, information was communicated to industry with workshops in 4 states and a fact sheet on Mo will be circulated to the CRC for Viticulture, On-line Viti-Notes series.

Executive Summary

Poor fruit set, as occurred in many vineyards in most cool climate, wine grape regions of Australia in 2001-2002, was associated with reduced bunch yields (a 30% reduction in the national crop). These unpredictable annual variations in fruit set, wine grape yield and bunch quality make it difficult for the industry to match supply to demand. It has been shown that many factors can influence fruit set and bunch yield, including molybdenum (Mo) deficiency.

Molybdenum is an essential micronutrient for normal growth and reproduction of crop plants. A deficiency of Mo can affect the occurrence of fruit set disorders, such as berry asynchrony. The technical term berry asynchrony is used to describe bunches with berries that have a great range of size and maturity at harvest. Such disorders are known in local jargon as 'hen and chickens,' where the bunch at harvest consists of a mix of a few large, normal berries (hens) and many small berries (chickens) of uneven ripeness and 'shot berries' where a bunch has excessive numbers of small, less than 5 mm diameter, green berries at harvest. Berry asynchrony or millerandage (seedless, usually unripe berries at harvest) are viticulture terms used to describe these fruit set disorders, which occur world-wide. Merlot is the most sensitive cultivar to berry asynchrony other cultivars less susceptible include Cabernet Sauvignon, Chardonnay, Cabernet Franc, Ruby Cabernet and Sauvignon Blanc.

Objectives of this project included: (a) to develop strategies for optimal use of Mo in fertiliser programs for wine grapes to reduce fruit set and bunch yield losses due to Mo deficiency, (b) examine responses of different rootstocks to applied Mo, (c) derive critical concentrations of Mo from petiole (leaf stalk) samples for the diagnosis of Mo deficiency (interpretation standards for industry) and (d) survey Mo and 12 other nutrient concentrations in petioles from commercial vineyards in 4 states and relate to berry asynchrony. Other aims were to: (i) assess optimal times, rates and number of Mo sprays to correct Mo deficiency, (ii) calculate Mo budgets in vineyards after 3 to 5 years of Mo spray regimes, (iii) assess potential for accumulation of Mo in soils and leaching from vineyards and (iv) communicate results to industry. Fifteen field experiments (in 3 states), a nutrient survey of commercial vineyards and workshops (in 4 states) were conducted to develop strategies to manage Mo deficiency in vineyards.

Key findings from this research project are outlined below. In field studies, Mo deficiency had little effects on vegetative growth of grapevines, the major effects were on reproduction.

Symptoms of Mo deficiency were poor fruit set resulting in berry asynchrony in bunches ('hen and chickens' and/or 'shot berry' disorders), being first evident post flowering, with symptoms of uneven size and ripeness of berries most evident at harvest.

Application of Mo foliar sprays, pre-flowering to Mo deficient grapevines increased bunch yield per vine mainly due to higher bunch weights. Bunch numbers per vine were similar for sprayed and unsprayed treatments. In Merlot vines, Mo deficiency may not only be about supply but also transport of Mo in the sap to the inflorescences, during the critical period of demand for Mo for normal fruit set and berry development. Long-term field experiments, up to five years with Mo foliar sprays each year indicated that usually both poor fruit set and Mo deficiency occurred together in an unpredictable fashion in different growing seasons, regions and sites. Other factors, such as the onset of cold, wet conditions prior to or during flowering, boron and zinc deficiency can also be associated with poor fruit set and berry asynchrony.

The survey of 100 commercial vineyards (SA, WA, NSW, Vic), focussed on those with a history of berry asynchrony. Since most vineyards surveyed had boron and zinc concentrations in the adequate or adequate to high range, it appeared that the boron and zinc concentrations in petioles (leaf stalks) of the grapevines were not at levels limiting bunch yield. However, all the varieties surveyed; Merlot, Chardonnay, Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranillo, in all four states, had Mo levels across the concentration range (from deficient to high for Merlot).

The seasonal variation and distribution of Mo were determined for Merlot and Cabernet Sauvignon grapevines. Fibrous roots < 2 mm diameter, had the highest Mo concentrations, with leaf blades having the highest of the above ground fractions.

Increased bunch yield responses from Mo application to Mo deficient grapevines were greater for Merlot on own roots (1.8 to 3.2 fold). Significant, but smaller yield increases (<1.8 fold) were recorded for Merlot on the rootstocks (SO4 [2136], 140 Ruggeri, Ramsey and Schwarzmann). However, 110 Richter did not respond, these findings suggest that 110 Richter should be considered as a suitable rootstock for new Merlot plantings in vineyards with a history of berry asynchrony and Mo deficiency (provided it meets other selection criteria).

A suggested scheme to assist in assessing the Mo status of irrigated Merlot vines is:

Deficient, vines with petioles containing less than 0.09 mg/kg Mo at peak flowering - yield response to pre-flowering foliar Mo spray likely;

Marginal, vines with petiole Mo concentrations of 0.09-0.45 mg/kg at peak flowering - response to pre-flowering Mo spray is uncertain;

Non-responsive, vines that have petiole Mo concentrations greater than 0.45 mg/kg at peak flowering - response to pre-flowering foliar spray unlikely.

The calibrated petiole test at peak flowering (the standard time and tissue used by industry for nutrient analysis in vines) can be used for diagnostic purposes but this will be too late for the most effective corrective measures to be taken in the current season. However, a scheme based on petiole sampling at flowering can still be used for troubleshooting (diagnostic testing), monitoring the vine Mo status on an annual basis (nutrient monitoring) and predictive testing. Our research

work has led to a new Mo analysis procedure that can detect minute concentrations of Mo accurately being available as a commercial service to industry in several states including, SA and WA to monitor Mo in grapevines and other crops.

As a result of these studies one Mo foliar spray of 250 –500 mg/L at the 5 up to the 14 leaf growth stage (up to when flower caps are still in place) to the point of canopy runoff ameliorated Mo deficiency in the current growing season. If rainfall over 2 mm occurs within 48 hours of application, a further Mo spray is needed. Molybdenum washed onto acid soils is likely to be fixed to iron and aluminium complexes in soils and be unavailable for root uptake in the current season. Use of higher rates of Mo had no benefits in terms of increased bunch yields per vine but were not toxic in terms of bunch yield, during these experiments. Caution should be used in Mo fertilization programs for vineyards, since soils should be tested after 3 years of continuous Mo spray regimes for total and extractable soil Mo, to measure any potential Mo accumulation in soils. Elevated concentrations of Mo in soils can lead to potential problems of surface runoff or leaching of Mo off site or high levels of Mo in pasture plants (10-20 mg/kg of dried herbage) in vine rows can lead to potential Mo toxicities such as molybdenosis in grazing ruminants (molybdenosis is a Mo induced copper deficiency).

Adoption of many of the early findings in this report by the Australian viticulture industry has occurred already. However, the most recent findings of a potential to accumulate Mo in soils after 3 to 5 years of annual Mo spray regimes and for potential surface runoff/leaching of Mo from vineyards requires further research and communication to industry. Other recommendations for future research include: nutrient accounting as a means of auditing nutrient inputs and outputs for Mo, nitrogen, phosphorus and all other nutrients, definition of ultra low rates of Mo to overcome Mo deficiency and yet minimise potential accumulation of soil reserves of Mo after 3 to 5 years of Mo spray regimes.

Future research is also required; (1) to define plant standards for adequacy of Mo for other scion/rootstocks prone to berry asynchrony, (2) to develop petiole and leaf blade standards for adequacy for the nutrient sulphur (S) for grapevines (none exist), also to devise diagnostic and predictive standards for other nutrients, especially N and P for new scion/rootstock combinations for vines grown under modern deficit drip irrigated systems. Other research needed includes: assessment of compatibility of Mo with other chemicals, evaluation of the leaf blade as a more sensitive indicator of trace element deficiency, and effects of liming on long term Mo uptake and soil Mo reserves. There is a need for research to examine the potential for nutrient optimisation in berries for fermentation and wine quality and to biofortify grape products for human health benefits, by manipulating mid season nutrient foliar sprays and other techniques.

Information on the optimum use of Mo application to correct Mo deficiency in grapevines was communicated through more than 12 presentations at industry workshops in SA, WA, NSW and Victoria in 2005 and 2006. Since little information is available worldwide on Mo deficiency in grapevines for reproduction, a fact sheet as presented in the final report will be forwarded to the CRC for Viticulture, online Viti-Notes series.

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Background

Mo role in grapevines

Molybdenum (Mo) is an essential micronutrient for normal growth, metabolism and reproduction of crop plants (Gupta 1997). It acts as a metallic cofactor in plant and animal enzymes. For example, Mo is involved in nitrate reductase for the conversion of nitrate taken up by the roots, into a form that the vine can use and in sulfite oxidase for sulphur-containing amino acid metabolism and other molybdoenzymes (Yu *et al.* 2002).

Symptoms of Mo deficiency for reproductive growth

Recent research has shown that Merlot grapevines have an essential need for adequate molybdenum concentrations during flowering and reproduction for fruit set, seed formation and bunch yield (Williams *et al.* 2003). Wet and /or cold conditions leading up to flowering may result in or accentuate a temporary molybdenum deficiency leading to:

- 'Hen and chickens' or millerandage (seedless berries) where the bunch at harvest consists of a mixture of a few large, normal berries (hens) and many small berries (chickens) of uneven ripeness.
- 'Shot berry' formation (or millerandage) where the bunch has excessive numbers of small, < 5mm diameter, green, seedless berries that may or may not ripen at harvest.
- Often there are no clear vegetative growth symptoms for molybdenum deficiency prior to flowering. Reliable indicators of possible molybdenum deficiency for reproduction are; vineyard history, susceptible varieties, petiole tests at peak flowering, cool climate region, acid soils and the onset of periods of cold wet conditions between bud burst and fruit set for that growing season.
- Some varieties and rootstocks (eg Merlot on its own roots) appear to be more susceptible to this temporary deficiency during flowering and its subsequent effects on fruit set, seed formation, berry asynchrony and reduced bunch yield.

Industry Issues

Berry asynchrony (often called 'hen and chickens' in Australia, in local jargon) is a major problem for many growers and wineries in certain growing seasons and vineyard sites mainly in cool climate wine regions (Jackson and Coombe 1988; Anonymous 2002; Williams *et al.* 2004). Reductions in bunch yields per vine of over 75% occurred at the 2002 harvest in several varieties in many cool climate regions of Australia. The tonnage of the national crop in 2001-2002 was reduced by 30%, largely due to fruit set disorders and berry asynchrony (Anonymous 2002). Poor fruit set, mainly expressed as berry asynchrony or 'hen and chickens' were the main disorders evident.

Berry asynchrony is called millerandage in Europe and 'shot berry' disorder in the USA and is a serious problem world wide (Sharma *et al.* 1995; Pool 1996; Anonymous 2002; Cholet *et al.* 2002). Merlot is the most susceptible cultivar to berry asynchrony, other less susceptible cultivars include; Cabernet Sauvignon, Chardonnay, Cabernet Franc, Ruby Cabernet,

Sauvignon Blanc in Australia (A. Ratcliff and J. Tisdall pers. Comm., 2002; Anonymous 2002), and many other varieties grown overseas (Sharma *et al.* 1995; Pool; Cholet *et al.* 2002).

Recent research showed Mo deficiency was likely to be a major factor associated with berry asynchrony (Williams *et al.* 2003; 2004). In the 2001/2002 growing season, spectacular bunch yield responses of 221 to 750 % were recorded when Mo foliar sprays were applied to Mo deficient Merlot grapevines at all 3 sites (Williams *et al.* 2003; 2004). This was the first published research to show that Merlot grapevines have an essential need for adequate Mo concentrations during flowering and reproduction for normal seed formation and bunch yield. It is important to note that responses to Mo foliar sprays will not occur every growing season at a given vineyard site. For example, no responses were recorded in the first year of these trials, 2000/01 (a good fruit set season) when petiole concentrations of Mo were not deficient at peak bloom (over 100% greater than the deficient range observed and defined in the 2001/2002 season).

Other factors; such as periods of low temperatures and wet and windy conditions before, and/or during flowering, deficiencies of boron or zinc can also be associated with the incidence of berry asynchrony (Sharma *et al.* 1995).

In view of the above, research was required to:

- Develop strategies to manage Mo in vineyard programs to minimise berry asynchrony and also minimise the potential for Mo accumulation in berries (Ch 1-9).
- Describe the distribution of Mo and other nutrients in vines and the effect of supply to allow effective plant test development and to diagnose deficiency (Ch 3 and 4).
- Re-examine critical concentrations of Mo for deficient vines at peak bloom and attempt to develop a predictive tissue test for Mo deficiency at the 10cm shoot stage (Ch. 4).
- Compare Mo and other nutrient levels in vineyards in four states to plant standards for adequacy and assess relationships with berry asynchrony (Ch. 6).
- Communicate results to growers and others in the viticulture industry.

Approved modification to the original proposal: the nutrient survey was extended to a fourth state WA and 2 workshops were held in WA in both 2005 and 2006.

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Project Aims and Performance Targets

PLANNED PROJECT OUTPUTS:

The project achieved all planned outputs and performance targets as listed in the original application.

Outputs and Performance Targets 2003-04

Outputs	Performance Targets
1. Define Mo concentrations and uptakes in petioles, shoots and berries.	Begin replicated trials on rates, sources and timing of Mo sprays. Describe Mo nutrition for vines.
2. Obtain information on Mo concentration and uptake and its impact on yield, quality, other nutrients and berry asynchrony.	Monitor 3 established Mo spray field trials in SA. Monitor established rootstocks and scions of Merlot trial at Mc Laren Vale (different set responses of rootstocks were observed in 2002/03- but not the equal of sprayed Mo plots).
3. Select treatments and establish trials.	Meet interstate with researchers and key growers
4. Modify our critical Mo levels at peak bloom. Attempt to develop a predictive tool for Mo deficiency at the 10cm shoot stage (E-L 12).	Conduct field trials using nil and adequate Mo applied levels in SA, Vic and NSW (select Mo sites in areas with a high incidence of shot berry problem, eg. Hanging Rock, Vic.).
5. Compare the relationship between commercial vineyard Mo levels and our standards at high risk sites.	Survey of 100 commercial vineyards in 3 states -across warm and cool climates (across scions and rootstocks)- at sites with high incidences of asynchronous berries-and advise if remedial actions are needed)..

Outputs and Performance Targets 2004-05*

Outputs	Performance Targets
1. Define Mo concentrations and uptakes in petioles, shoots, wood and berries. Collate information on critical temporal changes in Mo and relate to berry asynchrony.	Continue replicated trials on rates, sources and timing of Mo sprays. Assess annual carryover of Mo in vines and calculate a Mo budget. Measure temporal changes in Mo concentrations in different vine tissues.
2. Obtain information on Mo concentration and uptake and its impact on yield, quality, other nutrients and berry asynchrony.	Monitor 3 established Mo spray field trials in SA. Monitor established rootstocks and scions of Merlot trial at Mc Laren Vale.
3. Modify our critical Mo levels at peak bloom. Attempt to develop a predictive tool for Mo deficiency at the 10cm shoot stage (E-L 12).	Conduct field trials using nil and adequate Mo applied levels in SA, Vic and NSW (select Mo sites in cool areas with a high incidence of shot berry problem, eg. Hanging Rock, Vic.).
4. Compare the relationship between commercial vineyard Mo levels and our standards at high risk sites.	Survey of 100 commercial vineyards in 3 states and advise if remedial actions are needed (for scions/ rootstocks), at sites with high incidences of asynchronous berries.
5. Communicate best practices for Mo spray adoption to industry.	Conduct workshops in 3 states* and publish results, inc., fact sheet on best practices for Mo use and Mo nutrition of vines.

Outputs and Performance Targets 2005-06*

Outputs	Performance Targets
1.A Mo budget will be produced for vines and information on Mo concentrations in vine tissues will be produced. Report information on critical temporal changes in Mo.	Complete replicated trials on rates, sources and timing of Mo sprays. Describe Mo nutrition for vines. Assess annual carryover of Mo in vines and calculate a Mo budget. Measure temporal changes in Mo concentrations in different vine tissues.
2. Obtain information on Mo concentration and uptake and its impact on yield, quality, other nutrients and berry asynchrony.	Monitor 3 established Mo spray field trials in SA. Monitor established rootstocks and scions of Merlot trial at Mc Laren Vale (different set responses of rootstocks were found in 2002/03 to nil Mo but not equal to Mo plots).
3. Modify our critical Mo levels at peak bloom. Attempt to develop a predictive tool for Mo deficiency at the 10cm shoot stage (E-L 12).	Conduct field trials using nil and adequate Mo applied levels in SA, Vic and NSW (select Mo sites in cool areas with a high incidence of shot berry problem, eg. Hanging Rock, Vic.).
4. Compare the relationship between commercial vineyard Mo levels and our standards at high risk sites.	Survey of 100 commercial vineyards in 3 states and advise if remedial actions are needed (for scions or rootstock), at sites with high incidences of asynchronous berries.
5. Communicate best practices for Mo spray adoption to industry.	Conduct workshops in 3 states* and publish results, inc., fact sheet on best practices for Mo use and Mo nutrition of vines.

* Approved modifications to the original proposal were successfully completed: -the nutrient survey was extended to a fourth state, WA and 2 workshops were held in WA in both 2005 and 2006.

Research Strategy and Method

Three field experiments were established in 2000 as part of the first participatory on farm trials program conducted for the CRC Viticulture. The aim of these experiments was to assess if Mo deficiency was associated with the unpredictable incidence of poor fruit set and low bunch yields in Merlot in certain growing seasons in the Mt Lofty Ranges of SA.

This final report is the end product of an expanded project approved by GWRDC in 2003. A major aim of this work was to develop strategies to manage Mo to improve fruit set and reduce berry asynchrony in grapevines. A list which provides site information and treatments for all fifteen Mo field experiments is provided in Table 1. The above 3 initial field experiments were maintained to examine the longer term effects of foliar applied Mo on berry asynchrony, bunch yield and on plant and soil reserves of Mo (Table 1, sites 1-3, results-Chapter 2). Other field experiments were conducted in SA to examine the effects of: rootstocks (Table 1, sites 4 and 5, results-Chapter1), different rates, times and number of Mo sprays (Table 1, sites 6-9 in SA and 11-13 in NSW and 14-15 in Vic, results-Chapters 5, 7), and the uptake and distribution of Mo and boron in grapevines (Table 1, sites 9-10, results Chapter 3).

Thereafter, results from all ten SA field trials were used to calibrate a plant tissue test for basal petioles at peak flowering to diagnose Mo deficiency (Chapter 4). A survey was also conducted of 100 vineyards in 4 states (SA, WA, NSW and Victoria) over 3 years to assess Mo and 12 other nutrient concentrations in commercial vineyards and relationships to bunch yield and berry asynchrony (Chapter 6). The impacts of foliar sprays of Mo on berry nutrient composition at harvest are reported in Chapter 8. Residual soil Mo reserves and vineyard Mo budgets after 3 or 5 years of Mo foliar applications are presented in Chapter 9.

Technique used for low limit Mo detection

For Mo, all analyses for tissue samples with less than 0.9 mg/kg measured on the inductively coupled plasma optical emission spectrometer (ICP-OES), a further sub-sample of the original acid extract was then measured on an ICP-mass spectrometer (ICP-MS). The ICP-MS had a limit of detection (LOD) of at least 0.004 mg/kg in the dry sample (L. Palmer, Waite Analytical Services, pers. comm., 2003). Reference samples of known Mo concentrations were included in each batch of analyses. Our research work has led to this Mo analysis procedure being available as a commercial service to industry in several states including, SA and WA.

Specific information on the detailed methods, design and biometrical analyses used at each site (eg. petiole sampling, Mo spray regimes) are described in the relevant chapters. Data was in general analysed by analysis of variance, to calculate significant differences between treatments, the least significant difference (LSD) test was used and calculated at the 5% level of probability. Genstat 8.1 (Lawes Agricultural Trust, Rothamsted Experimental Station, 2005) and Statistix 8 (Analytical Software, 2003) were the two software statistical packages used.

Table 1: Site information for all molybdenum experiments

Site number	Location	Age of Vines (yrs)	Vine Spacing (m)	Harvest Date	Scion	Rootstock	Trts x Reps	Design
SA sites								
1	Lower Hermitage [y]	4	2.7 x 1.8	8/03/2001	Merlot	Own roots	2 x 4	RCB
		5		20/03/2002			2 x 4	RCB
		6		17/03/2003			2 x 4	RCB
		7		18/03/2004			2 x 4	RCB
		8		17/03/2005			2 x 4	RCB
2	Meadows [y]	5	2.4 x 1.5	27/03/2001	Merlot	Own roots	2 x 4	RCB
		6		30/04/2002			2 x 4	RCB
		7		11/04/2003			2 x 4	RCB
		8		31/03/2004			2 x 4	RCB
3	Kuitpo [y]	5	2.7 x 1.5	28/03/2001	Merlot	Own roots	2 x 4	RCB
		6		4/04/2002			2 x 4	RCB
		7		11/04/2003			2 x 4	RCB
		8		30/03/2004			2 x 4	RCB
		9		18/03/2005			2 x 4	RCB
4	McLaren Vale	15 16 17 18	3.4 x 1.8	20/03/2003 18/03/2004 17/03/2005 2/03/2006 [z]	Merlot	Own roots Schwarzmann SO4 (2136) 110 Richter 140 Ruggeri Ramsey	12 x 4	Split plot
5	Nuriootpa RC	20	3.5 x 2.25	7/03/2005	Merlot	Own roots Schwarzmann	6 x 5	RCB
6	Lenswood [y]	5	2.4 x 1.5	7/03/2004	Merlot	Own roots	15 x 4	RCB
		6		30/03/2005 [z]			15 x 4	RCB
		7		28/04/2006			15 x 4	RCB
7	Carey Gully [y]	6	2.5 x 1.6	25/03/2004	Merlot	Own roots	15 x 4	RCB
8	Carey Gully [y]	11	2.4 x 1.2	19/02/2004	Chardonnay	Own roots	2 x 3	RCB
9	McLaren Vale	5	2.7 x 1.5	23/03/2004	Merlot	Own roots	15 x 4	RCB
	(Ranges)	6	2.7 x 1.5	22/03/2005			15 x 4	RCB
10	Lenswood RC [y]	9	3.0 x 1.5	14/03/2005	Cab. Sav.	Own roots	10 x 2	Block
		9	3.0 x 1.5	14/03/2005	Merlot	Own roots	10 x 2	Block
Interstate sites								
11	Mudgee, NSW	9	2.3 x 1.8	16/03/2005	Merlot	Own roots	2 x 4	RCB
12	Mudgee, NSW	10	3.3 x 1.8	14/03/2006	Merlot	Own roots	2 x 4	RCB
13	Mudgee, NSW	6	2.8 x 1.5?	13/03/2006	Picolit	Own roots	3 x 4	RCB
14	Yarra Valley, Vic	6	2.75 x 1.8	26/03/2004	Merlot	Schwarzmann	4 x 4	RCB
15	Yarra Valley, Vic	14	3.4 x 1.8	29/03/2005	Merlot	Own roots	4 x 4	RCB

[y] Mount Lofty Ranges, SA
NB: Merlot in all cases was clone 2093 (D3V14)
RCB: Randomised Complete Block

[Z] No Mo sprays applied in spring 2005.
RC = Research Centre
Cab. Sav = Cabernet Sauvignon

Chapter 1

1 Rootstock

1.1 Effect of molybdenum and rootstock on growth, fruit set, yield and bunch characteristics of Merlot grapevines

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Abstract

Effects of molybdenum (Mo) foliar sprays on the growth, fruit set, bunch yield and berry characteristics were examined in *Vitis vinifera* L. cv Merlot on own roots and 5 rootstocks. There were no major effects of Mo foliar application on the vegetative growth of grapevines. In contrast, applied Mo improved fruit set, reduced numbers of green berries (< 5 mm in diameter) and increased numbers of coloured berries per bunch (at site 4, in 2003/04). However, the magnitude of such effects varied with growing season, site and rootstock.

Rootstock genotype had significant effects on fruit set of Merlot, with Ramsey (34.0%) having significantly higher fruit set than all other rootstocks tested and own roots the lowest (22.7%). Own rooted Merlot vines had the highest numbers of undesirable green berries per bunch at harvest and Ramsey vines the fewest.

Increased bunch yield from Mo application was greatest for Merlot on own roots (1.8 to 3.2 fold). Smaller increases were recorded for the rootstocks: SO4 (2136), 140 Ruggeri, Ramsey and Schwarzmann (<1.8 fold) and 110 Richter did not respond. Changes in relative bunch yield per vine and relative bunch weight confirmed the above groupings of rootstocks responses to applied Mo.

Bunch yield responses to applied Mo varied greatly between growing seasons, presumably due to differences in environmental conditions. At site 4, 110 Richter, 140 Ruggeri and Ramsey produced the highest yields. These findings suggest that 110 Richter should be considered as a suitable rootstock for new Merlot plantings in vineyards with a history of Mo deficiency and millerandage (provided it meets other key selection criteria).

The bunch yield response to applied Mo was mainly due to higher bunch weights. Bunch numbers per vine were similar for sprayed and unsprayed treatments and for different rootstocks. Molybdenum by rootstock interactions for bunch weight occurred in all three growing seasons at site 4, suggesting that selection of rootstock can have a major impact on responses to applied Mo.

Introduction

Foliar application of molybdenum (Mo) to Mo deficient vines has previously been shown to increase yield and bunch weight of Merlot grapevines grown on own roots (Williams *et al.* 2004). Rootstocks are known to influence a broad range of grapevine production parameters, including vigour, yield and nutrient utilisation (May 1994; Ezzahouani and Williams 1995; Avenant *et al.* 1997; Keller *et al.* 2001b; Walker *et al.* 2002).

Growth and reproduction in either own rooted or grafted plants is regulated by functional interactions between the shoot and root (May 1994; Walker *et al.* 2000; Zerihun and Treeby 2002). A diverse range of such interactions between below and above ground growth for

different scion/rootstock combinations has been described by May (1994). For example, root number per unit area and stomatal conductivity were both lower for Cabernet Sauvignon grafted on ARG 1 than when grafted on 5 C Teleki (Williams and Smith 1991). Where shoot and root genotypes are different in grafted vines, root-shoot interactions may affect plant growth and nutrient utilisation in ways not expressed in own-rooted vines (Zerihun and Treeby 2002). In particular, changes in the root-shoot Mo interactions could be expressed in different vine functions including uptake, translocation, assimilation and allocation of vine resources/metabolites containing Mo. Little information is available on how these processes in different scion/rootstock combinations are likely to affect vine responses to Mo, nutrient status, growth, reproduction and berry characteristics.

Field experiments were conducted to investigate the effects of Mo application and rootstocks on the growth, fruit set, yield and bunch characteristics of Merlot grapevines.

Materials and Methods

The main experiment was conducted in a commercial vineyard located at McLaren Vale (site 4) in the Southern Vales district of South Australia over three seasons (2003/04, 2004/05 and 2005/06). The secondary experiment was conducted in a research vineyard located at the Nuriootpa Research Centre (site 5) in the Barossa Valley in South Australia. Chemical properties of the soil at site 4 are shown in Table 1.

Table 1. Selected chemical properties of the soil at site 4 in 2003/04.

Depth (cm)	pH_{Ca}	CEC[a] (meq/100g)	Organic C (g/kg)	Total N %	HCO_3 P (mg/kg)	HCO_3 K (mg/kg)	Fe (EDTA) (mg/kg)
0-15	5.8	7.26	1.30	0.10	140	166	250
15-30	5.6	3.86	0.76	0.04	94	133	181
30-45	5.7	4.50	0.49	0.02	60	142	120

[a]Sum of exchangeable Ca, Mg, K, Na in meq/100 g of soil.

Site 4 experimental plots consisted of eight rows of 15-year-old Merlot grapevines (clone 2093, D3/V14) on own roots or five rootstock genotypes. The rootstocks were: (1) Schwarzmann (*V. riparia x V. rupestris*), (2) SO4 (2136) (*V. berlandieri x V. riparia*), (3) 110 Richter, (4) 140 Ruggeri (*V. berlandieri x V. rupestris*), and (5) Ramsey (*V. champini*). A split plot design with four replicates was used to vary the rate of Mo (with Mo sprayed and unsprayed rows the main-plot) and rootstocks (sub-plots randomised within the main plot). Three vines within the rootstock sub-plots were selected for data collection. In the first three years of the experiment, vines in four of the eight rows were sprayed with knapsack sprayers used to deliver sodium molybdate ($Na_2Mo_4.2H_2O$, laboratory grade, 39.65% Mo) at a rate of 300 g/ha dissolved in deionised water (DI) to the point of runoff. A red vegetable dye (made by Queen, a food colouring called pillar box red) was added to the foliar spray (50 mL to 20 L of deionised water and 7.5 g sodium molybdate,) to enable the spray of 149 mg Mo/L to be seen and applied to the point of runoff (equivalent to 419 L/ha). Control rows were sprayed with deionised water and red dye only. The spray regimes (149 mg Mo/L or DI water) were applied on two occasions each year before flowering: the first at Eichorn-Lorenz (E-L) growth stages 12-15, the second at 16-18, as described by Williams *et al.* (2004).

At site 5, on Nuriootpa Research Centre, three Mo spray treatments, (1) 0 mg/L, (2) 250 mg/L and (3) 500 mg/L were randomly allocated and applied to 30, three vine panels of Merlot (clone 2093, D3V14); 15 panels growing on own roots and 15 panels growing on Schwarzmann rootstock. The Mo spray at site 5 was applied once, during growth stages E-L

16-18. Information on vine age, vine spacing, harvest dates, and other site details for sites 4 and 5 are given in the Research Strategy and Method section.

Both plantings were drip irrigated. Irrigation, pest and disease control were carried out according to normal growing practices. Each autumn, after harvest chicken manure was applied to the grapevines at site 4 at a rate of 3.7 tonnes per hectare and spread evenly across the vineyard. No fertiliser had been applied directly to grapevines at site 5 since 2001, but in 2003 and 2004 DAP fertiliser containing 18% nitrogen and 20% phosphorus had been applied to the cover crop growing between rows at a rate of 200 kg/ha.

Measurements of plant growth and fruit set

Shoot length was assessed by selecting at random five canes from the centre vine of each replicate, and measuring length from the stem base to the growing point from October to December 2003, at 7 to 11 day intervals. For each replicate plot, five canes were selected at random from the centre vine and the length of the fifth internode measured in late January 2004. Vigour has been related to the length of the fifth internode by Smart and Robinson (1991) as low (<5 cm: moderate 6-8 cm and high > 8 cm).

Fruit set is the major parameter used for assessing the success of sexual reproduction (Lebon *et al.* 2004). It was determined by a modification of the method of Bernard and Vergnes (1982). Three typical inflorescences were selected on the centre vine of each plot before flowering on 17 November, 2003, at E-L stage 18-19. A tulle bag of approximately 25 x 18 cm, stitched on three sides, was placed around each inflorescence and the top of the bag sealed with metal staples. Calyptras (flower caps) were extracted from the tulle bags (by removing staples) after peak balloon (11 December, 2003, E-L stage 31), and the bags resealed. A proportion of the calyptras had not fallen but remained attached to developing berries or aborted flowers and these were collected on 13 January and on 8 March, 2004 (at harvest). The total number of calyptras was counted for each bunch to estimate total flower numbers per inflorescence. Fruit set was determined as the percent ratio of coloured berries per bunch at harvest (excluding the green seedless berries under 5 mm diameter or shot berries) over the number of flowers (by counting the number of calyptra).

On the day before commercial harvest, the three bunches in tulle bags were also harvested. A further ten bunches were selected at random and harvested from the centre vine of each plot, placed in plastic bags on frozen cooler blocks in insulated containers for transport to the laboratory. For berry asynchrony assessment, three of these bunches were selected at random plus the three bunches enclosed in the tulle bags from each replicate plot. Berry asynchrony was measured for each replicate, by fractionating six bunches into the number and weight of coloured (black) and green berries in the <5 mm, 5-10 mm, 10-15 mm, and >15 mm diameter size grades. The <5 mm berries were considered as residual, swollen ovaries which were seedless berries or shot berries. This bunch disorder has been called millerandage (May 2004) and consists of small seedless berries that do not mature and remain green at harvest. Such small green Merlot berries were not considered as berries in the fruit set calculations. On the afternoon of 8 March, 2004 all remaining bunches were harvested from the centre vine of each plot, the number of bunches was counted, total weight recorded and the mean bunch weight calculated for each plot.

Results and Discussion

Plant vegetative growth

Shoot growth was similar in grapevines sprayed with or without Mo, except that early growth was slightly reduced at site 4 (Table 2).

Table 2. Effect of foliar application of molybdenum and rootstock on vine shoot growth at site 4 between October and December in 2003.

	Shoot Length (cm)						
	11 Oct	22 Oct	4 Nov	11 Nov	20 Nov	27 Nov	8 Dec
Treatment							
Unsprayed	12.3	29.4	41.9	55.7	76.6	87.7	102.7
Sprayed	9.7	26.9	39.9	52.7	72.2	83.4	97.7
Significance	**	ns	ns	ns	ns	ns	ns
LSD	1.4						
Rootstock							
Own roots	13.3	31.2	44.8	57.7	76.8	87.7	100.2
Schwarzmann	12.2	29.8	41.5	54.1	72.2	80.2	92.9
SO4 (2136)	11.4	28.3	40.1	52.7	72.5	82.2	93.8
110 Richter	9.3	26.3	39.8	53.7	75.2	88.0	104.6
140 Ruggeri	9.3	26.1	40.2	55.0	77.9	92.0	112.1
Ramsey	10.5	27.4	39.1	52.0	72.0	83.2	97.9
Significance	**	*	*	ns	ns	*	**
LSD	1.7	1.5	3.5			7.8	10.5
Interaction							
Significance	ns	ns	ns	ns	ns	ns	ns

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

It was noted in work reported by Longbottom *et al.,* (2005) that Mo applied in the previous season may delay budburst and early season shoot growth in the following season. However, shoot growth and length of such sprayed vines was similar to that of comparable unsprayed vines within 2 weeks (Table 2). There were some significant differences between rootstocks in shoot lengths, for example, vines on own roots or Schwarzmann had longer shoots in early spring (11 October to 4 November) and vines on own roots, 110 Richter and 140 Ruggeri had the longest shoots in late spring (Table 2). This could be due to differences in the genotypes of the rootstocks assessed as reported by May (1994).

There were no significant main effects or interaction of Mo or rootstock treatment effects on the length of the fifth internode at site 4 (Table 3a). All treatments in both years at site 4 had average shoot vigour using the criteria of Smart and Robinson (1991), of 5 to 8 cm long fifth internodes (Table 3a).

Table 3a. Effect of foliar application of molybdenum and rootstock on 5th internode length of vines in 2003/04 and 2004/05 and pruning weight per vine in 2004/05 at site 4.

	5th Internode Length (cm)		Pruning Weight (kg)
Year	2003/04	2004/05	2004/05
Treatment			
Unsprayed	6.73	6.64	1.5
Sprayed	6.69	6.70	1.3
Significance	ns	ns	*
LSD			0.1
Rootstock			
Own roots	6.79	6.38	1.4
Schwarzmann	6.48	6.70	1.1
SO4 (2136)	6.61	6.28	1.2
110 Richter	6.88	6.60	1.3
140 Ruggeri	6.90	7.13	1.8
Ramsey	6.60	6.94	1.7
Significance	ns	ns	**
LSD			0.4
Interaction			
Significance	ns	ns	ns

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

Application of Mo foliar sprays compared to nil treatment, in spring, 2004 was associated with a significant reduction (13.3%) in pruning weights per vine after harvest in July 2005 at site 4. However, no significant effects were recorded at site 5 (Table 3b). Such effects could be associated with greater yield responses to applied Mo at site 4 compared with site 5 in 2005 and the former vines allocating more plant resources to fruit compared to stem tissues. Ramsey and 140 Ruggeri produced the highest pruning weights per vine at site 4 (Table 3a), whereas own roots and Schwarzmann had similar pruning weights at both sites 4 and 5 (Table 3a, b). These effects were likely due to genetic differences between rootstocks (Pongracz 1983; PGIBSA 2003). Overall Mo application had little effects on the vegetative growth of Merlot vines on different rootstocks.

Table 3b. Effect of foliar application of molybdenum and rootstock on pruning weight per vine in 2004/05 at site 5.

	Pruning Weight (kg)
Mo rate	
0	1.6
250	1.2
500	1.3
Significance	ns
Rootstock	
Own roots	1.4
Schwarzmann	1.4
Significance	ns
Interaction	
Significance	*
LSD	0.4

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

Flower numbers, fruit set and berry numbers

Mo application (2 sprays of 149 mg/L) and rootstock treatments had no effects on the number of flowers per inflorescence (Table 4).

Table 4. Effect of foliar application of molybdenum and rootstock on number of flowers per inflorescence, % fruit set per vine, and number of green and coloured berries per bunch at site 4 in 2003/04.

	Flowers per inflorescence	Fruit set (%)	Green berries per bunch	Coloured berries Per bunch
Treatment				
Unsprayed	394	22.8	51.2	77.4
Sprayed	385	30.0	31.0	92.2
Significance	ns	**	*	**
LSD		1.9	13.3	4.8
Rootstock				
Own roots	412	22.7	62.1	80.6
Schwarzmann	353	25.2	41.4	84.4
SO4 (2136)	373	28.7	28.9	89.4
110 Richter	454	20.9	29.5	76.3
140 Ruggeri	392	26.8	47.1	87.2
Ramsey	354	34.0	37.5	90.8
Significance	ns	**	*	ns
LSD		7.1	20.5	
Interaction				
Significance	ns	ns	ns	ns

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

It is important to note that all Mo treatments to all rootstocks were also applied in the 2002/03 season before flowering (see methods) so that Mo treatments had been applied before the usual period of floral initiation, around peak bloom the previous season (Coombe 1988; May 2004), as well as the 2003/04 season.

The beneficial effects of Mo application resulted in improved fruit set, reduced numbers of green berries (< 3mms in diameter) and increased numbers of coloured berries per bunch (Table 4). This supports the initial findings of Williams *et al.* (2003; 2004) who were the first to report that Mo deficiency was one of the main causes of poor seed formation and low bunch yield in Merlot. They also found that Mo application to such vines increased the percent of coloured berries with one or more functional seeds and decreased the proportion of green berries at harvest. This suggests that Mo application affected pollination and/or fertilisation, and thereafter berry development. Subsequent work by Longbottom *et al.* (2004; 2005) showed that Mo deficiency affected the fertilisation process in the vine flowers and it was reported that the deficiency affects the female parts of flowers, reducing pollen tube growth and the penetration of the ovules, while the pollen vitality was unaffected.

Rootstock had a significant effect on fruit set of Merlot, with Ramsey having significantly higher fruit set than all other rootstocks and own roots the poorest fruit set (Table 4). Phillips (2004) also reported a higher fruit set for Merlot on Ruggeri 140 compared with own roots. Own roots had vines with the highest numbers of undesirable green berries per bunch and Ramsey vines with the lowest (Table 4). The small, green berries were not included in fruit set, so that only 22.7 to 34.0% of the original flowers developed into mature, coloured berries. At harvest, total numbers of coloured berries per bunch were similar for all rootstocks (Table 4), as reported by (Keller *et al.* 2001a).

Bunch yield and components of yield

Fruit yield varied from 2.5 to 12.0 kg/vine, for vines not sprayed with Mo at McLaren Vale (site 4). Mo addition (2 foliar sprays) and rootstocks had greater effects on bunch yield per vine and bunch weight in 2004/05, compared with the other 2 growing seasons (Table 5a). Mo application increased yield by 43% in 2004/05 compared with the unsprayed treatments (Table 5a). For the 2005/06 growing season, the 'sprayed' vines had not been sprayed with Mo for 18 months (since spring 2004) to examine the plant's ability to carryover Mo from season to season. Presumably, for these 'sprayed' vines, storage of a proportion of the previous three years Mo sprays (spring 2002-2004) was associated with the 18.2 % increased yield compared to the unsprayed controls (Table 5a). In 2004/05, 110 Richter, 140 Ruggeri and Ramsey, produced the highest bunch yields of Merlot, in both sprayed and unsprayed plots. Bunch numbers per vine were not effected by treatments in either year (Table 5a) and this supports the findings of Williams *et al.* (2004) who reported little effects of applied Mo on bunch numbers per vine.

Table 5a. Effect of foliar application of molybdenum and rootstock on yield and the number of bunches per vine harvested from site 4 in 3 growing seasons. (Note in the 2005/06 season sprayed vines had not been sprayed with Mo for 18 months, since spring 2004)

	Yield/vine (kg)			Bunches/vine		
Year	2003/04	2004/05	2005/06	2003/04	2004/05	2005/06
Treatment						
Unsprayed	4.8	7.2	7.7	80.4	91.7	101.4
Sprayed	5.0	10.3	9.1	77.1	90.8	107.3
Significance	ns	*	*	ns	ns	ns
LSD		2.4	1.1			
Rootstock						
Own roots	4.6	5.2	4.0	82.5	84.5	98.9
Schwarzmann	4.1	6.9	7.2	75.9	84.6	100.8
SO4 (2136)	4.2	8.2	8.0	71.1	90.1	99.2
110 Richter	5.7	11.4	11.6	84.5	97.8	113.2
140 Ruggeri	5.3	11.0	10.7	81.3	102.5	115.9
Ramsey	5.5	9.9	8.8	77.4	88.0	107.0
Significance	ns	**	**	ns	ns	ns
LSD		2.5	2.0			
Interaction						
Significance	ns	ns	ns	ns	ns	ns

Significance of differences: *, ** = $P < 0.05, 0.01$; ns = not significant.

Average bunch weights per vine for vines not sprayed with Mo ranged from 29.4 to 112.8 g. The application of Mo significantly increased bunch weight per vine at site 4 in all three years (Figure 1). Significant Mo by rootstock interactions for bunch weight were recorded in 2003/04 and 2004/05. In 2003/04 applied Mo increased average bunch weights for vines on Schwarzmann and own roots and in 2004/05 for vines on these latter two rootstocks and on SO4, 140 Ruggeri and Ramsey (Figure 1).

The absolute increases in bunch yield from Mo application were clearly greatest for Merlot on own roots with 1.8 and 3.2 fold increases. However, there was less response from the 4 rootstocks (Schwarzmann, SO4 [2136], Ramsey and 140 Ruggeri) with 0 to 1.8 fold increases in yield, in 2003/04 and 2004/05, respectively. Similarly, relative yield and bunch weight were lower (and therefore responses to Mo greater) for own rooted vines than for rootstocks (Figures 2 and 3). The increased bunch yield response to applied Mo was due to higher bunch weights and not bunch numbers per vine (Figures 2 and 3).

Relative yield and bunch weight were useful to examine and rank the responses over three growing seasons of different rootstocks to Mo application. In terms of relative yield and bunch weight response to applied Mo; own rooted Merlot exhibited clearly the lowest relative values (52%) and thus can be classed as highly responsive, whereas the 4 rootstocks; Schwarzmann, SO4 (2136), Ramsey and 140 Ruggeri, can be grouped as moderately responsive and 110 Richter did not respond to applied Mo (Figures 2 and 3). In the 2002/03 growing season at this site, (Gridley 2003) reported a 2.5 fold increase in yield from Mo treatment on own rooted vines, and less of a response on Schwarzmann and 140 Ruggeri (1.5 and 1.3 fold increase, respectively). These results suggest that 110 Richter may be the best rootstock for new Merlot plantings in vineyards with a history of Mo deficiency and millerandage.

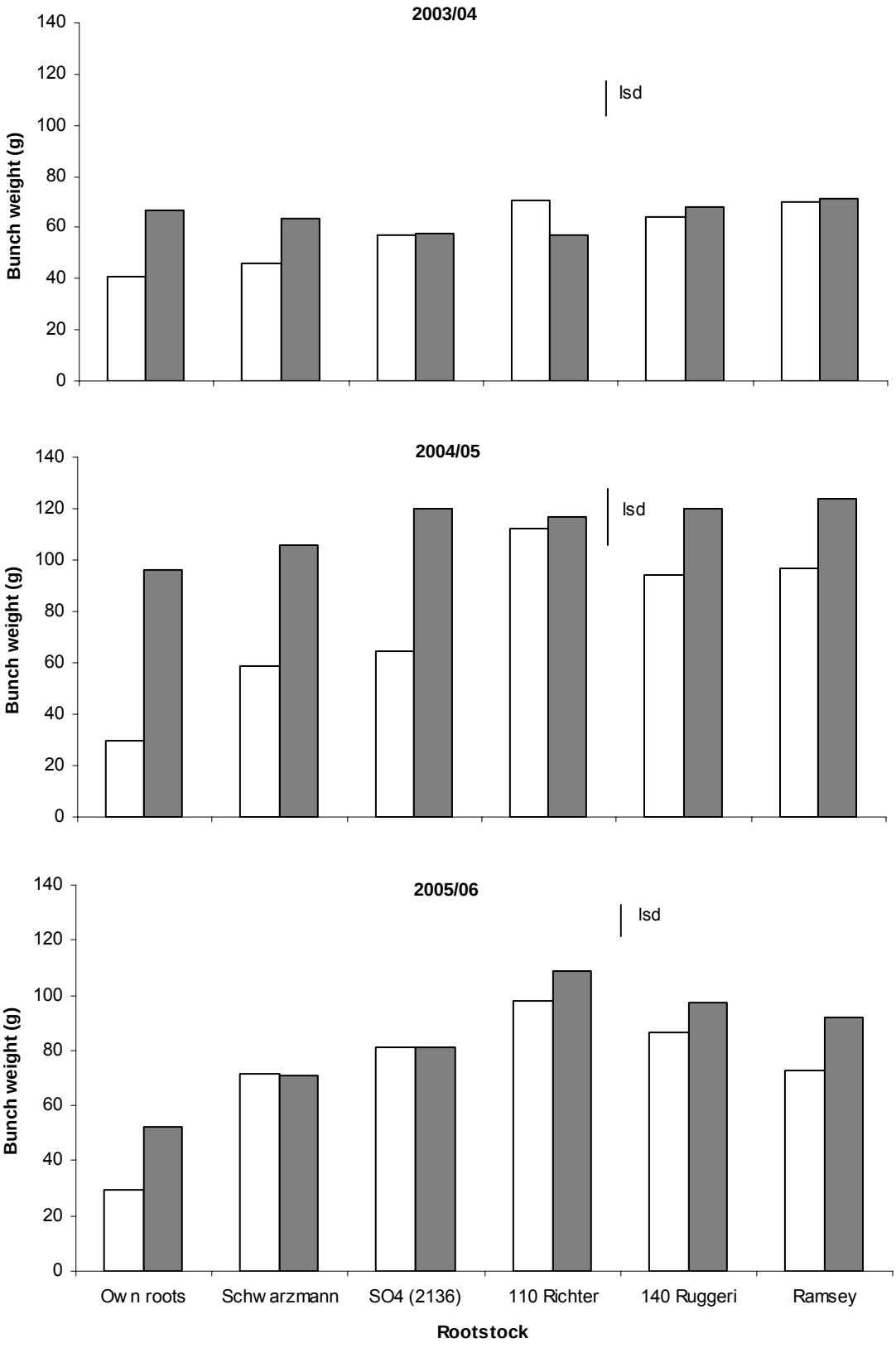


Figure 1. Effects of Mo application (unshaded =unsprayed, shaded= sprayed) and rootstock on average bunch weight at site 4 in 3 growing seasons. Note in the 2005/06 season sprayed vines had not been sprayed with Mo for 18 months, since spring 2004.

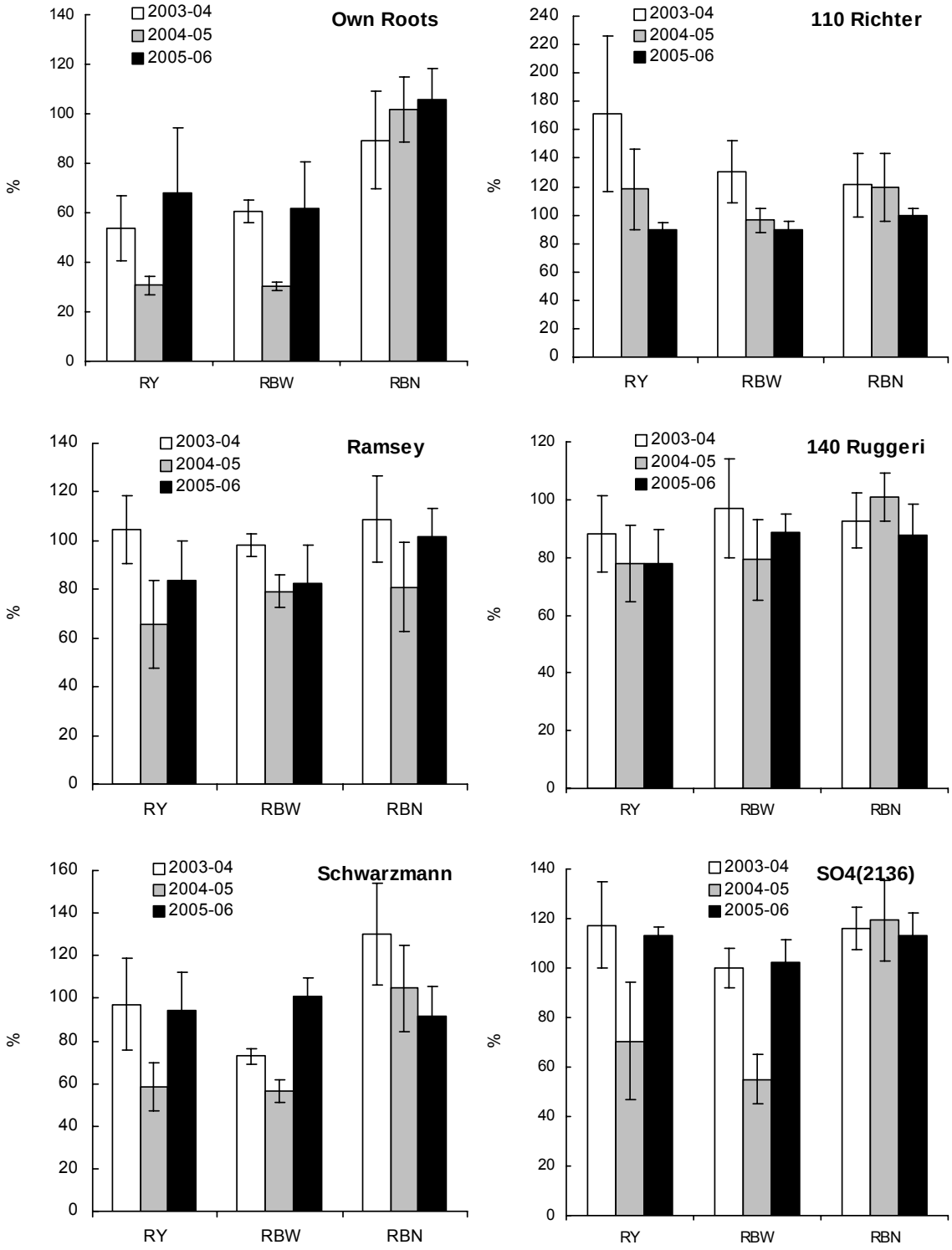


Figure 2. Percent relative yield (RY), relative bunch weight (RBW) and relative bunch number (RBN) per vine for 3 growing seasons for Merlot on rootstocks specified. Data are for site 4, with relative values defined as 100 x (average without Mo/average with Mo). Standard errors of the means are shown as vertical bars.

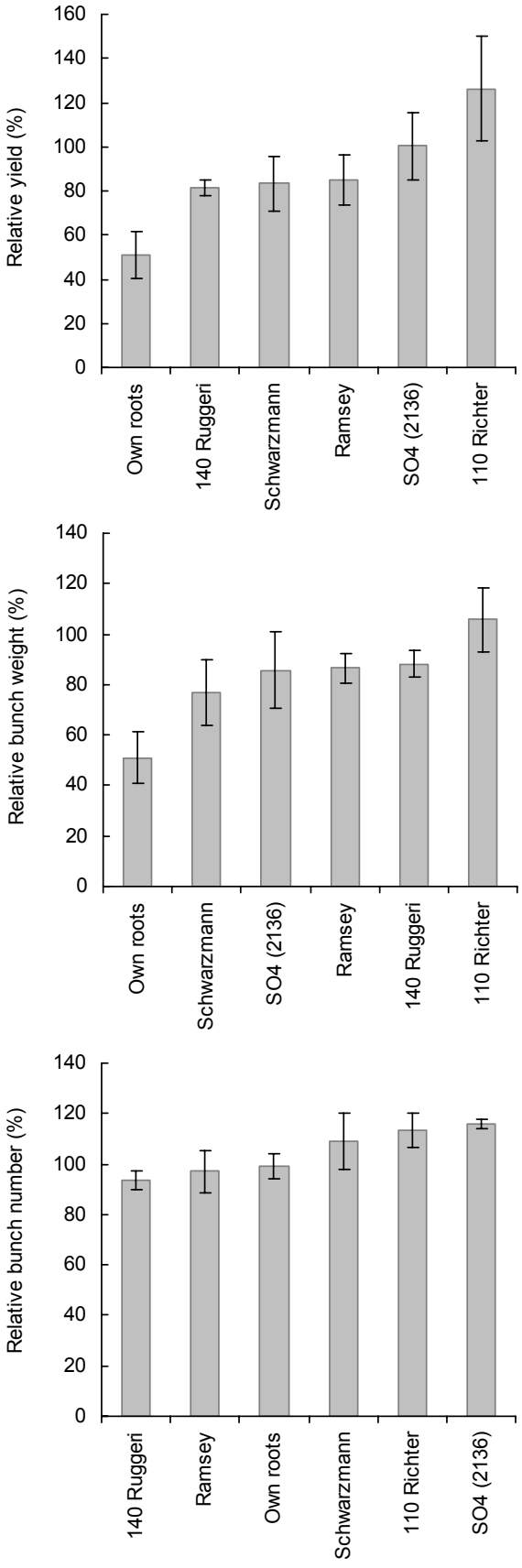


Figure 3. Percent relative yield, relative bunch weight and relative bunch number per vine averaged over 3 growing seasons for Merlot on rootstocks specified. Data are for site 4, with relative values defined as 100 x (average without Mo/average with Mo). Standard errors of the means are shown as vertical bars.

Therefore, differences in rootstocks may have major effects on the magnitude of the vines response to applied Mo in terms of average bunch weight at harvest in different years.

Bunch yield from vines not sprayed with Mo varied from 8.0 to 15.4 kg/vine at Nuriootpa (site 5).

At site 5 in 2004/05, the main effects of application of Mo and rootstock had no effects on bunch yield nor bunch number per vine at harvest. However, average bunch weight was improved (Table5b). Mo spray at 250 and 500 mg/L, increased bunch weight by 18.2 and 23.8% compared with the unsprayed treatment at site 5 (and Schwarzmann had higher bunch weight compared to own roots, refer to Table 5b).

Table 5b. Effect of foliar application of molybdenum and rootstock on yield and the number of bunches harvested from site 5 in 2004/05.

	Yield/vine (kg)	Bunches/vine	Weight/bunch (g)
Mo rate			
0	12.4	146.8	83.2
250	13.3	138.5	98.3
500	15.0	147.4	103.0
Significance	ns	ns	*
LSD			13.4
Rootstock			
Own roots	12.7	152.5	82.8
Schwarzmann	14.3	135.9	106.9
Significance	ns	ns	***
LSD			11.5
Interaction			
Significance	ns	ns	ns

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; ns = not significant.

Berry number and size at harvest

The number of <5 mm diameter green berries on a bunch was decreased by the application of Mo by 39.1 and 51.7 %, in 2003/04 and 2004/05, respectively and the weight of green berries reduced in 2004/05 at site 4 (Table 6). Merlot own rooted vines had a higher weight of green berries per bunch compared to all other rootstocks and tended to produce more green berries per bunch in 2003/04 and Merlot on the five rootstocks produced similar numbers and weight of green berries per bunch within each season (Table 6).

Table 6. Effect of foliar application of molybdenum and rootstock on the number and weight of green berries harvested from site 5 in 2003/04 and 2004/05. All numbers and weights are per bunch.

	2003/04		2004/05	
	No.	Weight (g)	No.	Weight (g)
Treatment				
Unsprayed	51.2	0.30	71.6	0.32
Sprayed	31.0	0.20	33.6	0.16
Significance	*	ns	*	*
LSD	13.3		22.9	0.1
Rootstock				
Own roots	62.1	0.74	66.1	0.28
Schwarzmann	41.4	0.14	53.1	0.21
SO4 (2136)	28.9	0.10	52.5	0.26
110 Richter	29.5	0.12	44.3	0.20
140 Ruggeri	47.1	0.19	45.0	0.18
Ramsay	37.5	0.16	54.5	0.30
Significance	**	**	ns	ns
LSD	20.5	0.40		
Interaction				
Significance	ns	ns	ns	ns

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

In year 2 (2004/05), the number and weight of <5mm coloured berries on a bunch was increased by the application of Mo at site 4 (Tables 7a, b). In contrast, the number and weight of 5-10 mm berries was decreased at site 4 in year 2. The number and weight of 10-15 mm coloured berries was increased when Mo was applied at site 4 in both seasons. However, berry numbers and weights of >15 mm in size were not significantly affected (Table 7a, b). The total number and weight of coloured berries per bunch increased with Mo application in both years.

Rootstock had no effects on the numbers or weights of coloured berries in 2003/04, or on total bunch yield per vine (Tables 5a, 7a, b). In contrast, in the 2004/05 season, significant bunch yield per vine differences between rootstocks were recorded (Table 5a), with 110 Richter, 140 Ruggeri and Ramsay producing the highest yields. These later rootstocks had the highest numbers and weights of coloured berries in the 5-10 and 10-15 mm berry size grades in 2004/05 (Tables 7a, b).

Table 7a. Effect of foliar application of molybdenum and rootstock on the number of coloured berries harvested from site 4 in 2003/04 and 2004/05. All numbers are per bunch.

	2003/04					2004/05				
	Berry Size (mm)				Total	Berry Size (mm)				Total
	<5	5-10	10-15	>15		<5	5-10	10-15	>15	
Treatment										
Unsprayed	2.1	16.8	57.2	1.3	77.4	4.5	13.2	45.4	9.9	76.1
Sprayed	1.2	13.9	76.8	0.3	92.2	8.8	4.5	86.3	12.9	117.5
Significance	ns	ns	**	ns	**	**	*	**	ns	**
LSD			8.7		4.8	2.5	7.6	21.7		18.3
Rootstock										
Own roots	1.8	17.4	60.6	0.8	80.6	7.8	19.2	43.9	11.1	84.4
Schwarzmann	2.5	12.8	68.9	0.2	84.4	11.1	10.8	55.1	5.4	85.6
SO4 (2136)	1.0	17.2	69.1	2.1	89.4	6.4	6.3	69.6	8.6	94.6
110 Richter	0.6	13.7	61.7	0.2	76.3	5.3	2.8	80.5	12.4	104.9
140 Ruggeri	2.4	18.5	66.0	0.3	87.2	6.2	5.8	74.4	18.1	110.4
Ramsey	1.5	12.2	75.8	1.2	90.8	3.2	8.3	71.8	12.6	101.0
Significance	ns	ns	ns	ns	ns	*	**	**	**	ns
LSD						4.5	12.1	27.1	5.3	
Interaction										
Significance	ns	ns	ns	ns	ns	ns	ns	ns	**	ns
LSD									7.8	

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

Table 7b. Effect of foliar application of molybdenum and rootstock on the weight of coloured berries harvested from site 4 in 2003/04 and 2004/05. All weights are per bunch.

	2003/04					2004/05				
	Berry Size (mm)				Total	Berry Size (mm)				Total
	<5	5-10	10-15	>15		<5	5-10	10-15	>15	
Treatment										
Unsprayed	0.3	6.8	54.9	1.8	63.8	0.19	2.8	58.4	20.3	83.2
Sprayed	0.1	4.6	72.2	0.6	77.4	0.10	1.2	104.6	24.7	133.1
Significance	ns	ns	**	ns	**	ns	*	**	ns	*
LSD			8.2		6.9		1.4	24.3		29.6
Rootstock										
Own roots	0.1	5.4	57.4	1.3	64.2	0.15	4.0	53.0	21.6	79.7
Schwarzmann	0.4	5.1	65.2	0.4	71.1	0.27	2.5	69.0	11.0	83.8
SO4 (2136)	0.1	7.5	64.6	2.1	74.2	0.25	1.6	85.7	17.7	106.6
110 Richter	0.0	5.0	57.2	0.4	62.7	0.06	0.8	100.1	24.9	128.3
140 Ruggeri	0.3	7.3	64.0	0.7	72.3	0.07	1.4	89.0	33.8	127.7
Ramsey	0.2	3.8	72.9	2.2	79.1	0.08	1.7	92.1	25.9	122.7
Significance	ns	ns	ns	ns	ns	ns	**	**	**	**
LSD							2.5	31.5	11.0	23.5
Interaction										
Significance	ns	ns	ns	ns	ns	ns	ns	ns	**	**
LSD									16.2	36.2

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

The application of Mo increased the mean weight per coloured berry at site 4 in 2003/04 (Table 8). In 2004/05 own roots had the lowest mean berry coloured weight compared with all rootstocks which had greater berry weights with Schwarzmann and SO4 intermediate and 110 Richter the highest (Table 8).

Table 8. Effect of foliar application of molybdenum on mean weight per coloured berry harvested from site 4 in 2003/04 and 2004/05.

	Mean weight (g)	
	2003/04	2004/05
Treatment		
Unsprayed	0.820	1.068
Sprayed	0.837	1.137
Significance	**	ns
LSD	0.004	
Rootstock		
Own roots	0.764	0.899
Schwarzmann	0.841	0.971
SO4 (2136)	0.829	1.101
110 Richter	0.824	1.240
140 Ruggeri	0.838	1.174
Ramsey	0.873	1.231
Significance	ns	**
LSD		0.160
Interaction		
Significance	ns	**
LSD		0.226

Significance of differences: *, ** = P < 0.05, 0.01; ns = not significant.

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1.2 Effects of rootstock on molybdenum concentrations in leaf petioles of Merlot grapevines

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Abstract

The effects of rootstocks compared to own roots on Mo concentrations in leaf petioles were determined for Merlot grapevines in two field experiments. Mo concentrations for unsprayed vines in petioles at flowering were consistently less for Merlot on own roots (0.04-0.05 mg/kg Mo) compared with Merlot on rootstocks (Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey, 0.05-0.13 mg/kg). Similar differences were also observed at veraison.

Merlot vines not sprayed with Mo and on the rootstocks; 110 Richter, 140 Ruggeri and Ramsey produced the highest bunch yields (5.1-12.0 kg/vine) compared to Merlot on own roots. These responses were associated with increased bunch weights and the highest petiolar Mo concentrations at both peak bloom and veraison.

These findings suggest that Merlot on the rootstocks; Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey are likely to have more efficient systems for Mo uptake, transport and/or redistribution compared with Merlot on own roots.

Introduction

Many factors need to be considered when selecting a rootstock/scion combination for a specific site (May 1994). In Australia the major rootstocks used have generally been chosen due to their tolerance of nematodes, phylloxera and salinity (Walker *et al.* 2000).

The efficiency in nutrient uptake by the American *Vitis species* (used in many rootstocks in Australia) can be considerably different compared with *Vitis vinifera* (Schaller and Lohnertz 1990; Delas 1992; Candolfi-Vasconcelos *et al.* 1997). Limited information is available on the effects of different rootstocks compared with own roots on the uptake and supply of Mo to the scion. Field experiments were conducted to examine the effects of rootstocks compared with own roots on the Mo concentrations in leaf petioles of Merlot grapevines (not sprayed with Mo).

Materials and Methods

Two experiments were conducted on rootstocks, one in a commercial vineyard at McLaren Vale (site 4) in the Southern Vales district of South Australia over three years (2003/04, 2004/05 and 2005/06) and the second at a research vineyard located at the Nuriootpa Research Centre (site 5) in the Barossa Valley in South Australia. Information on the experimental design, rootstocks, Mo spray regimes and Research Strategy and Method used has been presented in the methods section in Chapter 1.1.

At site 4 a minimum of 30 petioles (leaf stalks) from leaves opposite basal bunches were collected from each replicate at growth stages as defined by Coombe (1995a), at E-L 23-25 (flowering) each year and at growth stage E-L 35 (veraison). At site 5 a similar number of petioles opposite basal bunches were collected from each replicate at flowering. Petioles were stored under frozen cooler blocks in insulated containers after collection and during

transportation. In the laboratory, petioles were dried at 60-70°C and then ground to <1 mm in preparation for chemical analysis. Petiole samples were then analysed for chemical composition as described in Williams *et al.* (2004). Low concentrations of Mo were analysed as described in the Research Strategy and Method section.

Plantings were drip irrigated, with irrigation, pest and disease control carried out according to normal growing practices. The experimental plots were harvested on 18 March 2004, 17 March 2005 and 2 March 2006 at site 4, and on 7 March 2005 at site 2. At each harvest and plot the number of bunches was counted, the total weight recorded and the mean bunch weight calculated.

Results and Discussion

Molybdenum concentrations for unsprayed vines in petioles at flowering were consistently lower for Merlot on own roots (0.04-0.05 mg/kg) compared with five rootstocks (0.05-0.12 mg/kg) in each of three growing seasons at site 4 (Table 1, Figures 1, 2). At site 5, Schwarzmann tended to have a higher petiolar Mo concentration (0.14 mg/kg) than own roots (0.09 mg/kg), although such differences were not significant. Similar findings, were reported at peak bloom by Gridley (2003), in that two Merlot clones on own roots had lower petiolar concentrations of Mo compared with Merlot on the rootstocks Schwarzmann or 140 Ruggeri. This led Gridley (2003) to suggest that there may be differences in the translocation of Mo between vines on own roots and on the rootstocks Schwarzmann and 140 Ruggeri.

Since Mo has been classified as variably phloem mobile from leaves (Gupta 1997), findings from Gridley (2003) and this current work suggest that certain rootstocks are likely to have more efficient systems for Mo uptake, transport and/or redistribution in the plant compared with own roots for Merlot.

Similar differences were also recorded in petiolar Mo at veraison, with unsprayed Merlot on own roots less than the five rootstocks tested at site 4 (Table 2).

At site 4, unsprayed vines of Merlot on 110 Richter, 140 Ruggeri and Ramsey produced the highest yields (5.1-12.0 kg/vine) in each growing season and this was associated with increased bunch weights (Table 3). Average bunch weight per vine from Schwarzmann was higher than on own roots at site 5 (Table 4). Own rooted Merlot vines produced the lowest yields at both sites. Changes in bunch numbers per vine between own roots and rootstocks were not significant (at both site 4 and 5, Tables 3 and 4). Earlier work by Williams *et al.* (2003; 2004) showed that Mo foliar sprays increased bunch yield and bunch weight.

Based on data presented in chapter 4, own rooted Merlot vines can be classed as deficient in Mo (< 0.09 mg/kg), whereas vines on rootstocks tested were marginal (0.09-0.45 mg/kg). Thus, the higher Mo concentrations in Merlot vines (not sprayed with Mo) on the rootstocks, 110 Richter, 140 Ruggeri and Ramsey, may be associated with their higher yields (in addition to other genetic effects).

Table 1. Petiole Mo concentrations at flowering for unsprayed (control, -Mo) vines only at site 4.

	Mo (mg/kg)		
	2003/04	2004/05	2005/06
Rootstock			
Own roots	0.05	0.05	0.04
Schwarzmann	0.07	0.08	0.05
SO4 (2136)	0.09	0.07	0.06
110 Richter	0.12	0.12	0.06
140 Ruggeri	0.13	0.12	0.07
Ramsey	0.12	0.12	0.08
Significance	***	**	**
LSD	0.03	0.04	0.02

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

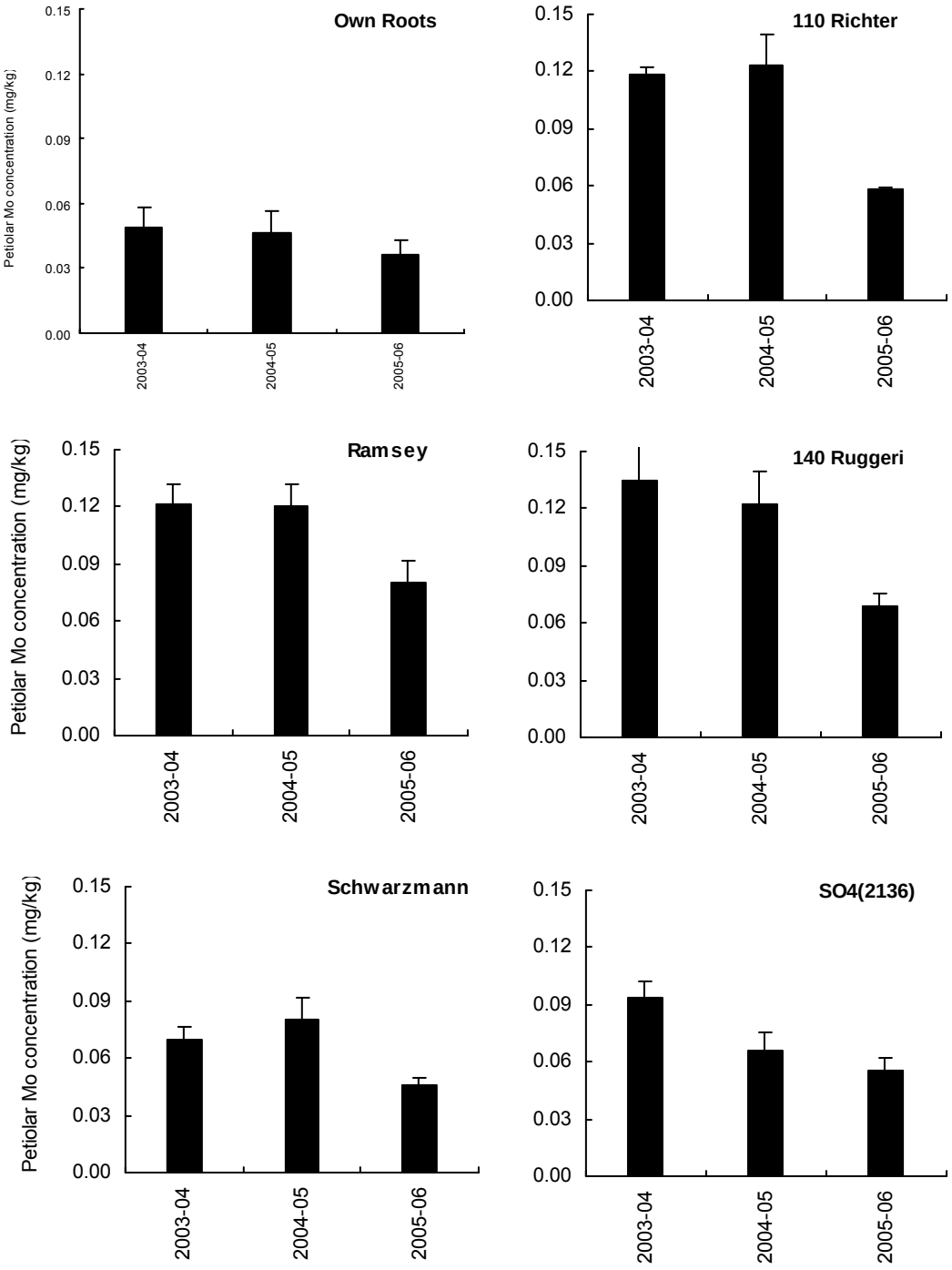


Figure 1. Petiolar Mo concentrations (mg/kg) at flowering for unsprayed Merlot vines on the rootstocks specified in three growing seasons at site 4. Standard errors of the mean are shown as vertical bars.

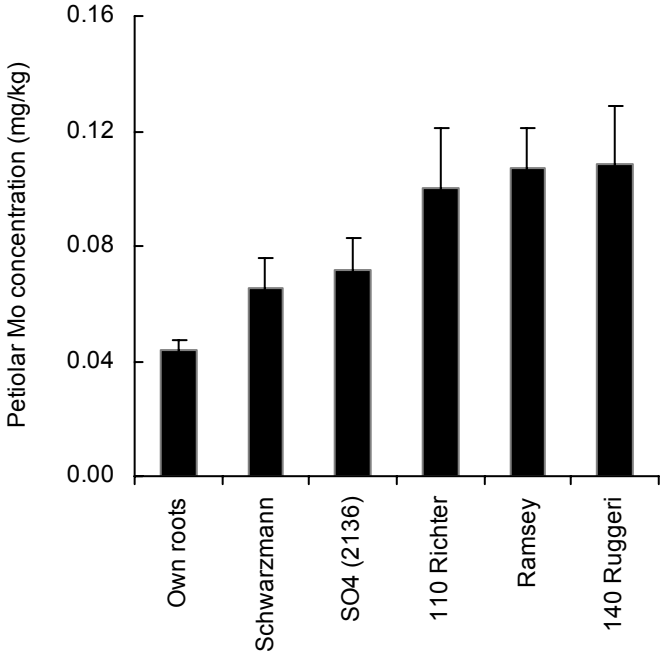


Figure 2. Mean petiolar Mo concentration over 3 growing seasons at site 4 for Merlot vines on the rootstocks specified. Standard errors of the means are shown as vertical lines.

Table 2. Petiole Mo concentrations in 2003/04 or unsprayed (control) vines only at site 4.

	Mo (mg/kg)	
	Flowering	Veraison
Rootstock		
Own roots	0.05	0.06
Schwarzmann	0.07	0.08
SO4 (2136)	0.09	0.10
110 Richter	0.12	0.12
140 Ruggeri	0.13	0.12
Ramsey	0.12	0.12
Significance	***	***
LSD	0.03	0.02

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

These results indicate rootstocks such as, Schwarzmann, SO4 [2136], 110 Richter, 140 Ruggeri and Ramsey have more efficient systems for Mo uptake, transport and/or redistribution compared with own roots for Merlot (refer to Chapter 4). Similar findings were reported by Phillips (2004), that the effects of rootstocks in reducing Mo deficiency in Merlot may be due in part to their greater capacity to re-translocate Mo, compared with Merlot on own roots.

Table 3. Bunch yield, number of bunches and bunch weight of unsprayed (control, -Mo) vines only at site 4.

	Yield (kg per vine)		
	2003/04	2004/05	2005/06
Rootstock			
Own roots	3.3	2.5	3.1
Schwarzmann	4.0	5.0	6.9
SO4 (2136)	4.4	6.5	8.5
110 Richter	6.7	12.0	10.9
140 Ruggeri	5.1	9.6	9.4
Ramsey	5.4	7.4	7.7
Significance	NS	**	***
LSD		4.4	2.9
	Number of bunches (per vine)		
	2003/04	2004/05	2005/06
Rootstock			
Own roots	75.8	84.8	100.5
Schwarzmann	84.2	84.5	95.2
SO4 (2136)	76.2	97.2	104.0
110 Richter	90.2	104.5	112.8
140 Ruggeri	77.8	102.8	106.2
Ramsey	78.2	76.5	107.5
Significance	NS	NS	NS
LSD			
	Bunch weight (g)		
	2003/04	2004/05	2005/06
Rootstock			
Own roots	41.0	29.4	29.7
Schwarzmann	46.1	58.5	71.4
SO4 (2136)	57.2	64.6	81.5
110 Richter	70.8	112.5	98.2
140 Ruggeri	63.9	94.2	86.5
Ramsey	70.2	96.6	72.9
Significance	**	***	***
LSD	16.4	26.9	21.0

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Table 4. Bunch yield, number of bunches and average bunch weight per vine for site 5 in 2004/05, for unsprayed (control, -Mo) vines only.

	Yield (kg per vine)	Number of bunches (per vine)	Bunch weight (g)
Rootstock			
Own roots	9.3	142	62.2
Schwarzmann	15.4	151	104.1
Significance	NS	NS	*
LSD			29.9

Significance of differences: * = P < 0.05; NS = not significant

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1.3 Effect of applied molybdenum and rootstocks on Mo concentrations in vegetative tissue of Merlot grapevines

Chris Williams, Norbert Maier and Kerry Porter

Abstract

The effects of applied Mo and rootstocks on the concentrations of Mo in different vegetative organs of Merlot grapevines were determined to provide information on the supply, annual carryover and Mo available for redistribution within the plant. Merlot vines not sprayed with Mo, on rootstocks, Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey had higher petiolar Mo concentrations (0.07-0.13 mg/kg) than own roots (0.05-0.06 mg/kg), for both flowering and veraison). Foliar sprays of Mo applied pre-flowering increased petiolar Mo concentrations at flowering (4.2-10.3 mg/kg) for all genotypes to well above the adequate or non responsive value of > 0.45 mg/kg, as described in Chapter 4.

Merlot vines sprayed with Mo in 2003/04 and 2004/05, had increased levels of Mo in the terminal 15 cm of shoot growth sampled at peak flowering for all genotypes compared with unsprayed vines. The magnitude of the increase was greater at peak flowering than veraison.

Leaf blades had the highest concentrations of Mo with leaf petioles intermediate and terminal 15 cm of shoot growth the lowest at flowering in 2005/06. This indicates that leaf blades may be a more sensitive indicator tissue of plant Mo status and future research should examine this prospect. Molybdenum concentrations for all these tissues and prunings, were lower for Merlot on own roots than for Merlot on rootstocks (Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri, Ramsey). These findings suggest when Mo is supplied as a pre-flowering spray, Mo can be translocated in grapevines and redistributed to newly formed shoot tissues. Furthermore, Merlot on the rootstocks; Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey compared to own roots may have more effective systems to absorb, store and/or translocate foliar applied Mo to new terminal shoot tissues.

In order to determine if any annual carryover of Mo reserves (and foliar applied Mo) may occur from the previous growing season, Mo was not applied to the sprayed treatments in the 2005/06 growing season at site 4. For this treatment, the Mo concentration in leaf blade tissues was higher (0.17 mg/kg) compared with the unsprayed control (0.13 mg/kg) at flowering in 2005/06. This indicates that the grapevine plant has some capacity to store and carryover a proportion of foliar applied Mo from the previous spring for redistribution and use in the next growing season. The annual carryover of Mo reserves and rootstock genotype in grapevines should be considered when remedial Mo spray regimes are planned.

Introduction

Petioles (leaf stalks) of basal leaves opposite basal bunches are generally used as the indicator tissue for determining nutrient levels, and therefore deficiencies, in grapevines (Robinson *et al.* 1997). The main time of sampling used by growers in Australia is when the majority of vines are flowering. This is the stage of growth for which plant standard concentrations have been estimated for several nutrients for diagnosing nutrient deficiency or toxicity. The best plant part to sample depends on the nutrient, young immature parts are usually the most sensitive for nutrients that are immobile or variably phloem mobile from leaves (Smith and Loneragan 1997). Molybdenum has been described as variably phloem mobile (Gupta 1997). Sampling different plant organs, such as shoot terminal growth, basal leaf blades, petioles and

stem prunings is likely to provide information on nutrient stores available for redistribution within the plant (Smith and Loneragan 1997).

Field experiments were conducted to examine the effects of applied Mo and rootstocks on the concentrations of Mo in different vegetative organs of Merlot grapevines to provide information on Mo supply, annual carryover and reserves available for redistribution within the plant.

Materials and Methods

The main experiment was conducted in a commercial vineyard located at McLaren Vale (site 4) in the Southern Vales district of South Australia over three years (2003/04, 2004/05 and 2005/06). The secondary experiment was conducted in a research vineyard located at the Nuriootpa Research Centre (site 5) in the Barossa Valley in South Australia. For both experiments, the experimental design, rootstocks, treatments and plant sampling have been described in the methods sections of Chapter 1.1 and 1.2. Methods for petiole sampling and chemical analyses have been described in the methods section in Chapter 1.1. At the same sampling times, for each replicate, 30 basal leaf blades left after sampling the 30 basal petioles were bagged separately as were six terminal 15 cm lengths of shoots. All such samples were stored and processed for chemical analyses as described in the Research Strategy and Method section and by Williams *et al.* (2004).

Results and Discussion

Concentrations of Mo in basal petioles for Merlot vines not sprayed with Mo were lower for own roots (0.05 mg/kg) compared with the rootstocks (0.07-0.13 mg/kg, for Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey) for 2 growing seasons at site 4 (Tables 1 and 2) and a similar trend was evident at site 5, (own roots 0.09 mg /kg and Schwarzmann 0.14 mg/kg, refer to Table 3). The unsprayed rootstocks, 110 Richter, 140 Ruggeri and Ramsey had the highest petiolar Mo concentrations in both growing seasons (0.12-0.13 mg/kg) at site 4 and these differences were recorded at both flowering and veraison (Tables 1 and 2). Pre-flowering foliar sprays of Mo increased petiolar Mo concentrations at flowering (4.2-10.3 mg/kg) for all genotypes (Tables 1-3) to well above the adequate or non responsive value of >0.45 mg/kg, as described in Chapter 4.

Table 1. Molybdenum concentrations in petioles at flowering and veraison for site 4 in 2003/04

	Flowering		Veraison	
Treatment	Unsprayed	Sprayed	Unsprayed	Sprayed
Own roots	0.05 (-1.31)	7.57 (0.86)	0.06 (-1.26)	5.76 (0.76)
Schwarzmann	0.07 (-1.16)	9.84 (0.99)	0.08 (-1.09)	8.13 (0.90)
SO4 (2136)	0.09 (-1.04)	6.73 (0.82)	0.10 (-1.01)	5.21 (0.71)
110 Richter	0.12 (-0.93)	8.55 (0.93)	0.12 (-0.94)	5.34 (0.71)
140 Ruggeri	0.13 (-0.89)	5.75 (0.75)	0.12 (-0.94)	4.28 (0.62)
Ramsey	0.12 (-0.92)	8.20 (0.91)	0.12 (-0.92)	5.24 (0.72)
LSD	(0.14)		(0.10)	

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values in parentheses refer to the interaction between treatment and rootstock, and are applicable to log-transformed data.

Table *2*. Molybdenum levels in petioles at flowering for Site 4 in 2003/04 and 2004/05

	2003/04		2004/05	
Treatment	Unsprayed	Sprayed	Unsprayed	Sprayed
Own roots	0.05 (-1.31)	7.57 (0.86)	0.05 (-1.37)	7.28 (0.85)
Schwarzmann	0.07 (-1.16)	9.84 (0.99)	0.08 (-1.11)	6.38 (0.79)
SO4 (2136)	0.09 (-1.04)	6.73 (0.82)	0.07 (-1.19)	7.30 (0.86)
110 Richter	0.12 (-0.93)	8.55 (0.93)	0.12 (-0.92)	10.28 (0.98)
140 Ruggeri	0.13 (-0.89)	5.75 (0.75)	0.12 (-0.93)	6.40 (0.79)
Ramsey	0.12 (-0.92)	8.20 (0.91)	0.12 (-0.92)	6.53 (0.81)
LSD	(0.14)		(0.16)	

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values in parentheses refer to the interaction between treatment and rootstock, and are applicable to log-transformed data.

Table 3. Molybdenum levels in petioles at flowering for site 5 in 2004/05

	Mo (mg/kg)
Mo Rate	
0	0.1 (-0.96)
250	8.9 (0.93)
500	7.0 (0.82)
LSD	(0.17)
Rootstock	
Own roots	4.2 (0.16)
Schwarzmann	6.5 (0.36)
LSD	(0.09)

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values in parentheses are applicable to log-transformed data.

Terminal 15cm growth of shoots

Molybdenum concentrations at peak flowering need to be interpreted with care on vines sprayed with Mo. Molybdenum was applied as a pre-flowering foliar spray, residues of Mo may be present on the surface of petioles. In order to minimise residue effects, the terminal 15 cm growth of shoots (which had not formed at E-L 12-18 when Mo sprays were applied) was also sampled at peak flowering and veraison. In the terminal 15 cm shoot growth Mo concentrations increased for all genotypes when pre-flowering foliar sprays of Mo were applied (Tables 4 and 5). However, the increase was least for Merlot on own roots. The magnitude of the increase was greater at peak flowering than veraison. These findings suggest that when Mo is supplied as a pre-flowering spray, Mo can be translocated (via the phloem) in grapevines and redistributed to newly formed shoot tissues. Furthermore, the rootstocks; Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey may have more effective systems to absorb, store and/or translocate foliar applied Mo to new terminal shoot tissues.

Gupta (1997) has classed Mo as variably phloem mobile from leaves in plants. This was based on findings such as reported by Jongruaysup *et al.* (1994) who suggested that Mo in *Vigna mungo* is phloem immobile at low Mo supply, but is phloem mobile in all plant parts at adequate Mo supply. Thus, foliar applied Mo may increase the supply of Mo at a time of peak demand (flowering in grapevines) and this may increase the mobility of Mo in the phloem.

Prunings

Unsprayed Merlot vine, Mo concentrations were less in the prunings on own roots (0.01 mg/kg) than for the 5 rootstocks (0.03-0.04) specified in Table 6. Application of Mo foliar sprays increased Mo concentrations in prunings to similar levels for Merlot on own roots and all rootstock genotypes (0.25-0.34 mg/kg).

Table 4. Molybdenum concentrations in terminal 15 cm growth of shoots at flowering and veraison for site 4 in 2004/05

	Flowering		Veraison	
Treatment	Unsprayed	Sprayed	Unsprayed	Sprayed
Own roots	0.04 (-1.47)	0.85 (-0.10)	0.03 (-1.62)	0.05 (-1.28)
Schwarzmann	0.04 (-1.44)	1.09 (0.02)	0.04 (-1.45)	0.08 (-1.10)
SO4 (2136)	0.03 (-1.49)	0.82 (-0.10)	0.04 (-1.41)	0.08 (-1.09)
110 Richter	0.06 (-1.23)	0.74 (-0.14)	0.05 (-1.29)	0.08 (-1.09)
140 Ruggeri	0.05 (-1.34)	0.89 (-0.16)	0.05 (-1.28)	0.13 (-0.91)
Ramsey	0.06 (-1.27)	0.62 (-0.22)	0.06 (-1.26)	0.09 (-1.05)
LSD	(0.19)		No interaction	

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values in parentheses refer to the interaction between treatment and rootstock, and are applicable to log-transformed data.

Table 5. Molybdenum levels in terminal 15 cm growth of shoots at veraison for site 4 in 2003/04 and 2004/05

	2003/04	2004/05
Treatment		
Unsprayed	0.053	0.044 (-1.38)
Sprayed	0.085	0.087 (-1.09)
LSD	0.018	(0.12)
Rootstock		
Own roots	0.049	0.039 (-1.45)
Schwarzmann	0.070	0.059 (-1.28)
SO4 (2136)	0.073	0.062 (-1.25)
110 Richter	0.077	0.068 (-1.19)
140 Ruggeri	0.072	0.091 (-1.20)
Ramsey	0.073	0.074 (-1.15)
LSD	0.014	(0.12)

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values in parentheses are applicable to log-transformed data.

Table *6*. Molybdenum levels in prunings for site 4 in 2004/05

Treatment	Mo (mg/kg)	
	Unsprayed	Sprayed
Own roots	0.01 (-1.86)	0.34 (-0.47)
Schwarzmann	0.03 (-1.56)	0.33 (-0.52)
SO4 (2136)	0.03 (-1.57)	0.25 (-0.62)
110 Richter	0.04 (-1.42)	0.28 (-0.57)
140 Ruggeri	0.04 (-1.38)	0.30 (-0.57)
Ramsey	0.04 (-1.44)	0.27 (-0.57)
LSD		(0.19)

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values in parentheses refer to the interaction between treatment and rootstock, and are applicable to log-transformed data.

Leaf blades

The leaf blades had the highest Mo concentrations compared with leaf petioles (Figure 1) and terminal 15 cm growth of shoots the lowest (Table 7). Since Mo had not been applied to the sprayed treatments since spring 2004, over 12 months before peak flowering in 2005, this indicates there has been carryover of Mo reserves over the previous winter for use in the following season (2005/06). Furthermore, leaf blades may be a useful indicator of plant Mo status and future research should examine this prospect.

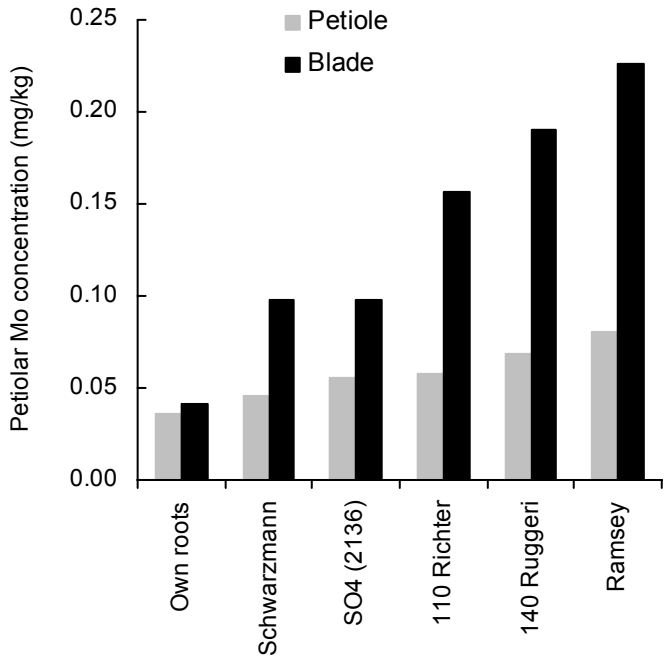


Figure 1. Comparison of Mo concentration in petioles and leaf blades at peak bloom for Merlot vines on the rootstocks specified in the 2005/06 growing season at site 4.

Table 7. Molybdenum levels in petioles, leaf blades and terminal 15 cm growth of shoots at flowering for site 4 in 2005/06

	Petioles	Blades	Terminal 15 cm of Shoot
Treatment			
Unsprayed	0.06	0.13	0.02
Sprayed	0.06	0.17	0.03
Significance	NS	*	NS
LSD		0.04	
Rootstock			
Own roots	0.03	0.06	0.01
Schwarzmann	0.05	0.11	0.02
SO4 (2136)	0.05	0.11	0.02
110 Richter	0.07	0.18	0.03
140 Ruggeri	0.08	0.23	0.03
Ramsey	0.09	0.24	0.03
Significance	***	***	**
LSD	0.01	0.03	0.01

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

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1.4 Effect of molybdenum and rootstock on nutrient composition of leaf petioles of Merlot grapevines

Chris Williams and Kerry Porter

Abstract

Field experiments were conducted to evaluate the effects of Mo foliar sprays on the concentrations of 12 other nutrients (eg. nitrogen, phosphorus, potassium, calcium, boron) in leaf petioles of Merlot on different rootstocks compared to own roots. Little information is available on the effects of application of Mo to different rootstocks compared with own roots on the potential impact, if any, on the profile of other nutrients in leaf petioles as this may affect plant nutrient needs and juice quality.

The effects of foliar applied Mo on the concentrations of other nutrients in basal petioles sampled at peak flowering were small and of little practical importance. Similar results were reported in chapter 2, in which the affects of Mo foliar sprays on petiolar composition of other nutrients were limited and secondary compared with the affects of different growing seasons.

Rootstocks *per se* affected the concentration of several nutrients in petioles at peak flowering. These differences were often variable between growing seasons and especially between sites. For example, petiolar K concentrations for Merlot on own roots (4.7 - 4.9%) were higher than for Merlot on the rootstocks (Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey), (1.6 - 3.6%) at site 4. However, at site 5, Merlot on own roots and on Schwarzmann had similar petiolar K concentrations (3.3 – 3.6%). Calcium and Mg petiolar concentrations were greater for Merlot on own roots than for Merlot on Schwarzmann at each site/year, but the magnitude of these differences for Ca and Mg is unlikely to influence rootstock selection *per se*.

This indicates that Mo foliar sprays as used in these experiments, was not associated with major changes in the concentrations of 12 other nutrients in petioles at peak flowering.

Introduction

Several characteristics of rootstocks need to be considered when selecting a rootstock/scion combination for a specific site (May 1994; PGIBSA 2003). In South Australia, the major rootstocks used have been chosen for their tolerance to phylloxera, nematodes, salinity, drought or waterlogging, lime or acid soils (PGIBSA 2003). The rootstock can significantly affect the nutritional status of the scion, petiole nutrient content, vine vigour and production, grape and wine quality (Ruhl *et al.* 1988; Avenant *et al.* 1997; Candolfi-Vasconcelos *et al.* 1997).

Little information is available on the effects of application of Mo to different rootstocks compared with own roots on the contents of other nutrients in petioles. It is important to obtain data on the potential impact, if any, of Mo foliar sprays on the profile of other nutrients in petioles as this may affect plant nutrient needs and juice quality. Field experiments were conducted to evaluate the effects of Mo foliar sprays on the concentrations of 12 other nutrients in leaf petioles of Merlot on different rootstocks compared to own roots.

Materials and Methods

The main experiment was conducted in a commercial vineyard located at McLaren Vale (site 1) in the Southern Vales district of South Australia over three growing seasons (2003/04, 2004/05 and 2005/06). The second experiment was conducted in a research vineyard located at the Nuriootpa Research Centre (site 5) in the Barossa Valley in South Australia. For both experiments, the design, rootstocks, treatments, petiole sampling and chemical analyses have been described in the methods section in chapter 1.1 and 1.2.

Results and Discussion

Boron (B) and zinc (Zn) have been reported to affect pollination and fertilisation of grapevine flowers and therefore berry formation including the incidence of millarandage ('hens and chickens'), (Gartel 1993; Sharma *et al.* 1995). The application of Mo did not affect petiolar B, except at site 4 in 2003/04 when B was reduced by 5% (Tables 1a, b and 2). At site 5, applied Mo did not affect petiolar B concentrations, but did increase Zn concentrations (Table 2). However, these changes in B and Zn concentrations were small and of little practical significance. Boron concentrations in petioles sampled at flowering (Tables 1b, 2 and 3) were adequate at both sites when compared with diagnostic standards (> 35 mg/kg) reported by Robinson *et al.* (1997) **.** Petiolar Zn was adequate at site 4 and marginal at site 5 when compared with the standards listed by Robinson *et al.* (1997).

Table 1a. **Main effects of Mo application on petiolar nutrient composition at flowering for site 4 in 2003/04 and 2004/05**

	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05
TREATMENT						
Unsprayed	1.8	1.4	0.71	0.65	3.0	3.3
Sprayed	1.7	1.5	0.66	0.68	2.6	3.4
Significance	NS	NS	**	NS	**	NS
LSD			0.02		0.1	
ROOTSTOCK						
Own roots	1.7	1.4	0.64	0.55	4.7	4.9
Schwarzmann	1.5	1.2	0.59	0.51	2.8	3.6
SO4 (2136)	1.5	1.2	0.63	0.60	2.6	3.3
110 Richter	1.6	1.2	0.71	0.75	1.6	2.1
140 Ruggeri	1.8	1.5	0.72	0.77	2.3	2.9
Ramsey	2.4	2.2	0.80	0.80	2.6	3.3
Significance	***	***	***	***	***	***
LSD	0.3	0.3	0.06	0.09	0.2	0.5
	Calcium (%)		Magnesium (%)		Sodium (%)	
	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05
TREATMENT						
Unsprayed	1.6	1.8	0.43	0.56	0.11	0.09
Sprayed	1.6	1.8	0.40	0.54	0.10	0.09
Significance	NS	NS	NS	NS	NS	NS
LSD						
ROOTSTOCK						
Own roots	1.8	2.1	0.51	0.68	0.10	0.09
Schwarzmann	1.5	1.7	0.36	0.47	0.12	0.09
SO4 (2136)	1.7	1.9	0.33	0.49	0.12	0.10
110 Richter	1.4	1.6	0.37	0.45	0.10	0.09
140 Ruggeri	1.5	1.7	0.44	0.58	0.09	0.09
Ramsey	1.5	1.7	0.46	0.63	0.10	0.09
Significance	***	***	***	***	**	NS
LSD	0.1	0.3	0.05	0.10	0.02	

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Table 1b. **Main effects of Mo application on petiolar nutrient composition at flowering for site 4 in 2003/04 and 2004/05**

	Sulphur (%)		Boron (mg/kg)		Copper (mg/kg)	
	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05
TREATMENT						
Unsprayed	0.20	0.20	44	43	16	14
Sprayed	0.18	0.20	42	41	15	14
Significance	NS	NS	**	NS	NS	NS
LSD			1			
ROOTSTOCK						
Own roots	0.24	0.23	48	44	17	15
Schwarzmann	0.15	0.14	39	37	9	8
SO4 (2136)	0.19	0.20	41	41	12	10
110 Richter	0.13	0.16	44	43	17	16
140 Ruggeri	0.18	0.21	43	43	17	16
Ramsey	0.27	0.27	44	44	21	20
Significance	***	***	***	***	***	***
LSD	0.02	0.02	2	2	2	2
	Zinc (mg/kg)		Manganese (mg/kg)		Iron (mg/kg)	
	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05
TREATMENT						
Unsprayed	53	45	42	41	21	19
Sprayed	49	45	40	40	22	19
Significance	NS	NS	NS	NS	NS	NS
LSD						
ROOTSTOCK						
Own roots	42	30	37	38	18	17
Schwarzmann	36	27	44	41	28	17
SO4 (2136)	48	38	39	37	22	20
110 Richter	53	53	44	46	18	19
140 Ruggeri	53	50	41	47	20	22
Ramsey	76	71	39	36	23	20
Significance	***	***	NS	**	NS	**
LSD	7	9		4		3

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Cook (1966) reported B deficiency symptoms, including millerandage, were often associated with B levels of 26-28 mg/kg in leaf blades or petioles at flowering. Concentrations of B > 30 mg/kg during flowering were adequate.

Table 2. **Interaction between Mo application and rootstock for Boron concentration in petioles at flowering in 2004/05 at site 4**

	Boron (mg/kg)	
Treatment	Unsprayed	Sprayed
Own roots	46	42
Schwarzmann	37	37
SO4 (2136)	40	42
110 Richter	44	42
140 Ruggeri	44	42
Ramsey	46	43
LSD	2	

Comparison of the nutrient concentrations at flowering (Tables 1-3) with the interpretation standards reported by Robinson *et al.* (1997) revealed that concentrations were in the adequate to high range for 11 nutrients, at both sites, except for Zn which was marginal at site 5.

The application of Mo affected the concentration of some nutrients (Tables 1-3). However, the changes were small and of little practical significance. Similar results were reported in chapter 2, in which the affects of Mo foliar sprays on petiolar composition of other nutrients were limited and secondary compared with the affects of different growing seasons. This is consistent with the findings of Williams *et al.* (2004) and the observation that vegetative growth was not affected (Chapter 1.1). If Mo application had affected vegetative growth and dry matter production, greater growth dilution effects on nutrient concentrations may have been expected.

Rootstocks *per se* affected the concentration of several nutrients in petioles at peak flowering (Tables 1-3), however, these differences were often variable between growing seasons and especially between sites. For example, petiolar K concentrations for Merlot on own roots (4.7 - 4.9%) were higher than for Merlot on the rootstocks, Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey (1.6 - 3.6%), at site 4. At site 5, Merlot on own roots and on Schwarzmann had similar petiolar K concentrations (3.3 – 3.6%). These differences in K provide evidence to support the need to consider differences between rootstocks when deriving nutrient standards (Hayes and Mannini 1988).

It is interesting to note that petiolar Ca and Mg concentrations were greater for Merlot on own roots than for Merlot on Schwarzmann at each site/year (Tables 1-3), but the magnitude of these differences is unlikely to influence rootstock selection *per se*.

Table 3. Main effects of Mo application on petiolar nutrient composition at flowering for site 5 in 2004/05

Mo RATE	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)
0	1.1	0.50	3.5	1.7
250	1.0	0.52	3.5	1.6
500	1.1	0.52	3.4	1.7
Significance	NS	NS	NS	NS
LSD				
ROOTSTOCK				
Own roots	1.2	0.50	3.6	1.9
Schwarzmann	1.0	0.53	3.3	1.4
Significance	**	NS	NS	**
LSD	0.1			0.1

Mo RATE	Magnesium (%)	Sodium (%)	Sulfur (%)	Boron (mg/kg)
0	0.59	0.06	0.18	35
250	0.60	0.07	0.18	36
500	0.64	0.07	0.18	36
Significance	NS	*	NS	NS
LSD		0.01		
ROOTSTOCK				
Own roots	0.82	0.07	0.24	35
Schwarzmann	0.40	0.06	0.12	35
Significance	***	NS	***	NS
LSD	0.01		0.01	

Mo RATE	Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
0	112	14	39	15
250	87	15	32	15
500	87	16	33	22
Significance	*	*	*	NS
LSD	20	2	5	
ROOTSTOCK				
Own roots	112	15	36	20
Schwarzmann	78	15	34	14
Significance	**	NS	NS	NS
LSD	19			

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

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Chapter 2

2 Effects of applied molybdenum on yield and petiole nutrient composition of Merlot grapevines over time

Kerry. Porter, Norbert Maier, Chris Williams and Louise Chvyl

Abstract

The effect of consecutive annual Mo sprays for up to five years on Mo concentrations and bunch yields were measured in four field experiments in commercial vineyards in the Mount Lofty Ranges of South Australia. Two foliar sprays of Mo (118 g/ha) were applied before flowering, and yield results were recorded at harvest each year. Basal petioles were sampled at flowering and veraison for nutrient analyses. Yield per vine and bunch weight were higher for sprayed vines than for unsprayed vines over the experimental period at all sites, and yield per vine, bunch weight and number of bunches per vine all varied significantly between years. An interaction was apparent between Mo treatments and years for petiolar Mo concentrations and was due to variations in the difference between sprayed and unsprayed results in each year. The concentration of Mo in petioles from sprayed vines was much higher than that from unsprayed vines at all sites. Concentrations of some of the other nutrients analysed from petioles differed between Mo treatments but almost all were significantly different between years.

Applied Mo had major effects on bunch yield in some years at certain sites when Mo was deficient. In other years or at different sites, when Mo concentrations were adequate in unsprayed vines, there were no benefits to yield from the application of Mo. The large variations between the years, in particular for the yield and nutrient results, suggest that in addition to Mo other factors have significant impacts on yield, such as climatic stresses, for example periods of low temperatures around flowering.

Introduction

Foliar applications of molybdenum (Mo) to Mo deficient grapevines have been shown to reduce the effects of fruit set disorders in Merlot grapevines, resulting in increased yields (Gridley 2003; Williams *et al.* 2003; Longbottom *et al.* 2004; Williams *et al.* 2004). It is likely that grapevines prone to these disorders may receive Mo applications each season, but little is known about the effects this may have on the vines, yields and nutrient uptake after a number of years.

Field trials, which were part of an earlier study (funded by CRCV) investigating Mo deficiency and the "Merlot" problem in the Mt Lofty Ranges in South Australia, were continued in this project for a further one or two years, giving either four or five year's data from the same sites. This presented an opportunity to examine the effects, if any, of annual Mo applications over several consecutive years on the yield and nutrient status of the grapevines.

Materials and Methods

The experiments were conducted in three commercial vineyards during the period 2000/01 to 2004/05. The vineyards were located at Lower Hermitage (site 1), Meadows (site 2), and Kuitpo (site 3) in the Mount Lofty Ranges of South Australia, which has a temperate climate of cool, wet winters and warm to hot, dry summers (Maschmedt 1987). The experiments

were carried out at sites 1 and 3 for five years from 2000/01 to 2004/05, and at site 2 for four years from 2000/01 to 2003/04.

At each site, the experimental plots contained Merlot vines (clone D3V14) on own roots, planted in 1996 or 1997, and trained to a single vertical plane trellis with two foliage wires and vertical shoot position. Vines were spur pruned with two bud spurs at sites 1 and 3 and three bud spurs at site 2. Inter- and intra-row spacings between plants were 2.7 and 1.8 m at site 1, 2.4 and 1.5 m at site 2, and 2.7 and 1.5 m at site 3. All plantings were drip irrigated, and irrigation, pest and disease control were carried out according to growers' normal practices. Apart from molybdenum treatments, no fertilisers were applied to grapevines at sites 1 and 2 during the experimental period.

Sprayed treatment plots at each site received two applications of sodium molybdate (39.65% Mo) each year, the first at growth stage E-L 12-15 and the second at growth stage E-L 16-18. Each spray applied Mo at a rate of 118 g/ha and the entire canopy was sprayed to the point of runoff. Waterproof plastic covers were placed over the unsprayed treatment plots to protect them from contamination during spraying.

Soil samples to a depth of 45 cm were collected from each site, using a 7.5 cm auger, in January 2001. Samples of the topsoils (0-15 cm) at each site were also collected in either December or January in years 2 and 3. Samples were air-dried and ground to <2 mm prior to analysis for pH, cation exchange capacity (CEC), organic carbon (C), and bicarbonate-extractable phosphorus (P) and potassium (K), using methods as described by (Maier *et al.* 1994).

A minimum of 30 petioles (leaf stalks) from leaves opposite basal bunches was collected from each replicate at growth stage E-L 23-25 (flowering) and growth stage E-L 35 (veraison). Petioles were stored under frozen cooler blocks in insulated containers after collection and during transportation. In the laboratory, petioles were dried at 60-70 °C and then ground to <1 mm in preparation for chemical analysis. Petiole samples were then analysed for chemical composition as described in Williams *et al.* (2004).

Experimental plots were harvested in either March or April each year, as listed in Table 1. At harvest, the number of bunches was counted, total weight recorded, and the mean bunch weight calculated for each plot.

Table 1. Dates on which grapes were harvested at sites 1 and 3 for five years and site 2 for four years.

	site 1	site 2	site 3
Year 1	8 March 2001	27 March 2001	28 March 2001
Year 2	20 March 2002	30 April 2002	4 April 2002
Year 3	17 March 2003	11 April 2003	11 April 2003
Year 4	18 March 2004	31 March 2004	30 March 2004
Year 5	17 March 2005		18 March 2005

At each site, the experiment was set out as a randomised complete block design with the sprayed and unsprayed plots replicated four times. The experimental plots consisted of 12, six or eight vines at sites 1, 2 and 3, respectively. The data for all variables were analysed for variance between treatments and years within each site. Petiole molybdenum concentration data were not normally distributed and required log-transformation prior to analysis of variance. Significant differences between treatments and years were calculated using the least significant difference (LSD) test at the 5% level of probability.

Results and Discussion

Soil chemical properties

Some chemical properties of the soils from each site are given in Table 2. All sites had moderate to strong acid topsoils (0-15 cm) with the pH_{Ca} values in the range 4.5 to 5.2. Texture of the topsoils ranged from sandy loam at site 1 and fine sandy loam at site 2 to loam at site 3. Organic C and bicarbonate-extractable P were higher in the topsoils compared with the subsoils.

Changes in topsoil acidity between years 1 and 3 were noted at all three sites. At sites 1 and 3 the changes were small, with pH_{Ca} increasing at site 1 from 4.7 to 4.9 and decreasing at site 3 from 4.5 to 4.3. At site 2 the pH_{Ca} increased from 5.2 in year 1 to 6.0 in year 2 and then decreased to 5.7 in year 3. Soil pH is an important factor affecting Mo availability to plants and Mo deficiency is often associated with acid soils (Brennan and Bruce 1999). Comparing yield responses to Mo application with the changes in pH_{Ca}, however, suggests that soil pH did not have a major effect on these results.

Table 2 . Selected chemical properties of the soils at each site.

Depth (cm)	pH_{Ca}	CEC[a] (meq/100g)	Organic C (g/kg)	HCO_3 P (mg/kg)	HCO_3 K (mg/kg)
		site 1			
0-15	4.7	5.45	13.8	27	224
15-30	4.8	5.29	11.2	10	149
30-45	4.9	5.32	7.4	10	121
		site 2			
0-15	5.2	9.01	30.2	25	150
15-30	5.0	10.05	12.2	15	191
30-45	4.9	5.61	8.6	12	156
		site 3			
0-15	4.5	4.55	26.5	22	90
15-30	4.4	4.09	17.2	12	70
30-45	4.5	5.08	8.3	7	63

[a]Sum of exchangeable Ca, Mg, K, Na in meq/100 g of soil.

Yield response

Yields from vines sprayed with Mo were significantly higher than yields from unsprayed vines at each site when averaged over the four or five year study period (Table 3). These results support findings by Williams *et al*. (2004) that foliar application of Mo produced increased yields in vines considered to be Mo deficient. Yields for sprayed and unsprayed vines in each year are shown in Figure 1 and illustrate that whilst differences between the two treatments varied from year to year, yields from sprayed vines were either the same as or greater than yields from unsprayed vines in all years. Average yields at each site varied between years, with yields in year 4 being significantly higher than those in other years at all sites. A significant interaction between Mo treatment and year was found for yield at site 1

and is due to the large difference between sprayed and unsprayed vines in year 2 in comparison to the difference in the other years.

The average bunch weight was significantly higher for sprayed vines than for unsprayed vines at sites 1 and 3 over five years (Table 3). At site 2 the average bunch weight from sprayed vines was higher than that from unsprayed vines over four years, but was not statistically significant. Williams *et al*. (2004) found that Mo application increased the weight of coloured berries in bunches and this is the most likely explanation for the higher average bunch weights (and yields) shown in these results. Significant differences in bunch weight were found between years at each site, with the highest bunch weight occurring in year 4 at all three sites. The major differences in the bunch weight results correspond to those in the yield results suggesting that the higher yields are directly related to the higher bunch weights. Significant interactions between Mo treatments and years were found at sites 1 and 3, and are due to the variation in magnitude of the difference between sprayed and unsprayed results in each of the years (Figure 2).

The number of bunches per vine was significantly higher for sprayed vines than for unsprayed vines over years at site 2 only. A similar lack of effect of Mo application on number of bunches was recorded by Longbottom *et al*. (2004) and Williams *et al*. (2004). Significant differences in the number of bunches were found between years, with year 4 having the highest number at sites 1 and 2 and year 1 having the highest at site 3. The interaction between Mo treatment and year for number of bunches was not significant.

For all three of the yield parameters, the variations between the years were greater than the differences between the treatments.

Table 3. Average yield and number of bunches per vine, and weight per bunch over five years for sites 1 and 3, and four years for site 2

	site 1	site 2	site 3
	Yield (kg/vine)		
Unsprayed	4.5	2.8	4.1
Sprayed	5.7	3.5	5.2
Significance	**	*	*
LSD (P=0.05)	0.6	0.7	0.9
Year 1	1.0	2.4	6.0
Year 2	3.0	1.0	1.9
Year 3	4.4	1.5	3.1
Year 4	10.9	7.7	8.7
Year 5	6.3		3.8
Significance	***	***	***
LSD (P=0.05)	0.9	0.9	1.2
Interaction			
Significance	*	NS	NS
LSD (P=0.05)	1.2		
	Bunch Weight (g)		
Unsprayed	63.1	59.3	62.0
Sprayed	91.8	67.3	78.7
Significance	**	NS	*
LSD (P=0.05)	9.9		13.3
Year 1	76.5	81.3	60.4
Year 2	55.5	18.7	31.0
Year 3	77.6	45.0	68.0
Year 4	105.1	108.2	113.0
Year 5	72.4		79.5
Significance	**	***	***
LSD (P=0.05)	16.4	16.2	11.0
Interaction			
Significance	*	NS	*
LSD (P=0.05)	21.7		17.0
	Number of bunches (per vine)		
Unsprayed	68.4	39.0	65.0
Sprayed	59.7	49.6	68.1
Significance	NS	*	NS
LSD (P=0.05)		7.7	
Year 1	13.5	28.9	97.6
Year 2	55.7	42.2	59.7
Year 3	57.4	32.8	51.2
Year 4	105.5	73.1	76.1
Year 5	88.0		48.1
Significance	***	**	***
LSD (P=0.05)	11.3	19.4	8.3
Interaction			
Significance	NS	NS	NS

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

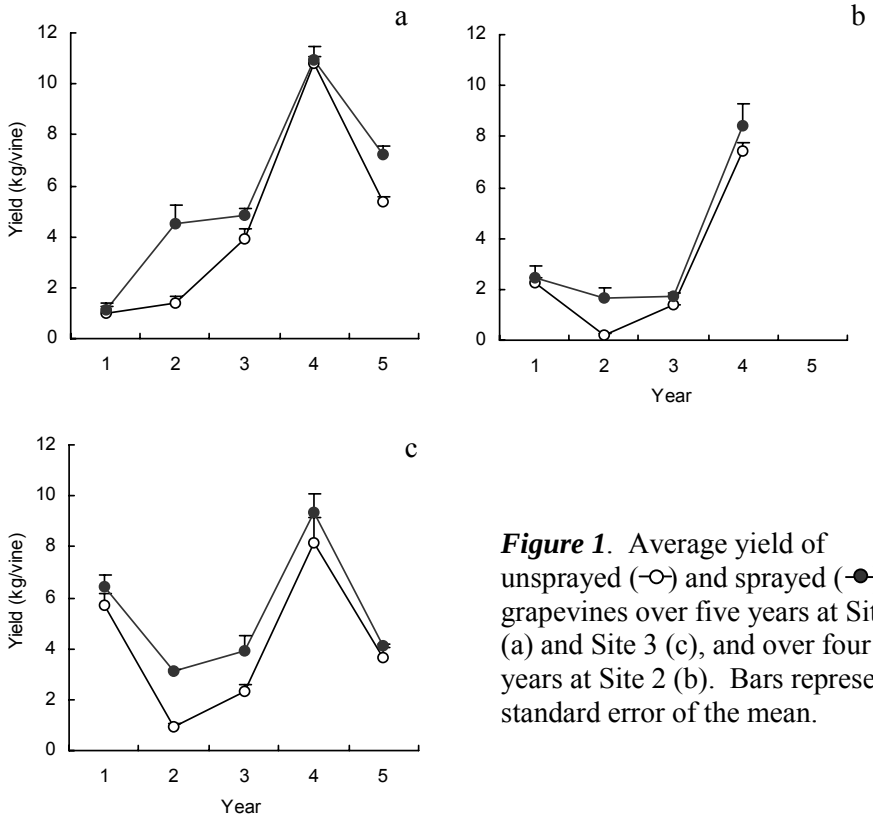


Figure 1. Average yield of unsprayed (-○-) and sprayed (-●-) grapevines over five years at Site 1 (a) and Site 3 (c), and over four years at Site 2 (b). Bars represent standard error of the mean.

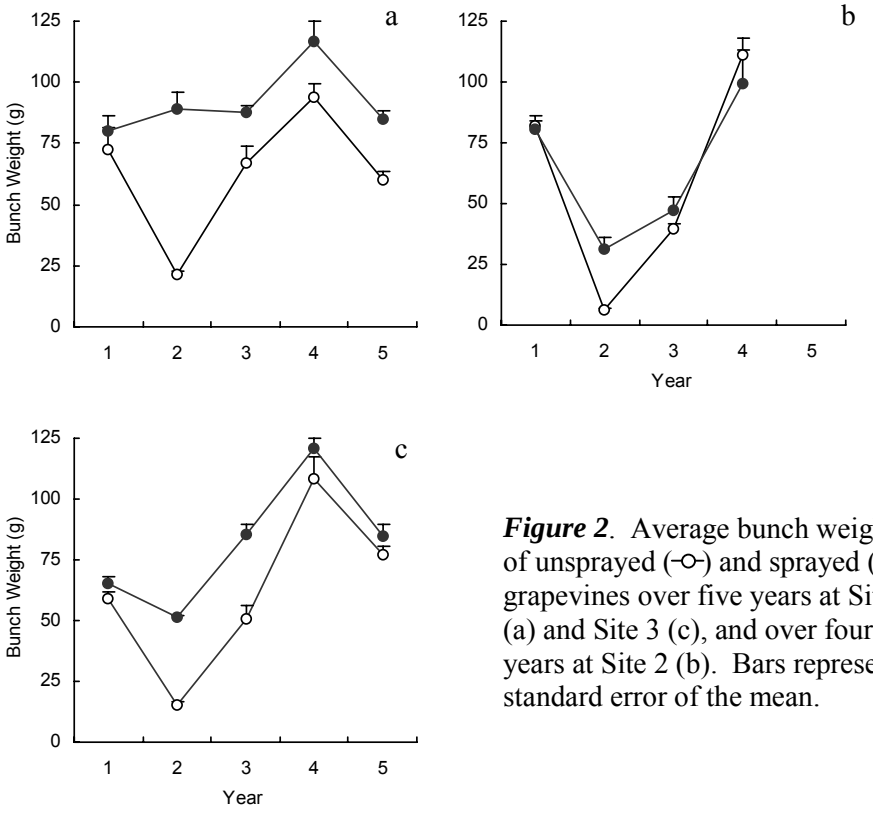


Figure 2. Average bunch weight of unsprayed (-○-) and sprayed (-●-) grapevines over five years at Site 1 (a) and Site 3 (c), and over four years at Site 2 (b). Bars represent standard error of the mean.

Petiolar molybdenum concentrations

There was a significant interaction between Mo treatment and years for petiolar molybdenum concentrations at all sites (Table 4). The interaction is again due to variation in magnitude of the difference between the sprayed and unsprayed results in each year. Concentrations in petioles from sprayed vines were higher than those from unsprayed vines, and concentrations varied between years. The elevated concentrations found in petioles from sprayed vines should be viewed with some caution, as it is not known how much is attributable to absorption by the foliage and how much may have been spray residue on the outer surface of the petioles. Longbottom *et al*. (2004) and Williams *et al*. (2004) recorded higher petiolar Mo concentrations from vines that received pre-flowering foliar applications of Mo when compared to control vines.

Table 4. Molybdenum levels in petioles sampled at flowering at sites 1 and 2 for four years, and site 3 for five years

	site 1	site 2	site 3
		Unsprayed	
Year 1		0.46 (-0.35)	0.12 (-0.94)
Year 2	0.08 (-1.17)	0.05 (-1.30)	0.05 (-1.32)
Year 3	0.39 (-0.42)	0.24 (-0.67)	0.09 (-1.08)
Year 4	0.63 (-0.33)	0.31 (-0.52)	0.33 (-0.55)
Year 5	0.07 (-1.19)		0.48 (-0.34)
		Sprayed	
Year 1		25.04 (1.39)	2.10 (0.32)
Year 2	20.56 (1.32)	10.20 (1.00)	8.06 (0.91)
Year 3	7.40 (0.86)	3.73 (0.56)	6.05 (0.78)
Year 4	8.66 (0.93)	20.17 (1.30)	4.42 (0.64)
Year 5	1.46 (0.16)		11.63 (1.06)
LSD	(0.33)	(0.26)	(0.22)

Values in parentheses are means obtained from analysis of variance of log-transformed data.
The LSD values (P=0.05) in parentheses refer to the interaction between treatment and year, and are applicable to log-transformed data.

Concentrations in petioles from the unsprayed vines varied widely from year to year, but were similarly low at all sites in year 2 (Figure 3). This suggests that Mo concentrations in grapevines are subject to a number of external factors that may affect the availability and/or uptake of Mo. Williams *et al*. (2004) suggested that these factors might be climatic.

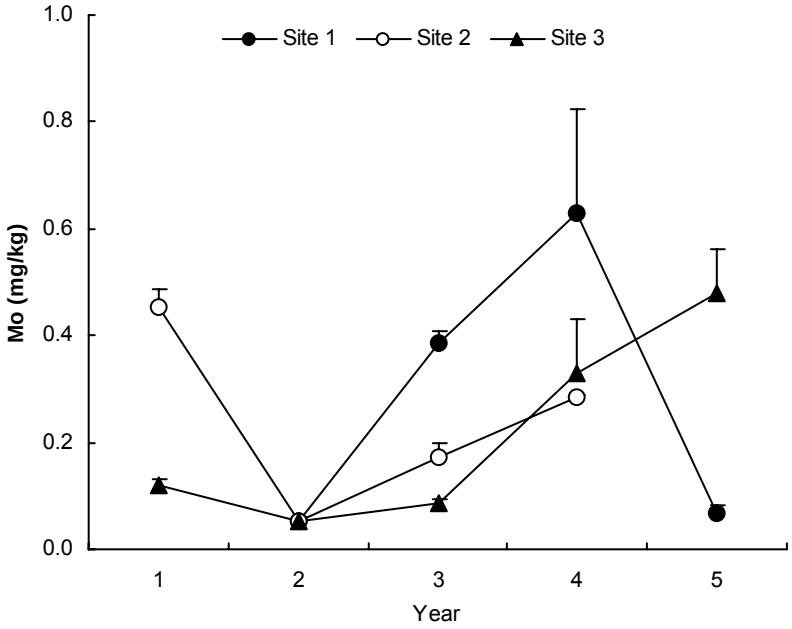


Figure 3. Average Molybdenum concentrations in petioles sampled from unsprayed grapevines at flowering (E-L 23-25). Bars represent the standard error of the mean.

Petiolar nutrient composition

Concentrations of various nutrients present in petioles at flowering are shown in Tables 5.1 (a) and (b), and at veraison in Tables 5.2 (a) and (b). Significant differences between Mo treatments were recorded for several of the nutrient concentrations at flowering when averaged over the experimental period. These differences, however, are not consistent across the sites and are small when compared to the differences recorded between the years, which for most nutrients were significant. Only two of the nutrients, copper and iron, measured at veraison showed significant different between Mo treatments whilst all nutrients, except for iron, were significantly differences between years. A comparison of nutrient concentrations between flowering and veraison indicate the role of particular nutrients in the grapevine during this time.

Nutrient concentrations at flowering were in the adequate or high categories in most years, according to interpretation standards reported by Robinson *et al.* (1997).

Positive yield responses over the 4–5 year period indicate that annual foliar applications of Mo prior to flowering for Mo deficient vines produce higher yields compared to those from unsprayed vines. Variations between years, however, were substantial for almost all results and were generally greater than those between the sprayed and unsprayed treatments. This suggests that over time other factors, such as the unpredictable incidence of climatic stress conditions (eg. cold, wet or very hot, dry periods) can also have significant impacts on yield and on the nutrient composition of Merlot grapevines.

Table 5.1(a). Levels of various nutrients in petioles sampled at flowering at sites 1 and 2 for four years, and at site 3 for five years

	Nitrogen (%)			Phosphorus (%)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	0.97	1.12	0.83	0.33	0.47	0.48
Sprayed	1.09	1.08	0.87	0.34	0.47	0.41
Significance	NS	NS	*	NS	NS	NS
LSD			0.02			
Year 1		1.19	0.81		0.52	0.46
Year 2	1.28	0.99	0.90	0.13	0.17	0.21
Year 3	1.26	1.33	1.13	0.57	0.59	0.60
Year 4	0.72	0.89	0.69	0.52	0.60	0.50
Year 5	0.86		0.72	0.12		0.46
Significance	***	**	***	***	***	***
LSD (P = 0.05)	0.19	0.17	0.06	0.13	0.09	0.07
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Potassium (%)			Calcium (%)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	5.04	5.02	2.86	1.52	1.43	1.55
Sprayed	4.98	4.48	2.73	1.38	1.38	1.51
Significance	NS	NS	NS	*	NS	NS
LSD				0.12		
Year 1		4.41	2.38		1.31	1.30
Year 2	6.10	4.83	2.52	1.36	1.47	1.43
Year 3	4.90	5.61	2.85	1.56	1.49	1.94
Year 4	3.91	4.14	2.50	1.43	1.35	1.56
Year 5	5.13		3.73	1.46		1.43
Significance	***	***	***	**	NS	***
LSD (P = 0.05)	0.46	0.33	0.39	0.10		0.12
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Magnesium (%)			Sodium (%)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	0.66	0.40	0.83	0.09	0.17	0.11
Sprayed	0.69	0.43	0.75	0.08	0.17	0.11
Significance	NS	NS	NS	*	NS	NS
LSD				0.01		
Year 1		0.36	0.73		0.20	0.10
Year 2	0.61	0.39	0.70	0.13	0.25	0.14
Year 3	0.82	0.44	1.13	0.09	0.09	0.09
Year 4	0.70	0.48	0.82	0.07	0.15	0.08
Year 5	0.58		0.58	0.05		0.13
Significance	***	*	***	***	***	***
LSD (P = 0.05)	0.07	0.07	0.08	0.01	0.04	0.01
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

Table 5.1(b). Levels of various nutrients in petioles sampled at flowering at sites 1 and 2 for four years, and at site 3 for five years

	Sulphur (%)			Boron (mg/kg)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	0.14	0.17	0.20	40	42	40
Sprayed	0.17	0.17	0.20	39	41	40
Significance	*	NS	NS	NS	**	NS
LSD	0.03				0.2	
Year 1		0.20	0.17		42	42
Year 2	0.14	0.13	0.17	43	50	41
Year 3	0.19	0.19	0.25	39	37	44
Year 4	0.19	0.18	0.19	38	37	37
Year 5	0.11		0.23	38		38
Significance	***	***	***	***	***	***
LSD	0.01	0.02	0.02	2	2	1
Interaction						
Significance	**	NS	NS	NS	NS	NS
LSD	0.01					
	Copper (mg/kg)			Zinc (mg/kg)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	26	33	114	73	94	85
Sprayed	23	28	100	71	89	81
Significance	NS	NS	*	NS	**	NS
LSD			13		2	
Year 1		38	38		71	73
Year 2	54	30	260	70	105	62
Year 3	15	28	118	78	123	89
Year 4	16	27	55	78	67	75
Year 5	13		65	63		114
Significance	***	***	***	*	***	***
LSD	6	4	16	8	16	9
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Manganese (mg/kg)			Iron (mg/kg)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	184	92	107	27	34	32
Sprayed	21	96	99	24	34	27
Significance	NS	NS	NS	NS	NS	*
LSD						4
Year 1		122	136		33	21
Year 2	177	85	58	28	39	28
Year 3	238	97	107	31	26	33
Year 4	298	71	118	24	38	32
Year 5	98		95	18		34
Significance	***	***	***	NS	**	**
LSD	35	16	18		6	7
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

Table 5.2(a). Concentrations of various nutrients in petioles sampled at veraison at sites 1 and 3 for five years (excluding N at site 1), and at site 3 for four years

	Nitrogen (%)			Phosphorus (%)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	0.46	0.50	0.47	0.15	0.21	0.21
Sprayed	0.47	0.50	0.47	0.15	0.22	0.18
Significance	NS	NS	NS	NS	NS	NS
LSD						
Year 1	0.42	0.48	0.46	0.08	0.15	0.21
Year 2	0.46	0.49	0.46	0.06	0.09	0.07
Year 3	0.51	0.55	0.51	0.29	0.31	0.20
Year 4	0.45	0.48	0.42	0.27	0.32	0.22
Year 5			0.49	0.06		0.29
Significance	**	**	**	*	***	***
LSD	0.04	0.04	0.03	0.13	0.09	0.06
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Potassium (%)			Calcium (%)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	5.42	5.83	2.61	1.60	1.53	1.49
Sprayed	5.70	5.71	2.20	1.55	1.49	1.41
Significance	NS	NS	NS	NS	NS	NS
LSD						
Year 1	4.90	5.55	2.11	1.47	1.38	1.21
Year 2	5.96	6.00	1.64	1.56	1.55	1.39
Year 3	6.24	6.28	2.35	1.82	1.64	1.56
Year 4	4.26	5.28	2.30	1.58	1.47	1.53
Year 5	6.44		3.62	1.45		1.48
Significance	***	***	**	***	**	***
LSD	0.57	0.32	0.65	0.09	0.09	0.08
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Magnesium (%)			Sodium (%)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	1.01	0.78	1.45	0.13	0.38	0.22
Sprayed	1.02	0.83	1.35	0.14	0.39	0.22
Significance	NS	NS	NS	NS	NS	NS
LSD						
Year 1	0.77	0.69	1.11	0.14	0.36	0.17
Year 2	0.99	0.81	1.5	0.14	0.46	0.21
Year 3	1.19	0.95	1.67	0.14	0.33	0.17
Year 4	1.22	0.77	1.45	0.15	0.39	0.19
Year 5	0.91		1.28	0.11		0.36
Significance	***	**	*	*	**	***
LSD	0.13	0.10	0.30	0.02	0.05	0.04
Interaction						
Significance	NS	NS	NS	*	NS	NS
LSD				0.03		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

Table 5.2(b). Concentrations of various nutrients in petioles sampled at veraison at sites 1 and 3 for five years and at site 3 for four years

	Sulphur (%)			Boron (mg/kg)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	0.12	0.14	0.17	37	38	37
Sprayed	0.14	0.15	0.17	37	37	37
Significance	NS	NS	NS	NS	NS	NS
LSD						
Year 1	0.12	0.16	0.16	40	38	38
Year 2	0.11	0.12	0.14	35	39	35
Year 3	0.15	0.14	0.15	36	37	39
Year 4	0.17	0.16	0.18	36	36	34
Year 5	0.11		0.23	36		39
Significance	***	***	***	**	**	***
LSD	0.02	0.01	0.02	2	2	2
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Copper (mg/kg)			Zinc (mg/kg)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	40	33	135	74	92	85
Sprayed	42	29	125	77	97	81
Significance	NS	*	NS	NS	NS	NS
LSD		3				
Year 1	9	47	81	67	71	75
Year 2	85	21	278	68	97	54
Year 3	85	13	134	79	125	74
Year 4	5	44	98	88	84	82
Year 5	19		62	76		130
Significance	***	***	***	*	***	***
LSD	19	6	22	13	17	11
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Manganese (mg/kg)			Iron (mg/kg)		
	site 1	site 2	site 3	site 1	site 2	site 3
Unsprayed	218	93	132	24	39	40
Sprayed	248	114	109	24	38	32
Significance	NS	NS	NS	NS	NS	*
LSD						8
Year 1	279	125	192	28	32	27
Year 2	181	131	84	22	46	44
Year 3	282	92	93	26	26	33
Year 4	314	68	117	26	50	45
Year 5	109		16	20		30
Significance	***	**	***	NS	NS	**
LSD	62	28	32			8
Interaction						
Significance	NS	NS	NS	NS	NS	NS
LSD						

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

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Chapter 3

3 Temporal variation and distribution of molybdenum and boron in grapevines *(Vitis vinifera* L.)

Norbert Maier, Louise Chvyl, Chris Williams and Kerry Porter

Abstract

The temporal variation and distribution of molybdenum (Mo) and boron (B) were determined for Merlot and Cabernet Sauvignon grapevines. Vines were excavated with all tops and a root ball and separated into plant fractions and sampled up to 10 times during the course of one year and analysed for Mo and B in the different tissue fractions.

The dry matter content of <2 mm roots decreased over time. In above ground fractions, percent dry matter increased over time in both cultivars. The trunk and cordon had the highest dry matter content, while leaf petiole, cane, inflorescence/bunch and tendril all had comparatively low percent dry matter early to mid season. The application of Mo did not affect the dry weight of any fraction. The dry weight of all fraction tended to increase over time for both Merlot and Cabernet Sauvignon. Sampling time only affected Mo concentration in the inflorescence/bunch fraction. The roots, in particular the < 2 mm roots, had the highest Mo concentration at each sampling time, with leaf blade having the highest of the above ground fractions. Molybdenum concentration in roots, leaf petioles and blades, tendrils and inflorescences/bunches of Cabernet Sauvignon vines were generally higher than those in Merlot vines. The application of Mo did not affect B concentration in any fraction. In contrast with Mo, B concentrations in the roots of both Merlot and Cabernet Sauvignon vines, were consistently lower than concentrations in the canes, leaf petioles and blades, inflorescences/bunches and tendrils. For the above ground parts, Mo content was highest in the leaf blades at 168 days after budburst. The application of Mo did not affect the B content of vines. There were significant differences in B content between fractions, with leaf blade and coloured berries having the highest and petioles, rachis, swollen ovaries and tendrils the lowest. The distribution of Mo and B in the above ground fractions changed with time. At 21 days from budburst, the trunk and cordon accounted for 97.5% of the total Mo in Merlot vines, and 89.5% in Cabernet Sauvignon. In contrast at 168 days, the percentages had decreased to 34.8 and 22.9%, respectively. The trends for B were similar. Leaf blades accounted for the highest percentage of Mo at 86 and 168 days. In contrast, the percentage of B was highest in the inflorescence/bunch fraction at 168 days. The total amount of Mo in the above ground fractions of both varieties was low compared with B.

Introduction

It has been shown that for Merlot vines, molybdenum (Mo) deficiency can affect seed formation and berry development and therefore the occurrence of disorders such as shot berry formation and hens and chickens (millerandage) (Williams *et al.* 2003; 2004). Pre-flowering foliar sprays were found to correct the deficiency. Boron (B) deficiency, which has also been reported to affect pollen development and viability and increase fruit set (Cook 1966; Dabas and Jindal 1985). We are not aware of any data published in Australia on the accumulation and distribution of B in grapevines. An understanding of the distribution of Mo and B in vines, the effect of supply and there phloem mobility is required to ensure that deficiencies are correctly managed and to allow effective plant tests to be developed to diagnose deficiency.

Few studies have reported the distribution of Mo in grapevines. Phillips (2004) reported on a pot trial using one year old rootlings of Merlot on own roots and Schwarzmann and 99 Richter rootstocks. He found that the largest pool of Mo in the vines was old wood, however, the highest concentration was in

new roots. Vines on own roots, translocated the greatest portion of foliar assimilated Mo basipetally, in contrast for vines on rootstocks, the greatest portion was translocated acropetally.

An investigation was undertaken to determine the temporal (seasonal) variation and distribution of Mo and B in Merlot and Cabernet Sauvignon grapevines.

Materials and Methods

Site 10 (Lenswood Research Centre)

Grapevines used in this experiment were removed from a research vineyard located at the Lenswood Research Centre in the Mt Lofty Ranges of South Australia. Samples were obtained from two separate blocks, one containing Merlot (clone D3V14) and the other Cabernet Sauvignon (clone CW44) grapevines, each grown on own roots. Both the Merlot and the Cabernet Sauvignon were planted in 1996 and trained to twin arm cordon with vertical foliage management. Inter- and intra-row spacings between vines were 3 m and 1.5 m respectively. Both plantings were drip irrigated.

Grapevines were treated with fungicides on eight occasions during the 2004/05 season. Fungicides used were Thiovit (Syngenta), Ridomil (Syngenta), Anvil and Agriphos, and these were mixed with either Vita Wet or Delan wetting agents and applied using an Airmist sprayer. Soils were sampled in September 2005 for classification according to the Australian Soil Classification (Isbell 2002). The soil in the Merlot planting was a Haplic, Eutrophic, Red Dermosol and that in the Cabernet Sauvignon planting was a Haplic, Melanic or Bleached Mottled, Eutrophic, Red or Brown Dermosol. Topsoil (0 –15 cm) in the Merlot planting varied from reddish brown to dark reddish brown friable loam with pH values of 6.5 to 7.5. In the Cabernet Sauvignon planting the topsoil (0 – 25 cm) ranged from dark brown or brown friable light clay loam to very dark greyish brown friable loam with pH values of 6.0 to 6.5.

Two randomly selected vines of each variety were sampled on 10 separate occasions during the 2004/05 growing season. Sampling dates, number of days from budburst and the corresponding E-L number and growth stage are presented in Table 1.

Table 1. Sampling times for vines at site 10 in the 2004/05 growing season

Days from Budburst	Date	E-L number		Stage
		Merlot	Cabernet Sauvignon	
-61	28 July 2004	1	1	Winter bud
0	27 September 2004	4-5	4-5	Budburst
21	18 October 2004	12	12	5 leaves separated; 10 cm shoot.
35	1 November 2004	14-15	14-15	7-8 leaves separated
56	22 November 2004	16-17	17	10-12 leaves separated. Inflorescence well developed. Single flowers separated.
70	6 December 2004	25-27	27	80% caps off – setting
86	22 December 2004	29-31	29-31	4 - 7 mm diameter berries.
107	12 January 2005	29-31	29-31	
133	7 February 2005	35	34-35	Berries softening – Veraison.
168	14 March 2005	37	36-37	Berries not quite ripe.

Each harvested vine was divided into fractions, and the above ground fractions were removed from the vine *in situ*, prior to digging up the roots and stump, to avoid contamination with soil and debris. The fractions, in order of removal, were bunches or inflorescences when present, canes with leaves and tendrils attached when present, cordons, trunk and roots. Only roots contained within a 3.24-m^3 volume of soil immediately surrounding the grapevine trunk were collected. Fractions were stored in labelled plastic bags and placed in insulated containers for transportation to the laboratory.

Initial grapevine fractions were further divided into smaller fractions, with the final fractions being coloured berries, swollen ovaries, rachis, tendrils, leaf blades, leaf petioles, canes, cordons, trunk, roots > 5 mm diameter, roots 2-5 mm diameter, and roots < 2 mm diameter. The trunk and root fractions were washed in deionised water to remove soil and debris. Total fresh weights were recorded prior to drying either the whole or a sub-sample of each fraction in fan-forced ovens at 60 °C to 70 °C, and dry weights were recorded after drying. Dried fraction samples were ground to < 1 mm for chemical analysis.

The data for all variables within each variety were analysed for variance between tissue types at each sampling date and between sampling dates for each tissue type. Significant differences between tissue types and between sampling dates were calculated using the least significant difference (LSD) test at the 5% level of probability.

Site 4 (McLaren Vale)

Eight vines were removed from a commercial vineyard at McLaren Vale after harvest in March 2006. Plant material was stored at 1 to 3 ^oC until fractionated, using the same methods as described previously. The plots from which the vines were removed were part of an experiment to study the effect of molybdenum and rootstock on the growth, yield and chemical composition of Merlot vines on own roots or rootstocks. Molybdenum applications were last made in the 2004/05 growing season. The vines were removed from sprayed and unsprayed plots of Merlot on own roots. Refer to Chapter 1.1, Materials and Methods section for more details concerning the experiment at this site.

Site 6 (Lenswood)

At harvest in 2006, 4 vines were removed from a field experiment investigating the effect of rate and timing of Mo applications on the growth, yield and chemical composition of Merlot vines. The vines were from plots not sprayed with Mo. Plant material was stored at 1-3^oC until fractionated, using the same methods as described previously. Refer to Chapter 7, Materials and Methods section for more details concerning the experiment at this site.

Results and Discussion

Dry matter content

The dry matter content decreased over time in < 2 mm roots, decreased and then recovered in 2-5 mm roots, remained relatively constant in > 5 mm Merlot roots and had increased by the last sampling time in > 5 mm Cabernet Sauvignon roots (Table 2). In above ground fractions, percent dry matter increased over time in both cultivars. For components of the canopy, the percentage increase in canes and tendrils was greater than that in leaf-petioles, leaf-blades and inflorescence/bunch. The dry matter content of canes, tendrils and inflorescences/bunches increased up to 168 days after budburst. Changes in dry matter content for each fraction are summarized in Figure 1.

For some fractions (eg. roots, trunks and canes) the fluctuations which occurred between samples collected mid to late in the season, could be due to variations between individual vines.

Comparison between fractions showed that there were significant differences at each sampling time (Table 2). The trunk and cordon had the highest dry matter content, while leaf petiole, cane, inflorescence/bunch and tendril all had comparatively low percent dry matter early to mid season.

At site 4, the application of Mo did not affect dry matter content (Table 3). There were significant differences in dry matter content between fractions at both sites, with trunk and cordons having the highest (Table 3). The fractions with the lowest dry matter contents were swollen ovaries at site 4 and swollen ovaries and leaf-petioles at site 6.

Table 2. Dry matter content (%) of grapevine fractions sampled at different times during the growing season at site 10 in 2004/05

Tissue fraction	*Days from budburst*											*LSD*
	-61	**0**	**21**	**35**	**56**	**70**	**86**	**107**	**133**	**168**		*(P = 0.05)*
						Merlot on own roots						
< 2 mm root	46.8	47.0	43.8	44.3	41.4	42.4	38.8	33.8	37.1	34.4	*	*7.7*
2 – 5 mm root	46.9	44.5	43.2	41.7	40.3	41.3	40.0	40.2	39.4	44.6	*	*4.2*
> 5 mm root	46.0	45.8	43.6	49.7	41.4	41.8	39.9	41.2	43.2	44.6	*NS*	
Trunk	52.8	51.9	54.3	53.4	53.5	51.3	50.2	53.7	53.1	58.8	**	*2.7*
Cordon	52.7	52.6	54.0	52.9	50.9	46.8	48.4	50.5	54.3	58.9	***	*2.3*
Leaf - petiole			12.3	13.7	13.8	13.1	14.7	17.3	17.0	17.4	**	*1.9*
Leaf - blade			23.9	23.9	25.8	22.6	25.9	30.3	28.4	30.0	**	*3.3*
Cane			11.8	13.6	16.6	19.0	21.9	26.4	32.3	43.1	***	*3.2*
Inflorescence/Bunch			15.7	15.8	15.7	15.0	11.7	9.8	11.0	23.7	***	*3.1*
Tendril					12.4	14.4	15.3	17.1	26.8	46.1	***	*6.4*
Sigtnificance	*	***	***	***	***	***	***	***	***	***		
LSD (P = 0.05)	*3.4*	*1.5*	*2.2*	*9.8*	*1.2*	*4.9*	*1.2*	*2.9*	*6.5*	*5.0*		
						Cabernet Sauvignon on own roots						
< 2 mm root	45.0	33.6	45.0	40.8	43.0	35.5	37.4	39.9	36.7	31.2	*	*7.0*
2 – 5 mm root	44.2	39.4	42.8	40.1	42.5	39.6	42.5	44.8	46.7	44.2	*	*3.3*
> 5 mm root	44.5	42.9	44.2	43.6	43.3	42.7	43.3	44.4	49.1	49.3	***	*2.4*
Trunk	52.7	52.1	53.7	52.6	51.2	48.4	48.1	51.4	55.9	58.7	***	*2.1*
Cordon	53.3	52.4	54.6	53.0	51.0	47.1	47.7	51.8	56.8	59.7	***	*1.9*
Leaf - petiole			12.7	12.8	12.7	13.3	14.9	16.3	17.0	16.9	**	*2.2*
Leaf - blade			23.1	23.5	25.9	22.3	27.1	27.9	27.4	28.6	***	*1.9*
Cane			12.0	14.3	18.4	21.6	25.9	29.9	35.9	46.9	***	*2.4*
Inflorescence/Bunch			15.4	15.7	15.8	15.8	14.0	11.0	15.7	22.8	***	*1.7*
Tendril					12.4	14.8	17.6	22.1	38.7	56.7	***	*8.3*
Significance	***	***	***	***	***	***	***	***	***	***		
LSD (P = 0.05)	*1.0*	*2.6*	*1.7*	*4.4*	*2.2*	*3.6*	*4.3*	*5.0*	*6.6*	*6.7*		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

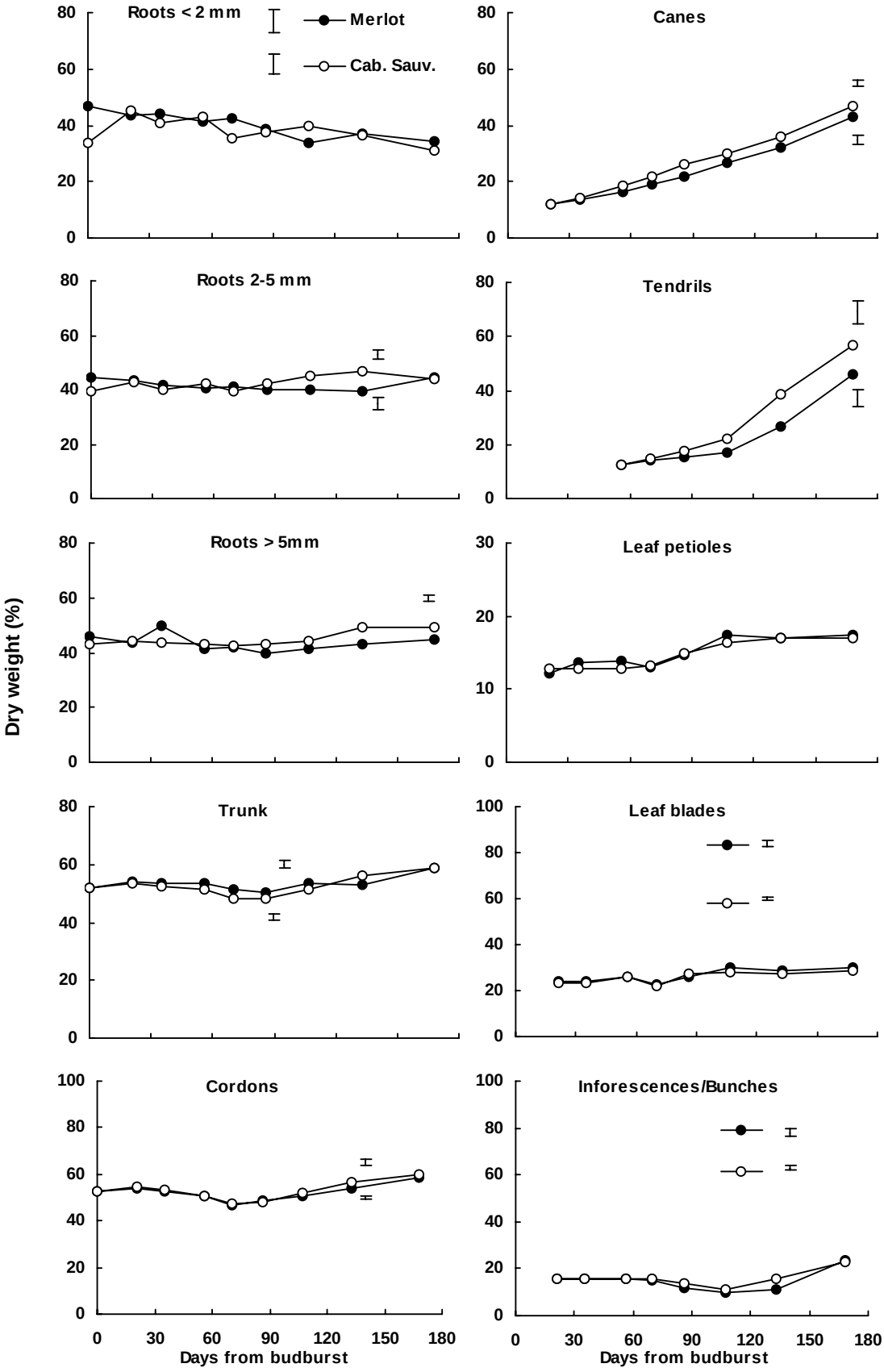


Figure 1. Changes in dry matter content (%) of grapevine fractions sampled at different times during the growing season at site 10 in 2004/05. Vertical lines indicate LSD at P = 0.05.

Table 3. Dry matter content and dry weight of grapevine fractions at sites 4 and 6 in the 2005/06 growing season

Vines were collected after harvest.

Variable	Dry matter (%)		Dry weight (g/vine)	
	Site 4	Site 6	Site 4	Site 6
Treatment				
Unsprayed[A]	40.3		783	
Sprayed[B]	40.7		704	
Significance	NS		NS	
Plant fraction				
< 2 mm root	42.5	40.1		
2 – 5 mm root	50.3	43.8		
> 5 mm root	50.4	47.1		
Trunk	58.1	57.1	2252	977
Cordon	60.4	56.6	2845	612
Leaf - petiole	21.2	17.8	133	42
Leaf - blade	36.1	29.5	1063	277
Cane	46.0	44.6	1187	575
Coloured berry	27.4	24.8	1146	261
Rachis	27.0	22.1	73	14
Swollen ovary	17.3	13.5	6	1
Tendril	49.7	32.4	37	8
Significance	***	***	***	***
LSD	*3.2*	*4.9*	*245*	*140.5*

[A] No pre-flowering foliar Mo sprays applied.

[B] Pre-flowering foliar Mo sprays applied in the 2002/03, 2003/04 and 2004/05 growing seasons. Not sprayed in the 2005/06 season.

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

Dry matter yield

The application of Mo did not affect the dry weight of any fraction (Table 3), even though Mo increased bunch yield and weight at this site. This is consistent with the hypothesis that the effect of Mo is reproductive and not vegetative.

There were significant differences in dry weight between fractions at sites 4 and 6 (Table 3). At Site 4, cordons were the heaviest, followed by the trunk, with leaf petioles, rachises, tendrils and swollen ovaries being the lightest. In contrast at site 6, the trunk was the heaviest, followed by cordons and canes, with leaf petioles, rachises, tendrils and swollen ovaries also being the lightest. The higher weight of each fraction at site 4 compared with site 6 is probably due to the difference in age of the vines at the sites (See Research Strategy and Method Section, Table 1).

The dry weight of all fraction tended to increase over time for both Merlot and Cabernet Sauvignon (Table 4). Fluctuations against the trend in mid to late season samples may be due to variations between individual vines. The increase in the weight of the canopy fractions and inflorescence/bunch were greater than that for the trunk and cordon (Table 4).

Table 4. Dry weight (g/vine) of grapevine fractions sampled at different times during the growing season at site 10 in 2004/05

Tissue fraction	Days from budburst											*LSD*
	-61	**0**	**21**	**35**	**56**	**70**	**86**	**107**	**133**	**168**		*(P = 0.05)*
Merlot on own roots												
Trunk	583.9	683.4	840.8	560.6	600.0	469.1	615.0	511.0	871.5	837.8	*	*202.9*
Cordon	536.1	645.1	763.2	493.5	463.6	543.3	521.4	527.4	968.0	733.5	*NS*	
Petiole			2.4	6.4	14.4	31.9	50.3	63.0	86.1	65.5	**	*39.3*
Blade			22.3	59.5	121.2	268.1	391.3	478.1	621.8	473.6	*	*254.3*
Cane			8.0	25.1	69.6	169.7	255.5	341.8	559.0	517.9	**	*234.9*
Inflorescence/Bunch			1.9	6.7	12.1	21.4	56.6	89.2	492.7	1181.7	***	*250.5*
Tendrils					2.9	8.2	10.9	12.7	9.1	6.4	*NS*	
Sigtnificance	*NS*	*NS*	***	***	***	***	***	*	**	***		
LSD (P = 0.05)			*67.2*	*185.9*	*56.9*	*135.6*	*29.7*	*314.6*	*331.7*	*99.0*		
Cabernet Sauvignon on own roots												
Trunk	651.6	676.4	781.0	792.4	674.0	677.3	773.3	755.6	881.3	900.2	*	*144.3*
Cordon	570.3	488.4	696.9	716.8	658.9	529.3	635.6	631.7	657.2	823.6	*NS*	
Petiole			1.6	5.4	14.0	21.2	38.9	49.0	48.4	47.0	**	*20.5*
Blade			21.4	65.6	158.9	225.2	368.1	402.0	376.5	363.0	***	*129.6*
Cane			9.6	32.8	96.3	157.1	286.5	380.0	386.1	533.3	**	*202.7*
Inflorescence/Bunch			2.4	6.7	22.9	26.1	86.2	182.1	400.3	987.5	***	*142.2*
Tendrils					1.9	3.9	5.8	9.7	3.7	6.2	*NS*	
Sigtnificance	*NS*	*	*	**	***	**	**	***	***	***		
LSD (P = 0.05)		*130.2*	*497.1*	*396.2*	*187.0*	*245.5*	*289.8*	*219.3*	*201.1*	*288.9*		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

The largest increase in leaf-blade and cane dry weight occurred between 35 and 107 days from budburst in both Merlot and Cabernet Sauvignon vines (Table 4). The rate of increase in bunch weight was greatest after 107 days. There were no consistent trends in trunk or cordon dry weights over the period studied. Williams and Biscay (1991) reported large variations in trunk dry weight of 18-year-old Cabernet Sauvignon vines sampled four times in the period from flowering to fruit maturity.

After budburst, there were significant differences between fractions at all sampling times (Table 4). In the Merlot vines, the trunk or the trunk and cordon were the heaviest, except at the last sampling time, when the weight of bunches was greater. Petioles and tendrils were the lightest along with blades, canes and inflorescences at the earlier sampling times. For Cabernet Sauvignon, the trunk and cordon were the heaviest except at the last sampling time when there was no significant difference in the weight of trunk, cordon and bunch.

Molybdenum concentration

Sampling time only affected Mo concentration in the inflorescence/bunch fraction of both varieties (Table 5). In this fraction, Mo concentrations were highest during the period 35-70 days from budburst, after which concentrations decreased particularly, between 70-86 days from budburst. Flowering occurred during the period 56-70 days from budburst (Table 1) therefore, the decline in Mo concentration corresponds with berry development.

Molybdenum concentration in the root fractions of both varieties, tended to increase during the period 21-133 days from budburst however, the magnitude of the increase depended on root age (Table 5). For Merlot, Mo concentrations at 21 and 133 days were: < 2 mm roots 0.18 and 0.35 mg/kg; 2-5 mm roots 0.10 and 0.15 mg/kg; and > 5 mm roots 0.08 and 0.10 mg/kg. The corresponding values for Cabernet Sauvignon were: < 2 mm roots 0.26 and 0.49 mg/kg; 2-5 mm roots 0.16 and 0.27 mg/kg; and > 5 mm roots 0.07 and 0.13 mg/kg. The magnitude of the increase in Mo concentration decreased with root age. It may be possible that Mo concentration in roots is increasing while the reproductive stage (eg. fertilisation) is Mo deficient. In Merlot vines, Mo deficiency may not be about supply but transport. Phillips (2004) reported that between 0.67 and 1.21%, of Mo applied to leaves was translocated. It was suggested that more than these amounts was assimilated but remained in the leaf to which the Mo was applied. In Cabernet Sauvignon vines, Mo concentration in canes decreased during the period 21-86 days from budburst. However, there was no such trend in the Merlot vines (Table 5).

Significant differences were found between fractions at all sampling times, except at 107 days from budburst in Merlot (Table 5). In both Merlot and Cabernet Sauvignon, the roots, in particular the < 2 mm roots, had the highest concentration at each sampling time, with leaf blade having the highest of the above ground fractions. At site 6, < 2 mm roots also had highest Mo concentration and trunk, cordon, cane, rachis and tendril had the lowest (Table 6). There was an interaction between Mo and plant fraction in their effect on Mo concentration at site 4 (Figure 2). Molybdenum concentration was generally higher in fractions from vines sprayed with Mo, however, the magnitude of the difference varied between fractions. The greatest difference occurred in the < 2 mm roots. Molybdenum concentrations in the trunk for the unsprayed and sprayed treatments were 0.12 and 2.0 mg/kg, respectively. The corresponding values for the cordon were, 0.09 and 5.4 mg/kg. However, these data need to be interpreted with caution because the higher concentrations may be due to residue (unassimilated Mo) from foliar sprays applied in previous seasons. Fractionating a cordon sample into bark and wood showed that Mo concentration in the bark was 67 mg/kg compared with only 0.30 mg/kg in the wood. Highest Mo concentration for both spray treatments at site 4 were found in < 2 mm roots (Figure 2).

Table 5. Molybdenum concentration (mg/kg) in grapevine fractions sampled at different times during the growing season at site 10 in 2004/05

Tissue fraction	Days from budburst											*LSD*
	-61	**0**	**21**	**35**	**56**	**70**	**86**	**107**	**133**	**168**		*(P = 0.05)*
Merlot on own roots												
< 2 mm root	0.15	0.22	0.18	0.20	0.26	0.28	0.29	0.30	0.35	0.32	*NS*	
2 – 5 mm root	0.07	0.10	0.10	0.09	0.14	0.15	0.09	0.14	0.15	0.11	*NS*	
> 5 mm root	0.07	0.10	0.08	0.08	0.09	0.11	0.09	0.09	0.10	0.09	*NS*	
Trunk	0.04	0.04	0.03	0.04	0.04	0.06	0.05	0.03	0.03	0.03	*NS*	
Cordon	0.03	0.03	0.04	0.04	0.04	0.06	0.05	0.04	0.03	0.03	*NS*	
Leaf - petiole			0.02	0.04	0.03	0.03	0.04	0.03	0.04	0.05	*NS*	
Leaf - blade			0.05	0.08	0.08	0.07	0.08	0.05	0.08	0.09	*NS*	
Cane			0.02	0.11	0.02	0.02	0.03	0.04	0.02	0.03	*NS*	
Inflorescence/Bunch			0.02	0.03	0.04	0.04	0.02	0.01	0.01	0.01	*	*0.02*
Tendril					0.02	0.02	0.04	0.01	0.01	0.02	*NS*	
Sigtnificance	***	***	*	*	***	***	***	*NS*	***	***		
LSD (P = 0.05)	*0.02*	*0.04*	*0.07*	*0.09*	*0.06*	*0.06*	*0.04*		*0.08*	*0.02*		
Cabernet Sauvignon on own roots												
< 2 mm root	0.43	0.29	0.26	0.56	0.37	0.40	0.55	0.47	0.49	0.49	*NS*	
2 – 5 mm root	0.17	0.18	0.16	0.15	0.16	0.21	0.28	0.22	0.27	0.20	*NS*	
> 5 mm root	0.09	0.10	0.07	0.09	0.14	0.14	0.09	0.11	0.13	0.11	*NS*	
Trunk	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	*NS*	
Cordon	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	*NS*	
Leaf - petiole			0.07	0.09	0.08	0.09	0.07	0.09	0.10	0.09	*NS*	
Leaf - blade			0.13	0.18	0.15	0.15	0.13	0.12	0.17	0.16	*NS*	
Cane			0.09	0.05	0.04	0.03	0.02	0.02	0.03	0.03	*NS*	
Inflorescence/Bunch			0.06	0.11	0.11	0.10	0.07	0.07	0.06	0.04	*	*0.04*
Tendril					0.09	0.10	0.07	0.08	0.08	0.06	*NS*	
Sigtnificance	*	***	**	**	***	*	***	***	***	***		
LSD (P = 0.05)	*0.17*	*0.05*	*0.09*	*0.20*	*0.06*	*0.16*	*0.15*	*0.06*	*0.06*	*0.04*		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

Table 6. Molybdenum and Boron concentrations in grapevine fractions at sites 4 and 6 in the 2005/06 growing season
Vines were collected after harvest.

Variable	**Molybdenum (mg/kg)**	**Boron (mg/kg)**	
	Site 6	**Site 4**	**Site 6**
Treatment			
Unsprayed[A]		39	
Sprayed[B]		34	
Significance		*NS*	
Plant fraction			
< 2 mm root	0.34	18	13
2 – 5 mm root	0.15	15	12
> 5 mm root	0.09	13	8
Trunk	0.04	10	12
Cordon	0.06	10	11
Leaf - petiole	0.08	43	38
Leaf - blade	0.12	38	38
Cane	0.04	17	15
Coloured berries	0.10	40	27
Rachis	0.04	45	31
Swollen ovaries	0.09	126	71
Tendril	0.02	61	46
Significance	***	***	***
LSD	*0.05*	*8*	*4*

[A] No pre-flowering foliar Mo sprays applied.
[B] Pre-flowering foliar Mo sprays applied in the 2002/03, 2003/04 and 2004/05 growing seasons, but not in the 2005/06 season.
Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

At all sites there was a Mo concentration gradient between the root and leaf fractions (Tables 5 and 6, Figure 2). Phillips (2004) suggested that the concentration gradient between roots and leaves may be due to Mo binding in the vascular parenchyma.

Phillips (2004) using one year old rootlings in a pot experiment, found that Mo application resulted in significantly higher Mo concentration of whole vines. Highest concentrations of Mo within vines were found in new roots for both treated and control vines. Treated vines, however, had higher Mo concentrations in other fractions when compared to control vines, in particular in new aerial growth. Jongruaysup *et al.* (1994) reported that Mo concentrations in fractions of black gram (*Vigna mungo* L. Hepper) increased with increasing supply of Mo solution to the soil and that over time, Mo concentrations within some fractions changed. Petioles and basal stems of black gram were put forward as the Mo storage organs due to their high Mo concentrations.

Molybdenum concentration in roots, leaf petioles and blades, tendrils and inflorescences/bunches of Cabernet Sauvignon vines were generally higher than those in Merlot vines. In contrast, although Mo concentrations were low in the trunks, cordons and canes of both varieties, they were lowest in Cabernet Sauvignon (Table 5).

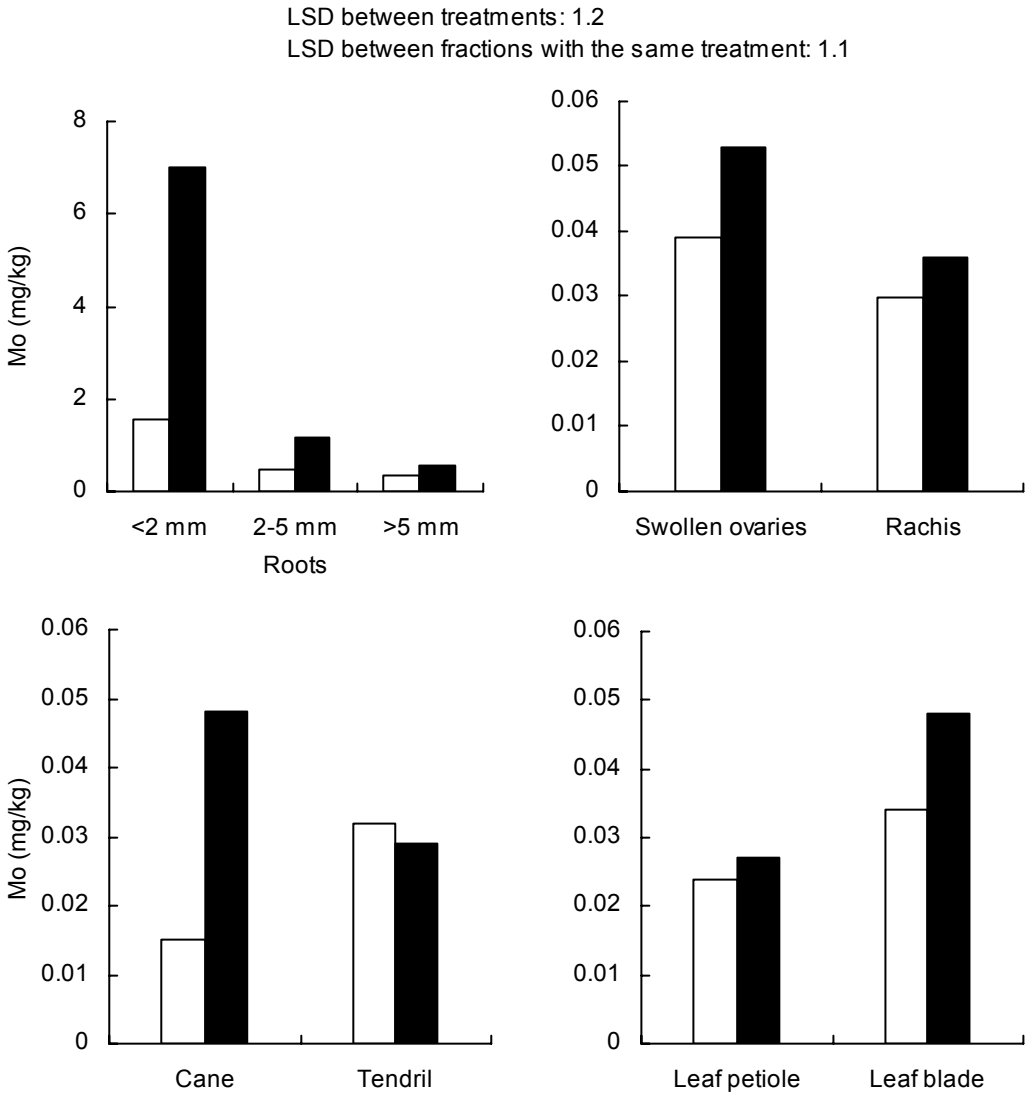


Figure 2. Molybdenum concentration in grapevine fractions at site 4 in the 2005/06 growing season. Open bars represent the unsprayed treatment (no pre-flowering foliar Mo sprays applied) and filled bars represent the sprayed treatment (pre-flowering foliar Mo sprays applied in the 2002/03, 2003/04 and 2004/05 growing seasons, but not in the 2005/06 season.). Data for coloured berries are not presented because values were below the detection limit.

Boron concentration

The application of Mo did not affect B concentration (Table 6).

There were significant differences between fractions for Mo and B at site 6 and for B at site 4 (Table 6). At site 6, < 2 mm roots had highest Mo concentration and trunk, cordon, cane, rachis and tendril had the lowest, in contrast, swollen ovaries had the highest B concentration and roots, trunk and cordon had the lowest (Table 6). At site 4, swollen ovaries had the highest B concentration and the roots, trunk, cordon and cane had the lowest.

Table 7. Boron concentration (mg/kg) in grapevine fractions sampled at different times during the growing season at site 10 in 2004/05

Tissue fraction	Days from budburst											*LSD*
	-61	0	21	35	56	70	86	107	133	168		*(P = 0.05)*
Merlot on own roots												
< 2 mm root	15	15	13	15	15	15	16	14	14	12	*	*2*
2 – 5 mm root	13	14	14	14	15	14	15	14	12	11	*NS*	
> 5 mm root	10	11	12	14	12	13	11	12	10	10	*	*2*
Trunk	9	10	10	13	11	13	13	12	9	8	**	*2*
Cordon	10	11	13	14	13	12	12	12	11	10	*NS*	
Leaf - petiole			25	32	34	36	35	31	37	33	**	*4*
Leaf - blade			19	26	24	35	30	27	29	28	*	*6*
Cane			23	25	24	22	23	17	17	12	***	*3*
Inflorescence/Bunch			26	33	34	37	37	35	41	21	**	*8*
Tendril					40	48	50	54	41	38	*	*10*
Sigtnificance	*	**	***	***	***	***	***	***	***	***		
LSD (P = 0.05)	*3*	*2*	*3*	*4*	*3*	*3*	*4*	*7*	*6*	*3*		
Cabernet Sauvignon on own roots												
< 2 mm root	14	14	14	13	14	14	13	12	11	10	*NS*	
2 – 5 mm root	11	13	13	14	14	15	14	12	10	11	***	*2*
> 5 mm root	9	9	10	10	10	11	10	9	7	7	*	*2*
Trunk	7	9	12	11	12	11	11	11	10	9	*	*2*
Cordon	9	12	13	14	12	12	12	11	11	10	*NS*	
Leaf - petiole			32	44	45	39	36	34	40	33	**	*5*
Leaf - blade			29	49	43	51	39	42	38	47	*	*10*
Cane			27	29	23	19	17	14	17	11	***	*5*
Inflorescence/Bunch			25	40	37	31	31	32	32	21	*	*8*
Tendril					41	46	38	39	38	38	*NS*	
Sigtnificance	NS	NS	***	***	***	***	***	***	***	***		
LSD (P = 0.05)			3	6	5	9	4	4	5	3		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

In contrast with Mo, B concentrations in the roots of both Merlot and Cabernet Sauvignon vines, were consistently lower than concentrations in the canes, leaf petioles and blades, inflorescences/bunches and tendrils (Table 7).

Boron concentrations in the canes of both varieties decreased during the period 35-168 days from budburst (Table 7). Schreiner (2005) reported that leaf B did not change appreciably over the season, our data for leaf petioles and blades are consistent with this finding.

Molybdenum content of above ground fractions

The Mo content of petioles, blades and inflorescences/bunches from both Merlot and Cabernet Sauvignon vines increased significantly over time (Table 8).

Trunks and cordons of both Merlot and Cabernet Sauvignon vines, had relatively high Mo contents for most sampling times, with blades having a high content towards the end of the sampling period for Merlot, and blades and inflorescences/bunches for Cabernet Sauvignon (Table 8). Petioles and tendrils had consistently low Mo content in both cultivars. Although not statistically significant, similar differences were found at site 6 (Table 9). The differences in content between the fractions largely reflects the different weight of the fractions (Tables 3 and 4).

For the aerial fractions of the vine, Mo content was highest in the leaf blades at 168 days from budburst.

There was an interaction between Mo and plant fraction in their effect on Mo content at site 4 (Table10). For sprayed vines, the Mo contents of trunks and cordons were significantly different, there was no difference in unsprayed vines. The Mo content of trunks and cordons was higher than other fractions, but the very high values recorded for the sprayed vines at site 4 were possibly due to surface contamination due to the application of Mo foliar sprays in earlier growing seasons.

Overall, the Mo content of the aerial fractions of the vines used in this study was low.

Change in dry matter yield and Mo content of foliage, inflorescence/bunch and total above ground parts over time are summarized in Figure 3.

Table 8. Molybdenum content (μg/vine) of grapevine fractions sampled at different times during the growing season at site 10 in 2004/05

Tissue fraction	Days from budburst											*LSD*
	-61	0	21	35	56	70	86	107	133	168		*(P = 0.05)*
Merlot on own roots												
Trunk	24.1	24.6	24.8	21.5	25.5	25.7	29.1	15.3	29.9	14.9	*NS*	
Cordon	14.6	19.3	27.3	19.7	19.0	29.2	25.4	19.8	31.2	24.3	*NS*	
Petiole			0.1	0.3	0.5	1.1	2.2	1.4	3.4	3.2	***	*0.7*
Blade			1.1	4.7	9.9	19.6	31.9	19.0	51.9	44.4	***	*10.5*
Cane			0.1	2.5	1.4	3.3	7.0	16.7	13.9	14.0	*NS*	
Inflorescence/Bunch			0.0	0.2	0.4	0.7	1.2	1.2	5.0	11.8	***	*2.5*
Tendrils					0.1	0.2	0.5	0.2	0.1	0.1	*NS*	
Sigtnificance	*NS*	*NS*	***	***	**	***	**	*NS*	**	***		
LSD (P = 0.05)			*2.6*	*3.0*	*9.1*	*5.6*	*14.1*		*17.6*	*1.4*		
Cabernet Sauvignon on own roots												
Trunk	22.7	13.7	14.4	16.3	14.8	15.4	17.2	26.5	18.9	19.5	*NS*	
Cordon	15.8	10.2	13.7	16.8	10.5	11.8	12.7	10.1	15.3	16.5	*NS*	
Petiole			0.1	0.5	1.1	2.0	2.7	4.2	5.0	4.6	**	*2.1*
Blade			2.5	11.7	25.3	34.7	48.7	48.9	66.5	59.8	**	*26.2*
Cane			0.6	1.8	3.9	5.5	6.6	8.8	12.9	17.6	*	*8.2*
Inflorescence/Bunch			0.1	0.8	2.7	3.0	6.2	12.1	25.4	38.7	**	*16.4*
Tendrils					0.2	0.5	0.4	0.7	0.3	0.4	*NS*	
Sigtnificance	*NS*	*NS*	*	*NS*	**	*	*	*	*	**		
LSD (P = 0.05)			*10.5*		*11.0*	*19.5*	*23.5*	*21.8*	*28.0*	*23.6*		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

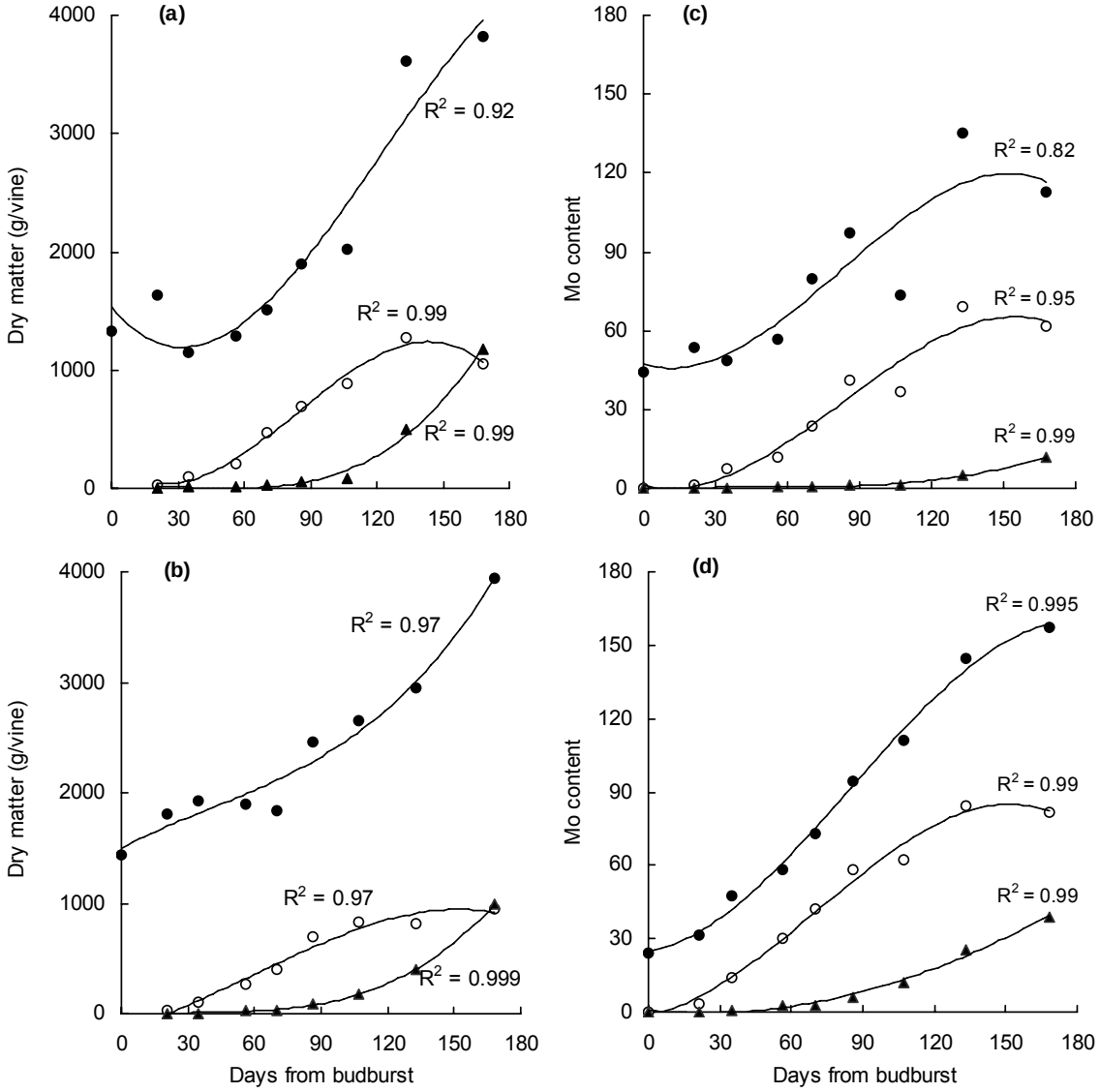


Figure 3. Changes in dry matter yield (a, b) and Mo content (μg/vine) (c, d) of foliage (○), inflorescence/bunch (▲) and total above ground parts (●) of Merlot (a, c) and Cabernet Sauvignon (b, d) vines

Table 9. Molybdenum and Boron contents of grapevine fractions at sites 4 and 6 in the 2005/06 growing season

Vines were collected after harvest.

Variable	Molybdenum (μg/vine)	Boron (mg/vine)	
	Site 6	Site 4	Site 6
Treatment			
Unsprayed[A]		20.6	
Sprayed[B]		16.6	
Significance		*NS*	
Plant fraction			
Trunk	150	21.4	42.4
Cordon	128	29.7	28.2
Leaf - petiole	8	5.8	5.4
Leaf - blade	78	40.9	38.8
Cane	109	20.5	27.4
Coloured berries	#	43.0	27.4
Rachis	2	3.3	1.7
Swollen ovaries	0.3	0.8	0.3
Tendril	1	2.2	2.1
Significance	*NS*	***	*NS*
LSD		*9.0*	

[A] No pre-flowering foliar Mo sprays applied.
[B] Pre-flowering foliar Mo sprays applied in the 2002/03, 2003/04 and 2004/05 growing seasons, but not in the 2005/06 season.
Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.
Below detection limit.

Table 10. Molybdenum content of grapevine fractions at sites 4 for sprayed and unsprayed vines in 2006

Vines were collected after harvest.

Plant fraction	Mo (μg/vine)	
	Unsprayed[A]	Sprayed[B]
Trunk	307	3865
Cordon	271	14633
Leaf - petiole	3	3
Leaf - blade	39	46
Cane	22	47
Coloured berries	#	#
Rachis	2	3
Swollen ovaries	0.2	0.4
Tendril	1	1
Significance	***	
LSD	*2372*	

[A] No pre-flowering foliar Mo sprays applied.
[B] Pre-flowering foliar Mo sprays applied in the 2002/03, 2003/04 and 2004/05 growing seasons, but not in the 2005/06 season.
Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.
Below detection limit.

Boron content of above ground fractions

The application of Mo did not affect the B content of vines (Table 9). There were, however, significant differences in B content between fractions, with leaf blade and coloured berries having the

highest and petioles, rachis, swollen ovaries and tendrils the lowest. There were no significant differences in B content between fractions at site 6 (Table 9).

There were significant differences in B content over time for all fractions except trunk, cordon and tendrils for Merlot, and cordon and tendrils for Cabernet Sauvignon (Table 11). Trunk and cordons had highest B contents at the early sampling period, with blades and inflorescence/bunch having the highest later in the period. Petioles and tendrils had the lowest B contents.

Changes in the B content of foliage, inflorescence/bunch and total above ground parts over time are summarized in Figure 4.

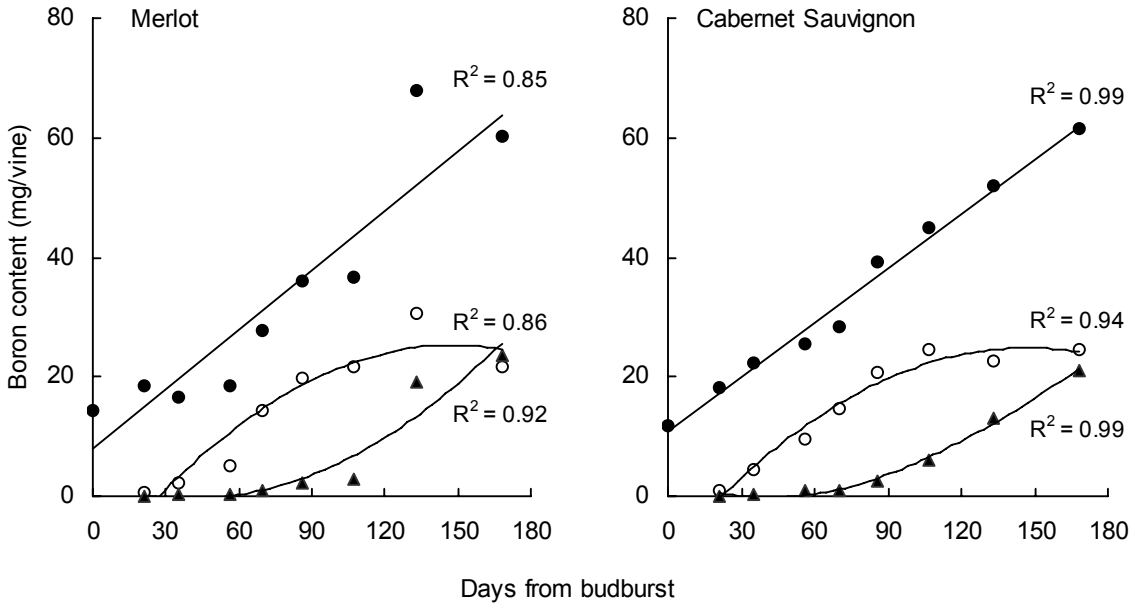


Figure 4. Changes in B content of foliage (○), inflorescence/bunch (▲) and total above ground parts (●) of Merlot and Cabernet Sauvignon vines.

Distribution of molybdenum and boron in above ground fractions

The distribution of Mo and B in the above ground fractions changed with time (Table 12). At 21 days from budburst, the trunk and cordon accounted for 97.5% of the total Mo in Merlot vines, and 89.5% in Cabernet Sauvignon. In contrast at 168 days, the percentages had decreased to 34.8 and 22.9%, respectively. The trends for B were similar. Leaf blades accounted for the highest percentage of Mo at 86 and 168 days. In contrast, the percentage of B was highest in the inflorescence/bunch fraction at 168 days (Table 12).

Table 11. Boron content (mg/vine) of grapevine fractions sampled at different times during the growing season at site 10 in 2004/05

Tissue fraction	Days from budburst											*LSD*
	-61	0	21	35	56	70	86	107	133	168		*(P = 0.05)*
Merlot on own roots												
Trunk	5.1	7.2	8.1	7.2	6.7	6.1	8.0	5.9	8.0	7.4	*NS*	
Cordon	5.3	7.1	9.7	6.9	6.2	6.6	6.2	6.0	10.0	7.3	*NS*	
Petiole			0.1	0.2	0.5	1.1	1.8	2.0	3.2	2.1	**	*1.4*
Blade			0.4	1.5	2.9	9.2	11.6	13.4	17.6	13.0	*	*8.5*
Cane			0.2	0.6	1.6	3.6	5.8	5.6	9.4	6.4	**	*4.1*
Inflorescence/Bunch			0.1	0.2	0.4	0.8	2.1	3.0	19.2	23.7	***	*7.2*
Tendrils					0.1	0.4	0.6	0.6	0.4	0.2	*NS*	
Sigtnificance	*NS*	*NS*	***	**	***	***	***	*NS*	*	***		
LSD (P = 0.05)			*1.3*	*3.1*	*1.4*	*2.3*	*1.1*		*9.0*	*1.1*		
Cabernet Sauvignon on own roots												
Trunk	4.4	6.0	8.2	8.1	7.8	6.7	8.0	7.9	8.9	7.8	***	*1.2*
Cordon	5.1	5.7	8.9	9.4	7.3	6.3	7.9	6.4	7.3	8.3	*NS*	
Petiole			0.1	0.2	0.6	0.8	1.4	1.7	1.9	1.5	**	
Blade			0.6	3.2	6.7	10.8	14.1	17.0	14.2	16.8	***	*5.6*
Cane			0.3	1.0	2.2	2.8	5.0	5.5	6.4	5.9	*	*3.3*
Inflorescence/Bunch			0.1	0.3	0.8	0.8	2.7	5.9	13.1	21.0	***	*4.8*
Tendrils					0.1	0.2	0.2	0.4	0.1	0.2	*NS*	
Sigtnificance	*NS*	*NS*	*	**	***	***	**	**	**	***		
LSD (P = 0.05)			*5.5*	*3.5*	*1.0*	*2.1*	*4.3*	*4.9*	*5.2*	*4.3*		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.

Table 12. Distribution of molybdenum and boron in above ground parts of Merlot and Cabernet Sauvignon vines sampled 21, 86 and 168 days after budburst at site 10 in 2004/05

Values are presented as the percent of total molybdenum in above ground parts

Plant part	Days from budburst					
	21		86		168	
	Merlot	Cabernet Sauvignon	Merlot	Cabernet Sauvignon	Merlot	Cabernet Sauvignon
Molybdenum						
Trunk	46.4	45.9	29.9	18.2	13.2	12.4
Cordon	51.1	43.6	26.1	13.4	21.6	10.5
Petiole	0.2	0.3	2.3	2.9	2.8	2.9
Blade	2.1	8.0	32.8	51.5	39.4	38.1
Cane	0.2	1.9	7.2	7.0	12.4	11.2
Inflorescence/Bunch	0.0	0.3	1.2	6.6	10.5	24.6
Tendrils	0.0	0.0	0.5	0.4	0.1	0.3
Total amount (μg/vine)	*53.4*	*31.4*	*97.3*	*94.5*	*112.7*	*157.1*
Boron						
Trunk	43.5	45.1	22.2	20.4	12.3	12.7
Cordon	52.2	48.9	17.2	20.1	12.1	13.5
Petiole	0.5	0.5	5.0	3.6	3.5	2.4
Blade	2.2	3.3	32.1	35.9	21.6	27.3
Cane	1.1	1.6	16.1	12.7	10.6	9.6
Inflorescence/Bunch	0.5	0.5	5.8	6.9	39.4	34.1
Tendrils	0.0	0.0	1.7	0.5	0.3	0.3
Total amount (mg/vine)	*18.6*	*18.2*	*36.1*	*39.3*	*60.1*	*61.5*

The total amount of Mo in the above ground fractions of both varieties was low compared with B (Table 12).

Phillips (2004) using one year old rootlings grown in pots, reported that the largest proportion of Mo was found in the old wood and new roots, with these two fractions accounting for approximately 97% in control vines and 73% in Mo treated vines. However, it was noted that the old wood of the vines used in this study, made up a large proportion of the dry matter and that the Mo content of the old wood at the time of planting of these young vines may have had an impact on the total Mo content when later sampled.

Studies with other species have shown that the pattern of Mo distribution is affected by Mo supply (Jongruaysup *et al.* 1994). At present it is not possible to reliably assess the Mo status of vines or the adequacy of Mo supply. However, petiolar Mo concentrations < 0.09 mg/kg at flowering have been associated with yield responses to applied Mo (Williams *et al.* 2004). Petiolar Mo concentrations at site 4 (Figure 1), site 6 (Table 6) and site 10 (Table 5) were lower that this value. Yield responses to applied Mo have occurred at site 4 (see Chapter 1.1). These data suggest that the distribution patterns reported in this study were for vines with deficient – marginal Mo supply.

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Chapter 4

4 Prognosis of molybdenum deficiency in Merlot grapevines (*Vitis vinifera*) by petiole analysis

Norbert Maier, Chris Williams, Louise Chvyl and Kerry Porter

Abstract

Field experiments were undertaken to, i) evaluate sampling error associated with collecting basal petioles (index tissue) and sampling leaves next in age to the index tissue; ii) define temporal changes in petiolar molybdenum (Mo) concentrations during the growing season, particularly during flowering; iii) assess the sensitivity of Mo concentrations in basal petioles to variations in Mo supply; and iv) determine the relationships between petiolar Mo concentrations at flowering and yield response to derive interpretation standards for the prognosis of Mo deficiency. For Mo the error associated with our sampling procedure and analytical error were acceptable, with coefficients of variation less than 10%. For Merlot on own roots and on Schwarzmann rootstock Mo concentrations in petioles increased with leaf age down the shoot. This complicates the use of petioles as an index tissue for plant testing. Molybdenum concentrations in petioles changed during the period E-L 12 to E-L 29-31. However, the changes in petiolar Mo concentrations during this period were not consistent and therefore it is not possible to reliably predict petiolar Mo concentrations during flowering from samples collected earlier in the season. Molybdenum concentration in basal petioles was sensitive to variation in Mo supply; however, the magnitude of the effect varied between sampling times. The yield from vines not sprayed with Mo ranged from 0.2 to 15.4 kg/vine and bunch weights were in the range 6.0 – 112.5 g. Molybdenum concentration and relative yield and bunch weight were lower for unsprayed vines than for sprayed vines. The relationships between petiolar Mo concentration and relative yield and bunch weight showed a narrow transition zone between deficiency and adequacy. Lowest relative bunch yields and weights were associated with petiolar Mo concentrations in the range 0.046 – 0.089 mg/kg. In the concentration range 0.092 – 0.386 mg/kg mean relative bunch yields and weights were lower for Merlot on own roots than for Merlot on rootstocks (Ramsey, Schwarzmann, SO4 [2136], 110 Richter, 140 Ruggeri). At a given Mo concentration, responsiveness varied between years. It appears that other factors (eg. climatic) are affecting the magnitude of the yield response at a given Mo concentration. This confounds the use of petiole analysis to assess plant Mo status. For Merlot, because the effect of Mo deficiency appears to be reproductive and not vegetative, sampling at flowering (the standard sampling time for petiole analysis in vines) would be too late for corrective measures to be taken in the current season. However, a scheme based on sampling at flowering can still be used for "trouble shooting" (diagnostic testing), monitoring the vine Mo status on an annual basis (nutrient monitoring) and predictive testing.

Introduction

Molybdenum deficiency has been reported in grapevines. Robinson and Burne (2000) showed that Mo deficiency may be a factor associated with the 'Merlot' problem. They reported that for one crop near Renmark, which showed symptoms of the problem, foliar Mo sprays resulted in vine growth and nitrate accumulation returning to normal after approximately 4 weeks. Gridley (2003), Williams *et al.* (2003; 2004) and Longbottom *et al.* (2004) have reported yield increases in response to foliar Mo sprays applied before flowering to Merlot vines on own roots.

Interpretation standards have not been set for Mo in grapevines (Reuter and Robinson 1997). The calibration of a plant test for Mo would be useful to allow growers to assess the Mo status of their vines and so determine the adequacy of their Mo fertiliser programs. To calibrate a plant test for a specified nutrient, the relationship between for example, yield or growth rate and the concentration of that nutrient in an index tissue sampled at specific growth stage, needs to be defined (Smith and Loneragan 1997). An appropriate level of relative yield, 90% for example, is selected and the corresponding concentration in the index tissue is by definition, the critical concentration at that time of sampling. Critical concentrations can be used by growers as "target levels" to assess the adequacy of their fertiliser program. However, critical concentrations often vary, depending on growing conditions, nutrient management strategy, cultivar or scion/rootstock grown and how they were derived (Lewis *et al.* 1993). Therefore, Dow and Roberts (1982) proposed a critical nutrient range (CNR), or a range of uncertainty, within which response to the applied nutrient is uncertain. Above the CNR the crop is likely to be amply supplied with the nutrient in question and below which, there is a high probability that the crop is deficient in the nutrient.

Factors which need to be considered when developing plant sampling procedures for perennial species include, (i) plant part sampled (index tissue), the chemical composition of index tissues, for example leaves, may change with age or position along a shoot. It is therefore important to determine the effect on nutrient composition of sampling leaves next in age to the index leaf. The index tissue should also have a narrow transition zone between deficiency and adequacy and exhibit a wide range of tissue concentrations of the nutrient concerned; (ii) sampling error, the index tissue should be easily identifiable and be able to be sampled in a reproducible manner to minimise sampling error; (iii) sampling time, changes in nutrient composition during the growing season, even in tissues of a specified physiological age, mean that sampling time needs to be carefully specified to ensure correct interpretation of plant analysis results. The preferred sampling time is when the rate of change in nutrient concentrations is minimal; and (iv) sensitivity of nutrient concentrations in the index tissue to variations in nutrient supply.

Plant analysis is extensively used to determine the nutrient status of a wide range of annual and perennial agricultural and horticultural crops (Reuter and Robinson 1997). In grapevines, plant analysis is based on sampling petioles of leaves opposite basal bunch clusters when the majority of vines are flowering (Reuter and Robinson 1997). However, standards have not been set for Mo. Williams *et al.* (2004) for Merlot on own roots, reported that at flowering, Mo concentrations in basal petioles of 0.05-0.09 mg/kg were associated with significant bunch yield response to applied Mo.

In this paper we report on field experiments designed to, firstly, evaluate sampling error associated with collecting the petioles (index tissue). Secondly, define temporal changes in petiolar Mo concentrations during the growing season, particularly during flowering. Thirdly, determine the relationships between petiolar Mo concentrations at flowering and yield response to derive interpretation standards for the prognosis of Mo deficiency.

Materials and Methods

Field experiments

Site, growth and yield response details of the field experiments (sites 1 – 10) involved in this study are described in the Research Strategy and Method section, Table 1 and in Materials and Methods sections in Chapters 1.2, 2, 3, 5 and 6.

Leaf sampling procedure

The index tissue we sampled was basal petioles as per Robinson *et al.* (1997). During flowering (E-L 23-25), a minimum of 30 petioles were randomly collected from leaves opposite basal bunches. For the effect of leaf position along a shoot on petiolar Mo concentration; 20 shoots were selected at random at site 5 during flowering from each replicate. All the shoots with leaves intact were immediately placed in labelled paper bags within a large plastic bag and stored over ice in an insulated box prior to being transported to the laboratory.

Sampling error

The reproducibility of the sampling procedure was tested by comparing the results of sampling uniform plantings at 2 sites on 5 consecutive occasions on the same day. Data are for Merlot on Ramsey rootstock sampled in 2002/03.

Analytical procedure

All leaf samples were dried at 60-70^{o}C in a forced-draught oven and ground to <1 mm prior to analysis. The samples were analysed for Mo and nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), zinc (Zn) and manganese (Mn) as described by Williams *et al.* (2004) and summarised in the Research Strategy and Method section.

Statistical methods

To show the changes in petiole Mo concentrations over time, mean Mo concentrations and standard errors are presented.

Results and Discussion

Symptoms of Mo deficiency

Symptoms include; reduction and irregularities in leaf blade formation (whiptail); local chlorosis and necrosis along the main veins of mature leaves; marginal chlorosis and necrosis on older leaves; cupping (upward curling) of leaf edges. These can often be confused with N deficiencies. Other than 'the Merlot problem' we are not aware of any published descriptions of Mo deficiency in grapevines. Symptoms of 'the Merlot problem' include stunted shoots with zigzag or distorted growth habit and small leaves, which may have burnt and papery leaf margins (Robinson and Burne 2000). Kaiser *et al.* (2005) reported that in Mo deficient Merlot vines visual symptoms included " zigzag-shaped internodes, pale green leaves, increased cupped and flaccid leaves and marginal leaf necrosis". In contrast, symptoms on

shoots or leaves were not reported by Williams *et al.* (2004), however, when a response to Mo occurred, many of the bunches on unsprayed plants were similar in appearance to the poor fruit set disorders, 'shot berry' formation and 'hen and chickens' or millerandage. The 'shot berry' disorder is characterised by the formation of excessive numbers of small green, seedless berries which fail to grow to normal size and may or may not ripen by harvest. 'Hen and chickens' is the mixture of a few large normal berries (hens) and many small berries (chickens) on a bunch at harvest, and the berries ripen unevenly. In this study, we found that the application of Mo did not increase shoot length, length of the 5th internode, weight of prunings (see Chapter 1.1) or the weight of above ground parts (see Chapter 3).

Bunch number and bunch weight versus yield

Earlier studies with Merlot on own roots have shown that pre-flowering applications of Mo affected bunch yield and weight (Gridley 2003; Williams *et al.* 2003; 2004; Longbottom *et al.* 2004). Bunch number was usually not affected. Therefore, although there were positive relationships between both bunch number and weight and yield (Figure 1) only the relationships between petiolar Mo concentration and yield and bunch weight were studied.

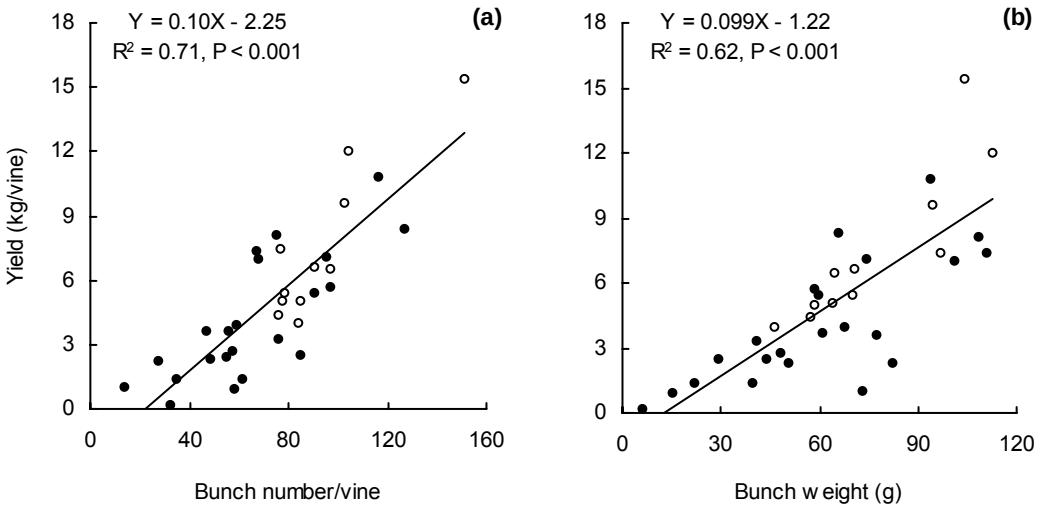


Figure 1. Relationships between (a) bunch number and yield and (b) bunch weight and yield for Merlot on own roots (●) and on rootstocks (○). Rootstocks were Ramsey, Schwarzmann, SO4 (2136), 110 Richter and 140 Ruggeri.

Sampling error

For Mo the error associated with our sampling procedure and analytical error were acceptable, with coefficients of variation less than 10% (Table 1). Our estimates were least reliable for Na, with coefficients of variation up to 16.1% at location 1.

Table 1. Range of concentrations and coefficients of variation (CV, %) for petiole analysis data from two locations in a commercial vineyard in the Barossa Valley

	Mo		**N**	**NO_3-N**	**P**	**K**	**Ca**	**Mg**
	mg/kg		%	mg/kg		%		
				Location 1				
Range	0.11-0.11		1.0-1.1	430-550	0.50-0.54	4.0-4.3	1.03-1.14	0.51-0.53
CV (%)	0.0		5.2	10.1	2.9	2.8	3.8	1.92
				Location 2				
Range	0.09-0.11		0.97-1.00	340-400	0.52-0.59	4.2-4.5	1.08-1.15	0.46-0.49
CV (%)	7.1		1.4	7.5	6.1	2.5	2.7	2.8
	Na	**Cl**	**S**	**B**	**Cu**	**Zn**	**Mn**	**Fe**
		%				mg/kg		
				Location 1				
Range	0.03-0.04	0.20-0.23	0.17-0.19	46-47	15-17	71-82	59-66	21-22
CV (%)	16.1	5.3	4.7	1.2	4.4	6.1	4.2	2.5
				Location 2				
Range	0.03-0.04	0.16-0.18	0.19-0.20	47-49	13-16	60-73	42-48	19-23
CV (%)	11.8	5.0	2.3	1.5	9.2	7.9	5.5	8.1

N = 5

Maier *et al.* (1995) for Protea 'Pink Ice', reported that for Cu, Zn, Mn and Fe their estimates were less reliable compared with other nutrients, with coefficients of variation up to 61.1% for Cu. Data reported by Cresswell (1989) for kiwifruit also showed that coefficients of variation for Cu, Zn, Mn and P were higher than for N, K, Ca and Mg.

It is suggested that the sampling procedure used in this study was satisfactory for all nutrients.

Temporal changes in petiolar molybdenum concentrations early in the season

Changes between E-L 12 (shoots 10 cm) and E-L 29-31 (berries 4-7 mm diameter)

The standard sampling time (full bloom) for petiole analysis in grapes may be too late to identify and correct Mo deficiency in the current season. The yield responses to pre-flowering foliar sprays of Mo reported by Gridley (2003), Williams *et al.* (2003; 2004) and Longbottom *et al.* (2004) occurred because Mo deficiency affected the reproductive phase, while the vegetative phase was relatively unaffected. Longbottom et al. (2004) suggested that Mo may affect the development of reproductive structures which affect pollen tube growth, penetration of ovules and fertilisation. We therefore monitored Mo concentrations in petioles between E-L 12 and E-L 23 (full bloom) to determine if changes in Mo concentrations during this period were consistent between sites and years. Relationships between for example, petiolar Mo concentrations at E-L 12 and E-L 23, could then be used to predict petiolar Mo concentrations at flowering from samples collected at an earlier stage of growth. Corrective foliar sprays could therefore be applied before full bloom.

Molybdenum concentrations in petioles changed during the period E-L 12 to E-L 29-31 (Figures 2 and 3). The magnitude of the change varied between sampling time, sites, rootstocks and years. Williams *et al.* (2004) reported that significant yield responses were associated with petiolar Mo concentrations in the range 0.05-0.09 mg/kg at flowering. Concentrations in this range at E-L 12 were found at some sites, however, concentrations increased during the period E-L 12 to flowering (Figures 2b, 3b, d, e). The data show that the changes in petiolar Mo

concentrations during this period were not consistent and therefore it is not possible to reliably predict petiolar Mo concentrations during flowering from samples collected earlier in the season.

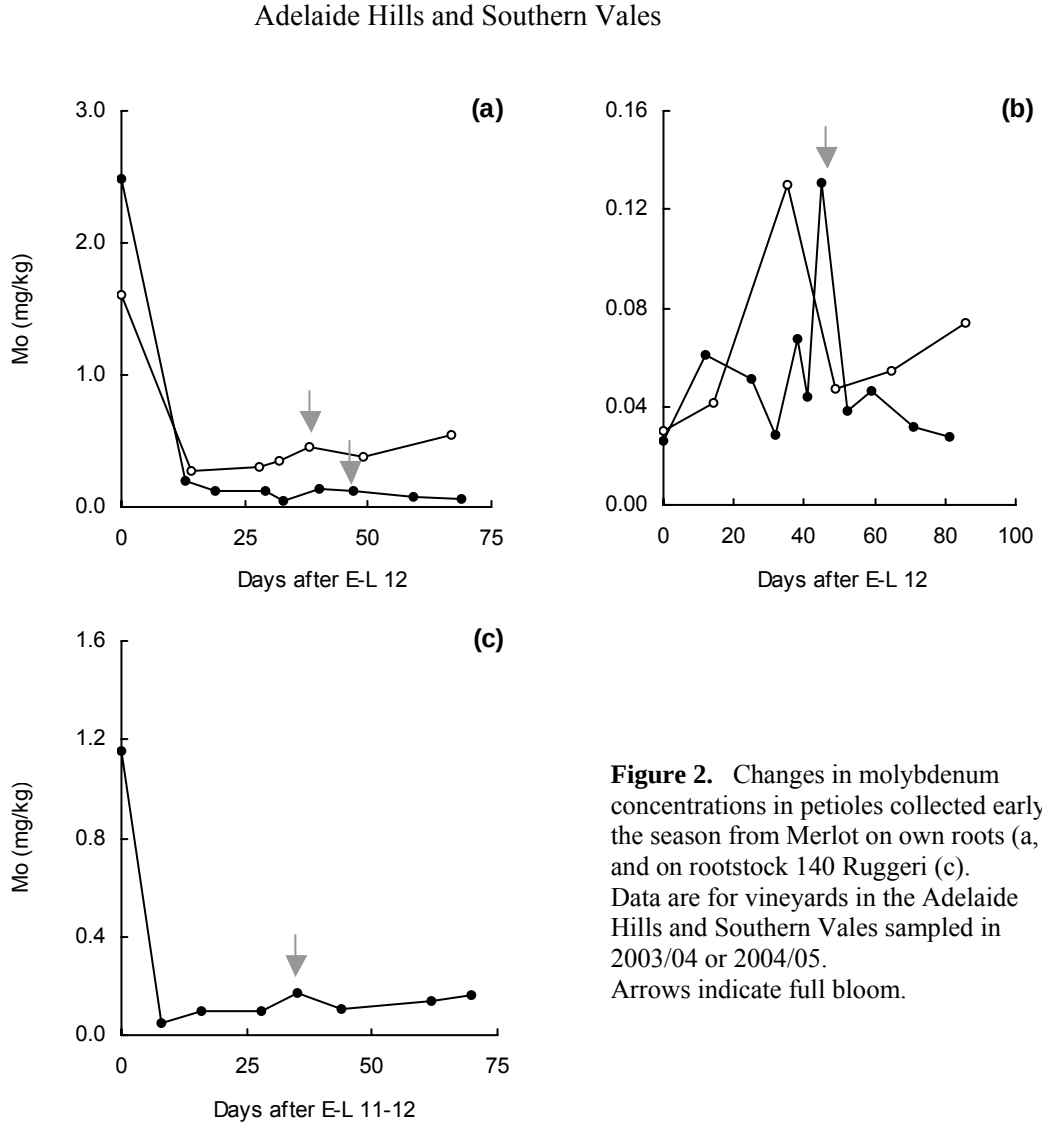


Figure 2. Changes in molybdenum concentrations in petioles collected early in the season from Merlot on own roots (a, b) and on rootstock 140 Ruggeri (c). Data are for vineyards in the Adelaide Hills and Southern Vales sampled in 2003/04 or 2004/05. Arrows indicate full bloom.

Molybdenum has been classified as variably phloem mobile from leaves (Grundon *et al.* 1997; Gupta 1997). Changes in Mo concentration may therefore depend on supply. Soil, climatic and plant factors can also affect Mo uptake, and therefore, distribution in the plant.

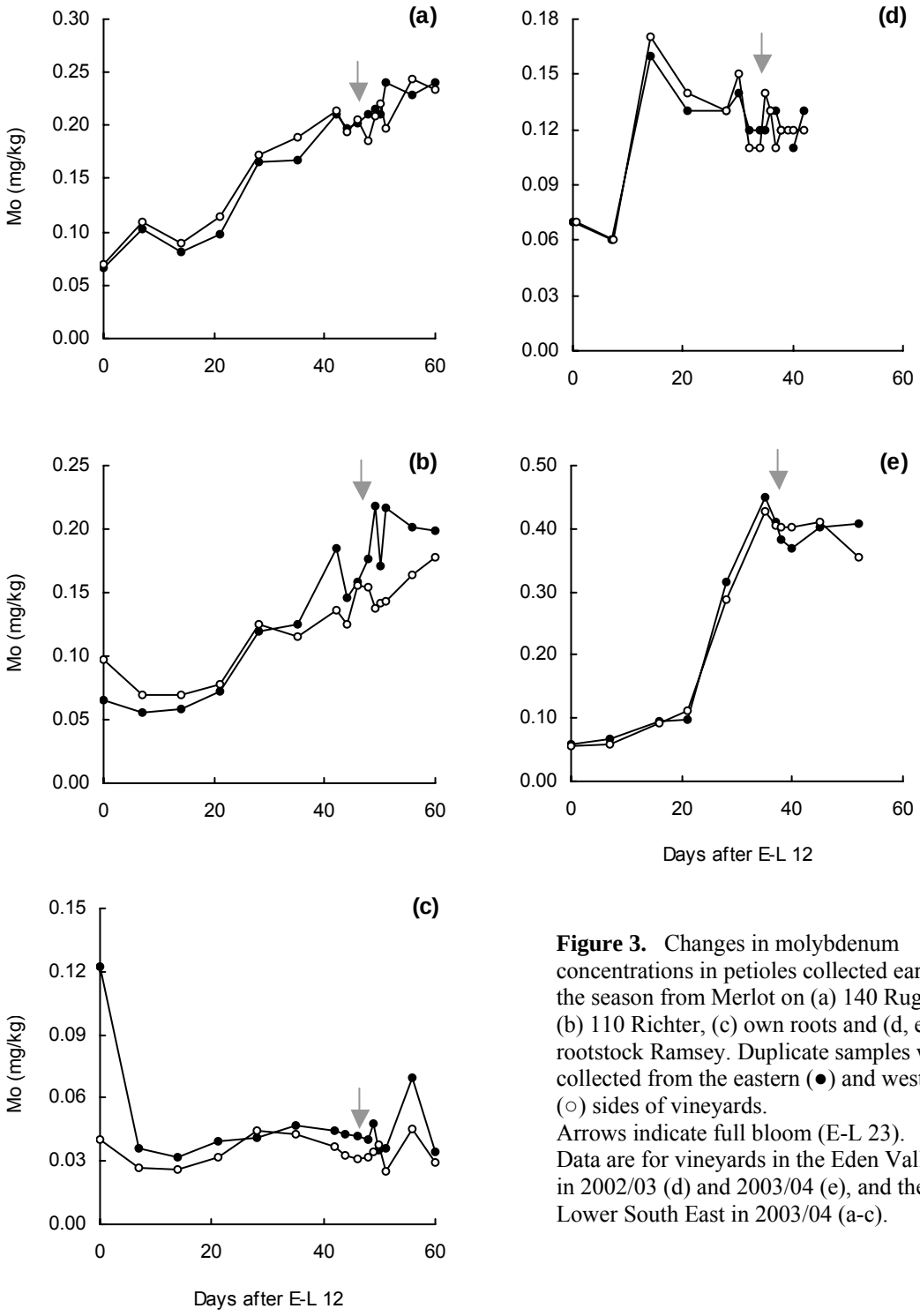


Figure 3. Changes in molybdenum concentrations in petioles collected early in the season from Merlot on (a) 140 Ruggeri, (b) 110 Richter, (c) own roots and (d, e) rootstock Ramsey. Duplicate samples were collected from the eastern (●) and western (○) sides of vineyards.
Arrows indicate full bloom (E-L 23).
Data are for vineyards in the Eden Valley in 2002/03 (d) and 2003/04 (e), and the Lower South East in 2003/04 (a-c).

The large seasonal changes in petiolar Mo concentrations have important implications for plant testing and emphasises the importance of sampling at the correct time.

Changes during flowering (E-L 19 to E-L 26)

Studies of other nutrients have demonstrated significant changes during flowering (Robinson and McCarthy 1985). No information is available on the behaviour of Mo during this period.

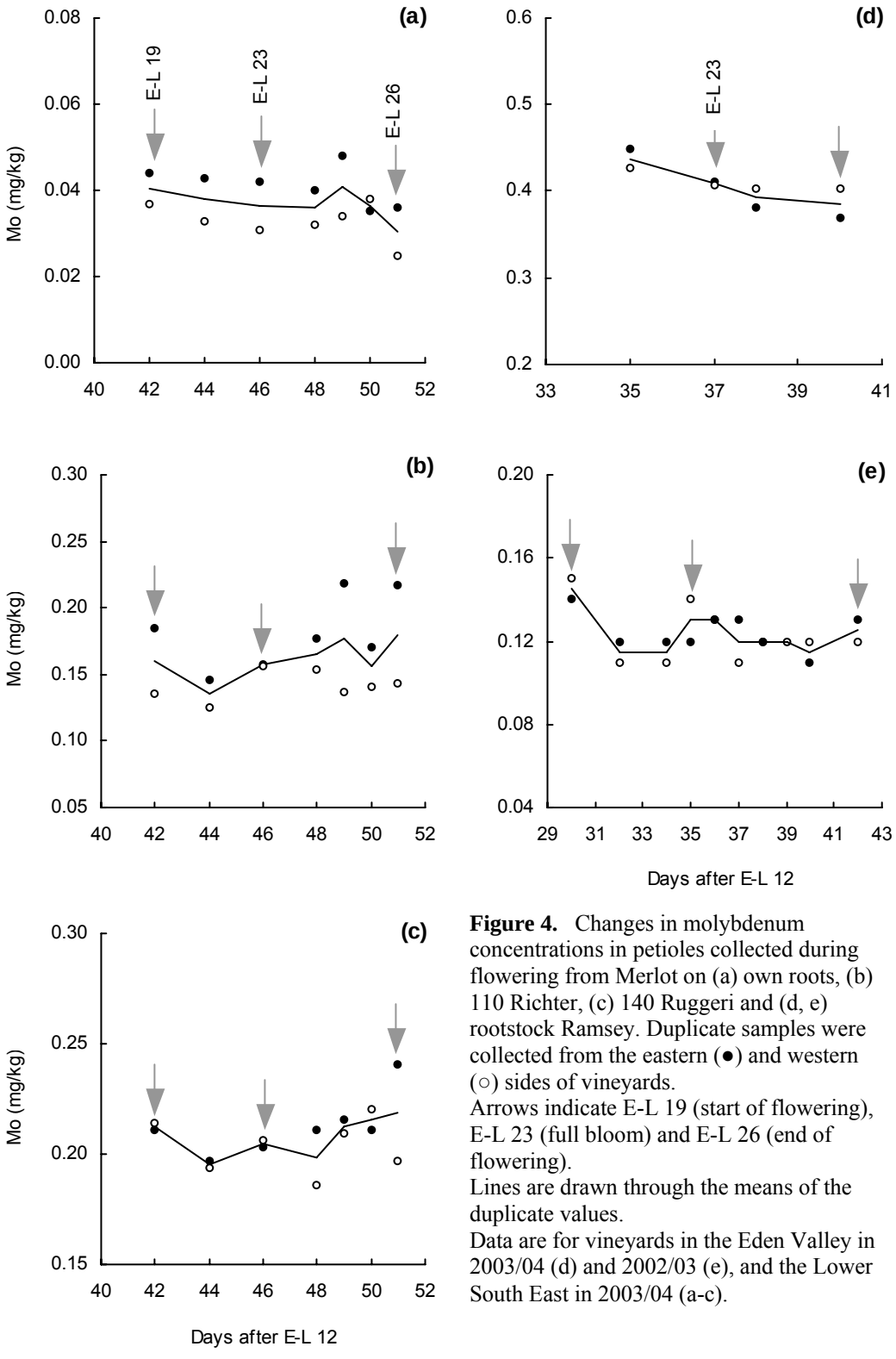


Figure 4. Changes in molybdenum concentrations in petioles collected during flowering from Merlot on (a) own roots, (b) 110 Richter, (c) 140 Ruggeri and (d, e) rootstock Ramsey. Duplicate samples were collected from the eastern (●) and western (○) sides of vineyards.
Arrows indicate E-L 19 (start of flowering), E-L 23 (full bloom) and E-L 26 (end of flowering).
Lines are drawn through the means of the duplicate values.
Data are for vineyards in the Eden Valley in 2003/04 (d) and 2002/03 (e), and the Lower South East in 2003/04 (a-c).

Changes in petiolar Mo concentrations between E-L 19 (start of flowering) and E-L 26 (end of flowering) were relatively small (Figure 4). This observation is important because the success of the sampling procedure relies on reasonably stable Mo concentrations during the sampling period.

Variation in petiolar molybdenum concentration with leaf position along a shoot

The chemical composition of leaf blades or petioles, can change with age or position along a shoot or stem. It is therefore important to determine the effect on nutrient composition of sampling leaves next in age to the index leaf. We found that for Merlot on own roots and on Schwarzmann rootstock Mo concentrations in petioles increased with leaf age down the shoot (Figure 5).

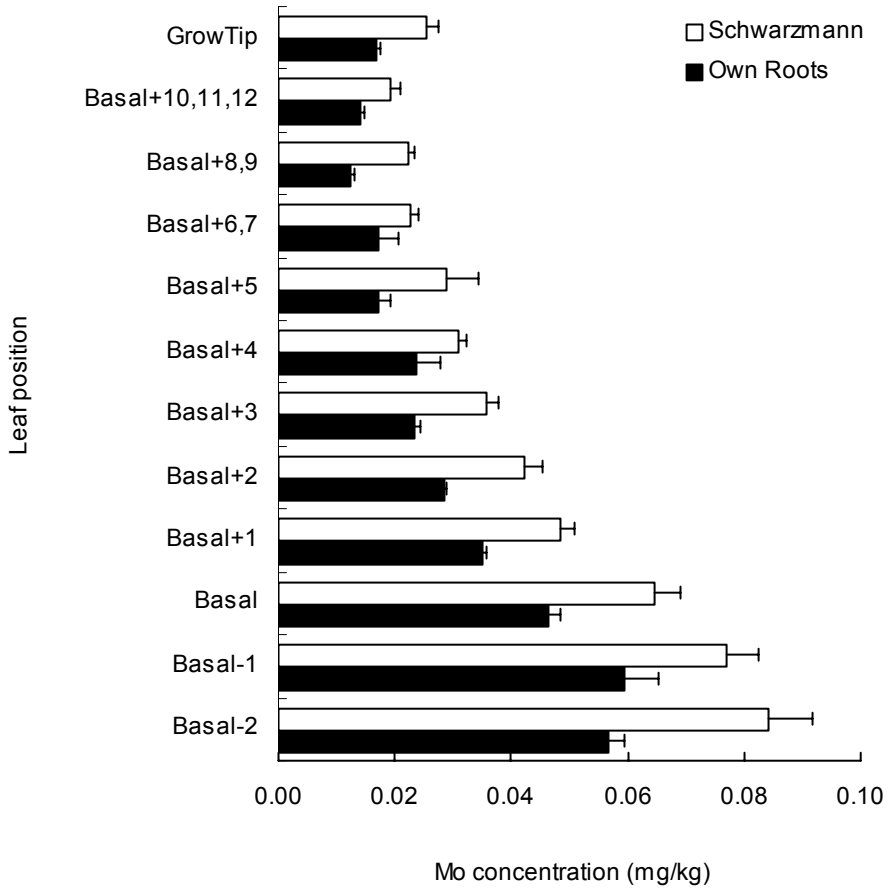


Figure 5. Effect of leaf position along a shoot on petiolar molybdenum concentration for Merlot on own roots and Schwarzmann rootstock. Basal refers to petioles sampled from leaves opposite the basal bunch. Vertical lines indicate standard errors of the means.

This complicates the use of petioles as an index tissue for plant testing. To minimise sampling error and ensure correct interpretation of plant test data, the position of the leaf sampled needs to be accurately described.

To minimise the effect of sampling petioles from leaves next in age to the index leaf (eg. leaf opposite basal bunch), the preferred leaf to sample is from a position on the stem where the rate of change in petiolar nutrient concentration between leaves is minimal. Inspection of the graphs presented in Figure 5 shows that the rate of change in petiolar Mo concentration was greatest from basal -1 to basal +3 leaves. Concentrations were relatively stable in basal +5 to basal +10-12 leaves (Figure 5). However, the Mo concentration in petioles of these leaves was very low and may not be sensitive to variations in Mo supply.

Molybdenum concentrations in petioles of leaves sampled from Merlot on own roots were consistently less than those from Merlot on Schwarzmann rootstock (Figure 5). The effect of rootstock on petiolar chemical composition is discussed Chapter 1.2 and 1.4).

Effect of applied molybdenum on the concentration of molybdenum in different plant tissues

Petioles

Molybdenum concentration in basal petioles was sensitive to variation in Mo supply; however, the magnitude of the effect varied between sampling times (Table 2, Figure 6). The increase in petiolar Mo concentration was greater at flowering than at veraison (Figure 6).

Table 2. Effect of rate of applied molybdenum on petiolar molybdenum concentrations at flowering (E-L 23-25) and veraison (E-L 35) at three experimental sites of Merlot on own roots in the Mount Lofty Ranges of South Australia in the 2003/04 growing season.

Molybdenum was applied as two foliar sprays, half the total rate at E-L 12-15 and half at E-L 16-18.

Variable	**Mo concentration (mg/kg)**		
	McLaren Vale	**Carey Gully**	**Lenswood**
Mo rate (mg/L)			
0	0.12	0.19	0.09
125	3.41	3.32	3.61
250	6.45	4.95	5.76
500	13.94	11.50	12.36
1000	24.55	19.32	23.93
2000	54.60	44.41	56.81
LSD (P=0.05)	*4.23*	*6.13*	*6*
Sampling time			
Flowering	11.88	12.33	13.88
Veraison	9.93	3.69	5.26
LSD (P=0.05)	*1.54*	*2.24*	*2.20*
Interaction			
Significance	***	***	***

*** $P < 0.001$.

The linear relationships between petiolar Mo concentrations and rate of applied Mo showed that petiolar Mo concentrations increased up to the highest rate of Mo applied (Figure 6).

There was a significant interaction between rate applied and sampling time in their effect on petiolar Mo concentration (Table 2). The difference in Mo concentration in petioles at flowering and veraison was dependent on supply (Figure 6). The difference was greatest at the highest rate applied.

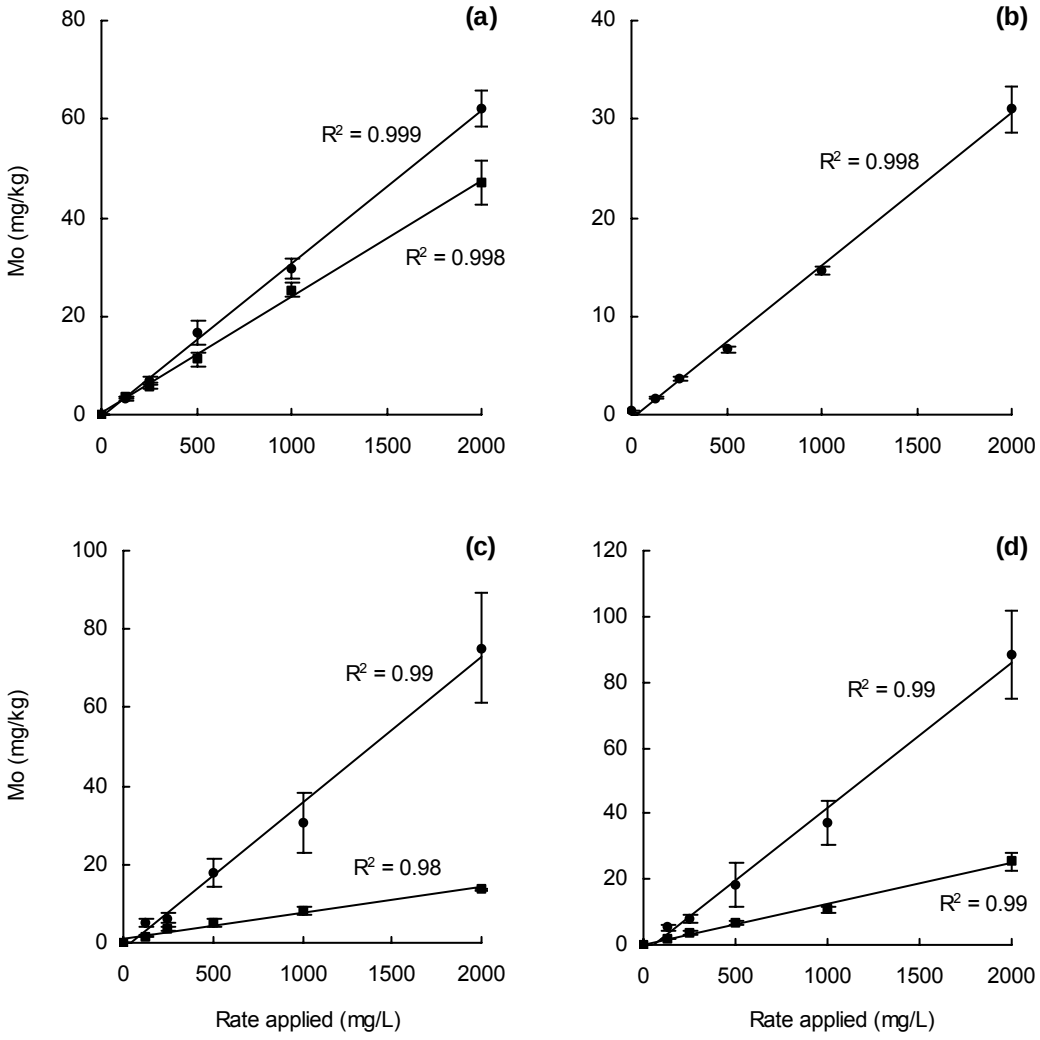


Figure 6. Effect of increasing rate of applied molybdenum on molybdenum concentrations in petioles sampled at flowering (●) and veraison (■) at three experimental sites of Merlot on own roots in the Mt lofty Ranges, (a, b) McLaren vale, (c) Carey Gully and (d) Lenswood. Data are for the 2003/04 (a, c, d) and 2004/05 (b) growing seasons. Vertical lines indicate standard errors of the means. Coefficients of determination (R^2) were determined by fitting a linear model to the data.

Molybdenum was applied as two foliar sprays, half the total rate at E-L 12-15 and half at E-L 16-18.

Terminal 15 cm of shoot

The petiolar Mo concentrations need to be interpreted cautiously, because Mo was applied as a pre-flowering foliar spray, residue may therefore be present on petioles. To minimise residue effects, the terminal 15 cm growth of shoots was also sampled at flowering and veraison. Molybdenum concentration in this tissue fraction also increased with increasing rates of applied Mo (Figure 7).

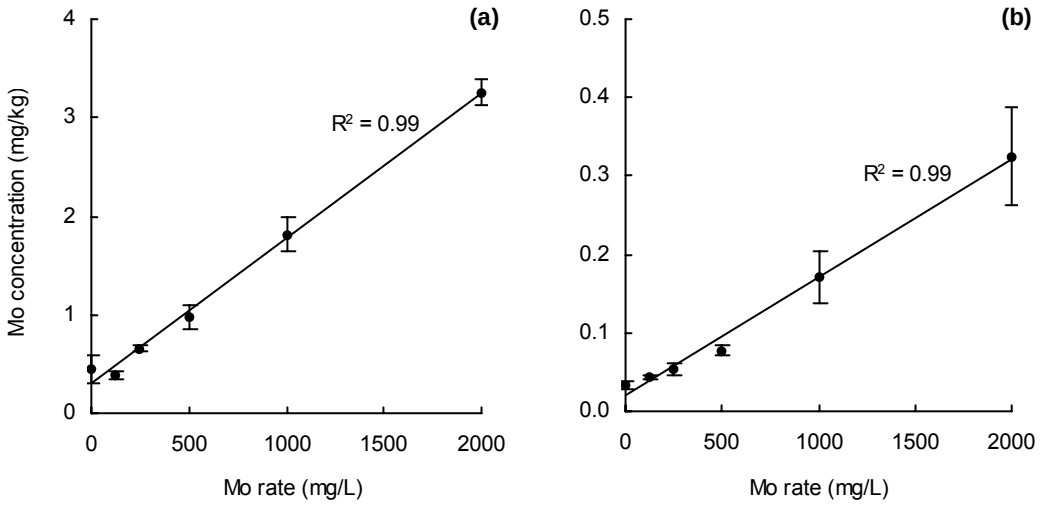


Figure 7. Effect of increasing rate of applied molybdenum on molybdenum concentrations in the terminal 15 cm of shoot sampled at (a) flowering and (b) veraison at one experimental site of Merlot on own roots at McLaren Vale in the Mt lofty Ranges in the 2004/05 growing season. Vertical lines indicate standard errors of the means. Coefficients of determination (R^2) were determined by fitting a linear model to the data. Molybdenum was applied as two foliar sprays, half the total rate at E-L 12-15 and half at E-L 16-18.

The magnitude of the increase was less than that in petioles (Figures 6 and 7).

Survey of petiolar molybdenum concentrations at flowering

A wide range of petiolar Mo concentrations was found in commercial vineyards across Australia (Figure 8).

Williams *et al.* (2004) for Merlot on own roots, reported that at flowering, Mo concentrations in basal petioles of 0.05-0.09 mg/kg were associated with significant bunch yield response to applied Mo.

We found that 39.5% of Merlot vineyards sampled at flowering, had petiolar Mo concentrations of less than 0.10% (Figure 8a). For Chardonnay vineyards, the value was 34.0% (Figure 8b).

On a State basis, the percentage of vineyards sampled which had petiolar Mo concentrations of less than 0.10% were: New South Wales (Hunter Valley, Mudgee, Sunraysia) 35.9%, South Australia (Mt Lofty Ranges, Southern Vales, Langhorne Creek) 37.6%, Victoria (Macedon Ranges, Yarra Valley) 77.3%, and Western Australia (Margaret River, Great Southern) 14.6% (Figure 8c-f).

At present there are no interpretation standards for petiolar Mo concentrations for grapes.

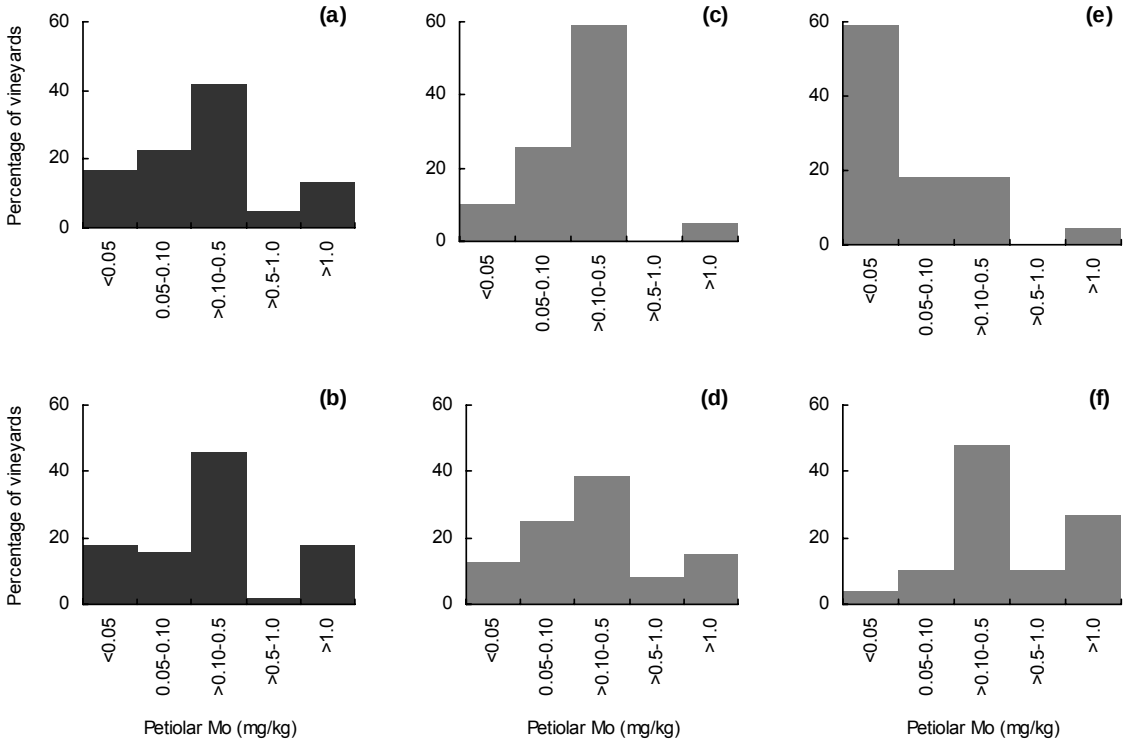


Figure 8. Percentage of vineyards which had petiolar molybdenum concentrations at flowering in the ranges specified. Vineyards have been grouped according to variety, (a) Merlot (N=119) and (b) Chardonnay (N=50), or State, (c) New South Wales (N=39), (d) South Australia (N=85), (e) Victoria (N=22) and (f) Western Australia (N=48). N, is the number of vineyards sampled.

Vine yield and yield response to applied molybdenum

The yield from vines not sprayed with Mo ranged from 0.2 to 15.4 kg/vine (Table 3). Bunch weights were in the range 6.0 – 112.5 g.

Molybdenum concentration and relative yield and bunch weight were lower for unsprayed vines than for sprayed vines (Table 4). Relative bunch number were similar for sprayed and unsprayed vines (Table 4).

Table 3. Growing season, rootstock, petiolar molybdenum concentrations at flowering (E-L 23-25), absolute and relative yield values for unsprayed vines

Site	Growing Season	Rootstock	Mo Concentration	Absolute value			Relative value[A]		
				Vine	Bunch		Vine	Bunch	
				Yield	Weight	Number	Yield	Weight	Number
			mg/kg	kg	g		%		
1	2000/01	Own roots		1.0	72.8	13.8	90.0	90.8	100.0
1	2001/02	Own roots	0.054	1.4	21.7	61.8	30.6	24.3	100.0
1	2002/03	Own roots	0.386	3.9	67.3	59.3	81.1	76.6	100.0
1	2003/04	Own roots	0.629	10.8	93.7	116.3	98.9	80.4	100.0
1	2004/05	Own roots	0.069	5.4	59.9	90.7	75.0	70.5	100.0
2	2000/01	Own roots	0.455	2.3	82.1	27.8	92.6	102.0	92.2
2	2001/02	Own roots	0.051	0.2	6.0	32.5	12.7	19.1	62.6
2	2002/03	Own roots	0.172	1.4	39.6	34.7	80.7	83.2	96.6
2	2003/04	Own roots	0.285	7.4	111.0	67.3	88.0	100.0	74.6
3	2000/01	Own roots	0.119	5.7	58.7	96.6	88.6	90.0	98.3
3	2001/02	Own roots	0.052	0.9	15.1	58.3	28.8	29.2	95.8
3	2002/03	Own roots	0.084	2.3	50.5	48.4	59.3	59.1	89.6
3	2003/04	Own roots	0.330	8.1	108.3	74.9	87.0	89.7	97.2
3	2004/05	Own roots	0.480	3.6	77.4	46.7	87.8	91.4	94.6
4	2003-04	Own Roots	0.049	3.3	41.0	75.8	53.8	60.6	89.3
4	2004-05	Own Roots	0.046	2.5	29.4	85	30.8	30.4	101.9
4	2003-04	Ramsey	0.122	5.4	70.1	78.3	104.8	98.2	108.9
4	2003-04	110 Richter	0.119	6.7	70.7	90.3	171.1	130.4	121.0
4	2003-04	140 Ruggeri	0.135	5.0	63.9	77.8	88.2	96.9	92.7
4	2003-04	Schwarzmann	0.070	4.0	46.1	84.3	97.2	72.7	130.4
4	2003-04	SO4(2136)	0.093	4.4	57.2	76.3	117.4	99.9	115.9
4	2004-05	Ramsey	0.121	7.4	96.6	77	65.5	79.1	80.8
4	2004-05	110 Richter	0.124	12.0	112.5	105	118.1	96.4	119.3
4	2004-05	140 Ruggeri	0.122	9.6	94.2	103	78.0	79.2	100.8
4	2004-05	Schwarzmann	0.081	5.0	58.5	85	58.6	56.5	104.7
4	2004-05	SO4(2136)	0.066	6.5	64.6	97	70.4	55.1	119.2
5	2004/05	Own roots	0.089	8.3	65.7	127	55.4	68.5	80.5
5	2004/05	Schwarzmann	0.141	15.4	104.1	151	104.8	92.2	117.1
6	2003/04	Own Roots	0.092	7.1	74.4	95.0	84.8	89.0	93.6
6	2004/05	Own Roots	0.175	2.5	43.6	55.3	81.0	88.9	90.7
7	2003/04	Own Roots	0.185	7.0	101.4	68.3	82.8	95.8	85.7
9	2003/04	Own Roots	0.115	3.7	61.0	55.5	74.3	75.0	93.3
9	2004/05	Own Roots	0.346	2.8	48.1	57.0	58.6	62.6	94.5

[A] Relative values were defined as 100 x (yield without molybdenum/yield with molybdenum) for each scion-rootstock combination at each site.

Table 4. Summary statistics for petiolar molybdenum concentrations (mg/kg, d wt) at flowering (E-L 23-25) and relative yield and bunch number for unsprayed (control) and sprayed treatments

Data are for Merlot on own roots

	Molybdenum concentration		Relative yield[A]	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Mean ± se	0.203 ± 0.038	12.7 ± 2.6	69.2 ± 5.2	100.0 ± 0
Range	0.046 – 0 63	0.29 – 62.1	12.7 – 98.9	100.0 – 100.0
Median	0.12	8.06	80.9	100.0
N[B]	21	27	22	22
	Relative bunch weight		Relative bunch number	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Mean ± se	71.7 ± 5.4	99.4 ± 0.5	92.3 ± 2.0	99.4 ± 0.5
Range	19.1 – 100.0	89.2 – 100.0	62.6 – 101.9	89.2 – 100.0
Median	78.5	100.0	94.6	100.0
N[B]	22	22	22	22

[A] Relative values were defined as 100 x (yield/maximum yield) for each scion-rootstock combination at each site.
[B] N, is the number of data points.

Relationships between petiolar molybdenum concentrations and bunch yield and bunch weight

The calibration of a plant test for a particular nutrient usually involves defining the relationship between the concentration of the nutrient in an index tissue and yield.

Merlot on own roots

The relationships between petiolar Mo concentration and relative yield and bunch weight shown in Figure 9 are typical calibration curves found in plants. The ascending portion shows that yield increases with increasing Mo concentration and this occurs over a narrow concentration range (0.046 – 0.63 mg/kg). There is therefore, a narrow transition zone between deficiency and adequacy. The plateau portion of the curve is where yield is not limited by Mo concentration (luxury accumulation). The curves did not show a descending portion, indicating that Mo did not extend into the toxicity range.

By fitting appropriate models (eg. Mitscherlich, Bent-Hyperbola or Cate-Nelson) or hand fitted curves to the data, critical concentrations at 90 or 95% can be derived. However, for the sprayed vines, the petiolar Mo concentrations need to be interpreted cautiously, because Mo was applied as a pre-flowering foliar spray, residue may therefore be present on petioles. Therefore, only petiole data for the unsprayed vines were used to develop interpretation standards for plant analysis.

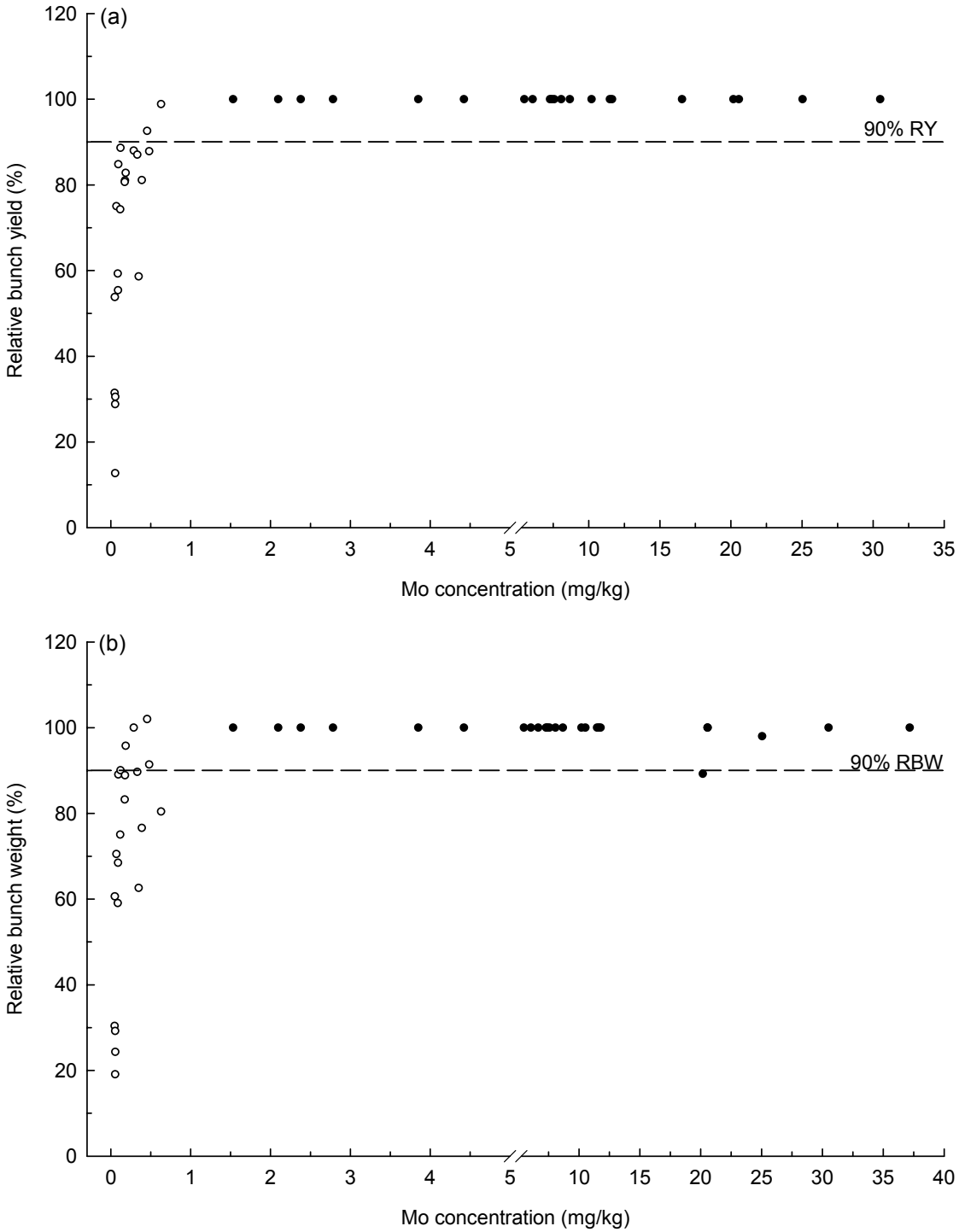


Figure 9. Relationship between molybdenum concentration in petioles sampled during flowering (E-L 23-25) from Merlot vines on own roots sprayed with molybdenum (●) or unsprayed (○) and (a) relative bunch yield and (b) relative bunch weight. RY, is relative yield and RBW, is relative bunch weight. Relative values were defined as 100 x (bunch yield or weight/maximum bunch yield or weight) for each scion-rootstock combination at each site.

Significant yield responses were associated with petiolar Mo concentrations in the range 0.046-0.089 mg/kg (Figure 10). However, the magnitude of the yield response varied considerably in this range.

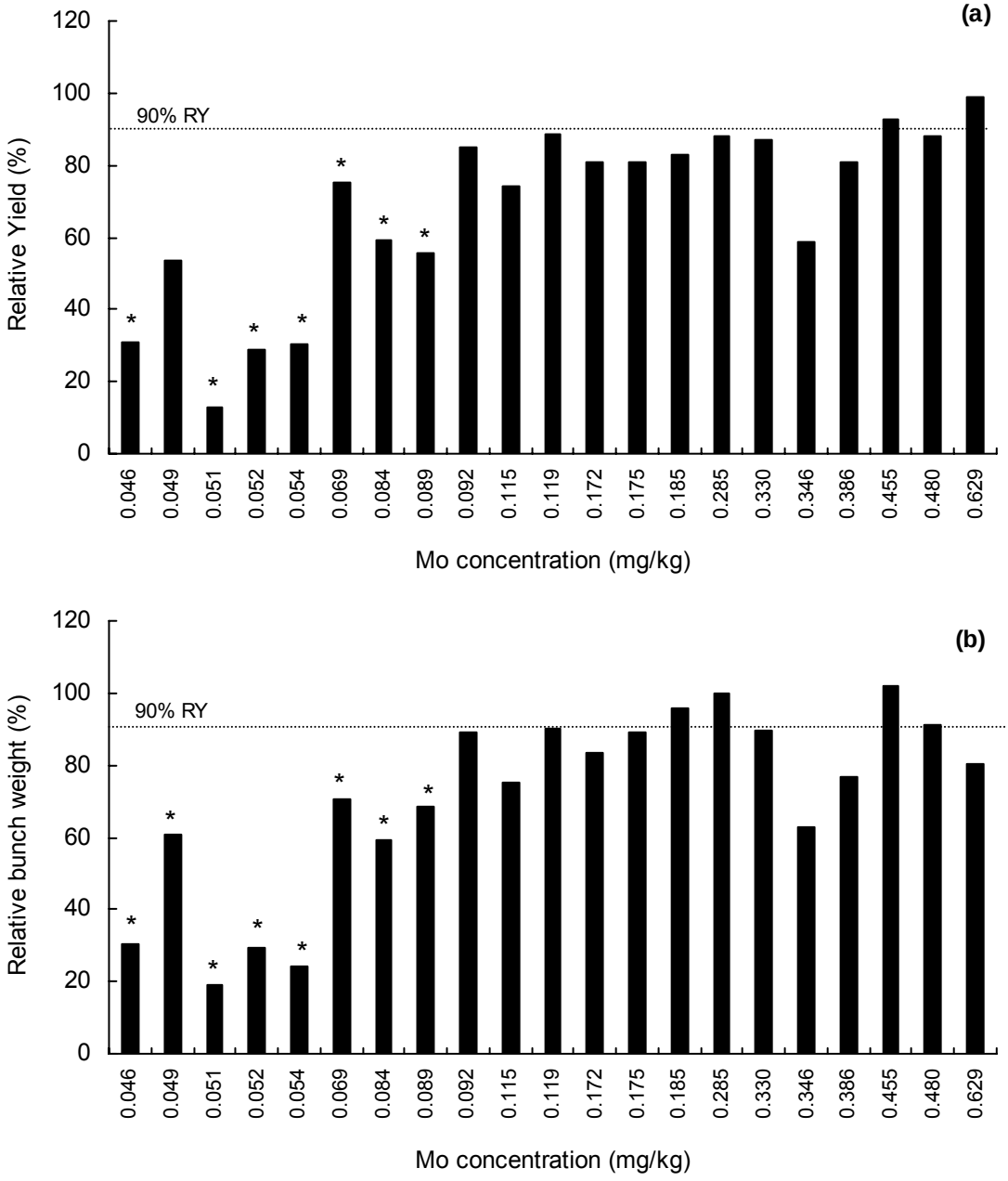


Figure 10. Relative bunch yields (a) and relative bunch weights (b) for molybdenum concentrations in petioles sampled during flowering (E-L 23-25) from Merlot vines on own roots not sprayed with molybdenum. Asterisk (*) indicates significant ($P<0.05$) yield response to applied molybdenum. RY, is relative yield and RBW, is relative bunch weigh. Relative values were defined as 100 x (bunch yield or weight without molybdenum/bunch yield or weight with molybdenum) for each site.

Merlot on rootstocks

Yield response

The magnitude of the yield responses were greater in 2004/05 compared with 2003/04 (Figure 11). For example, relative bunch yields ranged from 88.2 to 171.1% in 2003/04 and from 58.6 to 118.1% in 2004/05.

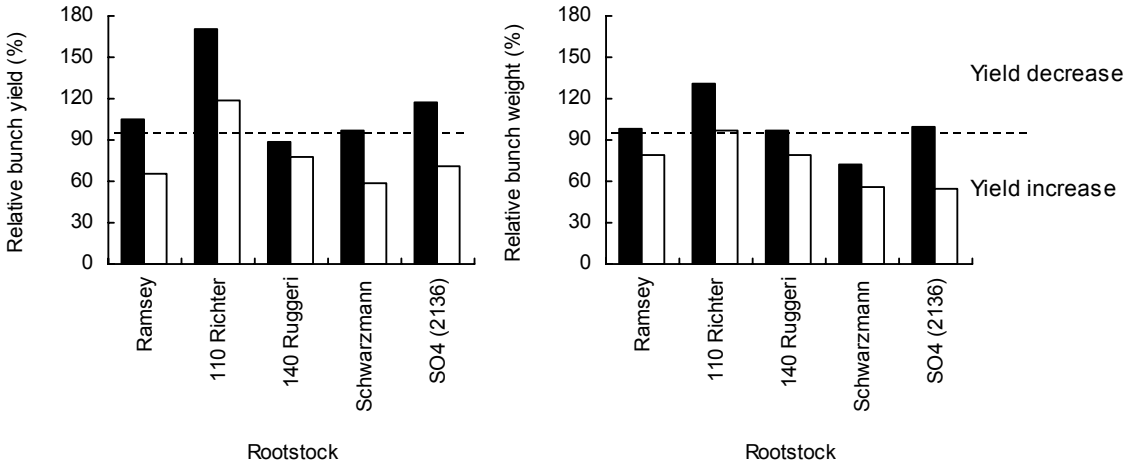


Figure 11. Relative bunch yields and relative bunch weights in the 2003/04 (filled bars) and 2004/05 (open bars) growing seasons for Merlot on rootstocks specified. Data are for site 4. Relative values were defined as 100 x (bunch yield or weight without molybdenum/bunch yield or weight with molybdenum) for each scion-rootstock combination. Dashed line is at 100% relative yield. Values > 100% indicate a decrease in yield in response to applied Mo.

Petiolar Mo concentrations

Petiolar Mo concentrations were similar in 2003/04 and 2004/05 (Figure 12). Concentrations ranged from 0.070 to 0.135 mg/kg in 2003/04 and from 0.066 to 0.124 mg/kg in 2004/05.

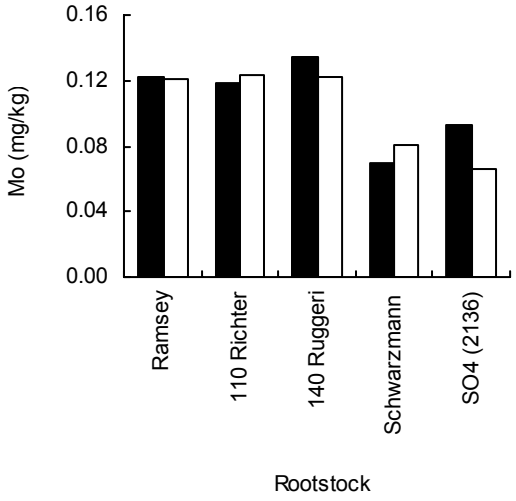


Figure 12. Molybdenum concentration in petioles at flowering (E-L 23-25) in the 2003/04 (filled bars) and 2004/05 (open bars) growing seasons for Merlot on rootstocks specified. Data are for site 4.

Interpretation standards

Lowest relative bunch yields and weights were associated with petiolar Mo concentrations in the range 0.046 – 0.089 mg/kg (Figure 13, Table 5). Studies with other crops have reported critical concentrations of < 0.1 mg/kg (Gupta *et al.* 1990; Jongruaysup *et al.* 1994; Reuter and Robinson 1997). In the concentration range 0.092 – 0.386 mg/kg mean relative bunch yields and weights were lower for Merlot on own roots than for Merlot on rootstocks (Table 5).

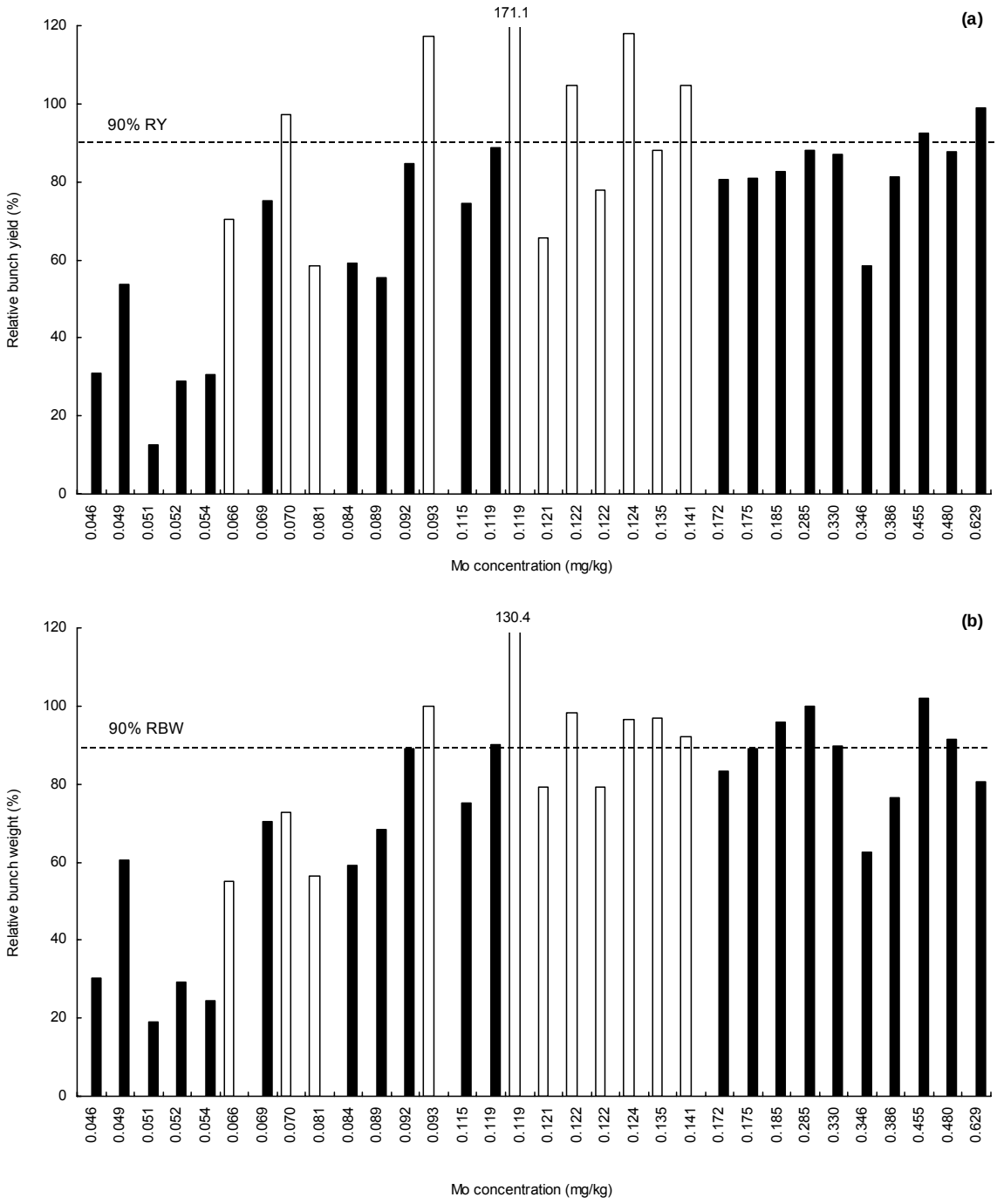


Figure 13. Relative bunch yields (a) and relative bunch weights (b) for molybdenum concentrations in petioles sampled during flowering (E-L 23-25) from Merlot vines not sprayed with molybdenum on own roots (filled bars) and on rootstocks (open bars). Rootstocks were Ramsey, Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri). RY, is relative yield and RBW, is relative bunch weigh. Relative values were defined as 100 x (bunch yield or weight without molybdenum/bunch yield or weight with molybdenum) for each scion-rootstock combination at each site.

Based on data presented in Table 5 and Figures 9, 10 and 13 a suggested scheme to assist in assessing the Mo status of irrigated Merlot vines is: *deficient*, vines whose basal petioles sampled at flowering contain less than 0.09 mg/kg Mo (response to pre-flowering foliar spray likely); *marginal* vines which have petiole Mo concentrations of 0.09 – 0.45 mg/kg (response to pre-flowering foliar sprays is uncertain and likely to be small); and *non-responsive*, vines which have petiole Mo concentrations greater than 0.45 mg/kg (response to pre-flowering foliar sprays unlikely).

For Merlot grapevines in the mar*ginal* zone, bunch yield responses although uncertain were often positive and worthwhile (Figures 10 and 13). For example, for the 10 site/year results for Merlot on own roots; 8 site/years (Figure 13) exhibited 10-20% relative yield responses to applied Mo and 2 site/year results had a 20-40% relative yield response to applied Mo (Figures 10 and 13). Whereas for Merlot on rootstocks of the 8 site/years in the *marginal* zone, 2 site/years showed a 20-40% yield response, 5 did not respond and one site/year exhibited a 10 to 20% relative yield response (Figures 10 and 13). A similar range of responses were recorded for Merlot grapevines on own roots and rootstocks which had *marginal* Mo status (as defined above) in interstate trials (see Chapter 7). Affects of application pre-flowering of Mo to Merlot grapevines of *marginal* Mo status may be related to enhanced activity of molybdoenzymes in plant metabolic processes for growth and reproduction (Gupta 1997)

Table 5. Mean, range and median relative bunch yields and relative bunch weights associated with petiolar molybdenum concentration ranges during flowering (E-L 23-25) for Merlot on own roots and rootstocks

The concentration ranges are based on yield response data presented in Figure 13

	Molybdenum concentration (mg/kg) range		
	0.046 – 0.089	0.092 – 0.386	0.455 – 0.629
Relative bunch yield			
Own roots			
Mean ± se	43.3 ± 7.3	80.7 ± 2.8	93.1 ± 3.2
Range	12.7 – 75.0	58.6 – 88.6	87.8 – 98.9
Median	42.3	82.0	92.6
Rootstock (Ramsey, Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri)			
Mean ± se	75.5 ± 11.4	106.0 ± 11.4	
Range	58.6 – 97.2	65.5 – 171.1	
Median	70.4	104.8	
Combined[A]			
Mean ± se	52.1 ± 7.4	91.9 ± 5.9	93.1 ± 3.2
Range	12.7 – 97.2	58.6 – 171.1	87.8 – 98.9
Median	55.4	85.9	92.6
Relative bunch weight			
Own roots			
Mean ± se	45.2 ± 7.6	85.1 ± 3.5	91.3 ± 6.2
Range	19.1 – 70.5	62.6 – 100.0	80.4 – 102.0
Median	44.8	89.0	91.4
Rootstock (Ramsey, Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri)			
Mean ± se	61.4 ± 5.6	96.5 ± 5.6	
Range	55.1 – 72.7	79.1 – 130.4	
Median	56.5	96.7	
Combined[A]			
Mean ± se	49.6 ± 6.0	90.2 ± 3.4	91.3 ± 6.2
Range	19.1 – 72.7	62.6 – 130.4	80.4 – 102.0
Median	56.5	89.9	91.4
N[B], Own roots	8	10	3
N[B], Rootstocks	3	8	0
N[B], Combined[A]	11	18	3

[A] Data for own roots and rootstocks combined.
[B] N, is the number of data points.

Use of the suggested scheme to assess Mo status of Merlot vines is complicated by the following:

(i) For Merlot, the effect of Mo deficiency reported in this and other studies (Gridley 2003; Williams et al. 2003; 2004; Longbottom *et al.* 2004) appeared to be reproductive (effect is on fertilisation) and not vegetative (see Symptoms of Mo stress above). Molybdenum was applied as pre-flowering foliar sprays, therefore, sampling at flowering (the standard sampling time for petiole analysis in vines) would be too late for corrective measures to be taken in the current season. Further, changes in petiolar Mo concentrations during the period E-L 12 to flowering (E-L 19-25) were not consistent, therefore, it is not possible to reliably predict petiolar Mo concentrations during flowering from samples collected earlier in the season.

The proposed scheme can be used for "trouble shooting" (diagnostic testing), monitoring the vine Mo status on an annual basis (nutrient monitoring) and predictive testing.

(ii) Although our data show that yield response was associated with petiolar Mo concentrations less than 0.09 mg/kg, at a given concentration, responsiveness varied between years (Figure 14). Data for site 4 show that for Merlot on Ramsey rootstock, a yield response occurred in 2004/05 but not in 2003/04 even though petiolar Mo concentrations were essentially the same in both years (0.121 vs 0.122 mg/kg) (Figure 14a). For Merlot on Schwarzmann rootstock, a yield response occurred in 2004/05 even though Mo concentration was higher in that year compared with 2003/04 (0.081 vs 0.070 mg/kg) (Figure 14b).

It appears that other factors (eg. climatic) are affecting the magnitude of the yield response at a given Mo concentration. This confounds the use of petiole analysis to assess plant Mo status.

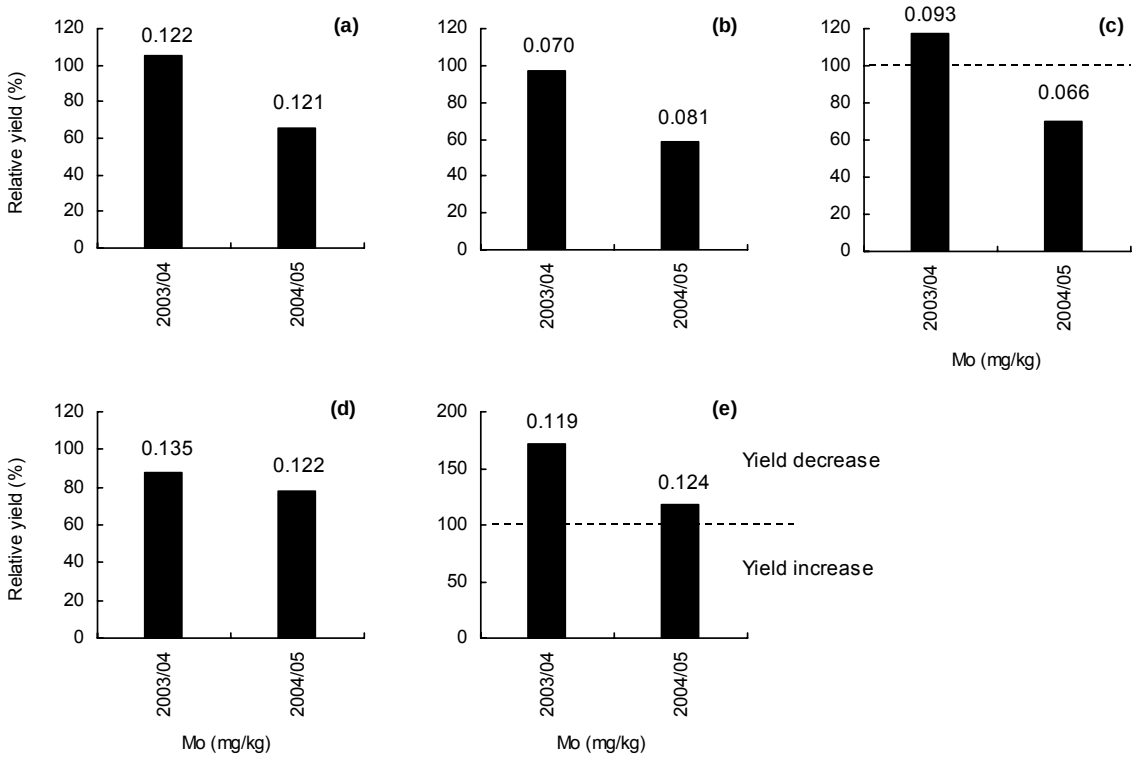


Figure 14. Relative bunch yields and molybdenum concentrations (mg/kg) at flowering (values above bars) for Merlot on (a) Ramsey, (b) Schwarzmann, (c) SO4 (2136), (d) 140 Ruggeri and (e) 110 Richter rootstocks in the 2003/04 and 2004/05 growing seasons. Data are for site 4. Dashed line is at 100% relative yield. Values > 100% indicate a decrease in yield in response to applied Mo.

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Chapter 5

5 Responses of grapevine to rate, time and number of molybdenum applications

Chris Williams, Norbert Maier, Kerry Porter and Louise Chvyl

Abstract

The response of Merlot grapevines to rate, timing and number of sprays of Mo was investigated at two commercial vineyard sites in the Mt Lofty Ranges and one at McLaren Vale, SA. Molybdenum (Mo) was applied at five rates from 0 to 2000 mg/L as foliar sprays. Other treatments included a rate of 250 mg/L applied once at seven different growth stages (from leaf tips visible to bunch closure), and a comparison of one with two pre-flowering Mo sprays.

There was a consistent trend for bunch yield and weight to increase with rate of Mo foliar application up to approximately 250 mg/L for Mt. Lofty Ranges trials (sites 6 and 7) and up to 500 mg/L at McLaren Vale (site 9) and thereafter remain similar. Findings from the three sites, with rates up to 2000 mg Mo/L, (including two growing seasons at McLaren Vale and Lenswood) gave no evidence that Mo was detrimental to bunch yield or average bunch weight per vine, since the sprayed treatments always produced higher yields than the unsprayed controls. However, high or excessive rates of foliar Mo sprays should be avoided as there are potential risks (eg. from the portion of sprays that miss the canopy) for Mo to accumulate in vineyard soils and pose potential sustainability issues (see Chapter 9 for data on the effects of foliar Mo sprays on soil Mo reserves and potential leaching). Petiolar Mo concentrations increased in linear relationships with increasing rate of applied Mo, so that petiolar Mo concentrations increased up to the highest rate of Mo applied.

There was a trend for bunch yield and weights to be higher when Mo sprays were applied pre-flowering (from E-L 5-18), than post-flowering (from E-L 20-32). Yield responses recorded were small and variable in magnitude as petiolar Mo for unsprayed vines was marginal but not deficient. However, these results suggest that the proposed 'most effective window of opportunity' to apply remedial Mo sprays to deficient Merlot grapevines is pre-flowering from E-L 5-18, before the first flower caps (calyptra) are loosening.

For a given rate of Mo application, one Mo foliar spray pre-flowering (at either E-L 12-15 or 16-18) was as effective as two foliar sprays in terms of bunch yield and weight responses at all sites. However, a higher rate (500 mg Mo/L) was required for maximum yield and bunch weight at McLaren Vale (site 9) than at the Mt Lofty Ranges trial sites (250 mg Mo/L). If rainfall (>2 mm) occurs within 48 hours of a solo Mo spray application, a repeat application is suggested.

The petiolar Mo concentration for unsprayed Chardonnay vines at site 8 was 1.74 mg/kg at peak flowering. This was likely to be adequate to high (considering the adequate range for Merlot is > 0.45 mg/kg, Chapter 4) and is the probable reason for the lack of bunch yield and weight response to applied Mo observed.

Further work is required to describe the Mo requirements, the optimal rates and times of remedial spray regimes and to calibrate tissue tests for Mo for a range of wine grape cultivars for different scion and rootstock combinations susceptible to berry asynchrony.

Introduction

In Australia, Mo was first reported to increase bunch yield of grapevines when two applications of sodium molybdate were applied pre-flowering to the canopy of own rooted Merlot grapevines in the Mt Lofty Ranges, South Australia (Williams *et al.* 2003; 2004), (shoot length 10-25 cm long with inflorescences emerged, but not open) and the second spray at E-L 16-18 (Coombe 1995b), (shoot length 50 cm and inflorescences well developed but flower caps still in place).

Subsequent work by Longbottom *et al.* (2004; 2005) included comparing a Mo rate similar to that of Williams *et al.* (2004) with double that rate. Williams *et al.* (2004) reported no further benefits of the higher dose on bunch yields, nor any detrimental effects on yield. However, in the spring following Mo application grapevines exhibited delayed budburst compared with control vines, which received no applied Mo. Similar results were reported in Chapter 1 of this report, where Mo application in the previous season was associated with a moderate reduction in early spring shoot growth and pruning weights per vine in the following season.

To our knowledge the effects of higher rates of Mo at several sites and definition of the "window of opportunity" for the time to apply Mo foliar sprays to Mo deficient vines (for fertilisation and berry set) in terms of impacts on bunch yield has not been reported in the literature. The relative effectiveness of rates and of pre- and post- flowering applications of foliar applied Mo was investigated in this study.

Materials and Methods

The experiments were conducted in three commercial vineyards during the 2003/04 and 2004/05 seasons. The vineyards were located at Lenswood (site 6), Carey Gully (site 7, 8), and McLaren Vale (site 9) in the Mount Lofty Ranges of South Australia, which has a temperate climate of cool, wet winters and warm to hot, dry summers (Maschmedt 1987). The experiments were carried out at sites 6 and 9 for both seasons, and at site 7, 8 for the 2003/04 season only.

At sites 6, 7 and 9, the experimental plots contained Merlot vines (clone D3V14) on own roots, trained to a single vertical plane trellis with two foliage wires and vertical shoot position. Vines were spur pruned. Site information, trial design, vine age and spacings for all trials are described in Table 1 of the Research Strategy and Method section. All plantings were drip irrigated, and irrigation, pest and disease control were carried out according to growers' normal practices.

Soil samples were collected from each site, using a 7.5 cm auger, in November and December 2004. Samples were air-dried and ground to <2 mm prior to analysis for pH, cation exchange capacity (CEC), organic carbon (C), and bicarbonate-extractable phosphorus (P) and potassium (K), using methods as described by (Maier *et al.* 1994).

The Chardonnay vineyard at site 8 had poor fruit set in 2001/2002 and 2002/2003 seasons, which led to low bunch yields of 4 t/ha. At site 8, Chardonnay grapevines received one spray

of Mo at a rate of 236 mg/L to canopy runoff at E-L 16 in 2003. Fifteen molybdenum (Mo) rate and spray timing treatments, as described in Table 1 below, were applied to vines at all three Merlot sites (6, 7 and 9) in 2003/04 and at site 9 in 2004/05. Vines at site 6 were not sprayed in 2004/05 in order to investigate carry-over effects from the previous year's treatments.

Table 1. Mo rate and spray timing for the experimental treatments applied at sites 6, 7 and 9 in 2003/04, site 9 in 2004/05 and at site 6 in 2005/06[z]

Treatment No.	Mo Rate (mg/L)	Spray Timing (Growth Stage)
1	0	E-L 12- 15 + E-L 16-18 (water +red dye only)
2	250	E-L 5-8
3	250	E-L 12-15
4	500	E-L 12-15
5	250 + 250	E-L 12–15 + E-L 16-18
6	250	E-L 16-18
7	500	E-L 16-18
8	62.5 + 62.5	E-L 12-15 + E-L 16-18
9	125 + 125	E-L 12-15 + E-L 16-18
10	250	E-L 20-22
11	250	E-L 23-25
12	250	E-L 28-30
13	250	E-L 32
14	500 + 500	E-L 12-15 + E-L 16-18
15	1000 + 1000	E-L 12-15 + E-L 16-18

[z]At site 6, the 5 rate treatments were not applied in 2004/05.

In October and November 2003 at all three sites, the number of nodes and shoots and the number of inflorescences on one vine in each replicate plot were counted at growth stages E-L 11-12 and E-L 16, respectively. The length of the fifth internode (the growth between the fifth and sixth nodes) of three shoots from one vine in each replicate plot was measured at growth stage E-L 33 in January 2004 at all sites as described by Smart and Robinson (1991).

A minimum of 30 petioles (leaf stalks) from leaves opposite basal bunches was collected from each replicate at growth stage E-L 23-25 (flowering) and at growth stage E-L 35 (veraison) from all sites in 2003/04, at flowering from sites 6 and 9 in 2004/05 and from site 6 in 2005/06. Fifteen centimetres of shoot terminal growth was collected from six shoots in each replicate at flowering and veraison in 2004/05 at sites 6 and 9 and at flowering in 2005/06 at site 6.

Petioles and shoot terminal growth of 15 cm were stored under frozen cooler blocks in insulated containers after collection and during transportation. In the laboratory, samples were dried at 60-70°C and then ground to <1 mm in preparation for chemical analysis. Petiole and shoot terminal growth of 15 cm samples were then analysed for chemical composition as described in Williams *et al* (2004).

Experimental plots were harvested in March and April each year. At harvest, the number of bunches was counted, total weight recorded, and the mean bunch weight calculated for each plot. In 2003/04, ten bunches were sampled from each replicate and stored on frozen cooler blocks in insulated containers for transport to the laboratory. Five randomly selected bunches

from each replicate were fractionated into green and coloured berries in <5 mm, 5-15 mm, and >15 mm diameter size grades and the berries in each grade were counted and weighed.

At each site, the experiment was set out as a randomised complete block design with the 15 treatment plots replicated four times. The experimental plots consisted of three vines per replicate at each site. The data for all variables were analysed for variance between treatments within each site. Significant differences between treatments and years were calculated using the least significant difference (LSD) test at the 5% level of probability.

Results and discussion

Rate of foliar Mo effects on bunch yield and weight and tissue Mo

Changes in bunch yield per vine and average bunch weight and petiolar Mo concentrations in response to rate of foliar applied Mo from 0 to 2000 mg /L are summarised in Figure 1. There was a consistent trend for bunch yield and weight to increase with rate of Mo application up to approximately 250 mg/L for the Carey Gully and Lenswood trials (sites 6 and 7) and 500 mg/L at McLaren Vale (site 9) and at higher rates yield was relatively constant (Figure 1). However, these increases were not statistically significant, due in part to the high variability between vines in these vineyards, and the concentrations of Mo in unsprayed vines, which had petiolar Mo concentrations from 0.09 - 0.346 mg/kg, which are in the marginal range (0.09 - 0.45 mg/kg) where yield responses are likely to be uncertain (Chapter 4).

Our findings at the three sites, with rates up to 2000 mg Mo/L, (for two growing seasons at McLaren Vale and Lenswood) indicate no evidence of Mo toxicity on bunch yield or weight since the sprayed treatments always produced higher yields than the unsprayed control (Figure 1). However, Gridley (2003) compared the effects of two rates of Mo (0 and 300 mg/L) on Merlot vines on own roots and rootstocks and suggested: “vines grown on rootstocks e.g. Schwarzmann and 140 Ruggeri generally have less of a yield response when treated with molybdenum. This could possibly demonstrate a toxicity effect within vines grown on rootstocks.” However, each of the rootstocks still showed increases in bunch yield response to Mo application. Furthermore, Longbottom *et al.* (2005) also reported no detrimental effects of foliar Mo on yield from the higher (approximately 320 mg/L) of two rates of Mo applied to Merlot. Further work is required to define long term effects and optimum rates of Mo for different new scion/rootstock combinations in different growing regions of Australia.

Petiolar Mo concentrations increased in linear relationship with increasing rate of applied Mo, so that petiolar Mo concentrations increased up to the highest rate of Mo applied (Figure 1). Molybdenum concentration in basal petioles increased in response to increasing Mo supply (rate): however, the magnitude of the effect varied between sites, growing seasons (Figure 1) and sampling times (Chapter 4-Table 2, Figure 6). The increase in petiolar Mo concentration was greater at flowering than at veraison (Chapter 4-Figure 6). Petiolar Mo concentrations increased in a linear fashion up to the highest rate of Mo applied (Figure 1). The difference in Mo concentrations in petioles at flowering and veraison was dependent on supply and the difference was greatest at the highest rate (2000 mg/L) applied (Chapter 4-Figure 6).

Molybdenum concentrations for petioles need to be interpreted with care because Mo was applied as two pre-flowering foliar sprays, thus residues may be present on petioles. Another plant tissue, which was not formed at pre-flowering, the terminal 15 cm growth of shoots was also sampled at flowering and veraison. The Mo concentration in this tissue segment also

increased with increasing rates of applied Mo (Chapter 4-Figure 7). This indicates the grapevines ability to store Mo and re-mobilise such reserves later in the growing season to supply newly formed tissues.

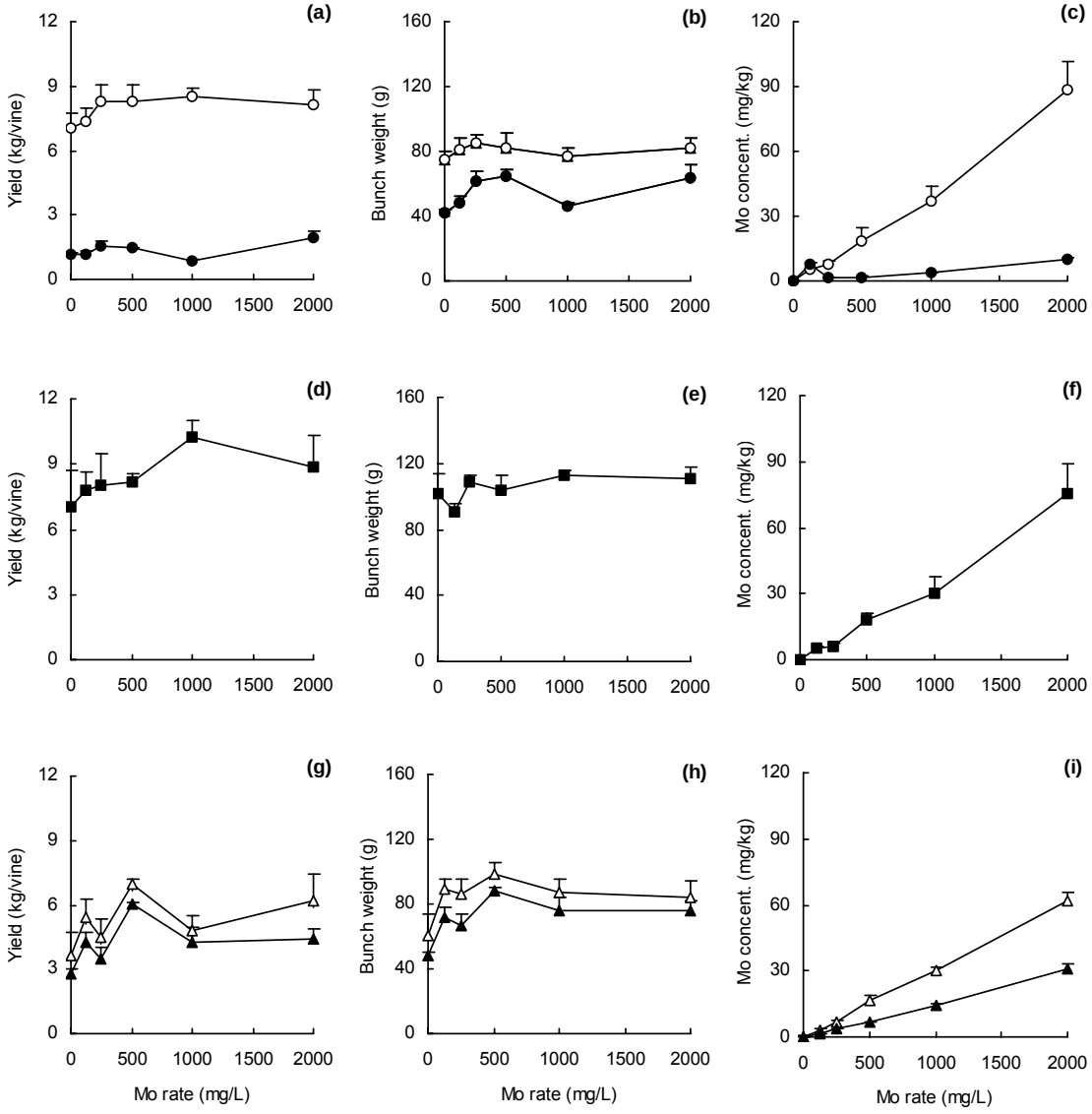


Figure 1: (a, d, g) Bunch yield, (b, e, h) average bunch weight per vine, and (c, f, i) petiolar Mo concentration responses to rate of foliar Mo applied at sites 6 (○ Lenswood 03/04 & ● Lenswood 05/06), 7 (■ Carey Gully 03/04) and 9 (△ McLaren Vale 03/04 & ▲ McLaren Vale 04/05), respectively.

Potential impacts of high rates of Mo to soil Mo status

Williams *et al.* (1999) reported high rates of N and P above 100 kg/ha were not detrimental to potato yields but increased soil N and P levels and the risk for excess dissolved N and P fractions to be leached from the rootzone. Similarly, McPharlin and Lanztke (2001) reported high rates of P, up to 160 kg/ha were not detrimental to carrot yield but increased soil P levels and the risk for excess dissolved P to be leached. (Brennan and Bruce 1999) reviewed information on soil Mo and suggested that high Mo levels in soils may cause molybdenosis or facilitate leaching. Likewise, there is potential for high/excessive rates of foliar Mo (eg from the portion of sprays that miss the canopy) to accumulate in vineyard soils and pose potential long term sustainability issues (see Chapter 9 for data on the effects of foliar Mo sprays on soil Mo reserves).

Annual carryover of Mo applied the previous season

The Mo rate treatments were not applied to the Lenswood experiment in 2004/05 to examine the annual carryover effects of different rates of Mo applied in the previous season. Rates of Mo were applied from 0 to 2000 mg/L pre-flowering in 2003/04, this increased petiolar Mo concentrations from 0.09 to 56.8 mg/kg, respectively, in spring 2004 (Figure 1). However, by spring 2005 at peak flowering, petiolar Mo concentrations for all rate treatments left unsprayed in 2004/05 ranged from 0.15 to 0.22 mg/kg and were not different from the control (0.15 mg/kg) which was unsprayed in all years.

Time of application of foliar sprays

Changes in bunch yield and average bunch weight per vine in response to time of foliar Mo application at Carey Gully and McLaren Vale are shown in Figure 2 and at Lenswood (site 6), Figure 3. There was a trend for bunch yield and weights to be higher when Mo sprays were applied pre-flowering (from E-L 5-8 to E-L 16-18), than post-flowering from E-L 20-32 (Figures 2 and 3). Since petiole Mo concentrations at peak bloom from unsprayed vines at all sites ranged from 0.09-0.346 mg/kg, these can be classed as marginal (0.09-0.45 mg/kg as defined in Chapter 4), yield responses recorded were uncertain (small and variable in magnitude). Therefore it is only possible to suggest a tentative conclusion that the proposed 'most effective window of opportunity' to apply remedial Mo sprays to Merlot is pre-flowering from E-L 5-18, before the first flower caps (calyptra) are loosening. Further research is needed to define the exact timing for Mo sprays to alleviate severe Mo deficiency during reproduction for winegrapes.

It is interesting that post-flowering Mo sprays, produced higher yields than unsprayed controls at certain site/years (eg McLaren Vale 2004/05), (Figures 2 and 3). It is suggested that foliar applied Mo may enhance the activity of enzymes that require Mo for activity (including nitrate reductase, aldehyde oxidase, sulfite oxidase, (Kaiser *et al.* 2005) for plant growth processes, as distinct from the Mo requirements for flowering and seed formation (Williams *et al.* 2003; 2004; Longbottom *et al.* 2004; 2005 and Chapters 1-4). Further research is required to elucidate and manage such mechanisms for wine grapes.

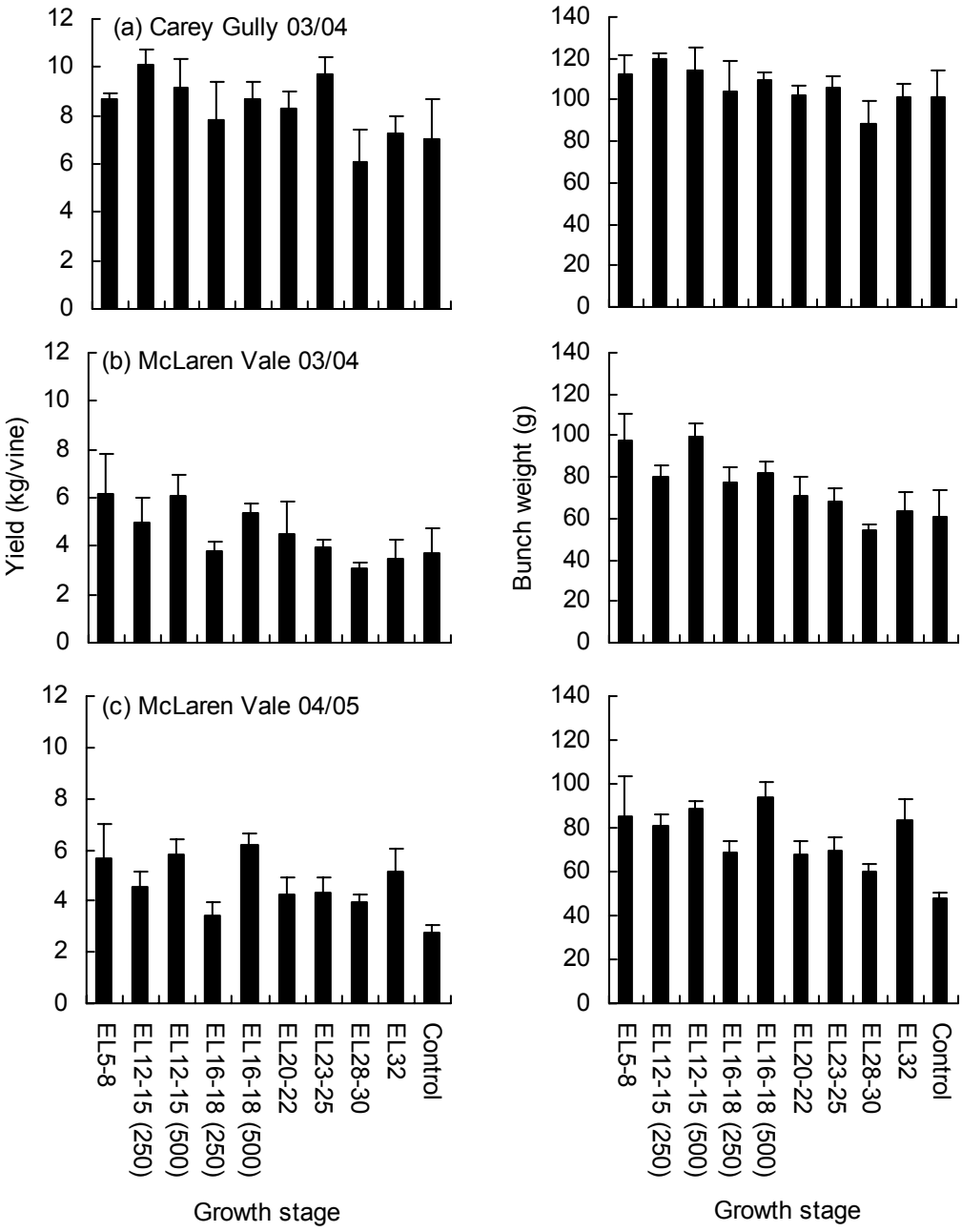


Figure 2. Bunch yield and average bunch weight per vine in response to time of foliar Mo application at site 7 (Carey Gully) and site 9 (McLaren Vale).

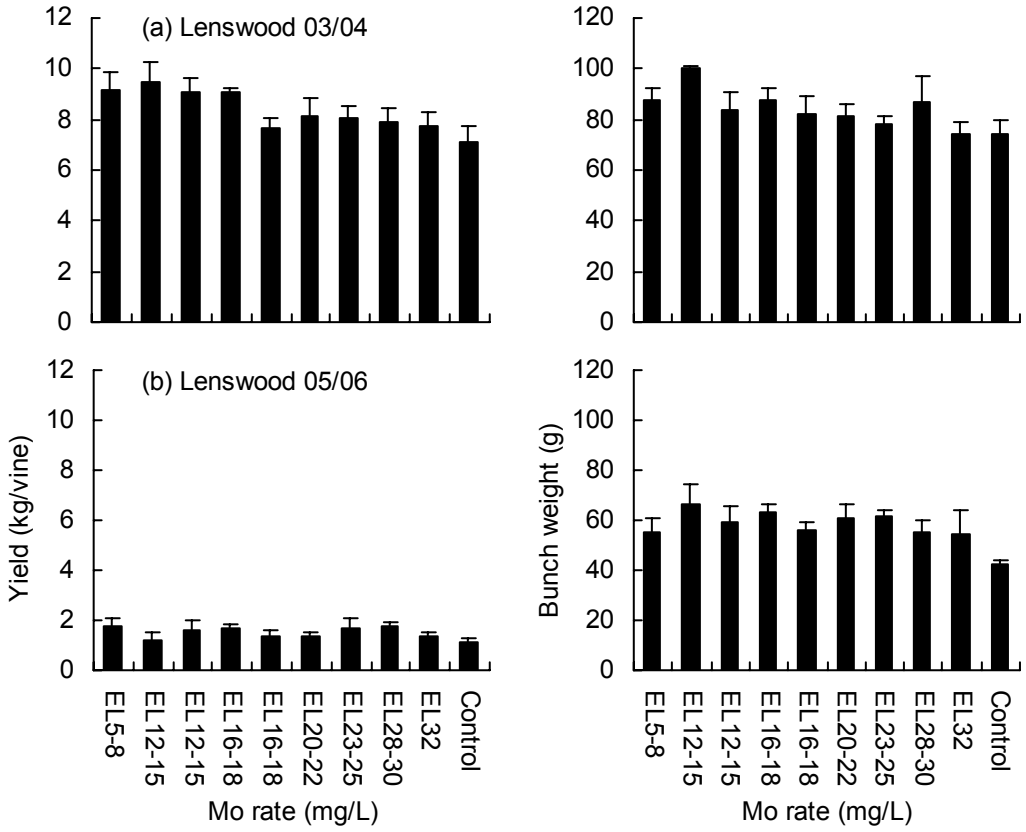


Figure 3: Bunch yield and average bunch weight per vine in response to time of foliar Mo application at site 6 (Lenswood). Growth stages as defined by Coombe (1995).

Number of Mo applications

For a given rate of Mo application, one Mo foliar spray pre-flowering (at either E-L 12-15 or 16-18) was as effective as two foliar sprays in terms of bunch yield and weight responses at all sites (Figures 5 and 6). However, a higher rate (500 mg Mo/L) was required for maximum yield and bunch weight at McLaren Vale (site 9) than at Carey Gully and Lenswood (250 mg Mo/L), (Figures 5 and 6). Our observations indicate if rainfall (over 2 mm) occurs within 48 hours of Mo spray application, that consideration be given to repeat the spray application, since Mo is readily washed off the canopy and can be rapidly fixed in the soil (Gupta 1997) making it unavailable for root uptake during the current flowering season of the grapevine. Furthermore, Phillips (2004) has estimated in glasshouse trials on Merlot that of the foliar applied Mo, only approximately 8 % per day is absorbed through the leaf surface into the vascular system (phloem) of the grapevine.

Changes in petiolar Mo concentrations at peak bloom in response to the number of pre-flowering Mo foliar applications are depicted in Figure 7. Petiolar Mo concentrations at peak flowering were at adequate or higher levels (> 0.45 mg Mo/kg) as defined in Chapter 4 for all Mo spray regimes applied (Figure 7). This indicates that one effective Mo spray applied pre-flowering is likely to be as effective two half rate sprays, for Mo applied at either 250 or 500 mg/L to Merlot (under the conditions in these experiments).

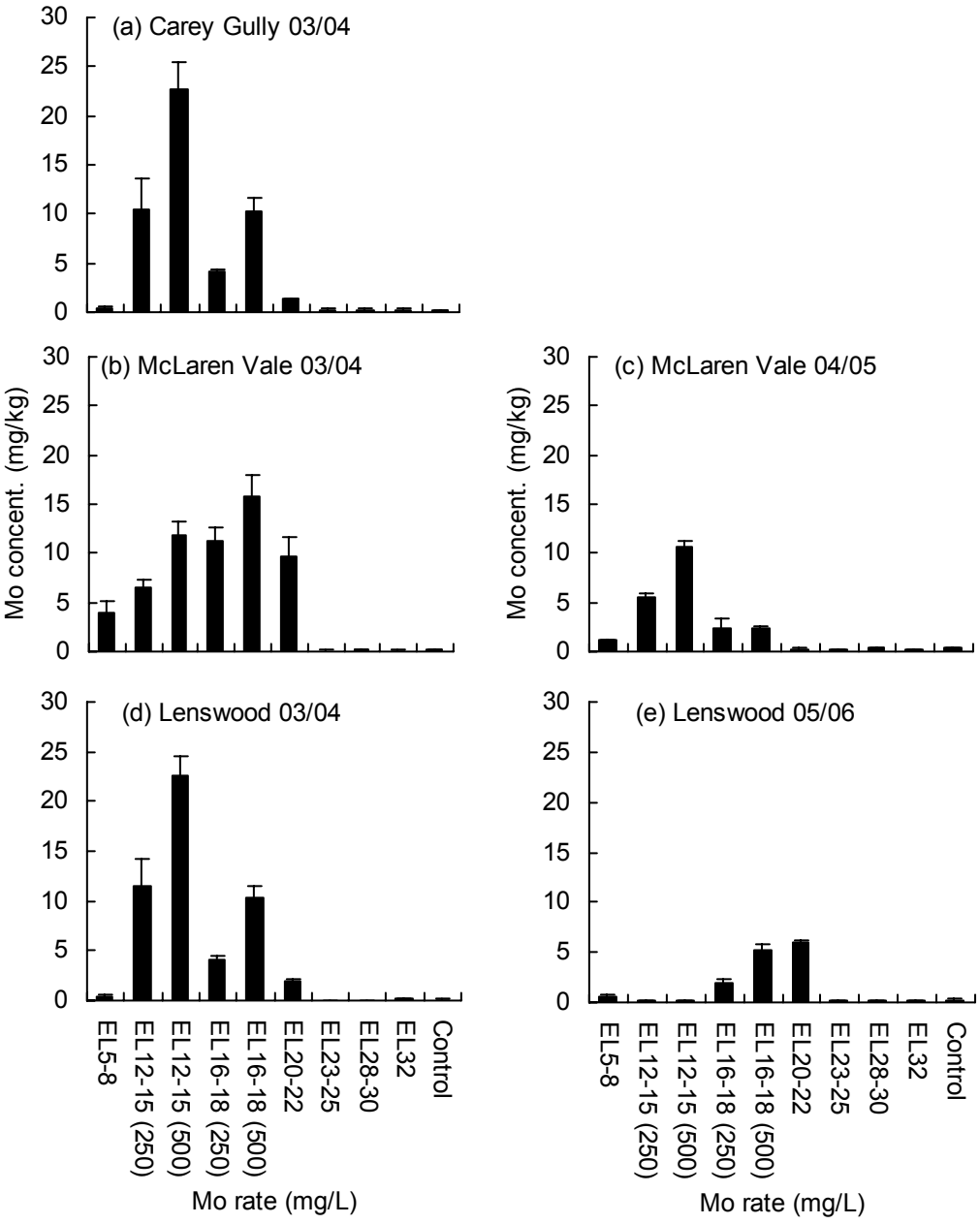


Figure 4. Petiolar Mo concentration in response to time of foliar Mo application at site 7 (Carey Gully) and site 9 (McLaren Vale). Growth stages as defined by Coombe (1995).

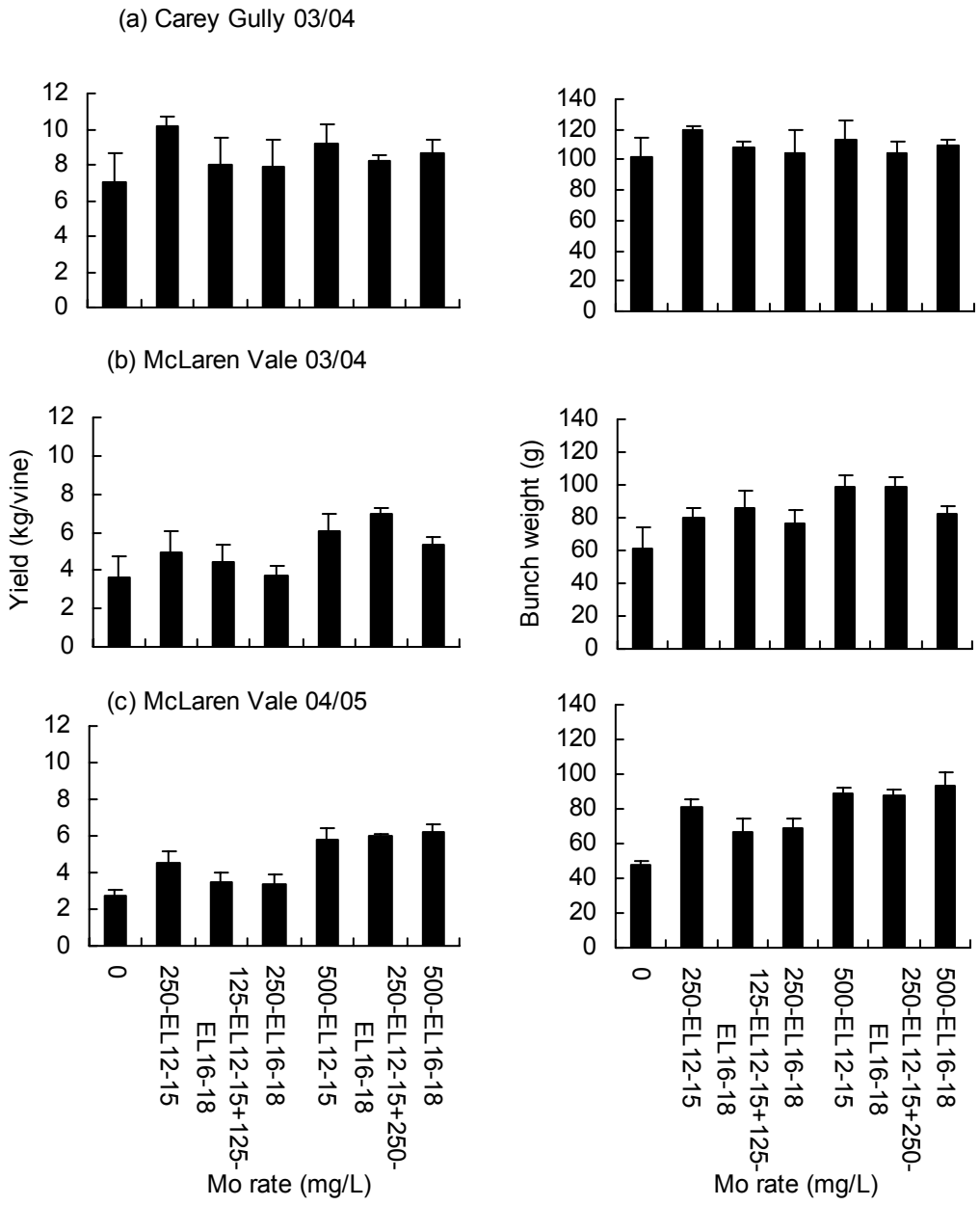


Figure 5: Bunch yield, average bunch weight per vine, in response to the number of foliar Mo applications at site 7 (Carey Gully) and site 9 (McLaren Vale). Growth stages as defined by Coombe (1995).

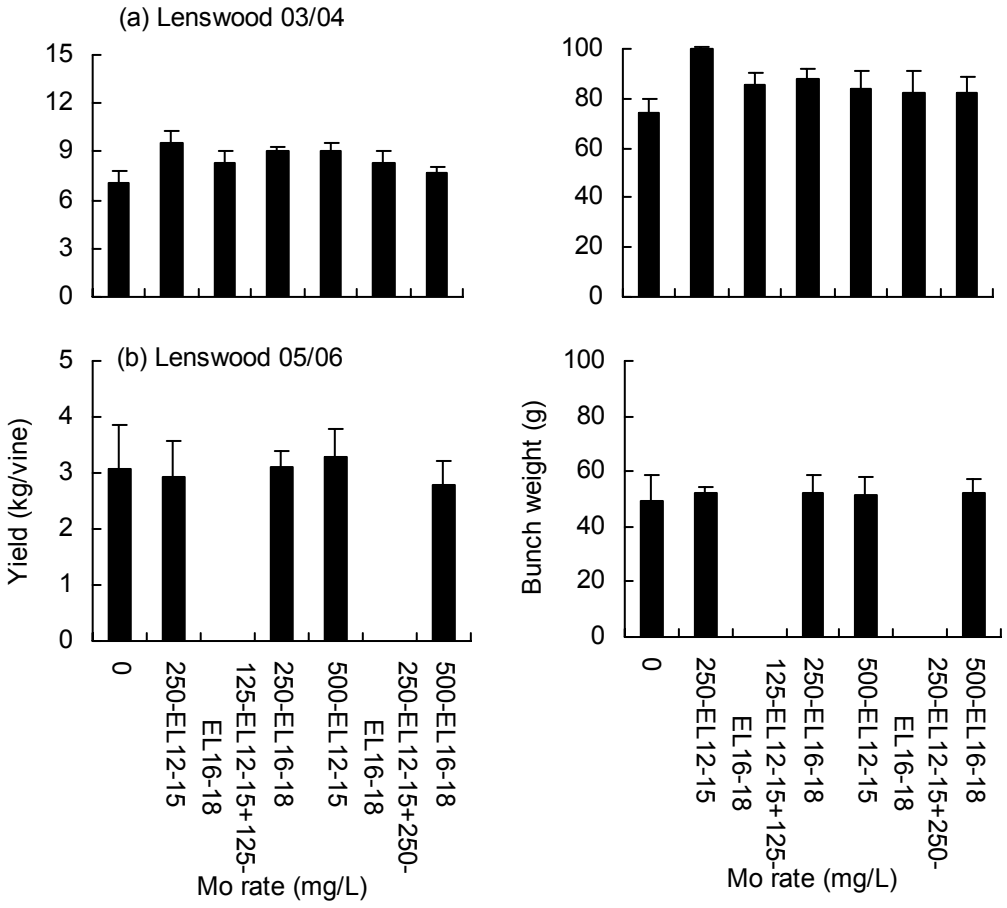


Figure 6. Effects of number of Mo foliar application on bunch yield and average bunch weight per vine at site 6 (Lenswood). Growth stages as defined by Coombe (1995).

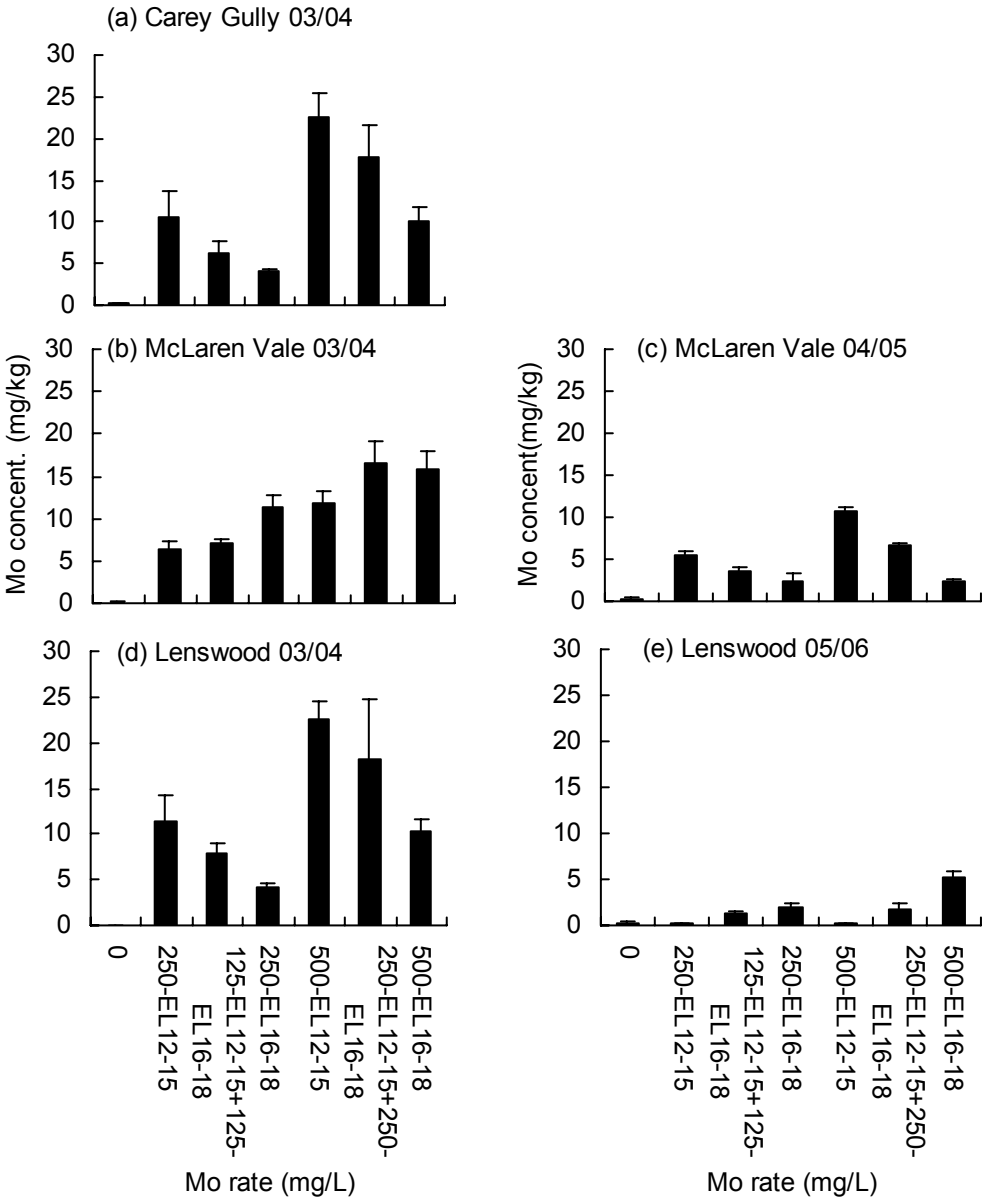


Figure 7. Petiolar Mo concentration at peak flowering in response to the number of foliar Mo applications at (a) Carey Gully (site 7), (b ,c) McLaren Vale (site 9) and (d, e) Lenswood (site 6). Growth stages as defined by Coombe (1995).

Bunch yield and average bunch weight per vine were similar for unsprayed and sprayed Chardonnay vines at Carey Gully (site 8), (Figure 8). The petiolar Mo concentration for unsprayed Chardonnay vines was 1.74 mg/kg at peak flowering and was likely to be adequate to high (considering the adequate range for Merlot is > 0.45 mg/kg, Chapter 4). This is the probable reason for the lack of yield response to applied Mo observed at site 8 (Figure 8). Further work is required to describe the Mo needs and to calibrate tissue tests for Mo for a range of winegrape cultivars (for scion and rootstock combinations) prone to berry asynchrony.

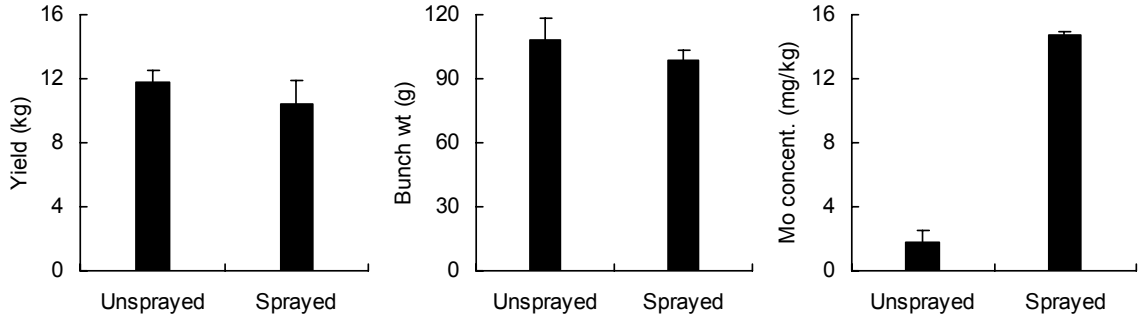


Figure 8. Chardonnay bunch yield, bunch weight and petiolar Mo concentration responses to applied Mo at Carey Gully in 2003/04 (site 8).

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Chapter 6

6 Survey of commercial vineyards

Louise Chvyl, Norbert Maier, Kerry Porter and Chris Williams

Abstract

One hundred commercial vineyards in four states (WA, SA, Vic, NSW) most with a previous history of high incidence of berry asynchrony were surveyed over three seasons, 2003/04 to 2005/06, to assess the occurrence of berry asynchrony, possible causes and the relationship between berry asynchrony and molybdenum (Mo) levels. The survey included a once only collection of the history of the vineyards and a soil sample, seasonal collection of petiole samples for complete nutrient analyses, and harvest and yield information for each of the three seasons.

Petiolar Mo levels at flowering ranged from less than 0.05 mg/kg to more than 1.0 mg/kg. Most vineyards had petiolar Mo levels between 0.1 and 0.5 mg/kg, and 36.1% had concentrations less than 0.1 mg/kg. All the varieties sampled, Merlot, Chardonnay, Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranillo, in all 4 states, had Mo levels across the concentration range. While Mo levels varied from season to season for all varieties, the variation was less for Merlot on own roots than Merlot grown on rootstock.

Analysis of Mo concentrations in petiole samples collected at the growth stages, E-L 12 and E –L 23-25 of grapevine development in Merlot on own roots and on rootstocks, and in Chardonnay and Verdelho did not show a consistent relationship. This indicates that it is not possible to use early season petiole sampling as a predictive tool for assessment of Mo concentrations at peak flowering.

Most vineyards surveyed had petiolar boron (B) and zinc (Zn) concentrations in the adequate or adequate to high range, suggesting these nutrients were not limiting yield. Petiole nutrients other than Mo, Zn and B as well as soil nutrient properties for each of the states surveyed are discussed in the results.

Introduction

The survey focussed on Merlot, but other varieties sampled (to a lesser degree) were Chardonnay, Verdelho Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranillo.

The survey component of the project was undertaken to:

- document the occurrence of asynchronous berry development and petiolar molybdenum (Mo) levels in grapevines in different regions of Australia;
- compare the Mo concentration of Merlot on its own roots and on rootstocks across Australia;
- assist in defining and validating a critical level for Mo in grapevines at peak bloom;
- provide data for the possible development of a predictive test at the 10 cm shoot stage;
- assess the nutrient status of vineyards across Australia.

Materials and Methods

The survey was undertaken over the three seasons, 2003/04, 2004/05 and 2005/06.

One of the main focuses of the survey was assessing the occurrence of berry asynchrony, also referred to as Hens and chickens or millerandage, which is characterised by a bunch at harvest having a mixture of a few large berries and many small berries that ripen unevenly. In earlier trials for Mo foliar sprays (Williams *et al.* 2004), bunches displaying these characteristics were found on control (unsprayed) vines when a response to Mo was recorded, suggesting a link between Mo and asynchronous berry development. Vegetative symptoms of Mo deficiency, such as irregularities in leaf blade formation, chlorosis and necrosis in mature leaves, stunted shoots, and small leaves with burnt or papery margins, were not reported.

Vineyards included in the survey were selected from a list of those with a history of berry asynchrony, which was compiled from information received from growers or advisors willing to participate. Eight vineyards from the Swan Hill region that did not have a history of berry asynchrony were included for comparative purposes. The number of vineyards surveyed in the first, second and third seasons were 92, 99 and 107 respectively. A number of these vineyards were from the same growers.

As Merlot, particularly when grown on its own roots, is known to be affected by berry asynchrony in South Australia the survey focussed on this scion/rootstock combination. Other scion/rootstock combinations and varieties, Merlot on rootstocks, Chardonnay, Grenache and Verdelho, were selected on the basis that they had displayed berry asynchrony and were of importance to a particular winegrowing region.

Survey kits were prepared, with appropriate quarantine adaptations, for the selected vineyards in a total of 11 grape growing areas in New South Wales, Victoria, South Australia and Western Australia, as delineated by the Phylloxera and Grape Industry Board of SA.

For the petiole sampling, the survey kits contained an instruction sheet for sampling, handling and mailing grapevine petiole samples, labelled sampling bags, plastic bags for quarantine purposes, health certificate where necessary, explanation page of modified Eichhorn-Lorenz (E-L) stages (Coombe 1995b), diagram of petiole to sample, and addressed express post bags.

The petiole opposite the basal cluster collected at full flowering was chosen as the base sampling unit, as this is the most commonly sampled tissue for standards in the viticultural industry at present.

A soil sampling kit was also sent out with the initial petiole sampling kit. This soil sampling kit consisted of an instruction sheet, labelled plastic clip-lock bags and an express post bag containing an instruction letter for the analysis laboratory.

The survey kit also contained a questionnaire requesting details of the site, history and management of each vineyard included in the petiole sampling.

Each year prior to harvest a follow up kit was mailed to all of the participants to obtain details of the harvest (yield and quality of set), seasonal factors possibly affecting fruit set, and the season's fertilisers. Included with the instruction and questionnaire sheets was a bunch rating sheet for the assessment of bunches for the level of berry asynchrony. No objective method of assessment of grape bunches appeared to be in use in the grape industry, so a rating chart was developed to enable a common assessment method for vineyard managers (Appendix 4).

In 2003-04 growers were requested to collect petiole samples at the 10 cm (E-L 12) and full flowering (E-L 23-25) stages. In the following two seasons samples at full flowering (E-L 23-25) only were requested.

Vineyard managers sent the collected 100 (for E-L 12) or 60-70 (for E-L 23-25) petioles to a designated receival laboratory where the samples were oven dried at 60^0 C before being ground and sent to an analytical laboratory. The samples were analysed for nitrogen, phosphorus, potassium, calcium, magnesium, sodium, sulphur, boron, copper, zinc, manganese, iron, aluminium, nitrate and molybdenum as described by Williams *et al.* (2004).

Results and discussion

Petiolar molybdenum concentration

National data

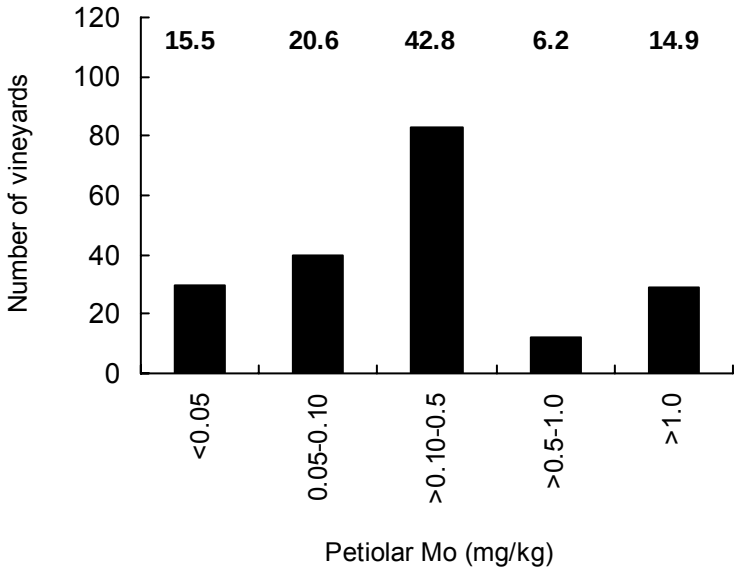


Figure 1. Number of vineyards (N = 194) with petiolar molybdenum concentrations at flowering in concentration ranges specified. Data were pooled across States, years and varieties. Numbers shown above the histogram indicate percentage of vineyards with petiolar molybdenum concentrations in each range.

Figure 1 shows that over all states, all years and all varieties, the largest proportion of petiolar Mo concentrations sampled were between 0.1 and 0.5 mg/kg, and, of the remainder, there were more samples with Mo concentrations less than 0.1 mg/kg than there were with Mo levels greater than 0.5 mg/kg.

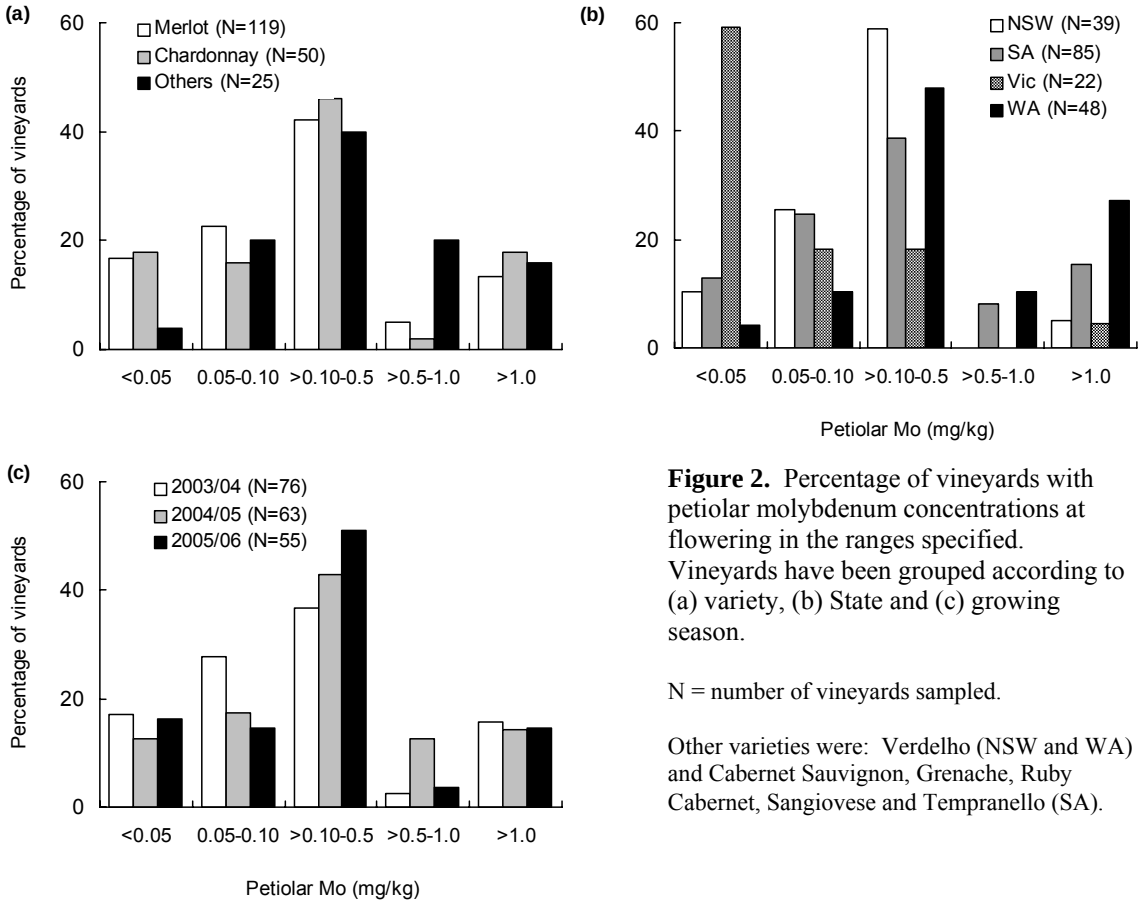


Figure 2. Percentage of vineyards with petiolar molybdenum concentrations at flowering in the ranges specified. Vineyards have been grouped according to (a) variety, (b) State and (c) growing season.

N = number of vineyards sampled.

Other varieties were: Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA).

Survey data over the three seasons confirms that low Mo levels do occur in some vineyards in Australia. However, based on results from previous trials (Williams *et al*., 2004), low Mo levels were expected as the vineyards surveyed were chosen on the basis of having a history of berry asynchrony. A response to foliar applications of Mo was found when the petiolar Mo levels were less than 0.1 mg/kg (Williams *et al*., 2004).

All varieties sampled had Mo levels in each of the concentration ranges, including the varieties other than Merlot, namely Chardonnay, Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranillo (Figure 2(a)).

Of the States sampled, Victoria had a higher proportion of vineyards with Mo concentrations of < 0.10 mg/kg, (Figure 2(b)). It should be noted, that the percentage of vineyards in each state is affected by the proportions of the different varieties sampled, as these were not the same for each state.

Mo levels in the vineyards were not constant but varied from season to season as shown in Figure 2(c).

State data

Table 1. Percentage of vineyards sampled in New South Wales, South Australia, Victoria and Western Australia with petiolar molybdenum concentrations at flowering in the ranges specified for Merlot, Chardonnay and other varieties.
N is the total number of vineyards sampled in that State for each variety.

State	Petiolar molybdenum (mg/kg)					N
	<0.05	0.05-0.10	>0.10-0.5	>0.5-1.0	>1.0	
Merlot						
NSW[A]	6.1	27.3	60.6	0.0	6.1	33
SA[B]	15.5	24.1	36.2	8.6	15.5	58
Vic[C]	50.0	21.4	21.4	0.0	7.1	14
WA[D]	14.3	7.1	42.9	7.1	28.6	14
All States[E]	16.8	22.7	42.0	5.0	13.4	119
Chardonnay						
NSW	20.0	20.0	60.0	0.0	0.0	5
SA	10.0	20.0	50.0	0.0	20.0	20
Vic	75.0	12.5	12.5	0.0	0.0	8
WA	0.0	11.8	52.9	5.9	29.4	17
All States[E]	18.0	16.0	46.0	2.0	18.0	50
Other varieties						
Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA)						
NSW	100.0	0.0	0.0	0.0	0.0	1
SA	0.0	42.9	28.6	28.6	0.0	7
WA	0.0	11.8	47.1	17.6	23.5	17
All States[E]	0.0	20.0	40.0	20.0	16.0	25

[A] New South Wales.
[B] South Australia.
[C] Victoria.
[D] Western Australia.
[E] Data for all States were combined for analysis.

Low Mo concentrations of < 0.10 mg/kg were found in Merlot and Chardonnay in all States sampled, and in Verdelho in NSW and WA (Table 1).

Year data

Table 2. Percentage of vineyards with petiolar molybdenum concentrations at flowering in the ranges specified in each growing season for different States of Australia.

N is the total number of vineyards sampled in each growing season.

Growing season	Petiolar molybdenum (mg/kg)					N
	<0.05	0.05-0.10	>0.10-0.5	>0.5-1.0	>1.0	
South Australia						
2003-04	12.8	35.9	38.5	2.6	10.3	39
2004-05	6.7	16.7	40.0	16.7	20.0	30
2005-06	25.0	12.5	37.5	6.3	18.8	16
2004-06[A]	12.9	24.7	38.8	8.2	15.3	85
New South Wales						
2003-04	20.0	26.7	40.0	0.0	13.3	15
2004-05	7.1	28.6	64.3	0.0	0.0	14
2005-06	0.0	20.0	80.0	0.0	0.0	10
2004-06[A]	10.3	25.6	59.0	0.0	5.1	39
Victoria						
2003-04	80.0	20.0	0.0	0.0	0.0	5
2004-05	100.0	0.0	0.0	0.0	0.0	4
2005-06	38.5	23.1	30.8	0.0	7.7	13
2004-06[A]	59.1	18.2	18.2	0.0	4.5	22
Western Australia						
2003-04	5.9	11.8	41.2	5.9	35.3	17
2004-05	6.7	13.3	40.0	20.0	20.0	15
2005-06	0.0	6.3	62.5	6.3	25.0	16
2004-06[A]	4.2	10.4	47.9	10.4	27.1	48

[A] Data for growing seasons 2003-04, 2004-05 and 2005-06 were combined.

Petiolar Mo concentrations, across all varieties, were found to vary between each of the three sampling seasons in each state (Table 2). Some variation was expected due to the inconsistency of vineyards sampled from season to season, however, it is probable that other factors, such as climate, affect Mo levels. Large variations in levels of Mo and other nutrients between years are also reported in Chapter 2.

Figures 3 and 4 also illustrate the variations in petiolar Mo levels across seasons. Figure 3(a) to (f) shows actual Mo concentrations of petioles at flowering sampled from the same vineyards, represented by joined points, where vineyards participated in the survey for all three seasons. The concentration of petiolar Mo in all varieties varied from season to season. While some seasonal changes had a similar trend, the petiolar Mo concentration of Merlot on rootstocks (Figure 3(c)) appears to be more consistent over the three seasons than that of Merlot on its own roots (Figures 3(a) and (b)).

The variations in petiolar Mo concentrations in Merlot on own roots found in the survey samples between years were consistent with the variations found in South Australian trial sites from 2001 to 2005, as shown in Figure 4.

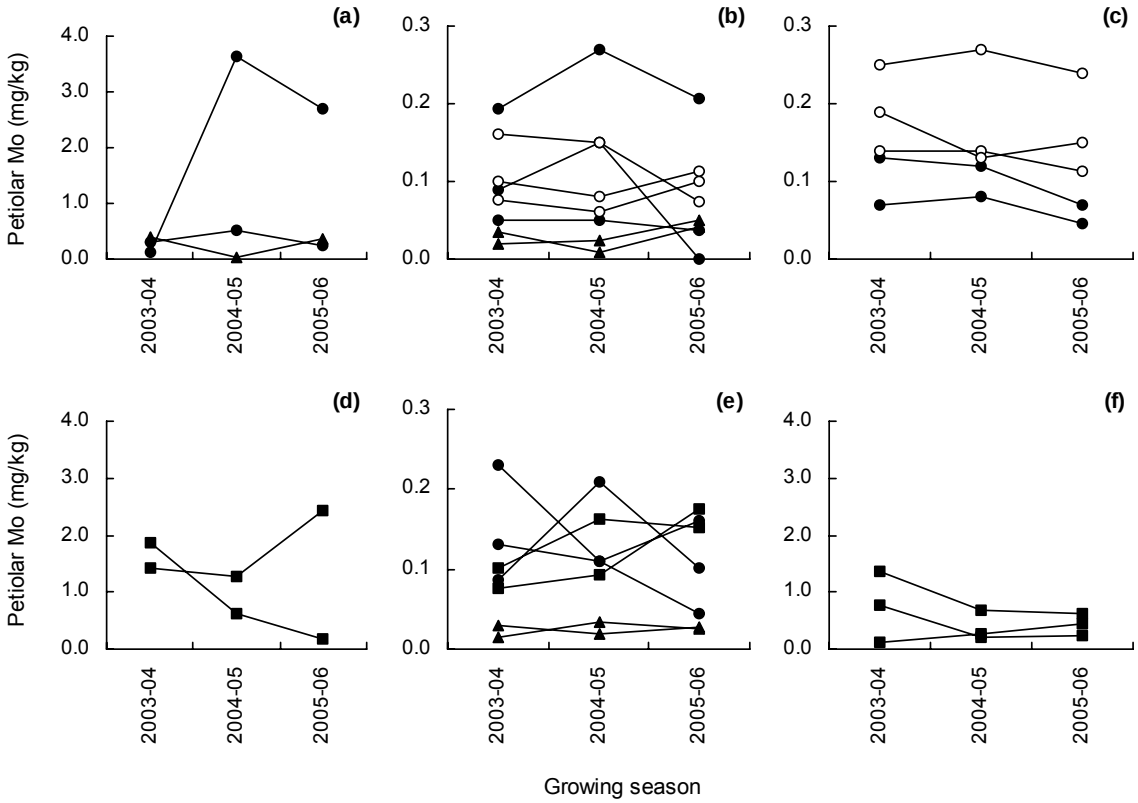


Figure 3. Changes in petiolar molybdenum concentrations over consecutive growing seasons at vineyards in New South Wales (○), Victoria (▲), South Australia (●) and Western Australia (■). Data are for Merlot on own roots (a, b), Merlot on rootstocks (c), Chardonnay (d, e) and Verdelho (f).

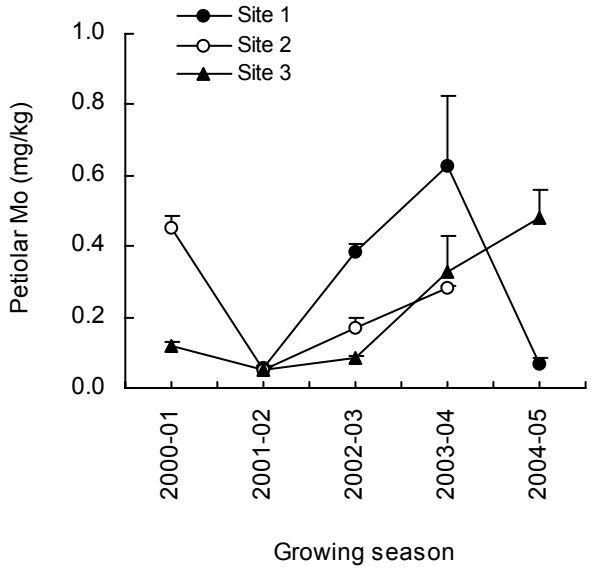


Figure 4. Changes in petiolar molybdenum concentrations at flowering over consecutive growing seasons at experimental sites in the Mount Lofty Ranges of South Australia.

Data are for Merlot on own roots.

Vertical lines are standard errors of the means.

Regional data

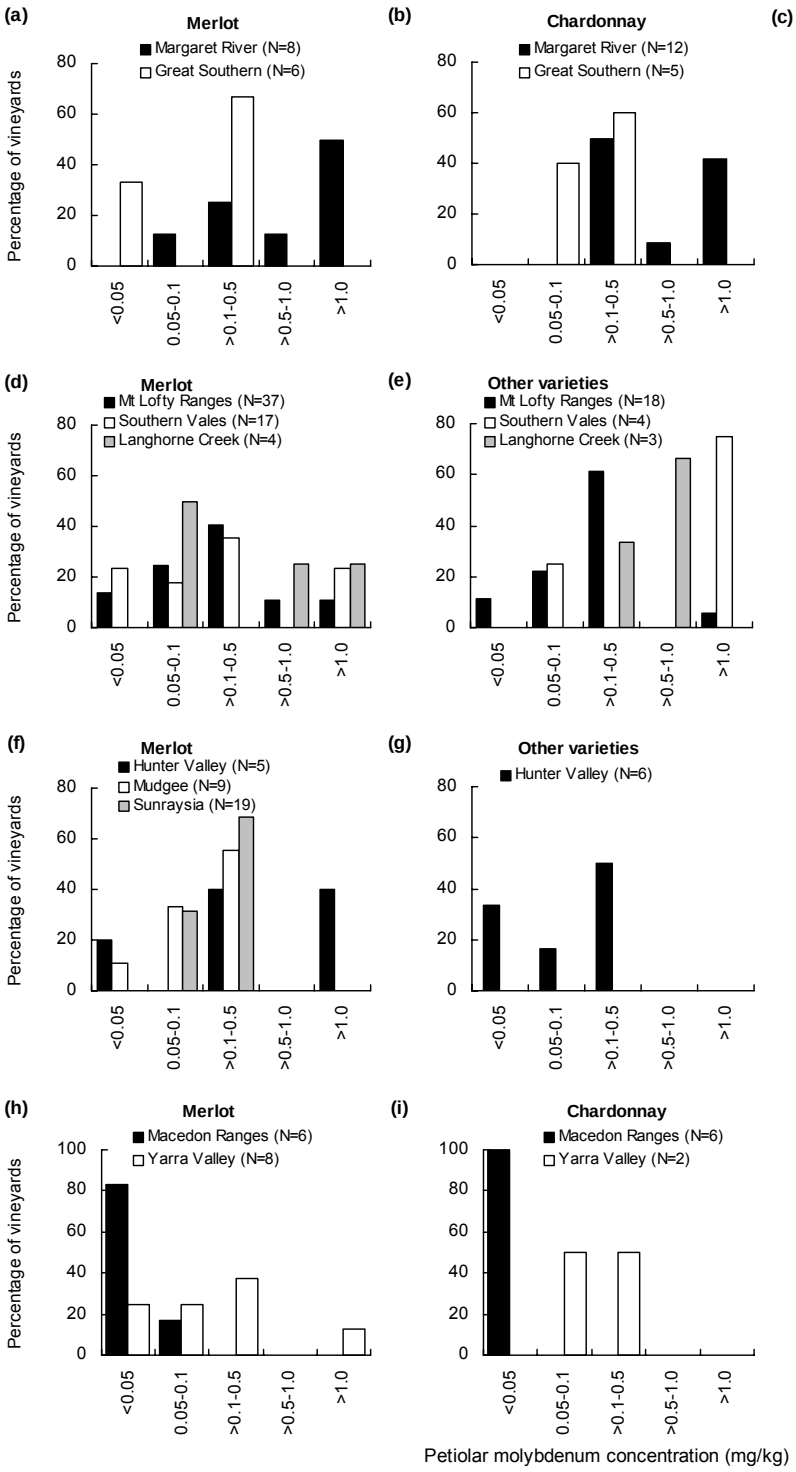


Figure 5. Percentage of vineyards with petiolar molybdenum concentrations at flowering in the ranges specified. Data are for Merlot, Chardonnay and other varieties grown in different regions of Western Australia (a-c), South Australia (d, e) New South Wales (f, g) and Victoria (h, i).

N is the number of vineyards sampled in the region.

Other varieties were: Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA).

In WA, the Mo levels across all varieties were in the higher concentration ranges in the warmer Margaret River region than in the Great Southern region (Figure 5(a), (b) and (c)). Only Merlot had petiolar molybdenum concentrations of < 0.5 mg/kg in WA. In contrast, varieties other than Merlot in all the other states surveyed had Mo levels in the lower concentration range of < 0.5 mg/kg (Figure 5(d) to (i)). In Victoria, only the Macedon Ranges had Mo levels of < 0.5 mg/kg in a variety other than Merlot (in Chardonnay). In each

of the states the colder regions had few or no vineyards with petiolar Mo levels in the >0.5 mg/kg range.

Merlot on own roots and rootstocks

Table 3. Percentage of vineyards with petiolar molybdenum concentrations at flowering in the ranges specified. Data are for Merlot grown on own roots and on rootstocks in each State.

N is the total number of vineyards sampled in each State.

State	Petiolar molybdenum (mg/kg)					N
	<0.05	0.05-0.10	>0.10-0.5	>0.5-1.0	>1.0	
Merlot on own roots						
NSW[A]	6.7	46.7	33.3	0.0	13.3	15
SA[B]	15.0	17.5	42.5	10.0	15.0	40
Vic[C]	66.7	11.1	22.2	0.0	0.0	9
WA[D]	14.3	7.1	42.9	7.1	28.6	14
All States[E]	19.2	20.5	38.5	6.4	15.4	78
Merlot on rootstock 140 Ruggeri, Schwarzmann, Ramsey and SO4						
NSW	5.6	11.1	83.3	0.0	0.0	18
SA	16.7	38.9	22.2	5.6	16.7	18
Vic	20.0	40.0	20.0	0.0	20.0	5
All States[E]	12.2	26.8	48.8	2.4	9.8	41

[A] New South Wales.
[B] South Australia
[C] Victoria.
[D] Western Australia.
[E] Data for all states combined.

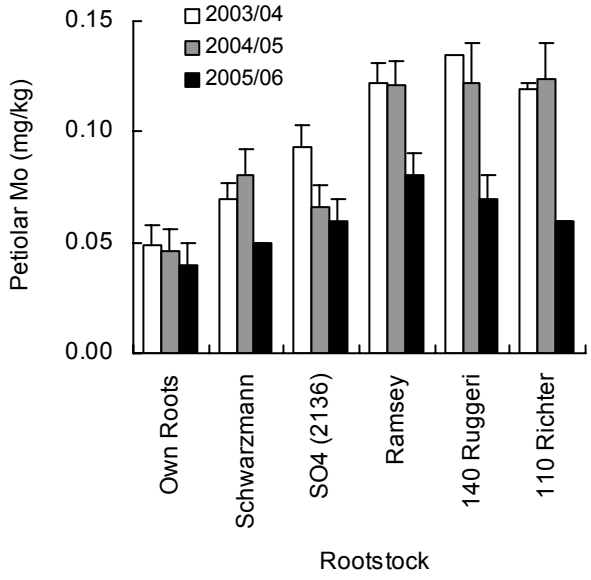


Figure 6. Changes in petiolar molybdenum concentrations at flowering over consecutive years for Merlot on own roots and rootstocks in the Southern Vales of South Australia.

Vertical lines are standard errors of the means.

In all States surveyed, Mo levels of < 0.5 mg/kg were recorded for Merlot on rootstocks 140 Ruggeri, Schwarzmann, Ramsey and SO4, and for Merlot grown on own roots (Table 3). Results from trials conducted over three seasons from 2003 to 2006 in the Southern Vales of South Australia confirm the variations in petiolar Mo concentration and the occurrence of low levels of Mo in the petioles of merlot on rootstocks as well as on own roots (Figure 6). The petiolar Mo concentration of Merlot on own roots varied little from season to season when compared with that of Merlot on rootstocks. This indicates that seasonal variation has less effect on the Mo levels of petioles from Merlot on own roots than from Merlot grown on rootstock.

Petiolar molybdenum concentrations at E-L 12 and E-L 23

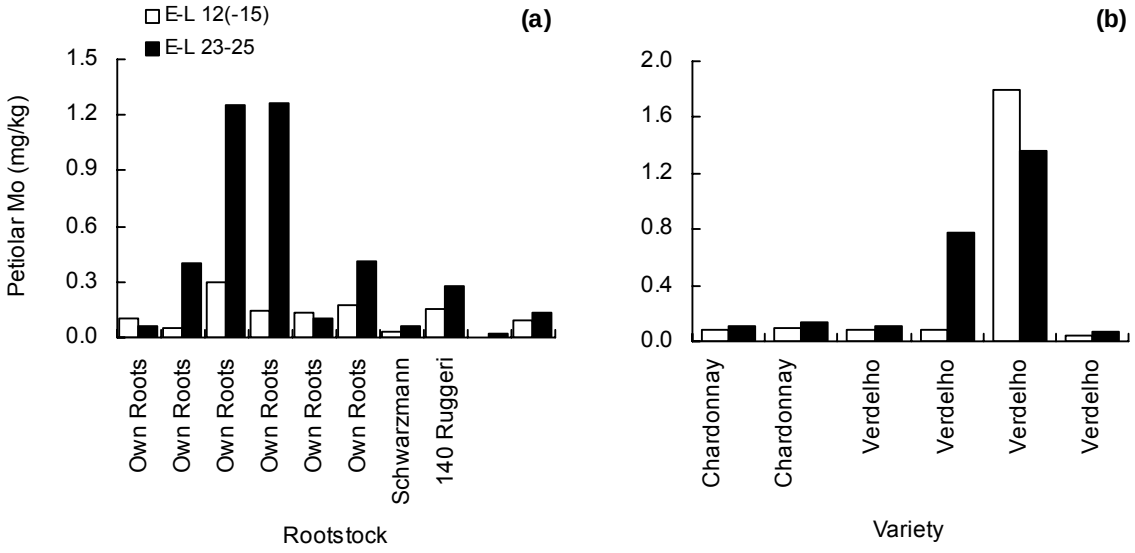


Figure 7. Petiolar molybdenum concentrations at E-L 12 (10 cm shoots) and E-L 23 (full bloom) for (a) Merlot on own roots and rootstocks and (b) Chardonnay and Verdelho, in the 2003-04 growing season.

Results from trials in South Australia suggested that foliar sprays of Mo would increase petiolar Mo concentration and improve fruit set/bunch yield (Williams *et al*., 2004). It was recommended that foliar sprays be applied by no later than E-L 18 when the flower caps are still in place, however, the standard time for petiole sampling is after this, at full bloom. In the first year of the survey, petiole samples were collected at the 10 cm stage or E-L 12 as well as at full bloom or E-L 23-25 in order to assess whether there was a relationship between petiolar Mo concentrations at these two stages. If a relationship was found it might be possible to predict whether grapevines were likely to have adequate Mo levels at full bloom. Petiolar Mo levels in Merlot on own roots and on rootstocks, and in Chardonnay and Verdelho did not show a consistent relationship when petioles were taken at E-L 12 and E-L 23-25, as shown in Figure 7, indicating that it is not possible to use early petiole sampling as a predictive tool for assessment of Mo levels.

Petiolar boron concentration

National data

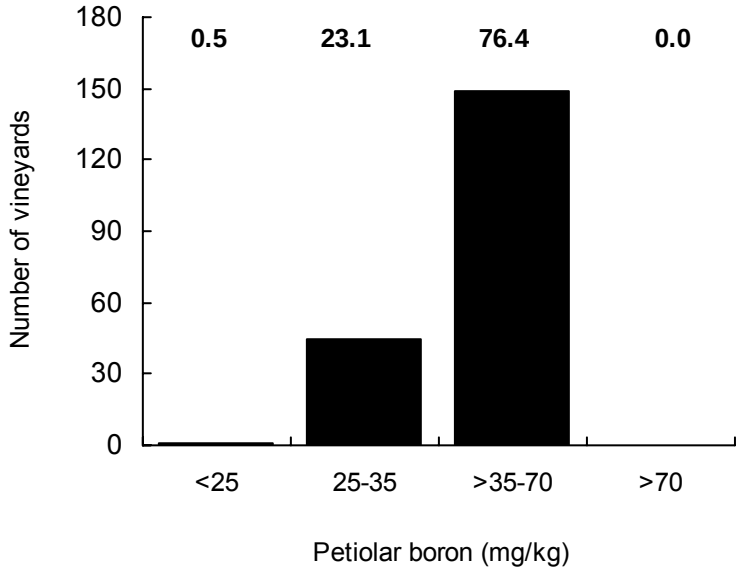


Figure 8. Number of vineyards (N = 195) with petiolar boron concentrations at flowering in concentration ranges used to categorize plant boron status (deficient, marginal, adequate, high and toxic or excessive). Data is pooled across States, years and varieties. Numbers above the histogram indicate percentage of vineyards with petiolar boron concentrations in each concentration range.

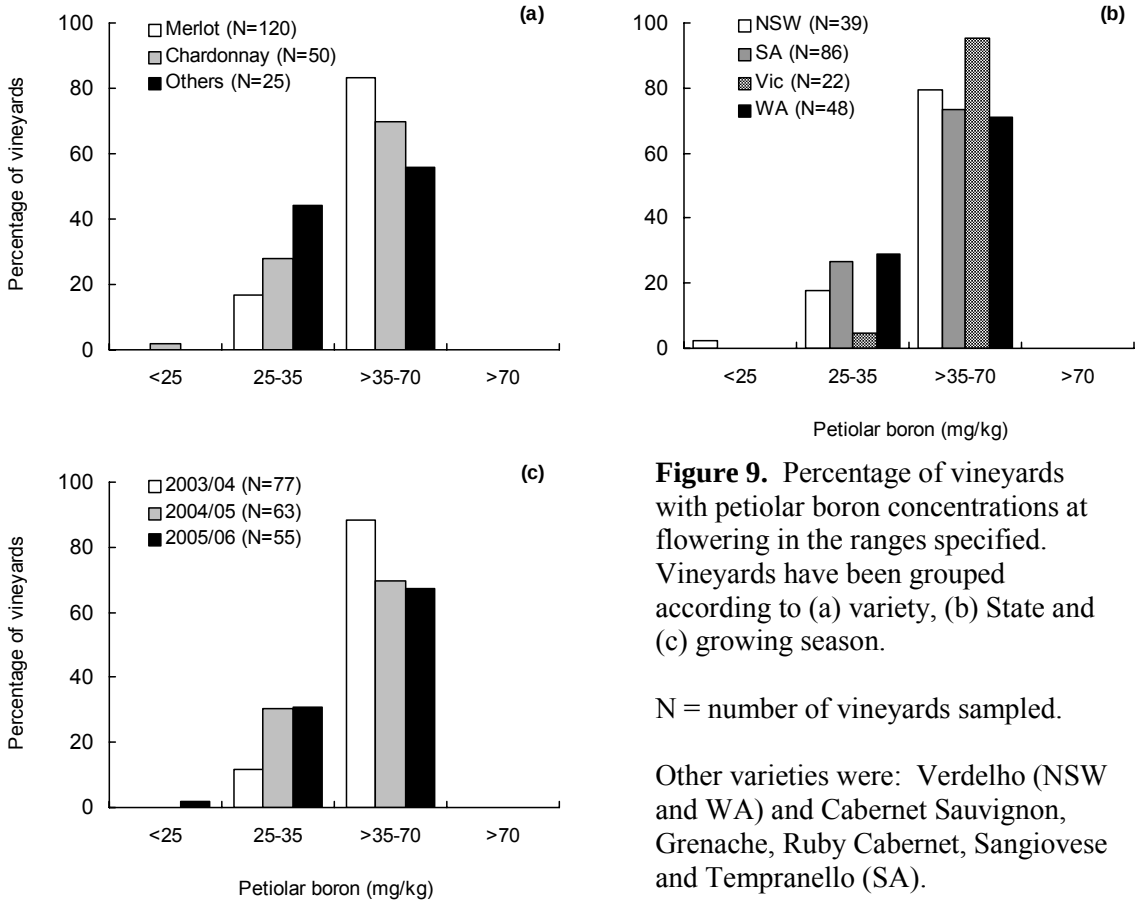


Figure 9. Percentage of vineyards with petiolar boron concentrations at flowering in the ranges specified. Vineyards have been grouped according to (a) variety, (b) State and (c) growing season.

N = number of vineyards sampled.

Other varieties were: Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA).

Boron (B) levels in grapevines according to the current standards are described as deficient, < 25 mg/kg**,** marginal, 25 – 35 mg/kg, adequate, 35 – 70 mg/kg, high, > 70 mg/kg, and excessive or toxic, >100 mg/kg. Boron deficiency is known to affect fruit set (Jardine 1946). Figure 8 shows that most vineyards surveyed had B concentrations in the adequate range, only one was in the deficient range and none had toxic levels. Thus it appears that the petiolar B concentrations of the grapevines were not at a level to be limiting yield.

In contrast to the common occurrence of poor fruit set, Figure 9(a) indicates that low levels of B are more of a concern in varieties other than merlot.

The levels of B shown for each of the seasons (Figure 9(c)) do not reflect the occurrence of Berry asynchrony in Figure 19 in that lower levels of B do not occur when there is poor fruit set. This further suggests that low levels of B are not contributing to the poor fruit set found.

State data

Table 4. Percentage of vineyards sampled in New South Wales, South Australia, Victoria and Western Australia with petiolar boron concentrations at flowering in the ranges specified for Merlot, Chardonnay and other varieties.

N is the total number of vineyards sampled in that State for each variety.

State	Petiolar boron (mg/kg)				N
	<25	25-35	>35-70	>70	
Merlot					
NSW[A]	0.0	12.1	87.9	0	33
SA[B]	0.0	22.0	78.0	0	59
Vic[C]	0.0	0.0	100.0	0	14
WA[D]	0.0	21.4	78.6	0	14
All States[E]	0.0	16.7	83.3	0	120
Chardonnay					
NSW	20.0	40.0	40.0	0	5
SA	0.0	40.0	60.0	0	20
Vic	0.0	12.5	87.5	0	8
WA	0.0	17.6	82.4	0	17
All States[E]	2.0	28.0	70.0	0	50
Other varieties Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA)					
NSW	0.0	100.0	0.0	0	1
SA	0.0	28.6	71.4	0	7
WA	0.0	47.1	52.9	0	17
All States[E]	0.0	44.0	56.0	0	25

[A] New South Wales.
[B] South Australia.
[C] Victoria.
[D] Western Australia.
[E] Data for all states were combined for analysis.

The petiolar B levels of Merlot, Chardonnay and other varieties are shown for each state in Table 4.

In the vineyards surveyed, Chardonnay was the only variety with marginal petiolar B concentrations. These occurred in NSW. The B levels of Chardonnay in all the other states surveyed, and in the Merlot, Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello in all states were adequate to high. No excessive or toxic B concentrations were found in this survey.

Year data

Table 5. Percentage of vineyards which had petiolar boron concentrations at flowering in the ranges specified in each growing season for different States of Australia.

N is the total number of vineyards sampled in each growing season.

Growing season	Petiolar boron (mg/kg) <25	25-35	>35-70	>70	N
South Australia					
2003-04	0.0	10.0	90.0	0	40
2004-05	0.0	26.7	73.3	0	30
2005-06	0.0	68.8	31.3	0	16
2004-06[A]	0.0	26.7	73.3	0	86
New South Wales					
2003-04	0.0	6.7	93.3	0	15
2004-05	0.0	28.6	71.4	0	14
2005-06	10.0	20.0	70.0	0	10
2004-06[A]	2.6	17.9	79.5	0	39
Victoria					
2003-04	0.0	0.0	100.0	0	5
2004-05	0.0	0.0	100.0	0	4
2005-06	0.0	7.7	92.3	0	13
2004-06[A]	0.0	4.5	95.5	0	22
Western Australia					
2003-04	0.0	23.5	76.5	0	17
2004-05	0.0	46.7	53.3	0	15
2005-06	0.0	18.8	81.3	0	16
2004-06[A]	0.0	29.2	70.8	0	48

[A] Data for growing seasons 2003-04, 2004-05 and 2005-06 were combined for analysis.

Seasonal changes in petiolar B concentrations at flowering for each of the states are shown in Table 5.

Figure 10, displaying the petiolar B concentrations in vineyards that participated in the survey for all three seasons, shows that the B concentrations did not vary from season to season as much as did the Mo concentrations (Figure 3).

Boron levels from vines at trial sites in the Mount Lofty Ranges for four or five years are shown in Figure 11 and, as with Mo concentrations, are similar to B levels found in the survey.

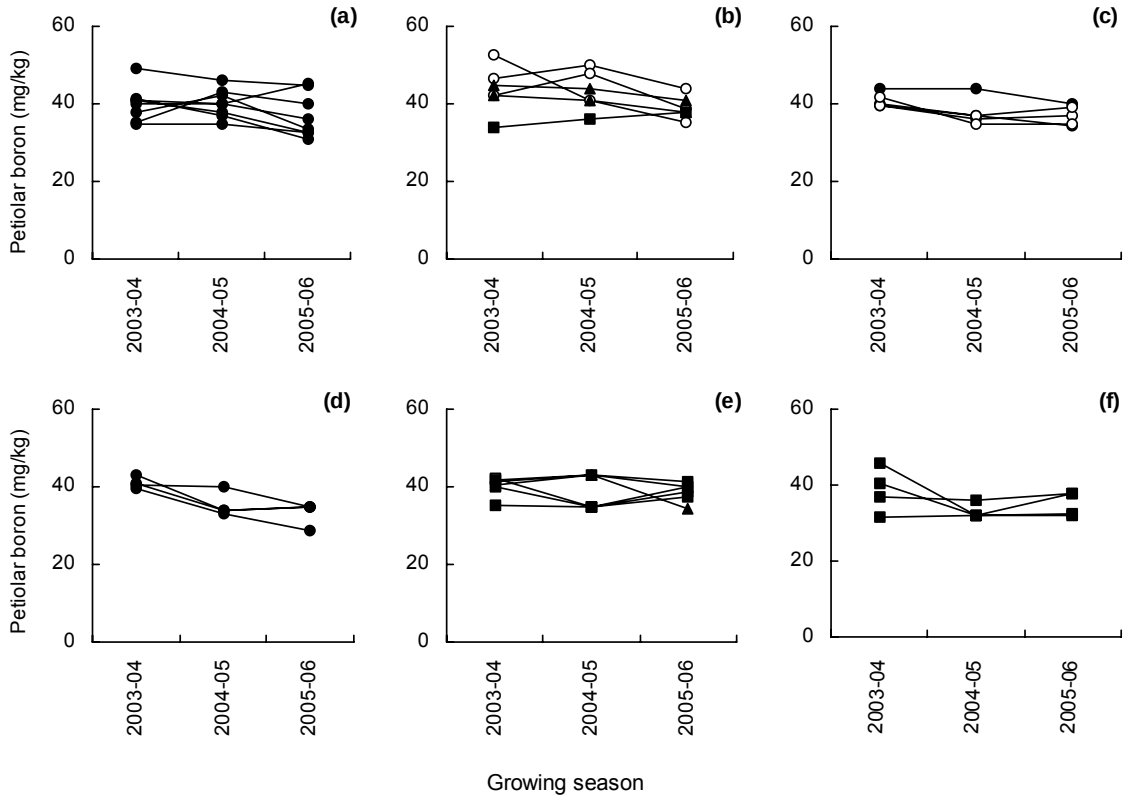


Figure 10. Changes in petiolar boron concentrations over consecutive growing seasons at vineyards in New South Wales (○), Victoria (▲), South Australia (●) and Western Australia (■). Data are for Merlot on own roots (a, b), Merlot on rootstocks (c), Chardonnay (d, e) and Verdelho (f).

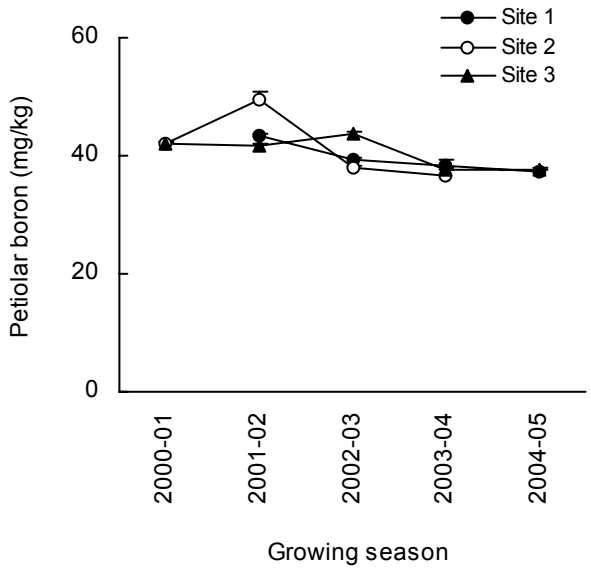


Figure 11. Changes in petiolar boron concentrations at flowering over consecutive growing seasons at experimental sites in the Mount Lofty Ranges of South Australia.

Data are for Merlot on own roots.

Vertical lines are standard errors of the means.

Regional data

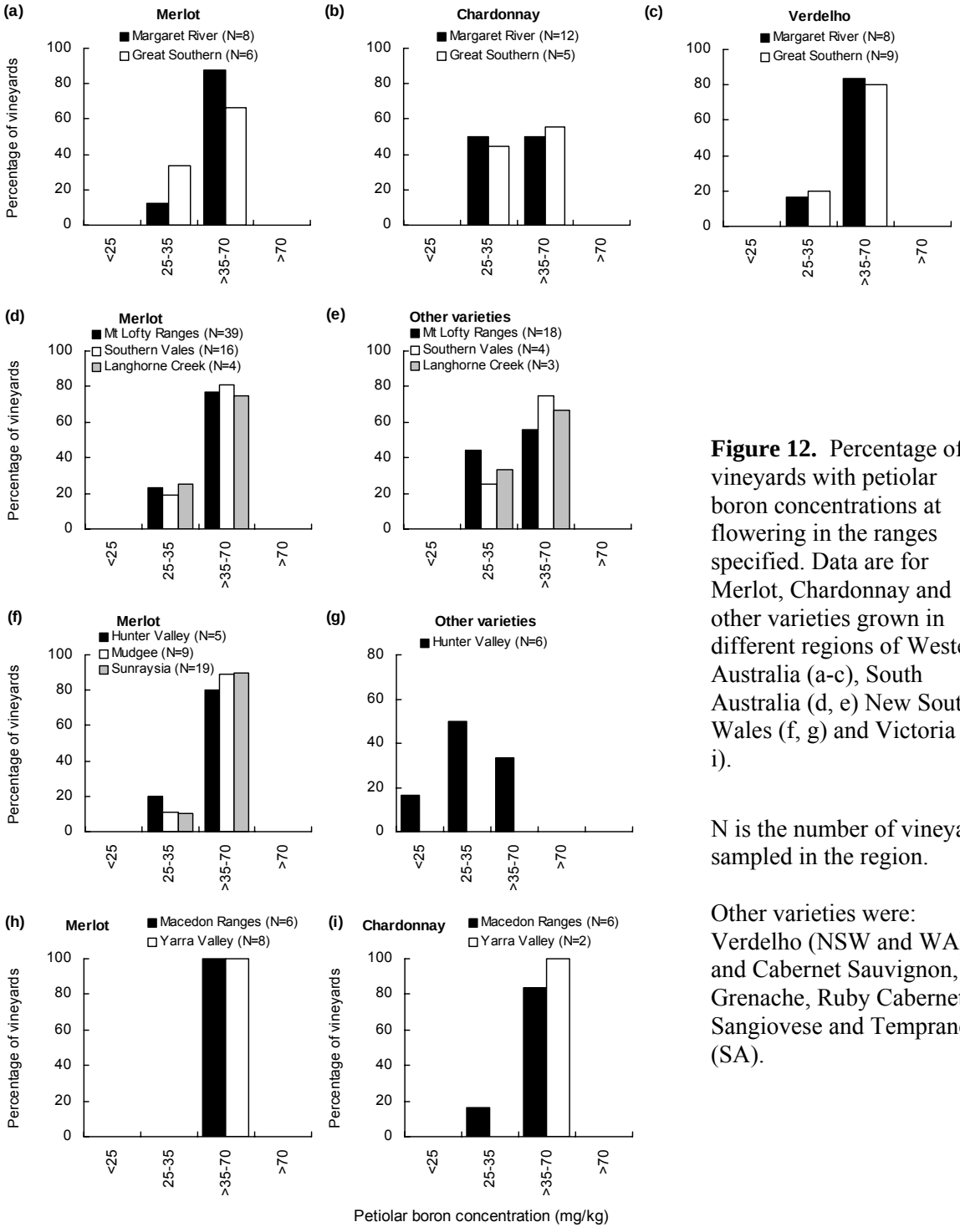


Figure 12. Percentage of vineyards with petiolar boron concentrations at flowering in the ranges specified. Data are for Merlot, Chardonnay and other varieties grown in different regions of Western Australia (a-c), South Australia (d, e) New South Wales (f, g) and Victoria (h, i).

N is the number of vineyards sampled in the region.

Other varieties were: Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA).

Within each state and within each variety surveyed, the spread of petiolar B concentrations at flowering was similar across the regions (Figure 12).

Petiolar Zinc concentration

National data

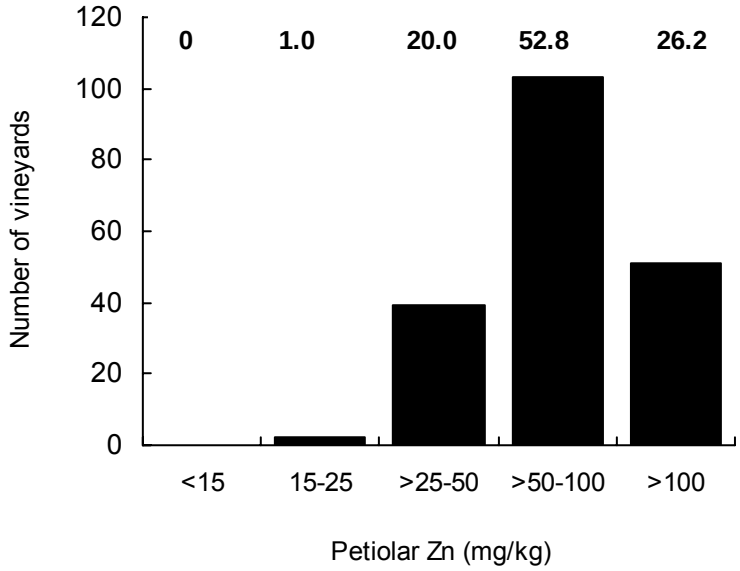


Figure 13. Number of vineyards (N = 195) with petiolar zinc concentrations at flowering in concentration ranges used to categorise plant zinc status (deficient, marginal and adequate). Data are pooled across States, years and varieties. Numbers above the histogram indicate percentage of vineyards with petiolar zinc concentrations in each concentration range.

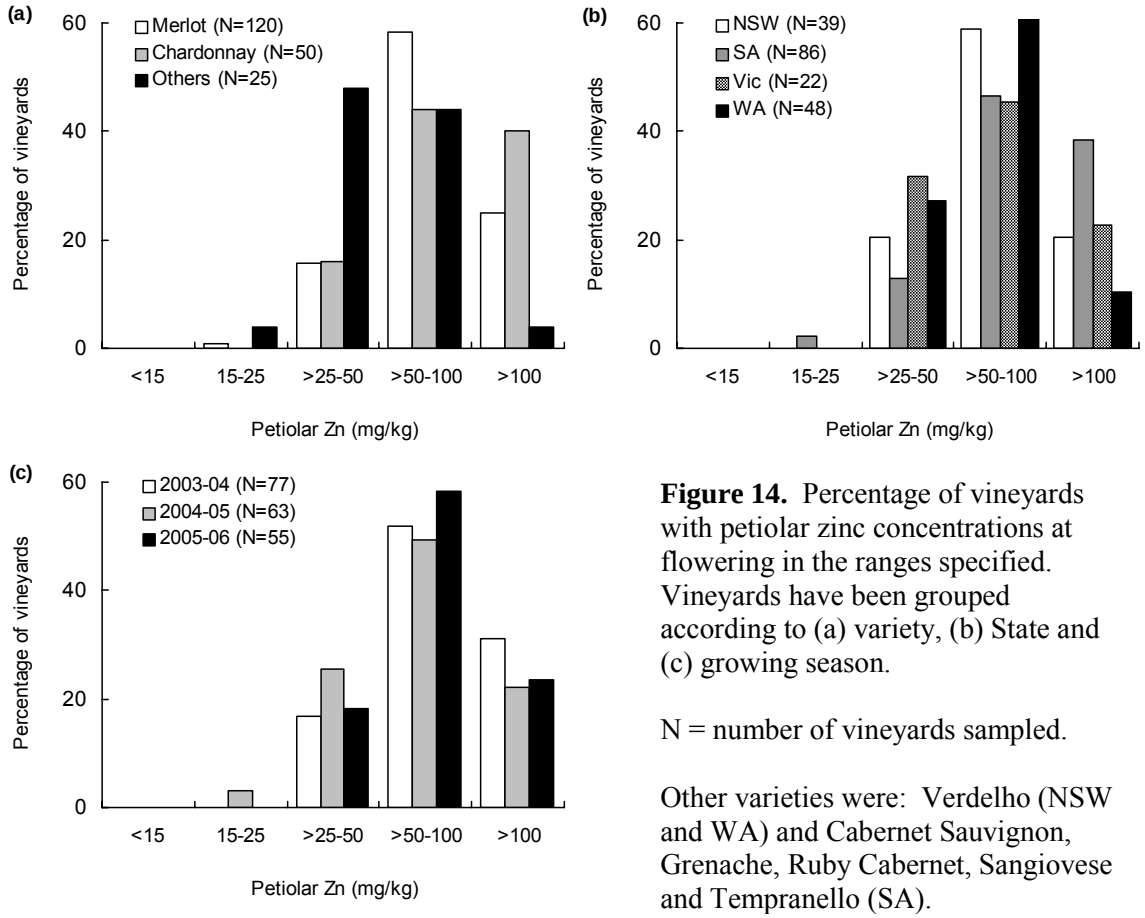


Figure 14. Percentage of vineyards with petiolar zinc concentrations at flowering in the ranges specified. Vineyards have been grouped according to (a) variety, (b) State and (c) growing season.

N = number of vineyards sampled.

Other varieties were: Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA).

Zinc levels in grapevines in the currently used standards are described as deficient, < 15 mg/kg**,** marginal 15 – 25 mg/kg, adequate 25 – 50 mg/kg, high > 50 - 100 mg/kg, and excessive or toxic, >100 mg/kg. As with boron, fruit set can be affected by zinc deficiency (Christensen 1986). Figure 13 shows that most vineyards surveyed had zinc concentrations in the adequate or higher ranges and only one was in the marginal range. Zinc levels found in the petioles of the grapevines appeared not to be limiting yield.

The high and excessive levels of zinc found in the petioles in this survey may be due to use of fungicide sprays containing zinc as the petiole samples were not washed before analysis.

Zinc concentrations found in each state (Figure 14(b)) were a reflection of the varieties sampled in that state (Figure 14(a)). Again, while Merlot is the variety in which berry asynchrony is considered to be a problem, the petiolar zinc concentrations found in this survey did not show levels low enough to cause concern with respect to poor fruit set. (Figure 14(a)). Similarly, low levels of petiolar zinc did not occur in seasons of greater berry asynchrony (Figure 14(c)).

State data

Table 6. Percentage of vineyards sampled in New South Wales, South Australia, Victoria and Western Australia with petiolar zinc concentrations at flowering in the ranges specified for Merlot, Chardonnay and other varieties.

N is the total number of vineyards sampled in that State for each variety.

State	Petiolar zinc (mg/kg)					N
	<15	**15-25**	**>25-50**	**>50-100**	**>100**	
Merlot						
NSW[A]	0	0.0	21.2	60.6	18.2	33
SA[B]	0	1.7	11.9	59.3	27.1	59
Vic[C]	0	0.0	14.3	50.0	35.7	14
WA[D]	0	0.0	21.4	57.1	21.4	14
All States[E]	0	0.8	15.8	58.3	25.0	120
Chardonnay						
NSW	0	0.0	20.0	40.0	40.0	5
SA	0	0.0	0.0	20.0	80.0	20
Vic	0	0.0	62.5	37.5	0.0	8
WA	0	0.0	11.8	76.5	11.8	17
All States[E]	0	0.0	16.0	44.0	40.0	50
Other varieties						
Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA)						
NSW	0	0.0	0.0	100.0	0.0	1
SA	0	14.3	57.1	14.3	14.3	7
WA	0	0.0	47.1	52.9	0.0	17
All States[E]	0	4.0	48.0	44.0	4.0	25

[A] New South Wales.
[B] South Australia
[C] Victoria.
[D] Western Australia.
[E] Data for all states were combined for analysis.

Table 6 shows the occurrence of each range of petiolar zinc levels in the states surveyed for Merlot, Chardonnay and other varieties. Zinc concentrations in the marginal range were recorded for Merlot and for other varieties in South Australia only.

Year data

Table 7. Percentage of vineyards with petiolar zinc concentrations at flowering in the ranges specified in each growing season for different States of Australia.
N is the total number of vineyards sampled in each growing season.

Growing	Petiolar zinc (mg/kg)					N
season	<15	15-25	>25-50	>50-100	>100	
South Australia						
2003-04	0	0.0	12.5	50.0	37.5	40
2004-05	0	6.7	13.3	40.0	40.0	30
2005-06	0	0.0	12.5	50.0	37.5	16
2004-06[A]	0	2.3	12.8	46.5	38.4	86
New South Wales						
2003-04	0	0.0	13.3	60.0	26.7	15
2004-05	0	0.0	21.4	64.3	14.3	14
2005-06	0	0.0	30.0	50.0	20.0	10
2004-06[A]	0	0.0	20.5	59.0	20.5	39
Victoria						
2003-04	0	0.0	40.0	60.0	0.0	5
2004-05	0	0.0	100.0	0.0	0.0	4
2005-06	0	0.0	7.7	53.8	38.5	13
2004-06[A]	0	0.0	31.8	45.5	22.7	22
Western Australia						
2003-04	0	0.0	23.5	47.1	29.4	17
2004-05	0	0.0	33.3	66.7	0.0	15
2005-06	0	0.0	25.0	75.0	0.0	16
2004-06[A]	0	0.0	27.1	62.5	10.4	48

[A] Data for growing seasons 2003-04, 2004-05 and 2005-06 were combined for analysis.

Within each state, levels of petiolar zinc varied from season to season (Table 7) but this may be due to different times of spraying depending on seasonal conditions.

Where the same vineyards were sampled over consecutive seasons (Figure 15), the zinc concentrations did not vary sufficiently between years to be a possible cause of the poor fruit set that was found.

Results from the sites in South Australia over four or five seasons for Merlot on own roots, including those from the survey, showed similar variations in petiolar zinc concentrations between years (Figure 16).

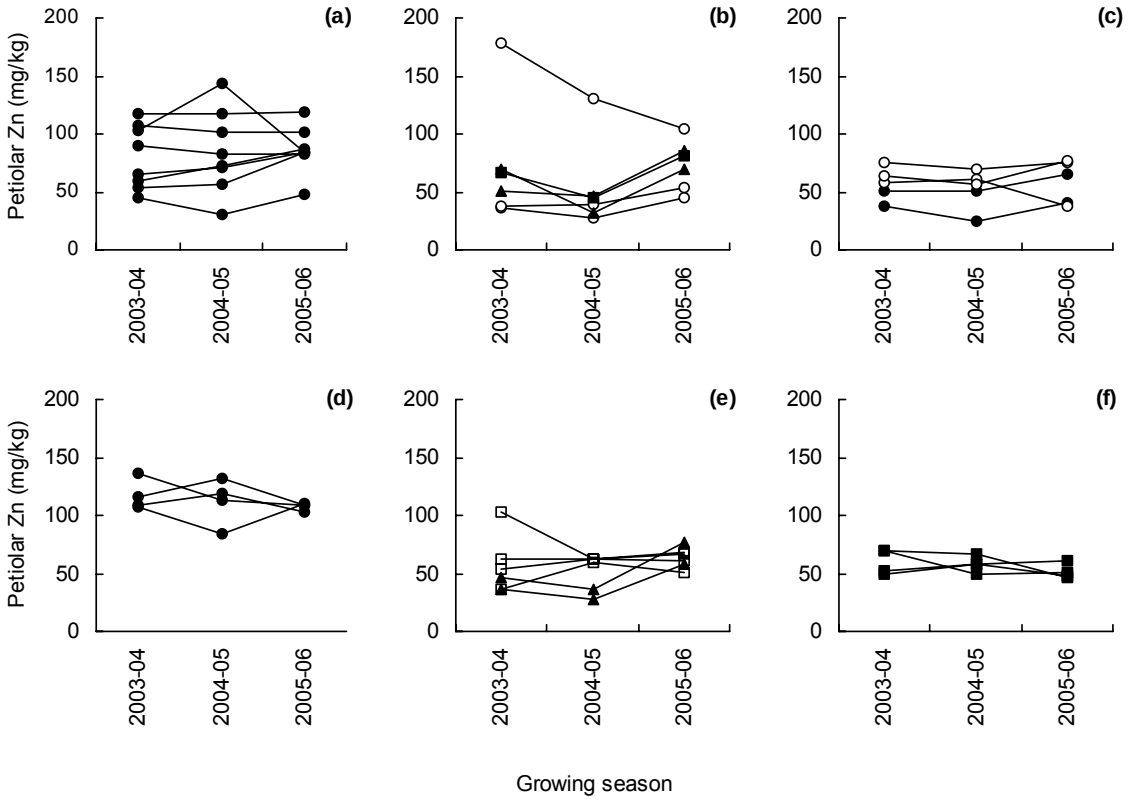


Figure 15. Changes in petiolar zinc concentrations over consecutive growing seasons at vineyards in New South Wales (○), Victoria (▲), South Australia (●) and Western Australia (■). Data are for Merlot on own roots (a, b), Merlot on rootstocks (c), Chardonnay (d, e) and Verdelho (f).

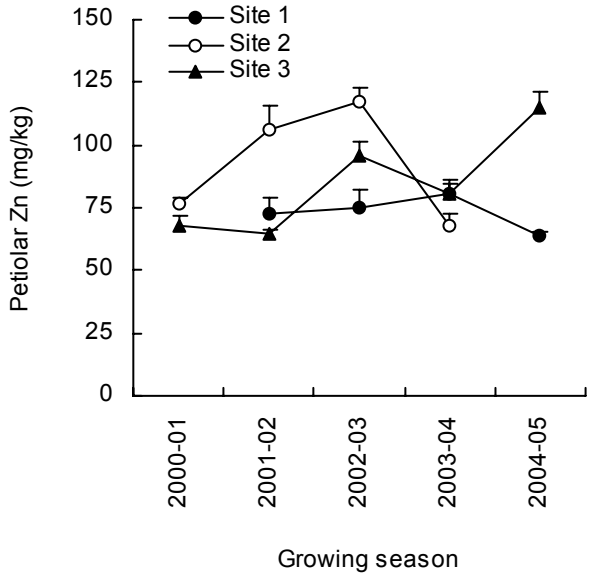


Figure 16. Changes in petiolar zinc concentrations at flowering over consecutive growing seasons at experimental sites in the Mount Lofty Ranges of South Australia.

Data are for Merlot on own roots.

Vertical lines are standard errors of the means.

Regional data

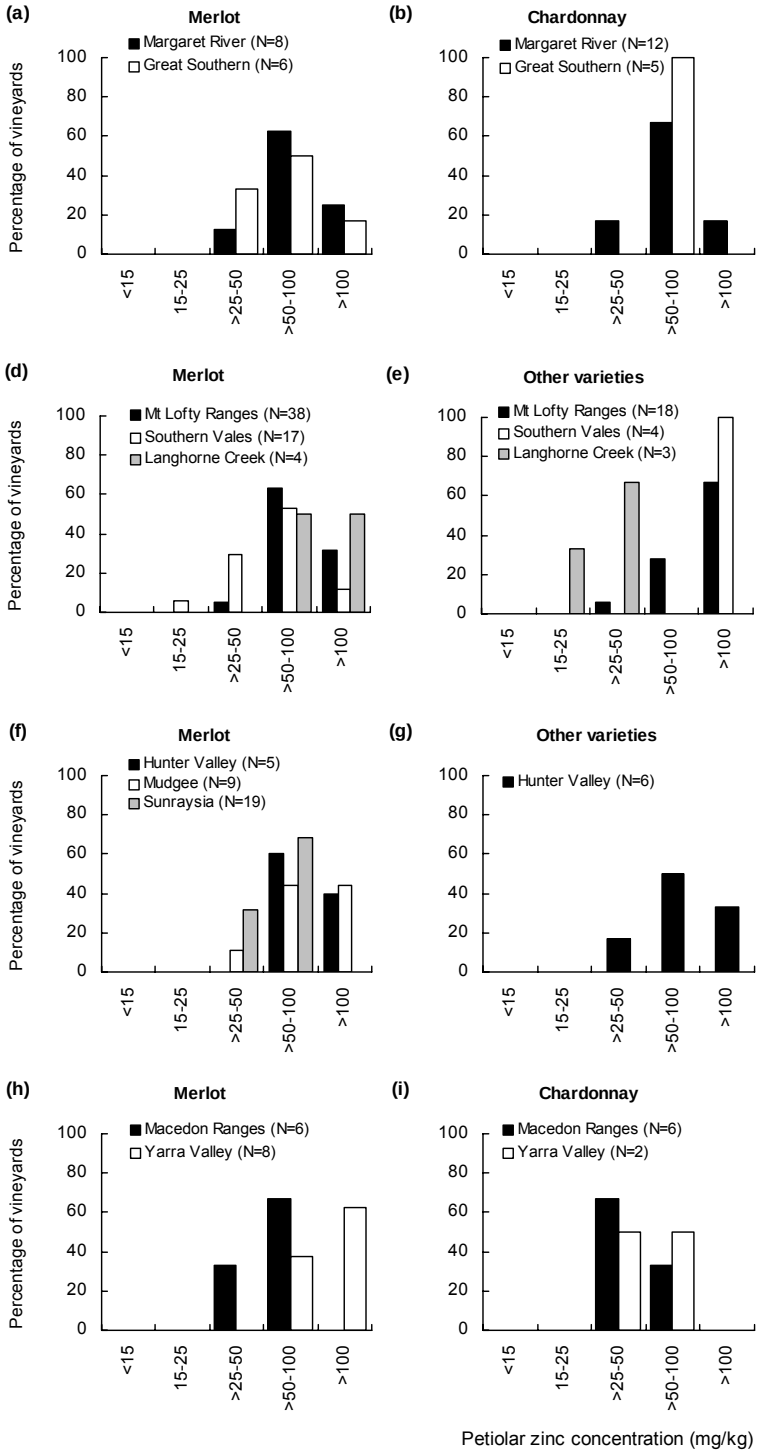


Figure 17. Percentage of vineyards with petiolar zinc concentrations at flowering in the ranges specified. Data are for Merlot, Chardonnay and other varieties grown in different regions of Western Australia (a-c), South Australia (d, e) New South Wales (f, g) and Victoria (h, i).

N is the number of vineyards sampled in the region.

Other varieties were: Verdelho (NSW and WA) and Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello (SA).

Petiolar zinc concentrations at flowering were in the adequate or higher ranges for all varieties in all states other than in South Australia where samples from a few Merlot vines in the Southern Vales and half of the vines of 'other varieties' from the Langhorne Creek district were in the marginal range (Figure 17).

Bunch rating

National data

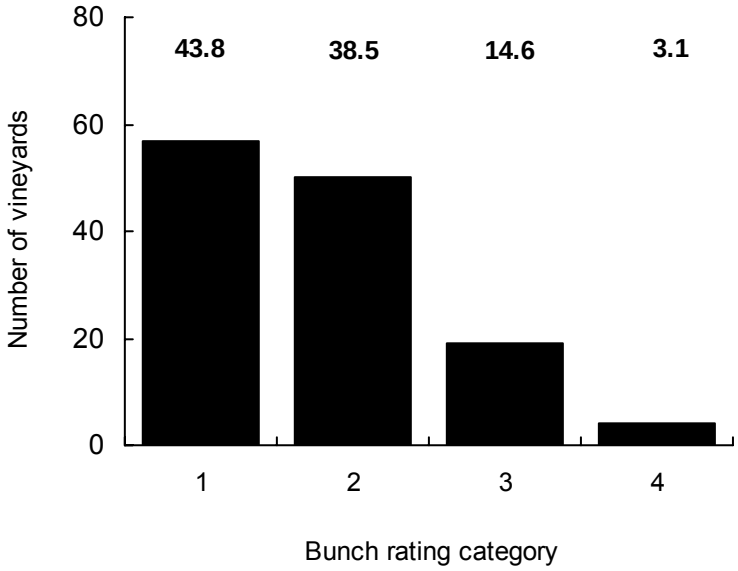


Figure 18. Number of vineyards in each rating category for bunches assessed in vineyards across Australia (N = 130). Data are pooled across States, years and varieties. Numbers above the histogram indicate the percentage of vineyards with each bunch rating.

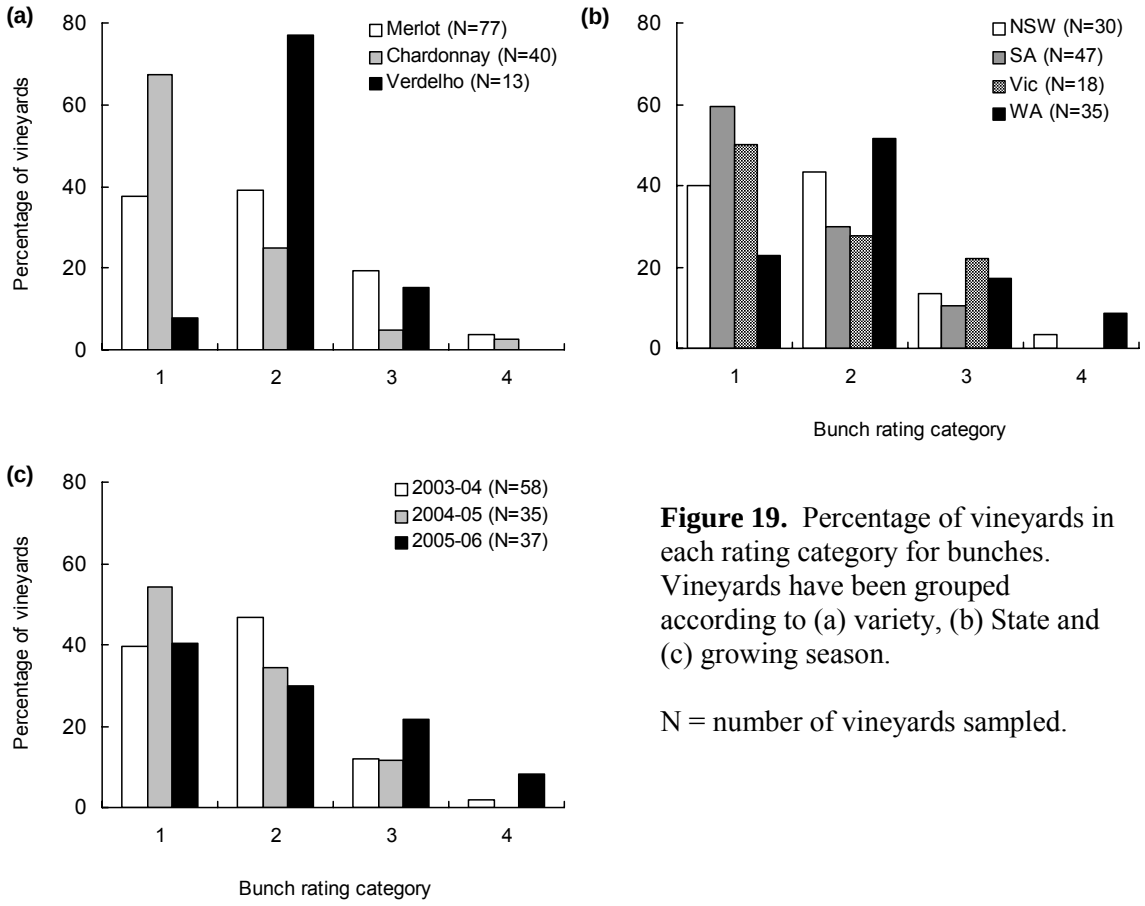


Figure 19. Percentage of vineyards in each rating category for bunches. Vineyards have been grouped according to (a) variety, (b) State and (c) growing season.

N = number of vineyards sampled.

Bunch rating provided a subjective evaluation of fruit set or the level of berry asynchrony. Bunches were rated from 1 to 4, with rating 1 having very good fruit set and rating 4 having very poor fruit set (see Appendix 4). While most vineyards reported bunch ratings of 1, ratings of 2 to 4 did occur in vineyards surveyed, as seen in Figure 18.

Bunch ratings differed between varieties (Figure 19(a)) and this is reflected to some extent in the ratings at the State level (Figure 19(b)). The distribution of ratings differed slightly between 2003/04 and 2004/05, but ratings in 2005/06 were noticeably different with more bunches rated in the poorer fruit set categories.

State data

Table 8. Percentage of vineyards sampled in New South Wales, South Australia, Victoria and Western Australia in each rating category for bunches of the varieties Merlot, Chardonnay and Verdelho.

N is the total number of vineyards sampled in that State for each variety.

State	Bunch rating category				N
	1	2	3	4	
Merlot					
NSW[A]	36.0	48.0	12.0	4.0	25
SA[B]	45.2	38.7	16.1	0.0	31
Vic[C]	36.4	27.3	36.4	0.0	11
WA[D]	20.0	30.0	30.0	20.0	10
All States[E]	37.7	39.0	19.5	3.9	77
Chardonnay					
NSW	50.0	25.0	25.0	0.0	4
SA	87.5	12.5	0.0	0.0	16
Vic	71.4	28.6	0.0	0.0	7
WA	46.2	38.5	7.7	7.7	13
All States[E]	67.5	25.0	5.0	2.5	40
Verdelho					
NSW	100.0	0.0	0.0	0.0	1
WA	0.0	83.3	16.7	0.0	12
All States[E]	7.7	76.9	15.4	0.0	13

[A] New South Wales.
[B] South Australia.
[C] Victoria.
[D] Western Australia.
[E] Data for all states were combined for analysis.

Bunch ratings differed between States particularly for Chardonnay and Verdehlo varieties (Table 8). Overall most bunches were rated as either 1 or 2, although Merlot in Victoria and Western Australia, and Chardonnay in New South Wales had bunches rated as 3. No bunches were rated as 4 in South Australia or Victoria.

Year data

Table 9. Percentage of vineyards in each rating category for bunches assessed in three growing seasons across different States of Australia.
N is the total number of vineyards sampled in each growing season.

Growing season	Bunch rating category 1	2	3	4	N
South Australia					
2003-04	60.9	26.1	13.0	0.0	23
2004-05	53.8	38.5	7.7	0.0	13
2005-06	63.6	27.3	9.1	0.0	11
2004-06[A]	59.6	29.8	10.6	0.0	47
New South Wales					
2003-04	14.3	64.3	14.3	7.1	14
2004-05	70.0	20.0	10.0	0.0	10
2005-06	50.0	33.3	16.7	0.0	6
2004-06[A]	40.0	43.3	13.3	3.3	30
Victoria					
2003-04	50.0	33.3	16.7	0.0	6
2004-05	50.0	25.0	25.0	0.0	4
2005-06	50.0	25.0	25.0	0.0	8
2004-06[A]	50.0	27.8	22.2	0.0	18
Western Australia					
2003-04	26.7	66.7	6.7	0.0	15
2004-05	37.5	50.0	12.5	0.0	8
2005-06	8.3	33.3	33.3	25.0	12
2004-06[A]	22.9	51.4	17.1	8.6	35

[A] Data for growing seasons 2003-04, 2004-05 and 2005-06 were combined for analysis.

In South Australia and Victoria, ratings differed very little between growing seasons. In contrast, ratings in New South Wales and Western Australia varied widely from year to year. There appears to be no trend in either the ratings or the variations across growing seasons.

Figure 20 shows the bunch ratings for varieties within the wine growing regions surveyed. Whilst there is some indication from these data that more bunches from the cooler regions in each State were rated as 3 and 4, the small number of actual ratings in most categories must be considered.

Regional data

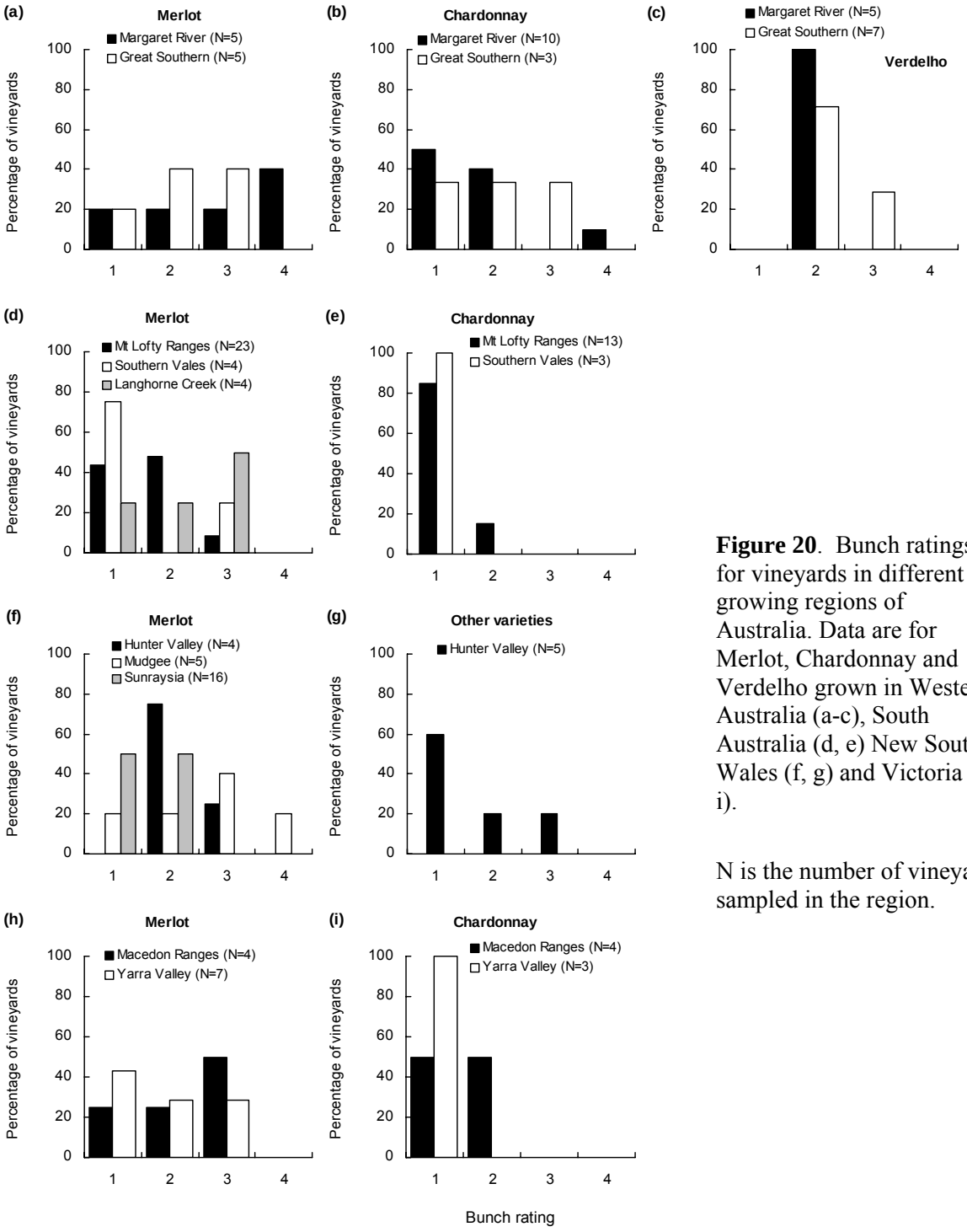


Figure 20. Bunch ratings for vineyards in different growing regions of Australia. Data are for Merlot, Chardonnay and Verdelho grown in Western Australia (a-c), South Australia (d, e) New South Wales (f, g) and Victoria (h, i).

N is the number of vineyards sampled in the region.

Merlot on own roots and rootstocks

Table 10. Percentage of vineyards in each rating category for bunches from Merlot grown on own roots and on rootstocks in each State.

N is the total number of vineyards sampled in each State.

State	Bunch rating category				N
	1	2	3	4	
Merlot on own roots					
NSW[A]	40.0	33.3	20.0	6.7	15
SA[B]	44.4	37.0	18.5	0.0	27
Vic[C]	30.0	30.0	40.0	0.0	10
WA[D]	20.0	30.0	30.0	20.0	10
All States[E]	37.1	33.9	24.2	4.8	62
Merlot on rootstock					
140 Ruggeri, Schwarzmann, Ramsey and SO4					
NSW[A]	30.0	70.0	0.0	0.0	10
SA[B]	50.0	50.0	0.0	0.0	4
Vic[C]	100.0	0.0	0.0	0.0	1
All States[E]	40.0	60.0	0.0	0.0	15

[A] New South Wales.
[B] South Australia.
[C] Victoria.
[D] Western Australia.
[E] Data for all states combined.

Bunch ratings for Merlot on own roots ranged from 1 to 4 whilst Merlot on rootstock rated 1 and 2 only (Table 10). The comparatively small number of reported ratings for Merlot on rootstocks must be taken into account when viewing this data.

Bunch rating and vine yield

The Box and Whisker plots used in this section show the central tendency and variability of data within categories. The box encloses the middle half of the data and is dissected by a line at the median value. The vertical lines on the top and bottom of the box (whiskers) indicate the range of the "typical" data values. Values outside the "typical" range are represented by either a star, for possible outliers, or a circle, for probable outliers.

Merlot

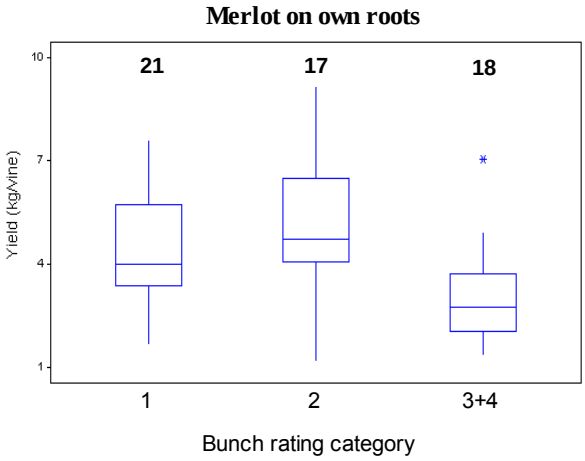


Figure 21. Box and Whisker Plots of the yield of Merlot vines for each rating category. Data were pooled across States and years.

Bold numbers indicate the number of vineyards in each rating category.

Figures 21 and 22 show bunch ratings compared to yield for Merlot on own roots for all respondents and split between South Australia and the remaining surveyed States respectively. Bunch rating categories of 3 and 4 (combined) corresponded to yields of approximately 4 kg/vine or less. Whilst bunch ratings of 1 or 2 were associated with yields greater than this, the range indicated by the whiskers and the results for rating 1 for States other than South Australia (Figure 22(b)) illustrate the large variation in yields found in conjunction with these ratings.

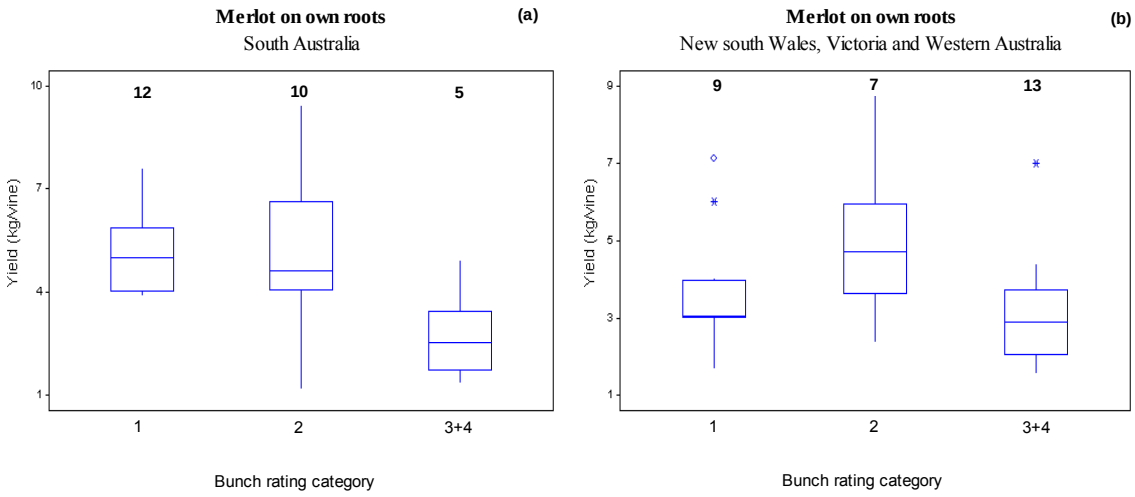


Figure 22. Box and Whisker Plots of the yield of Merlot vines in (a) South Australia and (b) New South Wales, Victoria and Western Australia combined, for each rating category. Bold numbers indicate the number of vineyards in each category.

Chardonnay

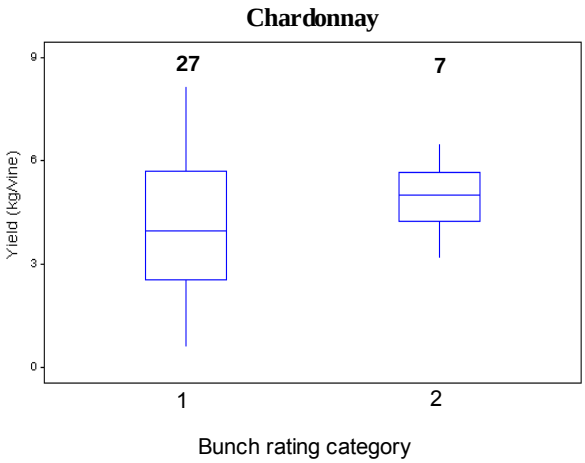


Figure 23. Box and Whisker Plots of the yield of Chardonnay vines for rating categories 1 and 2. Data were pooled across States and years.

Bold numbers indicate the number of vineyards in each rating category.

Bunch rating is compared to yield for Chardonnay in all States over all years in Figure 23. No ratings of 3 or 4 were recorded for Chardonnay bunches. The wide range of yield results shown here in the rating 1 category for Chardonnay and shown in Figure 21 for ratings 1 and 2 for Merlot on own roots demonstrate that bunches with little or no symptoms of berry asynchrony are not necessarily associated with high yields for these grape varieties.

Bunch rating and petiolar molybdenum, boron and zinc concentrations

Molybdenum

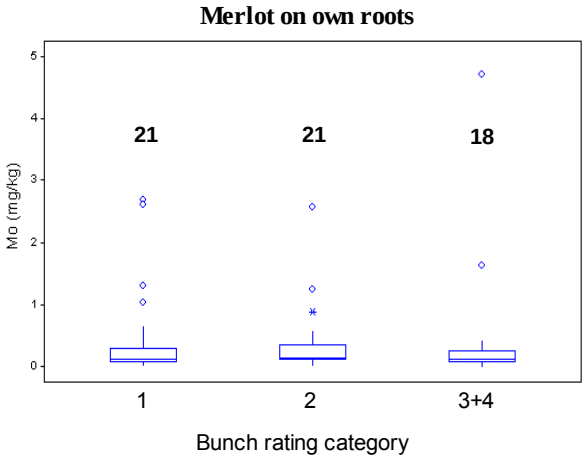


Figure 24. Box and Whisker Plots of molybdenum concentration in petioles of Merlot vines for each rating category. Data were pooled across States and years.

Bold numbers indicate the number of vineyards in each rating category.

Flowering petiolar Mo levels were similar for all rating categories for bunches from Merlot on own roots (Figure 24).

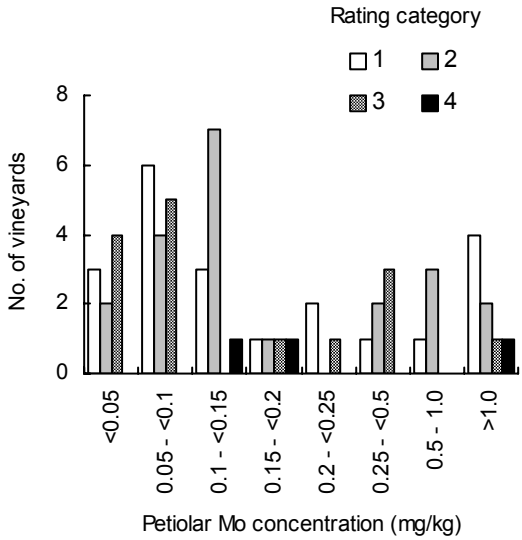


Figure 25. Number of vineyards in each rating category for different petiolar molybdenum concentration ranges.

Data were pooled across States and years.

Whilst bunch ratings are spread across the range of petiolar Mo concentrations, relatively large numbers of bunch ratings of 1, 2, and to a lesser extent, rating 3, were recorded for bunches from vines with petiolar Mo levels of below 0.15 (Figure 25). From this data there appears to be no correlation between bunch ratings and Mo levels in petioles at flowering.

Boron

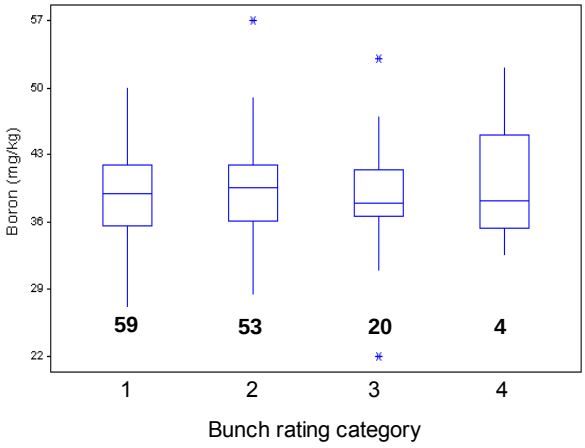


Figure 26. Box and Whisker Plots of petiolar boron concentrations at flowering for each rating category

Data were pooled across varieties, States and years.

Bold numbers indicate the number of vineyards in each rating category.

Petiolar boron levels at flowering were similar for all of the bunch rating categories (Figure 26).

Zinc

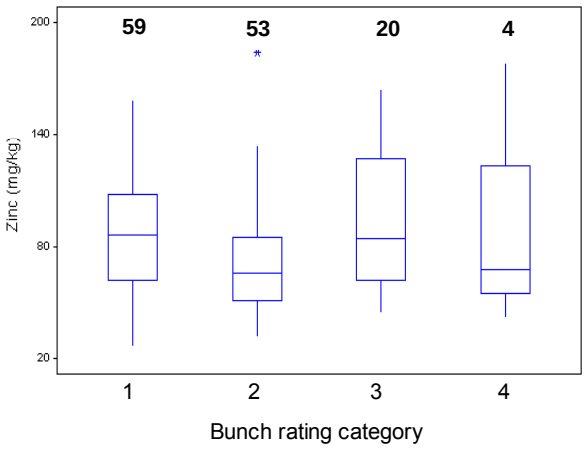


Figure 27. Box and Whisker Plots of petiolar zinc concentrations at flowering for each rating category

Data were pooled across varieties, States and years.

Bold numbers indicate the number of vineyards in each rating category.

Whilst there is some variation in levels of zinc found in petioles at flowering between the four bunch ratings, most are within similar ranges suggesting that there is no correlation between zinc levels and bunch rating (Figure 27).

Soil chemical properties

Median concentrations and concentration ranges

Table 11. Median values and range of values for chemical properties of the surface (0-15 cm) soils of vineyards included in the survey.

N is the number of vineyards

Variable	New South Wales (N=10)		South Australia (N=33)	
	Median	Range	Median	Range
Organic Carbon (%)	0.8	0.3 – 2.4	1.9	0.7 – 4.5
pH_{Ca}	7.5	5.4-8.1	5.8	4.7-7.5
EC (dS/m)	0.11	0.07 – 0.27	0.10	0.05 – 0.58
Mineral nitrogen (mg/kg)	9	6 – 72	11	3 – 42
Phosphorus (mg/kg)	55	9 – 153	64	20 – 300
Potassium (mg/kg)	344	161 – 717	295	65 – 591
Sulphur (mg/kg)	7	2 – 46	10	4 – 111
Calcium (meq/100g)	9.8	3.7 – 17.0	7.9	2.5 – 20.6
Magnesium (meq/100g)	2.0	1.1 – 2.9	1.9	0.6 – 4.5
Sodium (meq/100g)	0.15	0.09 – 0.91	0.20	0.06 – 1.82
Potassium (meq/100g)	0.8	0.4 – 2.2	0.7	0.2 – 1.4
Copper (mg/kg)	4.0	0.8 – 10.9	3.2	1.0 – 52.5
Zinc (mg/kg)	2.0	0.2 – 42.8	3.5	0.7 – 19.7
Manganese (mg/kg)	4.8	3.2 – 68.4	7.5	1.8 – 62.2
Iron (mg/kg)	16	6 – 214	100	21 – 481
Chloride (mg/kg)	13	5 – 114	35	11 – 395
Variable	Victoria (N=10)		Western Australia (N=26)	
	Median	Range	Median	Range
Organic Carbon (%)	3.1	1.2 – 3.8	2.5	1.5 – 6.4
pH_{Ca}	6.1	4.8-6.8	5.7	4.4-6.5
EC (dS/m)	0.11	0.05 – 0.33	0.09	0.06 – 0.18
Mineral nitrogen (mg/kg)	10	8 – 28	11	5 – 34
Phosphorus (mg/kg)	35	11 – 167	92	11 – 315
Potassium (mg/kg)	194	48 – 414	112	44 – 337
Sulphur (mg/kg)	16	3 – 44	19	8 – 79
Calcium (meq/100g)	10.2	3.8 – 19.7	7.4	2.9 – 14.5
Magnesium (meq/100g)	3.0	0.9 – 10.5	1.2	0.5 – 2.9
Sodium (meq/100g)	0.39	0.06 – 1.03	0.20	0.09 – 0.46
Potassium (meq/100g)	0.4	0.1 – 0.6	0.3	0.1 – 0.9
Copper (mg/kg)	4.1	0.8 – 12.4	3.4	0.6 – 18.9
Zinc (mg/kg)	2.6	1.1 – 90.9	2.6	0.4 – 8.4
Manganese (mg/kg)	8.1	4.3 – 14.8	3.2	1.1 – 12.9
Iron (mg/kg)	137	51 – 460	53	24 – 703
Chloride (mg/kg)	48	10 – 466	23	5 – 94

The variation in values for the chemical properties of the surveyed surface soils as shown in Table 11 are not only a reflection of the different soils but also of the different times at which the samples were taken. Seasonal temperatures affecting mineralisation and fertiliser applications can both affect soil chemical properties and cause larger ranges in values.

The median soil acidity in the 0-15 cm sample varied from moderately acidic in Western Australia to slightly alkaline in New South Wales (Table 11). However individual vineyards ranged from strongly acidic to moderately alkaline.

On the basis of organic carbon, fertility of the surveyed soils ranged from infertile to highly fertile.

Electrical conductivity values (EC) ranged from 0.05 to 0.58 dS/m indicating that salinity was not a problem in any of the vineyards surveyed.

While the median values of phosphorus and potassium in the 0-15 cm soil samples were adequate, some vineyards in New South Wales did have low potassium concentrations.

DTPA extractable levels of <0.2 mg/kg for copper, <0.5 mg/kg for zinc, <1.0 mg/kg for manganese, and <2.5 mg/kg for iron are considered to be deficient (Hannam 1985). Based on these interpretation standards, only individual vineyards in New South Wales and Western Australia showed a deficiency in zinc.

Soil acidity

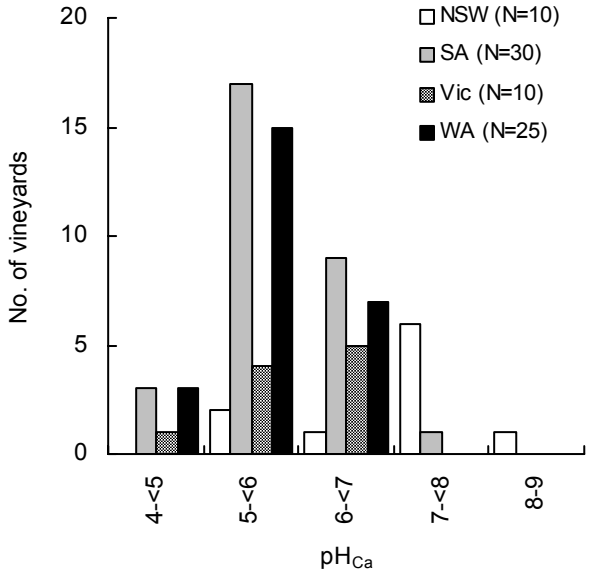


Figure 28. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with soil pH_{Ca} in the ranges specified.

Data were pooled across varieties and years.

N is the number of vineyards.

Overall the pH_{Ca} in the surface soil of surveyed vineyards in South Australia, Victoria and Western Australia was in the acid to neutral range, whereas most sites in New South Wales had neutral to slightly alkaline surface soil (Figure 28).

Iron

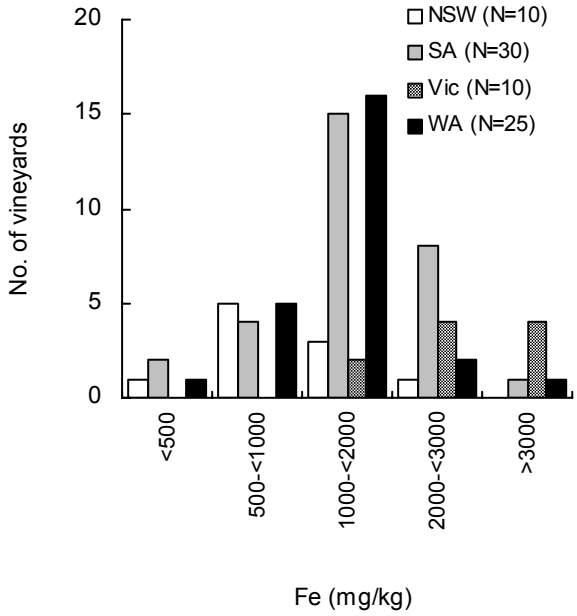


Figure 29. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with soil iron levels in the ranges specified.

Data were pooled across varieties and years.

N is the number of vineyards.

Iron levels in the soil are not a good indication of iron available for uptake by vines as this is affected by other factors, such as pH, moisture content, temperature, and bicarbonate concentration (McFarlane 1999). There was no correlation between soil pH_{Ca} and iron concentration in the soil samples in this survey.

Organic carbon

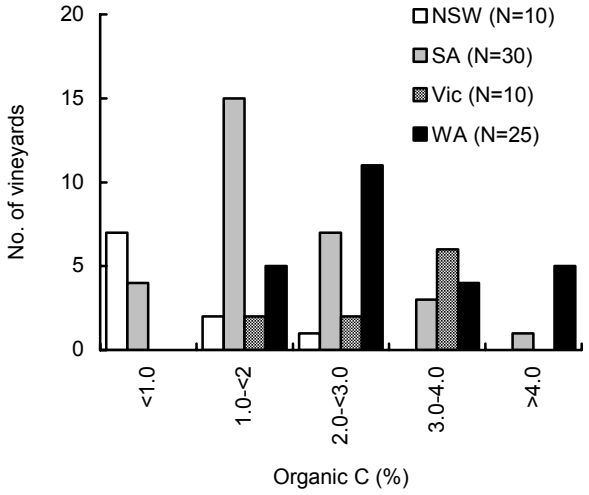


Figure 30. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with soil organic carbon levels in the ranges specified.

Data were pooled across varieties and years.

N is the number of vineyards.

Variations in organic carbon are expected as organic carbon content is related to differences in management, climate and soil mineral composition among other things (Baldock and Skjemstad 1999)**.**

Extractable phosphorus and potassium

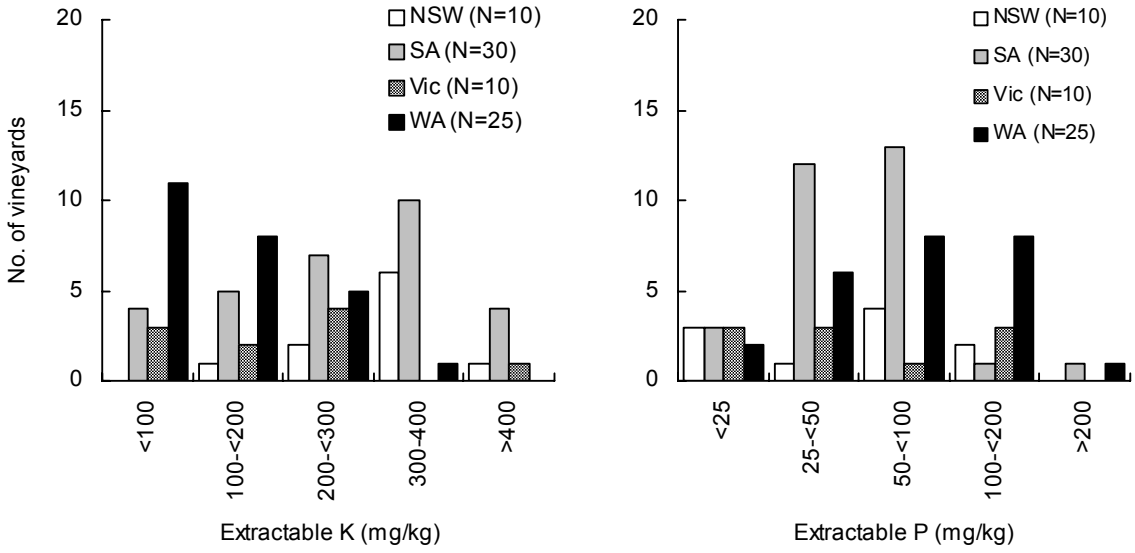


Figure 31. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with soil extractable phosphorus and potassium levels in the ranges specified. Data were pooled across varieties and years. N is the number of vineyards.

Different soil types, past and current management practices, and climate all contribute to the range of phosphorus and potassium concentrations found in the vineyard soils sampled.

Petiolar nutrient concentration at flowering

Median concentrations and concentration ranges

The median concentration and concentration range for each nutrient in petioles sampled at flowering are presented in Table 12.

Table 12. Median concentrations and concentration ranges for nutrients in petioles sampled at flowering (E-L 23-25) during the 2003-04, 2004-05 and 2005-06 growing seasons.

Nutrient	2003-04[A]		2004-05[B]		2005-06[C]	
	Median	Range	Median	Range	Median	Range
Nitrogen (%)	0.88	0.61-2.51	0.79	0.47-1.52	0.84	0.57-2.18
Nitrate-N (mg/kg)	725	106-8400			198	37-1884
Phosphorus (%)	0.51	0.12-1.14	0.41	0.09-0.95	0.45	0.15-0.99
Potassium (%)	3.10	1.19-5.80	3.70	1.50-6.40	3.04	0.91-6.10
Calcium (%)	1.61	0.96-3.20	1.64	0.94-2.50	1.52	1.00-2.50
Magnesium (%)	0.67	0.29-1.41	0.62	0.26-1.30	0.58	0.22-1.47
Sodium (%)	0.07	0.02-0.33	0.09	0.01-0.35	0.10	0.01-0.57
Chloride(%)	0.61	0.18-1.20			0.71	0.21-1.52
Sulfur (%)	0.19	0.05-0.36	0.18	0.09-0.38	0.17	0.07-0.36
Boron (%)	40	29-54	37	27-50	38	22-57
Copper (mg/kg)	37	5-380	30	7-320	44	7-240
Zinc (mg/kg)	75	32-178	64	19-157	75	38-184
Manganese (mg/kg)	80	12-649	60	12-430	62	15-283
Iron (mg/kg)	31	17-91	26	15-66	32	12-430

[A] Number of data points was chloride 17, nitrate-N 62 and the rest 77.
[B] Number of data points was nitrogen 62 and the rest 63.
[C] Number of data points was chloride and nitrate-N 27, nitrogen 54 and the rest 55.

The concentration of nutrients varied over the three years of the survey as expected due to differences between seasons and the varying number of vineyards responding in each year. No trend can be assessed, as the vineyards sampled are not all the same from year to year.

Comparison with interpretation standards at flowering

Nutrients in this section are categorised and compared using concentration ranges as given in Robinson *et al*. (1997) except for sulfur.

Nitrogen

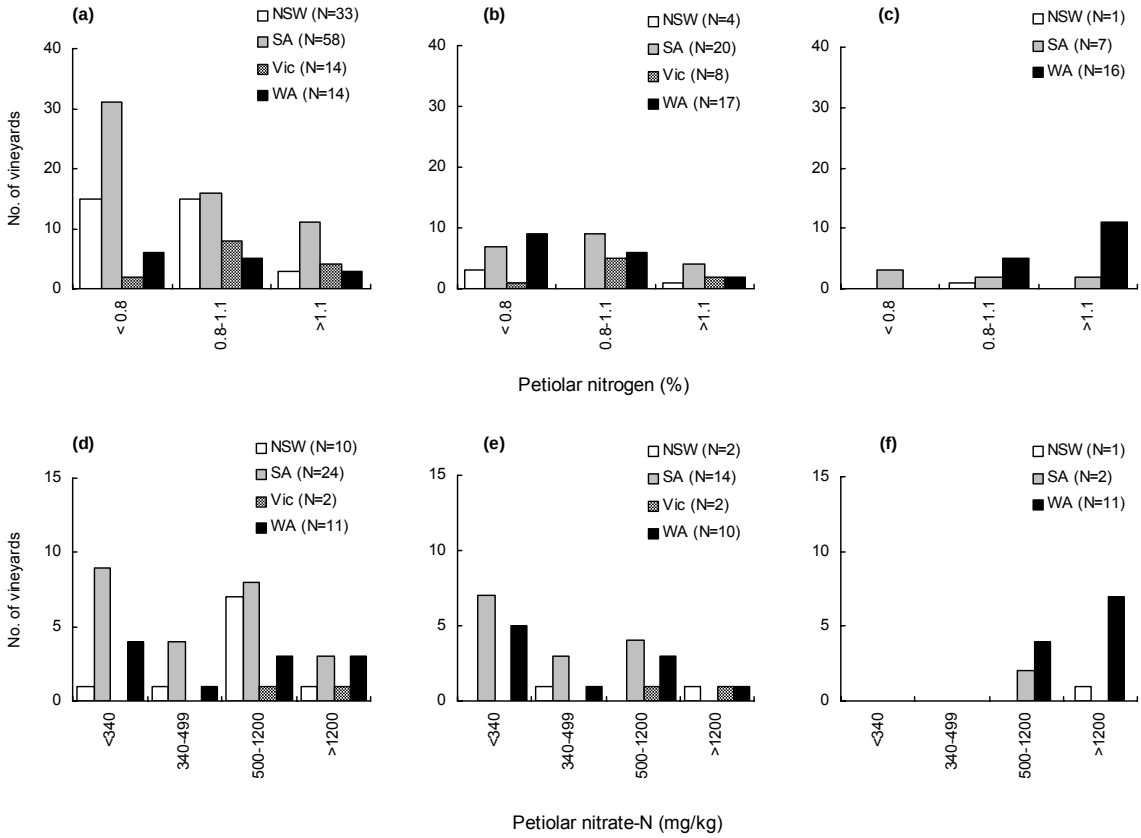


Figure 32. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar nitrogen (a-c) and nitrate-N (d-f) concentrations at flowering in concentration ranges used to categorize plant nitrogen status. N indicates the number of vineyards sampled in each State. Data are for Merlot (a, d), Chardonnay (b, e) and other varieties (c, f). Other varieties included were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

In South Australia, approximately half of Merlot petiole samples had less than adequate levels of nitrogen (%) and nitrate-N (Figure 32 (a) and (d)). New South Wales and Western Australia also had relatively high numbers of samples in the less than adequate range for nitrogen (%) when compared to numbers in other ranges. Nitrate-N levels for most samples from New South Wales were within the adequate range, while those for Western Australia were spread. Almost all the Merlot petiole samples from Victoria had nitrogen (%) and nitrate-N levels of adequate or above.

For petioles samples from Chardonnay vines (Figure 32 (b) and (e)), Western Australia had 50% or more in the less than adequate ranges for both nitrogen (%) and nitrate-N, and most samples from South Australia had less than adequate levels of nitrate-N. Nitrogen levels for Chardonnay samples from Victoria were similar to those for Merlot samples. Nitrogen (%) and nitrate-N levels for other varieties (Figure 32 (c) and (f)) were mostly adequate or above.

Phosphorus

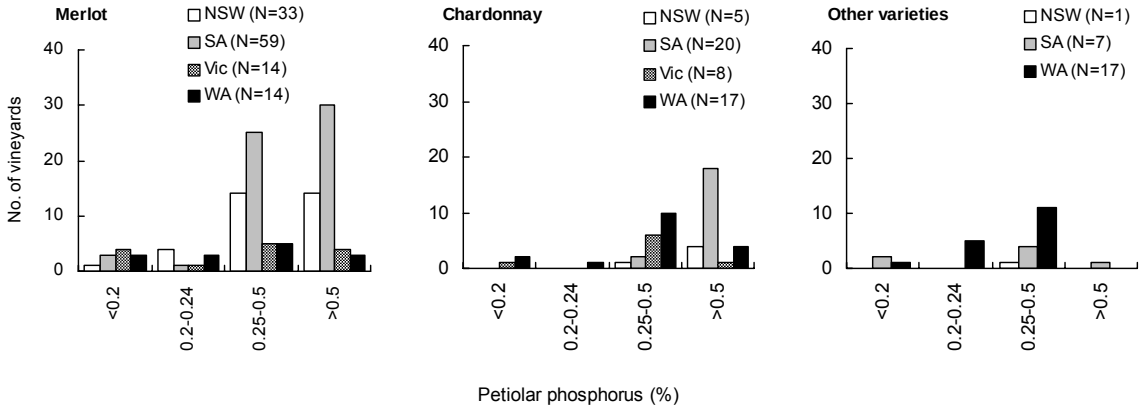


Figure 33. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar phosphorus concentrations at flowering in concentration ranges used to categorize plant phosphorus status (deficient, marginal, adequate and high). N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Petiolar phosphorus levels were mostly in the adequate or high range for all varieties and all States surveyed (Figure 33). Small numbers of Merlot samples from each State had less than adequate levels, and very few samples from Chardonnay and other varieties had below 0.25% phosphorus.

Potassium

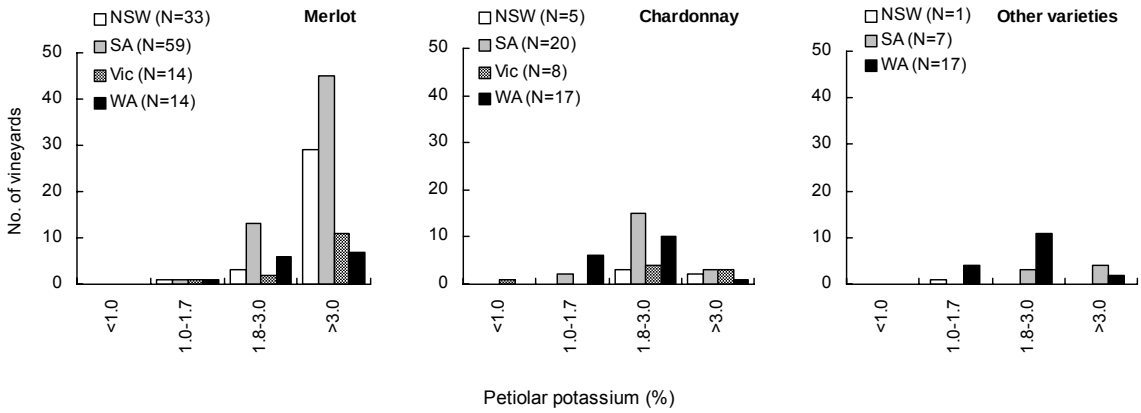


Figure 34. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar potassium concentrations at flowering in concentration ranges used to categorize plant potassium status (deficient, marginal and adequate). N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

The majority of petiole samples had potassium levels in the adequate or above adequate ranges (Figure 34), and Merlot samples in particular generally had higher than adequate potassium levels.

Calcium

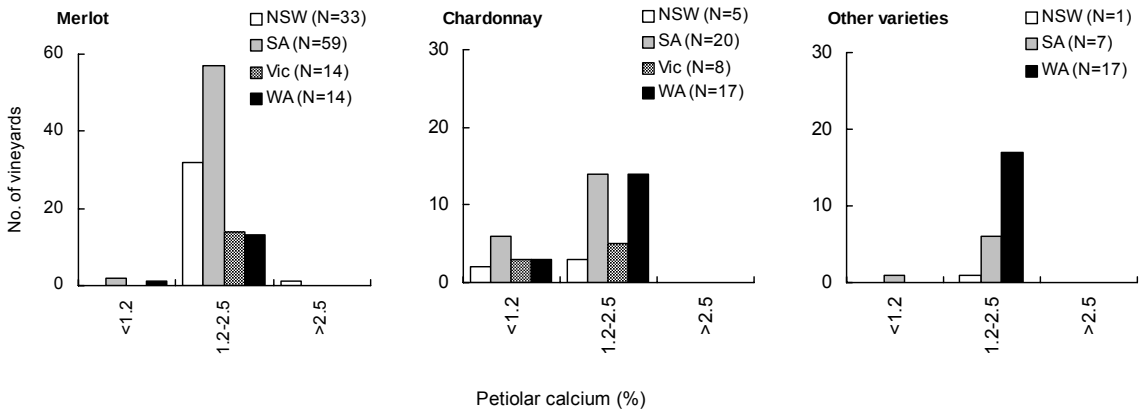


Figure 35. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar calcium concentrations at flowering in concentration ranges used to categorize plant calcium status. N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Almost all petiole samples from Merlot and other varieties had calcium levels in the adequate range (Figure 35). Calcium levels in Chardonnay petioles were also mostly in the adequate range except for a small number from each of the States that were less than adequate.

Magnesium

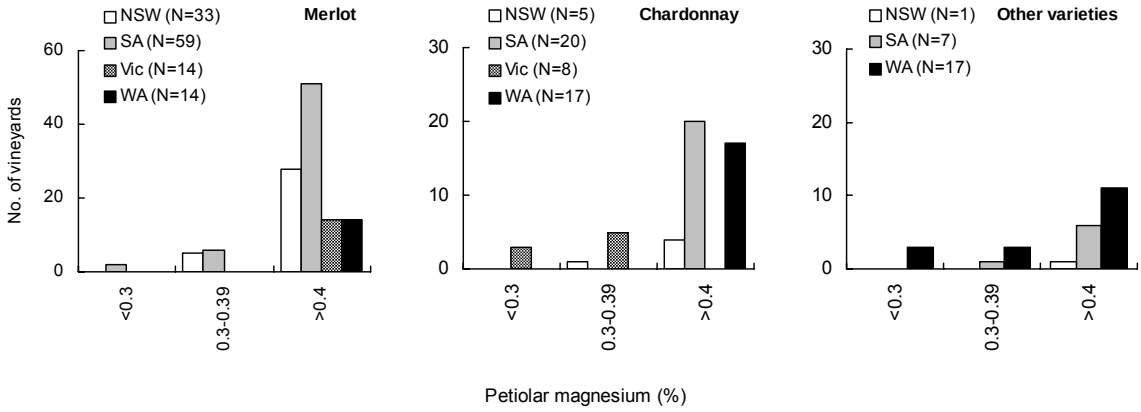


Figure 36. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar magnesium concentrations at flowering in concentration ranges used to categorize plant magnesium status (deficient, marginal and adequate). N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Magnesium levels in all varieties' petiole samples were predominantly in the adequate range (Figure 36), except for a few samples from each of the States but for different varieties that were either marginal or deficient.

Sodium

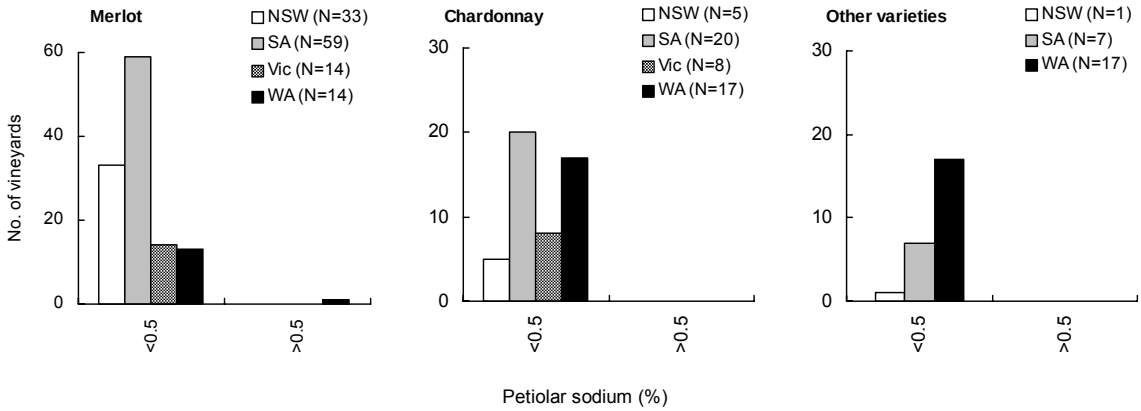


Figure 37. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar sodium concentrations at flowering in concentration ranges used to categorize plant sodium status. N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Only one petiole sample from all those surveyed had a sodium level in the toxic or excessive range (Figure 37).

Sulfur

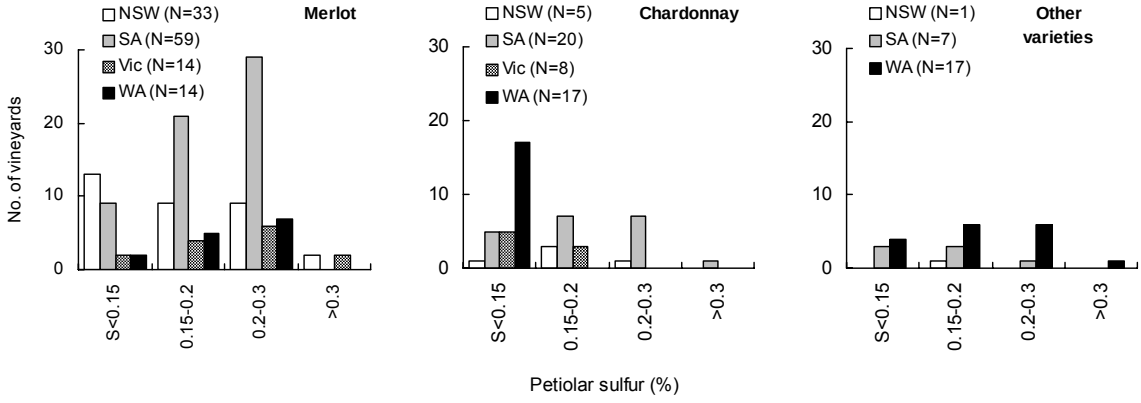


Figure 38. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar sulfur concentrations at flowering in concentration ranges used to categorize plant sulfur status. N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Copper

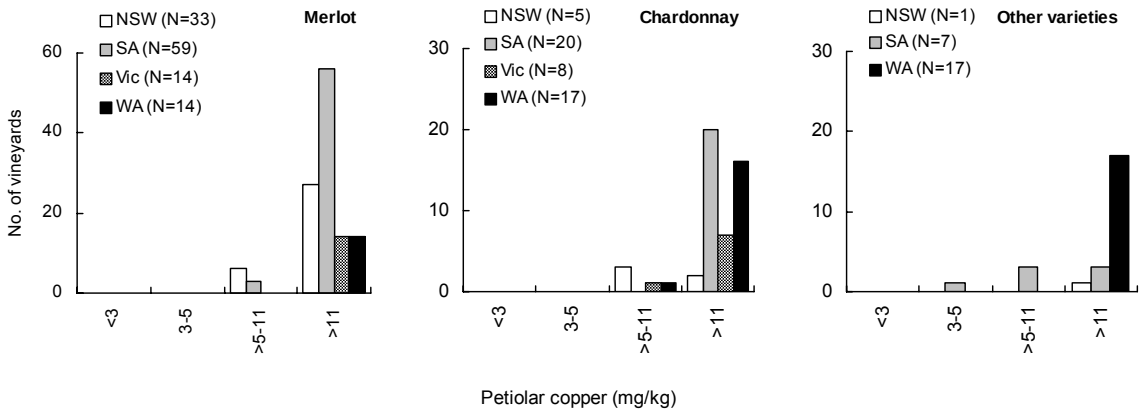


Figure 39. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar copper concentrations at flowering in concentration ranges used to categorize plant copper status (deficient, marginal and adequate). N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Almost all petiole samples for all varieties and from all State surveyed had copper levels in either the adequate range or above (Figure 39). Levels of >15 mg/kg are most likely due to surface contamination with copper-based fungicide sprays (Robinson *et al.* 1997).

Manganese

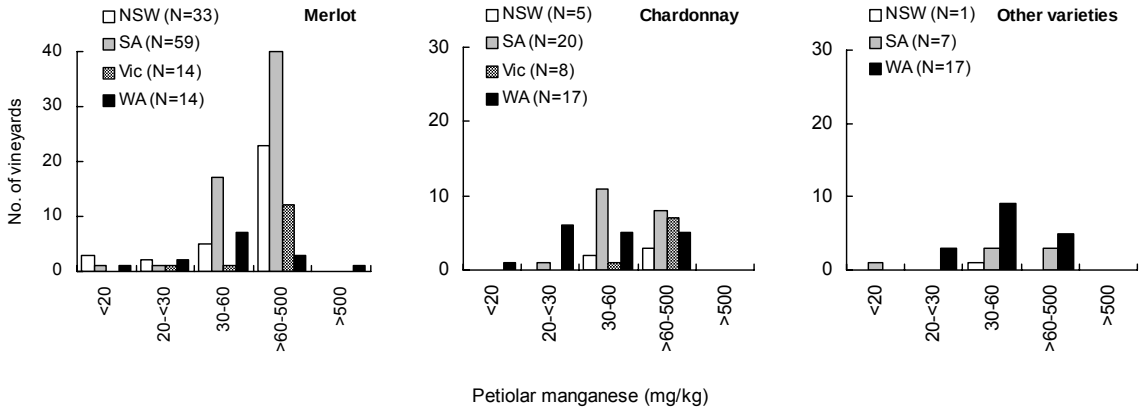


Figure 40. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar manganese concentrations at flowering in concentration ranges used to categorize plant manganese status (deficient, marginal, adequate and toxic or excessive). N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

Manganese levels in petiole samples for all varieties are spread across all concentration ranges but are most numerous in the adequate and above adequate categories (Figure 40). Most Merlot samples from New South Wales, South Australia and Victoria had higher than adequate manganese, and a small number of samples from each variety category had marginal or deficient levels.

Iron

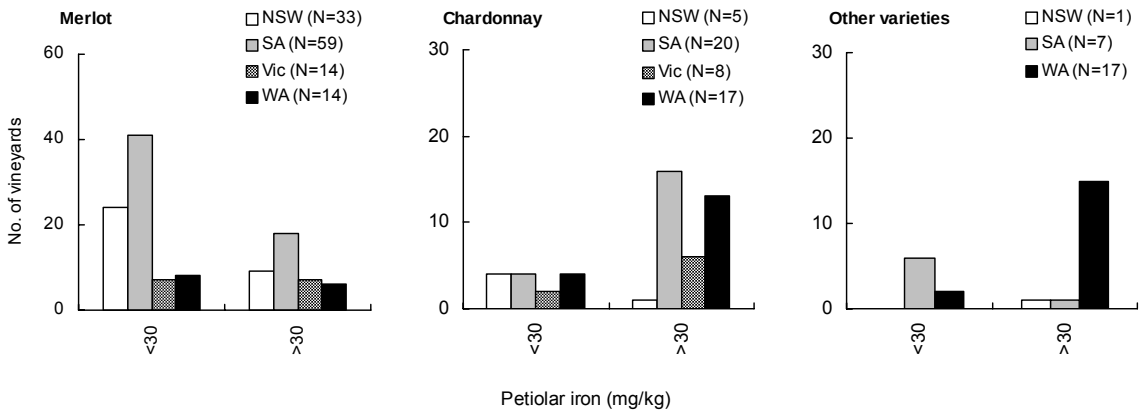


Figure 41. Number of vineyards sampled in New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA) with petiolar iron concentrations at flowering in concentration ranges used to categorize plant iron status. N indicates the number of vineyards sampled in each State. Other varieties were Verdelho, Cabernet Sauvignon, Grenache, Ruby Cabernet, Sangiovese and Tempranello.

A larger proportion of Merlot petiole samples from New South Wales and South Australia had less than adequate iron levels than adequate when compared to samples from Victoria and Western Australia, which had approximately even number in both ranges (Figure 41). Petiole samples from Chardonnay and other varieties were mostly in the adequate range for iron. Dust can be a contaminant in the iron analysis process leading to higher results (Robinson *et al*., 1997).

Other factors

Aspect

There is a perception that vines planted in areas with a cooler aspect, that is East or South, are more prone to berry asynchrony, however, this survey found that vineyards with all aspects were susceptible.

Age of vines

No correlation was found between the age of vines and the occurrence of berry asynchrony or the Mo concentration in petioles at flowering over the course of this survey.

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Chapter 7

7 Interstate trials on response to grapevines to rate and time of molybdenum application

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Abstract

The effects of molybdenum (Mo) foliar sprays on bunch yield, components of yield and on and bunches graded for the incidence of millerandage ('hen and chickens') were examined in field experiments on Merlot and Picolit vines in the Mudgee region of NSW and on Merlot vines on Schwarzmann and own roots in the Yarra Valley of Victoria.

Although not statistically significant, there was a trend for bunch yields from vines sprayed with Mo to be moderately higher than yields from unsprayed vines for all sites (sites 11-15) in NSW and Victoria. Increased yields for vines sprayed with Mo ranged from 7.1-29.6% for Merlot on own roots (sites 11-12), 8.2% for Picolit (site 13) at Mudgee, NSW and 14.5% for Merlot on Schwarzmann (site 14) and 1.8% for Merlot on own roots (site 15) at Yarra Glen, Victoria. Mo sprays applied pre-flowering increased petiolar Mo concentrations at peak bloom at all sites compared to unsprayed treatments.

The Mo status of unsprayed vines at all sites (11-15) were classed as marginal (0.1-0.45 mg/kg Mo at E-L 23-25), using the scheme to assess the Mo status for Merlot described in chapter 4. The yield responses to pre-flowering Mo sprays at these five interstate trials were were variable and small as was the incidence of berry asynchrony. These results also confirm that other factors (eg climatic) affect the magnitude of the yield response at a given Mo petiole concentration.

Pre-flowering sprays of Mo may be desirable to help stabilise yields and berry size to meet long term contracts, for vineyards with a history of millerandage ('hen and chickens') and low petiole Mo status in cool climate growing regions, especially in seasons where periods of adverse growing conditions occur (eg low temperatures, high rainfall) between budburst and flowering.

Introduction

Molybdenum is essential for the growth of plants (Gupta 1997), but is the least abundant micronutrient (except for copper) found in most plant tissues (Kaiser *et al.* 2005). Molybdenum deficiency may effect vegetative growth of young vines known as the Merlot problem in Australia (Robinson and Burne 2000) and/or reproductive growth of grapevines (Williams *et al.* 2003; 2004) and can be overcome by foliar Mo sprays. For grapevines, Williams *et al.* (2003) and Longbottom *et al.* (2005) showed that Mo foliar sprays could increase bunch yields per vine (from 75-750%), mainly by increasing average bunch weight where Mo supply was limited prior to pre-flowering. An increased percent of coloured berries with one or more functional seeds and a decrease in the proportion of green berries per bunch, which suggests that Mo application affected pollination and/or fertilization and thereafter berry development was also reported. Subsequent work by Longbottom *et al.*

(2004; 2005) has shown that Mo deficiency affected the fertilisation process in vine flowers, reducing pollen tube growth and the penetration of the ovules, while pollen vitality was unaffected.

The disorders, millerandage (seedless berries) and 'shot berries' (green ovaries at harvest) were reduced when Mo sprays were applied to overcome Mo deficiency (Williams *et al.* 2003; 2004). Millerandage (the technical term) or in local jargon 'hen and chickens', is a fruit set disorder, in which bunches develop unevenly, and remain uneven in berry size at harvest. Furthermore, at harvest, many bunches consist of a range of severity of millerandage or mixtures per bunch of minimal numbers of large, normal berries (hens) and many small berries of uneven ripeness as well as swollen green ovaries. A bunch/berry size grade chart has been developed to help assess the severity of millerandage (hen and chickens) in quantitative terms (see Chapter 6 and Appendix 4).

Field experiments were carried out near Mudgee, NSW and Yarra Glen, Victoria to elucidate the effects of molybdenum (Mo) foliar sprays on bunch yield, components of yield and the incidence and severity of millerandage ('hen and chickens') at harvest.

Materials and Methods

The experiments were conducted in five commercial vineyards during the period 2003/04 to 2005/06. The vineyards were located near Mudgee, NSW (sites 11-13) and Yarra Glen, Victoria (sites 14 and 15, see Research Strategy and Method section, Table 1).

Mudgee, NSW experimental protocols

At sites 11 and 12, the experimental plots contained Merlot vines (clone D3V14), on own roots, planted in 1999 and trained to a vertical shoot position single cordon vertical plane trellis with two foliage wires. Vines were spur pruned with two bud spurs. Inter and intra row spacings between plants were 3.3 by 1.8 metres at sites 11 and 12.

Picolit (clone Merbein 848 473)**,** an Italian variety, grown on own roots, was planted in 1999 and used at site 13. Vines were double cordon, cane pruned and the two cordon wires were 20cm apart. Inter and intra row spacings between vines were 3.0 by 1.8 metres. Basal fertilisers applied to the Merlot trial sites 11 and 12 each year consisted of 15 kg/ha of nitrogen, fertigated and a pre-flowering, nutrient foliar spray of Foliacin® at 2 L/ha (NPK of 5:5:5). All plantings were drip irrigated, and irrigation, pest and disease control were carried out by the growers who used their normal vineyard management practices.

For the Merlot trials at Mudgee, sites 11 and 12 were laid out in different areas of the same vineyard, in 2004/05 and 2005/06, respectively. Each experiment was set out as a randomised block design with sprayed and unsprayed plots replicated four times. The experimental plots consisted of 12 vines.

Sprayed treatment plots at each site received one application of sodium molybdate (39.65% Mo) each year. The Mo spray was applied at the growth stage E-L 15-18 as per Williams *et al.* (2004). Molybdenum was applied at a rate of 118 g/ha (equivalent to 300 grams sodium molybdate/ha) and the entire canopy was sprayed to the point of runoff, using 500 L water/ha, equivalent to 236 mg Mo/L.

The experiment on Picolit was set out as a randomised block design, with three treatments (unsprayed, one spray of Mo as above and treatment 3 had the latter Mo spray treatment plus zinc and magnesium) and four replicates. Treatment 3 on Picolit, had zinc applied as Zintrac® at 500 ml/ha (with 70% zinc as zinc oxide plus 1.8% nitrogen as urea) and magnesium applied as Mag Flow ® at 3 L/ha (30% magnesium as magnesium oxide).

Soil properties, Mudgee, NSW, sites 11-13

Soil types at the Merlot vineyard near Mudgee for sites 11 and 12 were duplex soils, slightly acidic, with a loamy clay surface soil overlying a medium clay subsoil. Selected chemical properties of the vineyard soil at 0 to 15 cm depth (for sites 11 and 12), sampled in 2003 were: organic carbon, 1.62%, nitrate-N, 67 mg/kg, ammonium N, 5 mg/kg, Colwell P, 153 mg/kg, Colwell K, 386 mg/kg, S, 22 mg/kg, iron, 1212 mg/kg, electrical conductivity, 0.266 dS/m, and soil acidity (pH in water) 5.8. Soil types at the Picolit trial (site 13) were brown and yellow Dermosols (a silty clay loam overlying a clay-rich subsoil of brown to yellow with some mottling), (Julia Page, pers. comm. 2006).

Yarra Glen, Victoria, experimental protocols

The two experiments at sites 14 and 15 were set out as a randomised block design with four treatments replicated four times. The four treatments at each site were: (1) unsprayed-no Mo applied, (2) one spray of 250 mg Mo/L at E-L 12-15, (3) same spray but applied at E-L 16-18, and (4) 250 mg Mo/L applied at each E-L 12-15 + E-L 16-18. Spray treatments were applied to the vine canopy to the point of runoff.

Merlot (clone 2093, =D3V14) on Schwarzmann rootstock was used at site 14 and on own roots at site 15, respectively. The vines were planted in 1998 and 1989, respectively at sites 14 and 15. The inter and intra row spacings were 2.75 by 1.8 m at site 14 and 3.5 by 1.8 m at site 15.

Soil properties, Yarra Glen, Victoria, sites 14 and 15

The experiment at site 14 was laid out on a light cracking clay to 50cm depth over a heavy brown clay. The soil at site 15 was a medium grey clay to approximately 45cm depth over a heavy brown clay. Selected chemical properties of the Merlot vineyard soil at 0 to 15 cm depth (for site 15), sampled in 2005 were : organic carbon, 3.01%, nitrate-N, 7 mg/kg, ammonium N, 8 mg/kg, Colwell P, 139 mg/kg, Colwell K,140 mg/kg, S, 25 mg/kg, iron, 2064 mg/kg, electrical conductivity, 0.161 dS/m, and soil acidity (pH in water) 5.4.

Plant sampling and harvest

A minimum of 30 petioles (leaf stalks) from leaves opposite basal bunches was collected from each replicate plot at the growth stage period E-L 23-25 (flowering) at all five sites and at E-L 12 (10 cm shoot stage) at sites 11 and 14. Petiole samples were stored, dried, ground and then analysed for chemical composition as described by Williams *et al.* (2004) and in the Research Strategy and Method section.

Experimental plots were harvested in March or April each year. At harvest, the number of bunches was counted, total weight recorded, and the average bunch weight calculated for each plot. Fifty bunches, selected at random from each plot were graded for the incidence of millerandage (hen and chickens) using a bunch assessment chart (described in chapter 6 and presented in Appendix 4). Bunches were scored from 1 (uniform, size and coloured berries) to 4 (few normal coloured berries and green berries dominate).

Statistical analyses

The data for all variables were analysed for variance between treatments for a given year within each site. Significant differences between treatments within a year and site were calculated using the least significant difference (LSD) test at the 5% level of probability (using Genstat 8, 2005 and Statistix 8, 2003).

Results and discussion

Total bunch yield and components of yield

Although not statistically significant, there was a trend for bunch yields from vines sprayed with Mo to be moderately higher than yields from unsprayed vines for all sites (sites 11-15) in NSW and Victoria. Increased yields for vines sprayed with Mo ranged from 7.1-29.6% for Merlot on own roots (sites 11-12), 8.2% for Picolit (site 13) at Mudgee, NSW and 14.5% for Merlot on Schwarzmann (site 14) and 1.8% for Merlot on own roots (site 15) at Yarra Ridge, Victoria (Tables 1 and 2).

Table 1. Yield, number of bunches and bunch weights from Mudgee (NSW) field trials treated with and without molybdenum sprays on Merlot vines in 2 seasons and Picolit vines in 2005/2006 (sites 11-13).

Treatment	Yield (kg/vine)	No. of bunches (per vine)	Bunch weight (g)
		Merlot 2004/05 (site 11)	
Unsprayed	5.4	65.6	83.5
Sprayed	7.0	79.9	87.5
Significance	NS	NS	NS
		2005/06 (site 12)	
Unsprayed	5.6	64.0	93.3
Sprayed	6.0	69.9	86.0
Significance	NS	NS	NS
		Picolit 2005/06 (site 13)	
Unsprayed	4.9	58.5	83.5
Sprayed – Mo	5.3	54.8	97.2
Sprayed – Mo, Zn, Mg	5.3	52.2	100.6
Significance	NS	NS	NS

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Table 2: Yield, number of bunches and bunch weights from Yarra Ridge (Victoria) field trials treated with and without molybdenum sprays on Merlot vines on Schwarzmann in 2003/2004 and on Merlot on own roots in 2004/2005 (sites 14 and 15).

Treatment	Yield (kg/vine)	No. of bunches (per vine)	Bunch weight (g)
		2003/04 (site 14)	
Unsprayed	6.9	58.1	121.1
Sprayed E-L 12-15	7.2	52.6	137.6
Sprayed E-L 16-18	7.6	62.3	122.2
Sprayed E-L 12-15 & 16-18	7.9	58.1	138.2
Significance	NS	NS	NS
		2004/05 (site 15)	
Unsprayed	5.5	68.5	80.3
Sprayed E-L 12-15	5.8	63.2	90.5
Sprayed E-L 16-18	4.6	49.1	91.5
Sprayed E-L 12-15 & 16-18	5.6	77.4	77.6
Significance	NS	NS	NS

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Changes in bunch number per vine and average bunch weights for sites 11-15 were variable and not significantly different (P<0.05) for vines sprayed with Mo compared to unsprayed vines (Tables 1 and 2). In contrast, Mo pre-flowering sprays increased petiolar Mo concentrations at peak bloom at all sites compared to unsprayed treatments (Tables 3 and 4).

Table 3: Molybdenum concentrations in petioles at growth stage E-L 12 and E-L 23-25 from Mudgee (NSW) field trials treated with and without molybdenum sprays on Merlot vines in two seasons and Picolit vines in 2005/2006.

Treatment	E-L 12	E-L 23
	Merlot 2004/05 (site 11)	
Unsprayed	0.6	0.4
Sprayed	0.1	5.0
Significance	NS	***
LSD		0.5
	2005/06 (site 12)	
Unsprayed		0.2
Sprayed		13.7
Significance		*
LSD		9.8
	Picolit 2005/06 (site 13)	
Unsprayed		0.1
Sprayed – Mo		2.6
Sprayed – Mo, Zn, Mg		3.0
Significance		***
LSD		0.7

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Table 4: Molybdenum concentrations in petioles at growth stage E-L 12 and E-L 23-25 from Victorian field trials treated with and without Molybdenum sprays on Merlot vines on Schwarzmann (2003/04) and Merlot on own roots (2005/06).

Treatment	E-L 12	E-L 23
	2003/04 (site 14)	
Unsprayed	0.03	0.1
Sprayed E-L 12-15	0.02	11.5
Sprayed E-L 16-18	0.02	7.2
Sprayed E-L 12-15 & 16-18	0.02	7.1
Significance	NS	NS
LSD		
	2005/06 (site 15)	
Unsprayed		0.1
Sprayed E-L 12-15		4.7
Sprayed E-L 16-18		1.0
Sprayed E-L 12-15 & 16-18		5.2
Significance		***
LSD		1.5

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Preliminary results indicate that the use of one compared to two Mo sprays applied pre-flowering at sites 14 and 15 had similar effects on petiole Mo concentrations at peak bloom and yield responses (Tables 2 and 4).

Relationships between petiolar Mo concentration and relative yield and bunch weight had a narrow transition zone between deficiency and adequacy (see chapter 4) and assisted in interpreting results of the interstate trials herein. The scheme (see chapter 4) to assist in assessing the Mo status of irrigated Merlot vines is: *deficient*, vines whose basal petioles at flowering contain less than 0.09 mg/kg Mo (yield response to pre-flowering foliar spray likely); *marginal*, vines with petiole Mo concentrations of 0.09 – 0.45 mg/kg (response to pre-flowering foliar sprays is uncertain); and *non responsive* vines that have petiole Mo concentrations greater than 0.45 mg/kg (response to pre-flowering Mo foliar sprays unlikely). The use of this suggested scheme to assess the Mo status of Merlot as discussed in chapter 4 is complicated by several factors, including (a) yield response at a given Mo concentration varied between years, (b) other factors (eg climatic) affect the magnitude of the yield response at a given Mo concentration. Therefore, the Mo status of unsprayed Merlot vines at sites 11, 12 and 15 can be classed as marginal (0.1-0.4 mg/kg Mo at E-L 23-25), using the above scheme, so that response to pre-flowering Mo sprays is likely to be uncertain and this corresponded to the limited yield responses recorded (Tables 1-4).

Responses to applied Mo may be greater for different sites and growing seasons when petiolar Mo concentrations at peak bloom for Merlot are less than 0.09 mg/kg (Chapter 4 and Williams *et al.,* 2004). The survey of Mo (Chapter 6) focused on vineyards with a history of millerandage ('hen and chickens') and reported that on a state basis, the percent of vineyards sampled that had petiolar Mo concentrations of less than 0.10% were; 35.9% for NSW (Hunter Valley, Mudgee, Sunraysia) and 37.6% for Victoria (Macedon Ranges, Yarra Valley).

Chemical composition of petioles

Concentrations of various nutrients present in petioles at flowering are shown in Tables 5-7. In general, the application of Mo foliar sprays had little effects on the concentrations of other nutrients in petioles sampled at peak bloom (Tables 5-7).

Table 5: Nutrient concentrations in petioles at growth stage E-L 23 from Mudgee (NSW) field trials treated with and without molybdenum sprays on Merlot vines in 2004/2005 and 2005/2006 (sites 11 and 12).

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	2004/05	2005/06	2004/05	2005/06	2004/05	2005/06
Unsprayed	1.1	1.1	0.2	0.3	5.1	4.3
Sprayed	1.0	1.1	0.2	0.3	5.0	3.8
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Calcium (%)		Magnesium (%)		Sodium (%)	
	2004/05	2005/06	2004/05	2005/06	2004/05	2005/06
Unsprayed	1.7	1.4	0.6	0.5	0.03	0.01
Sprayed	1.7	1.4	0.6	0.5	0.04	0.02
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Sulphur (%)		Boron (mg/kg)		Copper (mg/kg)	
	2004/05	2005/06	2004/05	2005/06	2004/05	2005/06
Unsprayed	0.20	0.17	39	33	22	12
Sprayed	0.22	0.16	41	32	19	11
Significance	*	NS	NS	NS	NS	NS
LSD	0.01					
	Zinc (mg/kg)		Manganese (mg/kg)		Iron (mg/kg)	
	2004/05	2005/06	2004/05	2005/06	2004/05	2005/06
Unsprayed	53	43	72	82	20	13
Sprayed	53	42	74	58	24	11
Significance	NS	NS	NS	NS	NS	*
LSD						1

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

At sites 11 and 12 on Merlot in NSW, applied Mo increased the concentration of sulphur (10%) and reduced iron by 15.4% (Table 5). For Picolit at Mudgee, site 13, application of Mo increased the sodium content of petioles. However, all concentrations recorded were very low and unlikely to be of biological importance (Reuter *et al.* 1997). Petiolar zinc was increased at site 13, most likely due to treatment 3 which included zinc application. It is interesting to note that the magnesium (Mg) foliar treatment did not alter the Mg concentration in petioles (Table 6).

Table 6: Nutrient concentrations in petioles at growth stage E-L 23 from Mudgee (NSW) field trials treated with and without various sprays on Picolit vines in 2005/2006.

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)
Unsprayed	1.0	0.6	2.0	1.5
Sprayed – Mo	1.0	0.6	2.4	1.5
Sprayed – Mo, Zn, Mg	1.1	0.6	1.8	1.7
Significance	NS	NS	NS	NS
LSD				
	Magnesium (%)	Sodium (%)	Sulphur (%)	Boron (mg/kg)
Unsprayed	0.4	0.01	0.12	37
Sprayed – Mo	0.4	0.02	0.12	39
Sprayed – Mo, Zn, Mg	0.4	0.04	0.13	38
Significance	NS	***	NS	NS
LSD		0.01		
	Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
Unsprayed	9	60	74	15
Sprayed – Mo	9	75	49	17
Sprayed – Mo, Zn, Mg	9	280	71	15
Significance	NS	***	NS	NS
LSD		30		

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

The application of Mo at sites 14 and 15 in Victoria only affected the concentrations of sulphur and boron in petioles (Table 7) and these effects were small and unlikely to be of biological importance (Reuter *et al.* 1997). Thus, the effects of applied Mo foliar sprays at rates and times used in these experiments on other nutrients were small and of little practical importance. This confirms similar findings by Williams *et al.* (2004).

Table 7: Nutrient concentrations in petioles at growth stage E-L 23 from Victorian field trials treated with and without molybdenum sprays at various growth stages on Merlot vines on Schwarzmann in 2003/2004(site 14), and Merlot on own roots in 2005/2006 (site 15).

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	2003/04	2005/06	2003/04	2005/06	2003/04	2005/06
Unsprayed	1.1	0.9	0.3	0.5	4.7	1.4
Sprayed E-L 12-15	1.0	0.9	0.3	0.5	3.2	1.2
Sprayed E-L 16-18	1.1	1.0	0.3	0.5	4.6	1.6
Sprayed E-L 12-15 & 16-18	0.9	1.0	0.3	0.5	3.7	1.3
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Calcium (%)		Magnesium (%)		Sodium (%)	
	2003/04	2005/06	2003/04	2005/06	2003/04	2005/06
Unsprayed	1.2	1.5	0.6	1.1	0.06	0.05
Sprayed E-L 12-15	1.3	1.5	0.6	1.1	0.06	0.07
Sprayed E-L 16-18	1.1	1.5	0.5	1.0	0.06	0.05
Sprayed E-L 12-15 & 16-18	1.1	1.5	0.6	1.1	0.06	0.06
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Sulphur (%)		Boron (mg/kg)		Copper (mg/kg)	
	2003/04	2005/06	2003/04	2005/06	2003/04	2005/06
Unsprayed	0.18	0.22	38	37	27	46
Sprayed E-L 12-15	0.14	0.22	34	37	24	43
Sprayed E-L 16-18	0.16	0.23	35	37	29	47
Sprayed E-L 12-15 & 16-18	0.15	0.22	35	38	28	46
Significance	*	NS	*	NS	NS	NS
LSD	0.02		2			
	Zinc (mg/kg)		Manganese (mg/kg)		Iron (mg/kg)	
	2003/04	2005/06	2003/04	2005/06	2003/04	2005/06
Unsprayed	99	118	286	282	27	57
Sprayed E-L 12-15	89	114	168	290	24	56
Sprayed E-L 16-18	98	124	350	328	20	51
Sprayed E-L 12-15 & 16-18	96	116	251	308	23	57
Significance	NS	NS	NS	NS	NS	NS
LSD						

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Bunch assessment of berry asynchrony ('hen and chickens')

Molybdenum application to Merlot increased the percent of bunches in the most desirable grade 1 (bunches with a majority of uniform size, coloured berries) and reduced the percent in grade 2 (bunches with some green and/or undersized coloured berries) at site 11 and had similar effects, although not significant ($P<0.05$) at site 12 (Figure 1, Table 8).

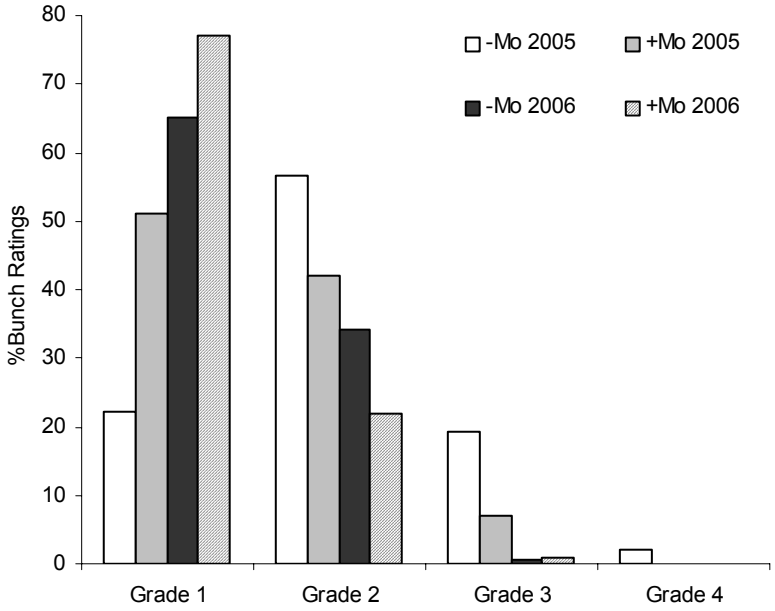


Figure 1. Bunch ratings (percent) of bunches harvested from unsprayed (-Mo) and sprayed (+Mo) grapevines in 2005 and 2006 from Merlot trials in Mudgee, NSW.

Table 8: Percent of bunches in four assessment grades from NSW field trials treated with and without molybdenum sprays on Merlot (sites 11 and 12) and Picolit (site 13), (grade 1=mainly normal berries , grade 4=majority green, small berries per bunch).

Treatment	Grade 1	Grade 2	Grade 3	Grade 4
		Merlot		
		2004/05 (site 11)		
Unsprayed	22.2	56.5	19.2	2.0
Sprayed	51.0	42.0	7.0	0.0
Significance	*	*	NS	NS
LSD	17.7	13.9		
		2005/06 (site 12)		
Unsprayed	65.2	34.2	0.5	0.0
Sprayed	77.0	22.0	1.0	0.0
Significance	NS	NS	NS	NS
LSD				
		Picolit		
		2005/06 (site 13)		
Unsprayed	12.0	41.2	37.2	9.5
Sprayed – Mo	45.8	38.2	14.5	1.5
Sprayed – Mo, Zn, Mg	32.2	42.2	28.8	1.2
Significance	**	NS	NS	NS
LSD	18.8			

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

For Picolit, applied Mo improved the percent of bunches in the desirable grade 1, and there was a trend, although non significant, for reduced percent of bunches in the undesirable grades 2 to 4 (Table 8). However, the magnitude of these responses in NSW trials were inconsistent with the moderate yield increases achieved. These preliminary results suggest that an increased number of replicate samples and/or bunches per sample need to be assessed to estimate the incidence of millerandage when there is high variability of incidence of the disorder.

At site 15, in Victoria, the treatment not sprayed with Mo had little evidence of millerandage so that application of Mo had no significant effects on the percent of bunches in each grade for millerandage assessment (Table 9).

Table 9: Percent of bunches in gradings from Victorian field trials treated with and without molybdenum sprays at various growth stages on Merlot vines in 2004/2005.

Treatment	Grade 1	Grade 2	Grade 3	Grade 4
Unsprayed	45.0	5.0	0.0	0.0
Sprayed E-L 12-15	45.2	4.75	0.0	0.0
Sprayed E-L 16-18	34.2	8.25	2.5	0.0
Sprayed E-L 12-15 & 16-18	41.2	6.0	2.5	0.0
Significance	NS	NS	NS	NS

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

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Chapter 8

8 Impacts of molybdenum foliar sprays on berry chemical composition

Chris Williams, Kerry Porter and Nancy Leo

Abstract

In field experiments Mo concentrations in coloured berries from unsprayed vines compared with vines sprayed with Mo pre-flowering were assessed and the effects of applied Mo on the concentrations of other nutrients in berries were assessed at harvest. The average Mo concentration in oven dried berries at harvest ranged from 0.027 mg/kg in unsprayed vines to 0.059 mg/kg for vines sprayed with Mo pre-flowering. In biological terms, both these results are very minute, almost undetectable concentrations of Mo in Merlot berries at harvest and are unlikely to affect fermentation processes. However, future research is needed to assess affects of these low concentrations of Mo, if any, on fermentation for red wine making.

To obtain the recommended dietary allowance (RDA) of Mo, an average adult would need to consume 5.6 litres/day of Merlot wine from unsprayed vines and 2.6 litres/day from vines sprayed with Mo pre-flowering. This preliminary information suggests that application of two pre-flowering sprays of Mo (each 148-288 mg Mo/L) are likely to have little practical significance in terms of increased intake of Mo in the average human diet.

The effects of applied Mo (two pre-flowering sprays, each of 148-288 mg/L) on the concentration of other nutrients (N, P, K, Ca, Mg, Na, S, B, Cu, Zn, Mn and Fe) in coloured, mature berries at harvest were small and of little practical importance.

Introduction

It has been shown that molybdenum (Mo) deficiency can affect berry development in Merlot and therefore the occurrence of the disorders 'hen and chickens' and 'shot berry formation' (millerandage, seedless berries at harvest), (Williams *et al.* 2003; 2004). Two pre-flowering foliar applications of Mo were effective in terms of producing significant bunch yield responses when compared to unsprayed control vines which were Mo deficient (the latter contained <0.09 mg/kg Mo in basal petioles at peak flowering), (Williams *et al.* 2004).

Molybdenum is essential in the diet of humans (Turnlund 2002). The recommended dietary allowance (RDA) of Mo for adults is 45 μg/day (or 0.043 mg/day), with an upper limit of 2 mg/day (Turnlund 2002). It is necessary to examine the recommended dietary allowance of Mo for humans and estimate intake of Mo in grapes, since there are no maximum limits specified for Mo in grape berries or wine at present (C. Stockley, Australian Wine Research Institute, pers. comm. 2007).

Since the nutrient composition of crushed berries for wine making can affect wine ferments and quality (Hamilton and Coombe 1988; Goldspink *et al.* 1997) it is important to determine the effects of Mo foliar sprays, if any, on the nutrient composition of the berry at harvest. No information could be found in the literature on effects of pre-flowering sprays of Mo on the concentrations of Mo and other nutrients in berries at harvest. Field experiments were conducted to investigate the effects of Mo applied as pre-flowering sprays on the concentrations of Mo and other nutrients in berries at harvest of Merlot grapevines.

Materials and Methods

Experiments were conducted in three commercial vineyards of Merlot during the period 2000/01 to 2004/05. The vineyards were located at Lower Hermitage (site 1), Meadows (site2), and Kuitpo (site 3), in South Australia. Information on the treatments, design, application of Mo sprays, plant sampling and harvest procedures have been described by Williams *et al.* (2004) and in Chapter 2 of this report.

One hundred coloured (black) berries from the 5 to 15 mm diameter size grade were collected randomly at harvest from each replicate plot at sites 1-3 in 2001/02 and 2002/03. These field samples were stored on frozen cooler blocks in insulated containers for transport to the laboratory. There, they were carefully oven dried at 30 to 40 °C then ground with a mortar and pestle for chemical analysis.

Dried berry tissue was analysed for macro and micro nutrients including Mo using the procedures for dried petioles as described in Williams *et al.* (2004), by Waite Analytical Services, Adelaide, South Australia.

Fresh berries were oven dried to increase the ability to detect the extremely low concentrations of Mo in fresh berries by removing the water component from the fruit. Even after oven drying, when the limit of determination for samples was calculated as ten times the standard deviation of the blank, some berry samples had Mo concentrations below this limit of determination. The limit of detection after determination of the method was then calculated as three times the standard deviation of the blank in order to estimate lower concentrations of Mo in dried berries.

Results and discussion

Molybdenum content of berries

Concentrations of Mo in coloured (black), oven dry Merlot berries at harvest were extremely low from both unsprayed vines and vines sprayed with Mo pre-flowering (from non detectable to 0.143 mg/kg) at three sites over two growing seasons (Table 1). On one occasion (site 2 in 2001/02), application of pre-flowering Mo sprays compared with the unsprayed control produced a significant increase in Mo concentration in berries at harvest (0.005 to 0.143 mg/kg, refer to Table 1).

In order to estimate the significance of these results to the diet of humans, it was necessary to examine the recommended dietary allowance of Mo for humans, since there are no maximum limits specified for Mo in grape berries or wine at present (C. Stockley, Australian Wine Research Institute, pers. comm. 2007).

Recommended dietary allowance (RDA) of Mo for adults is 45 μg/day (or 0.043 mg/day), with an upper limit of 2 mg/day (Turnlund 2002). The average Mo concentration for dried berries from vines not sprayed with Mo was 0.027 mg/kg compared with 0.059 mg/kg for vines sprayed with Mo pre-flowering (Table 1). If Merlot grapes at harvest are approximately 80% water (Hamilton and Coombe 1988), then a human would need to consume 7.95 kg/day of fresh berries from unsprayed vines or 3.65 kg/day of fresh berries from vines sprayed with Mo to obtain the RDA of Mo.

Likewise, the similar calculations for red wine indicate if 1 kg of Merlot grapes can produce 0.7 litre of red wine (Rankine 1989) then a human would need to drink 5.6 litres/day of

Merlot wine from unsprayed vines to obtain their RDA of Mo and 2.6 litres/day from vines sprayed with Mo pre-flowering. This preliminary information suggests that applications of two pre-flowering sprays of Mo (each 148-288 mg Mo/L) are likely to have little practical significance for Mo intake in the diet of humans.

In biological terms, the range of berry Mo from 0.027-0.059 mg/kg for sprayed and unsprayed grapevines are almost undetectable concentrations of Mo in Merlot berries at harvest and are unlikely to affect fermentation processes. However, future research is needed to assess affects of these low concentrations of Mo, if any, on fermentation for red wine making.

It is useful to note that people allergic to sulfites used as preservatives in wine and dried fruit may be helped by the intake of Mo. Aburnrad *et al.* (1981) reported Mo supplementation of 160 µg/day/adult greatly improved the resolution of symptoms of sulfite toxicity such as increased heart rates, headache, nausea and vomiting. This suggests that the modest increase in berry Mo from Mo foliar sprays (Table 1) may be beneficial to reduce sulfite intolerance symptoms and allow people to enjoy more wine and dried fruit with less sulfite intolerance. However, people should be careful not to overuse Mo supplements, as an excessive intake could lead to gout or other side effects (Aburnrad *et al.* 1981).

Table 1: Molybdenum concentrations analysed in oven dry berries at harvest from molybdenum sprayed and unsprayed Merlot vines at Lower Hermitage, Meadows and Kuitpo (sites 1-3) in 2001/2002 and 2002/2003

Mo Treatment	Mo (mg/kg) in dried berries		
	Lower Hermitage Site 1	Meadows Site 2	Kuitpo Site 3
		2001/02	
Unsprayed	0.012	0.005	0.072
Sprayed	0.008	0.143	0.080
Significance	NS	*	NS
LSD		0.077	
		2002/03	
Unsprayed	0.020	ND[z]	ND[z]
Sprayed	0.033	0.030	0.041
Significance	NS		
LSD			

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant.
[z] Three of the four replicates showed less than the limit of detection of determination of the method, and classed as ND= not detectable.

The application of Mo affected the concentration of some other nutrients in berries. However, the changes were small and inconsistent (only occurred at some sites in one of the 2 years, refer to Table 2). The effects of two pre-flowering sprays of Mo, (each 148-288 mg/L) on the concentrations of other nutrients (N, P, K, Ca, Mg, Na, S, B, Cu, Zn, Mn and Fe) in coloured berries at harvest were small and of little practical significance.

Table 2: Comparison of nutrient concentrations in berries at harvest from molybdenum unsprayed and sprayed Merlot vines at three sites, Lower Hermitage (site 1), Meadows (site 2) and Kuitpo (site 3) in 2001/2002 and 2002/2003

Treatment	Nitrogen (%)			Phosphorus (g/kg)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	2001/02			2001/02		
Unsprayed	0.73	0.86	0.73	0.11	0.15	0.12
Sprayed	0.95	0.66	0.80	0.15	0.09	0.12
Significance	NS	*	NS	NS	**	NS
LSD		0.12			0.02	
	2002/03			2002/03		
Unsprayed	NA	NA	NA	0.12	0.14	0.10
Sprayed	NA	NA	NA	0.09	0.13	0.09
Significance				NS	NS	NS
LSD						
	Potassium (g/kg)			Calcium (g/kg)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	2001/02			2001/02		
Unsprayed	1.18	1.10	1.25	0.12	0.12	0.10
Sprayed	1.34	1.17	0.98	0.13	0.10	0.12
Significance	NS	NS	NS	NS	NS	NS
LSD						
	2002/03			2002/03		
Unsprayed	1.16	1.06	0.91	0.12	0.15	0.07
Sprayed	1.07	1.05	0.80	0.09	0.13	0.07
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Magnesium (g/kg)			Sodium (g/kg)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	2001/02			2001/02		
Unsprayed	0.07	0.11	0.07	0.006	0.014	0.019
Sprayed	0.09	0.06	0.08	0.017	0.007	0.013
Significance	*	*	NS	**	**	NS
LSD	0.01	0.02		0.005	0.003	
	2002/03			2002/03		
Unsprayed	0.07	0.07	0.06	0.006	0.010	0.008
Sprayed	0.06	0.07	0.05	0.006	0.011	0.008
Significance	NS	NS	NS	NS	NS	NS
LSD						

Continued next page

Table 2. continued

Treatment	Sulphur (g/kg)			Boron (mg/kg)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	2001/02			2001/02		
Unsprayed	0.06	0.08	0.06	28	41	29
Sprayed	0.09	0.05	0.07	38	22	33
Significance	*	**	NS	*	**	NS
LSD	0.02	0.004		7	8	
	2002/03			2002/03		
Unsprayed	0.05	0.06	0.05	32	25	25
Sprayed	0.05	0.05	0.05	27	23	24
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Copper (mg/kg)			Zinc (mg/kg)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	2001/02			2001/02		
Unsprayed	9.4	19.4	7.2	7.8	9.2	10.6
Sprayed	11.7	8.7	17.6	10.6	9.3	10.8
Significance	NS	*	*	NS	NS	NS
LSD		6.3	9.1			
	2002/03			2002/03		
Unsprayed	9.9	7.9	11.4	5.8	6.0	5.9
Sprayed	7.5	7.8	10.8	5.0	6.1	4.3
Significance	NS	NS	NS	NS	NS	NS
LSD						
	Manganese (mg/kg)			Iron (mg/kg)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	2001/02			2001/02		
Unsprayed	6.3	6.1	6.1	19	26	25
Sprayed	7.1	6.4	6.2	28	19	27
Significance	NS	NS	NS	**	NS	NS
LSD				4		
	2002/03			2002/03		
Unsprayed	7.7	7.2	4.0	18	20	20
Sprayed	6.6	6.3	3.4	17	17	18
Significance	NS	NS	NS	NS	*	NS
LSD					2	

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant; NA= not available

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Chapter 9

9 Residual soil molybdenum concentrations after Mo foliar applications to grapevines

Chris Williams, Norbert Maier, Kerry Porter, Louise Chvyl and Nancy Leo

Abstract

Four field experiments were undertaken in South Australia to assess the changes in soil Molybdenum (Mo) concentrations and contents after 3 to 5 years of consecutive, annual Mo spray applications to grapevines. Molybdenum budgets were also estimated in terms of auditing Mo inputs and outputs in Merlot vineyards. We are not aware of any published literature on this topic. Molybdenum (Mo) is normally one of the least abundant of the essential nutrients for plant growth found in most agricultural soils. For sites 1 and 3, after 5 years of consecutive spring, foliar Mo sprays (with applications of 236 g Mo/ha/year), were compared with the unsprayed control. Total soil Mo concentrations increased in the top 0-5 cm deep soil layer by 94-136% after five years and extractable soil Mo concentrations by 301-314% per five years. At site 4, after three years of Mo application total soil Mo concentration in the 0-15 cm soil layer increased by 78 % over three years and extractable soil Mo by 239% over three years for Merlot on own roots. Similar responses in soil Mo accumulation were recorded for the Merlot on 140 Ruggeri treatment at site 4. Leaching of soil Mo was evident at site 1 and a significant increase in extractable soil Mo of 137% over five years was recorded at the 15-30 cm soil depth layer. The application of Mo did not affect the B concentration in soils at any site.

Molybdenum budgets were estimated for two Merlot vineyards as a means of auditing Mo inputs and outputs. Inputs of Mo per year far outweighed outputs. Therefore it is desirable to monitor soil Mo accumulation after 3 years of annual Mo foliar spray regimes and vine petiole and blade Mo concentrations at peak bloom to develop sustainable systems. If there is evidence of accumulation of soil Mo in a given vineyard, it is desirable to consider cessation or a reduction in the rate of Mo foliar sprays (depending on soil and plant Mo test results). Future research is required to assess the efficacy of ultra low rates of Mo application for grapevines to overcome Mo deficiency. Further research is required to refine the use of Mo budgets as a tool to audit Mo inputs and outputs in vineyards, to optimise bunch yield and quality and minimise losses of Mo to the environment.

Introduction

It has been reported recently by Williams *et al.* (2004), that Mo deficiency can affect berry development and the occurrence of the disorders; shot berry formation and hen and chickens (millerandage or seedless berries). Pre-flowering Mo sprays were found to ameliorate the deficiency. Boron (B) deficiency has also been reported to decrease fruit set and affect millerandage (Cook 1966; Dabas and Jindal 1985). We are not aware of any data published on the accumulation of Mo in vineyard soils after several years of Mo spray application nor of its affects, if any, on the status of soil B. An understanding of the accumulation of Mo in soils after Mo sprays is required to ensure that remedial sprays are correctly managed in the context of the long term sustainability of vineyards.

The soil residual value of foliar applied Mo fertiliser depends on several physical, chemical and biological properties of soil, in addition to the removal of Mo from the soil via plant and animal products and by erosion/surface run-off or leaching (Barrow 1978; Gupta 1997; Yu *et*

al. 2002). Losses of Mo from the soil by surface run-off and leaching in high rainfall, cool temperate winegrape growing regions of Australia have not yet been reported in the literature. Sandy soils are subject to Mo leaching, but the magnitude depends on soil acidity and chemistry. Riley (1987) reported, minimal leaching losses in from acid sands in pot trials with cereals, whereas Jones and Belling (1967) recorded 60 to 90% of added Mo was leached from calcareous sands in soil columns. The molybdate anion is strongly sorbed in acid soils by iron and aluminium ions at exposed surfaces of clays and sesquioxides, which reduces the effectiveness of soil applied Mo for plant uptake in the short term (Barrow 1978; Gupta 1997; Brennan 2002).

The usual range of total Mo content in soils is between 500 and 3000 µg/kg of dry soil and is dependent on the Mo content of the parent rock (Gupta 1997). However, some soils contain less than 100µg/kg of total Mo (Williams 1971) or others up to 30,000 µg/kg (Kubota 1976). Most values of the critical concentration for deficiency of soil B range from 0.15 to 0.5 mg/kg of soil (Bell 1999), yet no values have been published for grapevines.

The use of soil tests for Mo to assess and predict the soil's capacity to supply plant-available Mo during crop growth is limited because of (a) the relatively minute amounts of Mo in soils, (b) the lack of accurate and reliable chemical procedures that are calibrated to plant performance, (c) the importance and variable effects of soil properties that affect Mo availability to the plant, (d) the low requirements of most crops for Mo (0.1-0.5 mg/kg of tissue) and minimal research conducted (Gupta 1997; Brennan and Bruce 1999; Kaiser *et al.* 2005; Brennan 2006).

Changes in soil Mo concentrations and contents after Mo foliar application to grapevines, have not been reported in the literature. Four field experiments were conducted to assess changes, if any, in residual soil Mo after foliar sprays of Mo had been applied from 2 or up to 5 years on Merlot grapevines. Molybdenum budgets were also estimated in terms of auditing Mo inputs and outputs in Merlot vineyards.

Materials and Methods

Experiments were conducted in four commercial vineyards of Merlot and received Mo foliar sprays for two, three or up to five years depending on the site, during the period 2000 to 2004. The vineyards were located at Lower Hermitage (site 1), Kuitpo (site 3), McLaren Vale (site 4), and McLaren Vale Ranges (site 9) in South Australia. Information on the treatments, design, application of Mo sprays, plant sampling, harvest procedures, growth and yield response details of the 4 field experiments have been described (a) for sites 1 and 3 in Chapter 2, (b) site 4 in Chapter 1 and (c) site 9 in Chapter 5 of this report. Information on the soil chemical properties and pedology for these sites is given in Appendix 3.

Soils were sampled in October, 2005 for Mo and B chemical analyses at all 4 sites. Samples were collected at soil depths from 0-5 cm, 5-15 cm and 15-30 cm at sites 1, 3 and 9 and from 0-15 cm and 15-30 cm at site 4. A 75 mm diameter auger was used to collect samples taken 30 cm out from the dripper into the vine mid row. Six such soil sub-samples were collected per replicate plot, mixed and sub-sampled for chemical analyses. Such samples were stored over frozen cooling blocks in insulated containers during transport to the laboratory. There they were oven dried at 40 °C, ground to 2 mm and sent to CSBP Limited, South Perth, Western Australia for chemical analysis.

For total soil Mo, soil samples were digested with Aqua Regia solution and then the digest solutions were read on an inductively coupled plasma- mass spectrometer (ICP-MS), (as per National Environment Protection Measure 1999; Solanpour *et al.* 2001). The ICP-MS was a Themo X Series and Mo was read at atomic weight 98. Extractable soil Mo was measured by

using Tamm reagent (ammonium oxalate and oxalic acid) to extract Mo (after Haley and Melsted (1957) and the solution was then read on an ICP-MS (Solanpour *et al.* 2001). For extractable B in soil, the sample was cooked in 0.01 M calcium chloride for 15 minutes at 100 °C and the solution then read on an ICP-MS (Solanpour *et al.* 2001).

The data for all soil variables were analysed for variance between unsprayed and sprayed treatments at each soil depth for each site. Significant differences between unsprayed and sprayed treatments were calculated using the least significant difference (LSD) test at the 5% level of probability.

Results and Discussion

Soil Mo changes after five years of Mo sprays

For sites 1 and 3, after five years of consecutive foliar Mo sprays, compared with the unsprayed control, total soil Mo concentration increased in the top 0-5 cm soil layer by 94-136% and extractable soil Mo by 301-314% (Tables 1 and 2). These increases were significant ($P > 0.05$) at site 3, for both total and extractable soil Mo at 0-5 cm soil depth (Table 2). A significant increase in extractable Mo of 137 percent was recorded at 15-30 cm soil depth a site 1 (Table 1). This indicated leaching of Mo down the soil profile at site 1. Extractable soil B concentrations were not affected by Mo spray regimes at any site (Tables 1 and 2).

Total soil Mo in the 0-15 cm soil layer increased at site 4, after three years of Mo application by 78 % and extractable soil Mo by 239 % for Merlot on own roots (Table 3). Similar responses were recorded for Merlot on 140 Ruggeri (Table 3).

Since Mo foliar sprays are usually applied early in the growing season, when there is little foliage to intercept spray (only from 5 to 14 leaves per shoot), a high proportion of spray inevitably blows through the canopy and falls on the soil in vineyards (as described by MacGregor *et al.* (2004). This is the probable major reason for accumulation of Mo in soils from early season foliar sprays of Mo. Use of spray equipment set-up guidelines as described by Furness (2005) is a key to minimising wastage, and the associated risk of a high proportion of Mo spray blowing through the open, small grapevine canopy and falling on topsoils in the sprayed and adjacent rows.

Estimates of Mo nutrient budgets, (inputs less outputs) for Merlot vineyards for sites 3 and 4 are presented in Table 4. After five years of foliar Mo application, Mo concentration was calculated at 908.7 g Mo/ha in the top 0-5 cm of soil. Five years of Mo fertiliser sprays had applied a total of 1180 g Mo/ha. The unsprayed control had 467.4 g Mo/ha in the top 0-5 cm of soil. Thus it was estimated that 37.4 % of the applied Mo had accumulated in the 0-5 cm topsoil layer. Harvest of berries for wine removed less than 1.05 g/ha of Mo per 5 years.

The total Mo content of above ground fractions of Merlot grapevines was estimated as 645.2 and 18,598.4 ug/vine in unsprayed and sprayed vines, respectively at site 4 (from Chapter 3, Table 10). This equated to 1.1 g Mo/ha from unsprayed compared to 30.4 g Mo/ha from sprayed vines at site 4.

The estimated Mo budget for two Merlot vineyards indicated that inputs of foliar Mo (236 g/ha/year) were significant and after 3-5 years were similar to (75-98%) the total soil reserves of Mo in the top 0-15cm soil layer of the comparable controls, which did not receive fertiliser Mo. In contrast, the outputs, in terms of Mo uptake/removal in: fruit harvested, above ground tops of standing vines and prunings were small (3.9 and 4.4% of the total applied Mo over five years at site 3 and over three years at site 4, respectively). Portions of the unaccounted

for Mo are likely to be in the root system of grapevines, in inter-row pasture plants or lost in erosion/surface runoff or leaching from the topsoil or other unknown processes. Study of these processes was beyond the scope of this work. Therefore, since inputs outweigh outputs of Mo/year to develop sustainable systems it is essential to monitor soil Mo accumulation after 3 years of Mo foliar spray regimes and vine petiole and blade Mo concentrations at peak bloom. If there is evidence of accumulation of soil Mo in a given vineyard, it is desirable to consider cessation or a reduction of rate of Mo foliar sprays (depending on soil and plant Mo test results).

Sandy soils are subject to Mo leaching, but the magnitude depends on soil acidity and chemistry. Jones and Belling (1967) reported 60 to 95% of added Mo was leached from 16 cm columns of calcareous sands in WA with the equivalent of 450 mm of water. However, less Mo is likely to be lost by leaching from acidic sands, as molybdate adsorption is greater in such soils. Riley (1987) studied the extent of leaching of Mo from acidic sandy soils in WA and found from 10% of added Mo to negligible amounts of Mo in the leachate in pot trials. Certain poorly drained wet soils (eg peat swamps, organic rich soils) tend to accumulate soluble molybdate to high levels (Gupta 1997). The major cause of the decreasing value of residual soil Mo appears to be decreasing Mo concentrations in soil solutions and so reduced plant availability of Mo applied to the soil, which in turn appears to be due to the irreversible fixation of Mo on the surfaces of particles (Barrow and Shaw 1975).

The amount of foliar fertiliser Mo added after 3 or 5 years of consecutive annual sprays of Mo (at 236 g Mo/ha/year) at sites 4 and 3 was similar to total soil reserves of Mo (98.1 and 75.2%, respectively) in comparable unsprayed treatments (Table 4). In contrast, the outputs in terms of Mo removed in: fruit harvested, above ground tops of standing vines and prunings was small and 4.4 and 3.9 % of the total applied Mo over three years at site 4 and five years at sites 3, respectively (Table 4). Portions of the unaccounted for Mo are likely to be in the root system of grapevines, in inter-row pasture plants or lost in surface runoff/leaching from the topsoil or other unknown processes (all of which were beyond the scope and budget of this work). For acid soils Mo can be fixed at anion exchange sites, and it can become a potential danger to animals and humans if the Mo is transferred by erosion/surface run-off into water resources and raises the concentration of Mo to the toxic range (Yu *et al.* 2002).

Table 1. Concentrations of molybdenum and boron in soil at three depths sampled from site 1, Lower Hermitage in October 2005 (after 5 years of Mo sprays in spring each year from 2000 to 2004)

Treatments Mo	Total Mo (Aqua Regia) (μg/kg)	Extractable Mo (Tamm reagent) (μg/kg)	Extractable B (Hot $CaCl_2$) (μg/kg)
	Depth 0-5 cm		
Unsprayed	299	77	0.34
Sprayed	704	319	0.33
Significance	NS	NS	NS
LSD			
	Depth 5-15 cm		
Unsprayed	199	54	0.28
Sprayed	353	152	0.26
Significance	NS	NS	NS
LSD			
	Depth 15-30 cm		
Unsprayed	196	46	0.29
Sprayed	283	109	0.27
Significance	NS	**	NS
LSD		23	

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Table 2. Concentrations of molybdenum and boron in soil at three depths sampled from site 3, Kuitpo in October 2005 (after 5 years of Mo sprays in spring each year from 2000 to 2004)

Treatments Mo	Total Mo (Aqua Regia) (μg/kg)	Extractable Mo (Tamm reagent) (μg/kg)	Extractable B (Hot $CaCl_2$) (μg/g)
	Depth 0-5 cm		
Unsprayed	719	95	0.44
Sprayed	1398	381	0.43
Significance	*	**	NS
LSD	642	133	
	Depth 5-15 cm		
Unsprayed	847	49	0.35
Sprayed	766	91	0.37
Significance	NS	NS	NS
LSD			
	Depth 15-30 cm		
Unsprayed	887	74	0.41
Sprayed	754	74	0.37
Significance	NS	NS	NS
LSD			

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

Table 3. Concentrations of molybdenum and boron in soil at two depths sampled from site 4 (McLaren Vale) in October 2005 (after 3 years of Mo sprays in spring from 2002 to 2004)

Treatment Rootstock and Mo sprays	Total Mo (Aqua Regia) (μg/kg)	Extractable Mo (Tamm reagent) (μg/kg)	Extractable B (Hot $CaCl_2$) (μg/g)
	Depth 0-15 cm [z]		
Own roots – Unsprayed	370 a	102 a	0.53
Own roots – Sprayed	661 b	343 b	0.61
140 Ruggeri – Unsprayed	391 a	150 a	0.45
140 Ruggeri - Sprayed	772 b	328 b	0.58
Significance	**	***	NS
LSD	231	97	
	Depth 15-30 cm		
Own roots – Unsprayed	352	79	0.36
Own roots – Sprayed	393	126	0.31
140 Ruggeri – Unsprayed	428	84	0.45
140 Ruggeri - Sprayed	457	148	0.35
Significance	NS	NS	NS
LSD			

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

[z] Data are averages from 4 replicates, where different superscripts within the column denote significant differences using the LSD test

Table 4. Estimates of Molybdenum budgets for Merlot vineyards at sites 3 and 4 (after 5 and 3 years of consecutive Mo sprays, respectively) for unsprayed and sprayed vines in 2005.

Soils were sampled for Mo in October 2005.

Source of Mo	**Mo (g/ha) site 3**		**Mo (g/ha) site 4**	
(g/ha)	**Unsprayed[A]**	**Sprayed[B]**	**Unsprayed[A]**	**Sprayed[B]**
Inputs				
Applied foliar Mo	0	1180	0	708
Total soil Mo, 0-5 cm	467.4	908.7	na	na
Total soil Mo, 0-15 cm	1568.5	1904.5	721.5	1289.0
Extract. soil Mo, 0-5cm	61.8	247.7	na	na
Extract. soil Mo 0-15cm	125.5	366.0	198.9	668.9
Mo in tops of vines [C]	1.6	45.9	1.1	30.4
Outputs				
Mo in prunings [C]	0.27	0.58	0.10	0.62
Mo in tops of vines	1.6	45.9	1.1	30.4
Mo in roots	na	na	na	na
Mo in fruit removed[D]	0.73	1.05	0.07	0.36
Leaching loss	na	na	na	na

[A] No pre-flowering foliar Mo sprays applied.

[B] Pre-flowering foliar Mo sprays applied at site 3 (5 years, spring, 2000-2004) and at site 4 (3 years, spring, 2002-2004) but not in the 2005/06 season.

[C] Mo in prunings (Chapter 1, Table 3a for site 4) and tops/vine (canopy + cordon) calculated from site 4 (Chapter 3, Table 10), for vines dug after harvest in 2006.

[D] Mo concentration in berries from site 3 (from Chapter 8, Table 1) used for site 3 and the mean of 3 sites (Chapter 8, Table 1) used at site 4.

na is not available.

Use of increased rates of foliar Mo at 1000 and 2000 mg/L to runoff for 2 years at site 9 had significantly increased both total and extractable soil Mo reserves in the top 0 to 5 cm of soil (Table 5). However, the concentrations of total soil Mo are at the higher end of the normal range of 500-3000 μg/kg of soil Mo (Gupta, 1997). A similar trend occurred in the 5-15 cm soil layer (although not statistically significant). There was also evidence of leaching of Mo to the sub-soil, since there was a significant increase in extractable soil Mo in the 15-30 cm deep subsoil (Table 5). This indicates the importance of not applying excessive rates of foliar Mo to vineyards as the soil reserves of Mo are likely to increase to high levels which may increase the potential for surface runoff/leaching losses of Mo to the environment and/or the incidence of molybdenosis if pasture plants between the vine rows are grazed by ruminants.

Table 5. Concentrations of molybdenum and boron in soil at three depths sampled from site 9, Mc Laren Vale (Ranges) in October 2005. **(**Total Mo spray rates applied each spring in each of 2 years, 2003 and 2004 are shown).

Treatments Mo Spray Rates/year	Total Mo (Aqua Regia) (μg/kg)	Extractable Mo (Tamm reagent) (μg/kg)	Extractable B (Hot $CaCl_2$) (μg/g)
	Depth 0-5 cm		
Unsprayed	580	79	0.63
125 mg/L	627	142	0.55
250 mg/L	693	157	0.56
500 mg/L	1042	172	0.53
1000 mg/L	2510	476	0.57
2000 mg/L	2828	739	0.57
Significance	***	***	NS
LSD	652	121	
	Depth 5-15 cm		
Unsprayed	586	55	0.57
125 mg/L	500	64	0.49
250 mg/L	509	53	0.51
500 mg/L	520	76	0.50
1000 mg/L	755	143	0.48
2000 mg/L	646	134	0.54
Significance	NS	NS	NS
LSD			
	Depth 15-30 cm		
Unsprayed	608	45	0.58
125 mg/L	500	50	0.59
250 mg/L	492	57	0.60
500 mg/L	578	116	0.57
1000 mg/L	740	154	0.51
2000 mg/L	666	187	0.52
Significance	NS	**	NS
LSD		74	

Significance of differences: *, **, *** = P < 0.05, 0.01, 0.001; NS = not significant

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Outcome/Conclusions

(a) Project performance

The project achieved all planned outputs and performance targets as listed in the original application (refer to Project Aims and Performance Targets section).

It should be noted we attempted to develop a pre-flowering predictive tool for Mo deficiency at the 10 cm shoot stage. However, Mo concentrations in petioles changed during the period E-L 12 (10 cm shoot length) to E-L 29-31 (peppercorn stage), such changes were inconsistent and therefore it is not possible to reliably predict petiolar Mo concentration during flowering from samples collected earlier in the season (Ch 4).

(b) Practical implications

The main findings from the results of this research have demonstrated the role of Mo in the reproduction of grapevines and developed strategies to ameliorate Mo deficiency. Some of the main findings and implications to industry are described below.

(i) Molybdenum deficiency probable mechanism in the reproduction stage of grapevines.

Preliminary research showed that Mo deficiency can be a major factor in the occurrence of berry development disorders such as shot berry formation and 'hen and chickens' (millerandage) in Merlot grapevines. This research also reported that the foliar application of Mo results in increased percent of coloured berries with one or more functional seeds and a decrease in the proportion of green berries at harvest suggesting that Mo application affected pollination and/or fertilisation and thereafter berry development.

The application of remedial Mo sprays to Mo deficient vines significantly increased fruit set. This probable mechanism for the role of Mo in the reproduction stage of grapevines is shown in the flow chart in Figure 1.

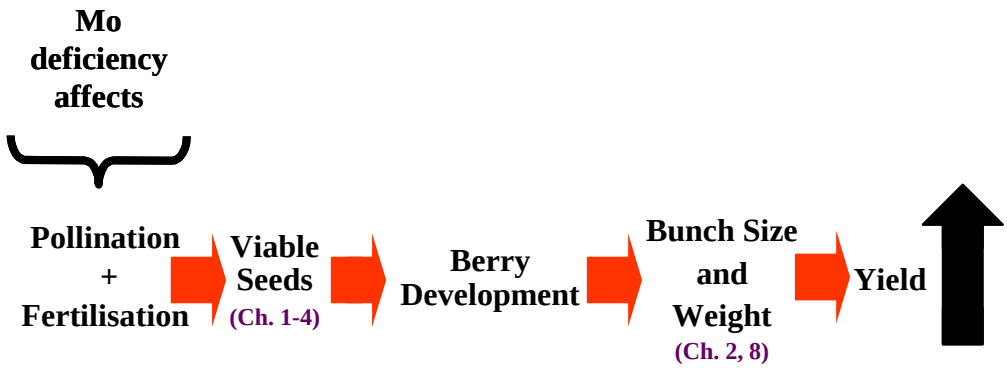


Figure 1. Flow chart of Mo deficiency and probable mechanisms in the reproductive stage of grapevines.

(ii) Re-distribution (transport) of Mo from foliar spray throughout the grapevine

- Mo concentration was generally higher in above ground tissues and roots from vines sprayed with Mo, however, the magnitude of difference varied between tissues (Ch 3).
- Mo concentration in roots increased while the reproductive stage (eg fertilisation) is Mo deficient. In Merlot vines, Mo deficiency for reproduction may not be only about supply but transport of Mo to the inflorescence, during the critical period of flowering and fertilisation (Ch 3).
- Remedial Mo sprays at the optimal rate and time (refer to Recommendations section and the fact sheet in Appendix 1), corrected any Mo deficiency and reduce possible problems of yield loss at the reproductive stage. If sprays are not applied until post flowering, they are likely to be far less effective.
- Mo concentration in terminal 15cm of shoot growth at peak flowering increased with increasing rates of applied Mo pre-flowering (Ch 4 and 5). This indicated translocation of a portion of applied Mo to shoot terminal growth formed weeks after Mo spray application.
- It is evident that environmental factors (climate, site, low temperature) in a given growing season interact and may have major effects on both the incidence of Mo deficiency and the magnitude of the bunch yield response at a given Mo petiolar concentration (Ch 1, 4, 5 and 7).

(iii) Molybdenum Supply

Mo foliar sprays supplemented the uptake of soil Mo when vines were deficient. Mo moved acropetally (upwards movement, eg from roots to top of grapevine) or basipetally (downwards movement, eg from tops of grapevine to the roots, Ch 3).

- Roots < 2 mm in diameter had the highest concentrations of Mo compared with roots > 5 mm which had the lowest. Leaf blades of all the above ground tissues, had the highest concentration of Mo, especially late in the growing season (Ch. 3).

- Foliar sprays of Mo, applied pre-flowering increased Mo concentrations in most tissues sampled in Merlot and Cabernet Sauvignon grapevines. Mo concentrations in the root fractions of both varieties tended to increase during the period 21 – 133 days after budburst. However, the magnitude of the increase depended on root age (Ch. 3). Mo deficiency may not only be about supply but also transport to the inflorescence at flowering.

- Both Merlot and Cabernet Sauvignon grapevines had Mo concentrations higher in all tissues (trunk, cane, petiole, rachis and tendril) from vines sprayed with Mo, but the size of the difference varied between tissues. Thus, the vine tops could both store and re-distribute Mo.

- Mo reserves in grapevines could be carried over from previous growing seasons. However, the magnitude of the reserves carried over varied greatly between sites and growing seasons (Ch. 1, 2, 4). These reserves should be taken into account when devising Mo fertiliser programs.

- Observations and trial results suggested that Mo and environmental factors (low temperature, rainfall, site, etc.) affect Mo supply and transport through the availability, uptake, and movement of Mo from the soil and/or canopy to the reproductive tissues (inflorescences). Variable climatic and stress (low temperature, winds, etc.) conditions are likely major factors in cool climate vineyards associated with the highly variable incidence and severity of both Mo deficiency for reproduction and poor fruit set and berry asynchrony.

(iv) Rootstocks (Ch. 1)

(a) Mo concentrations

- Deficient concentrations of Mo at peak flowering only occurred in certain growing seasons at different sites, presumably due to differences in climatic and other site conditions affecting the availability, supply and transport of Mo in the soil/plant systems to the inflorescences.
- Mo application had little effect on the vegetative growth of grapevines. In contrast, positive effects of applied Mo were recorded on grapevine reproduction (fruit set and bunch yield), when Mo was deficient.

(b) Yield response

- Bunch yield responses to applied Mo varied greatly between growing seasons, due to the variable incidence of Mo deficiency, presumably due to differences in climatic conditions and other site factors.
- Merlot on own roots had the greatest increases in bunch yield (1.8 to 3.2 fold) when Mo was deficient. Significant, but smaller increases were recorded for Merlot on the rootstocks: SO4 (2136), 140 Ruggeri, Ramsey and Schwarzmann (< 1.8 fold). Mo foliar spray regimes applied pre-flowering (Ch. 1, 2, 5) are likely to be still required for Merlot on these 4 rootstocks if deficient. When petiole concentrations of Mo at peak bloom were adequate (>0.45 mg/kg), no significant yield responses were recorded in any genotype.
- Merlot on 110 Richter did not respond to applied Mo, possibly due to a more efficient Mo transport system. This rootstock could be considered for new plantings of Merlot at sites prone to berry asynchrony, provided it meets other key selection criteria, such as pest and disease resistance.
- The bunch yield response to applied Mo was mainly due to higher individual bunch weights. Bunch numbers per vine were similar for sprayed and unsprayed treatments and for the five different rootstocks reported above.
- Mo concentrations for unsprayed vines in petioles at peak flowering were consistently less for Merlot on own roots (0.04 - 0.05 mg/kg) compared with rootstocks Schwarzmann, SO4 (2136), 110 Richter, 140 Ruggeri and Ramsey (0.05-0.13 mg/kg). This suggests that the rootstocks are likely to have more efficient systems for Mo uptake, transport and/or redistribution compared with Merlot on own roots.
- Both rootstocks and own roots were shown to have some capacity to store and carryover a proportion of foliar applied Mo from the previous spring (>12 months) for redistribution and use in the next growing season (Ch. 1, 3). However, since a proportion of foliar Mo spray most likely went through the sparse canopy (<EL 19) and increased soil Mo reserves, there was also some potential for increased soil uptake of Mo.

- Effects of foliar applied Mo on the concentration of 12 other nutrients in basal petioles sampled at peak flowering were small and of little practical importance.
- Rootstocks *per se* affected the concentration of several nutrients in petioles at peak flowering. This is evidence to support the need to consider differences between rootstocks when deriving nutrient standards for wine grapes.
- Environmental factors (climate, site, soil types, etc.) can have major affects on uptake and translocation of Mo in Merlot on own roots and on rootstocks.

(c) Benefits of the project

Economic returns and benefits to grape growers and wine makers from the application of Mo sprays may be high in certain years, for a given vineyard deficient in Mo in the current growing season, and nil in other years in the same vineyard in which Mo was not deficient. For example, at site 1 in the 2001/2002 growing season, there was a large increase in bunch yield per vine from 1.4 kg for unsprayed compared to 4.5 kg for sprayed vines (equivalent to an additional 6250 kg/ha of fruit harvested). The cost of sodium molybdate and its application is less than $50 /ha and its application produced a benefit to cost ratio of over 50 to 1 in 2001/2002 (Ch 2). However, in the first season 2000/2001 of Mo spray application at site 1, there were no economic benefits in terms of increased bunch yield nor bunch size per vine (Ch 2). Similarly, variable responses to Mo sprays occurred at other sites (2, 3 and 4).

Environmental conditions (especially climatic factors) are major determinants of the incidence and severity of both fruit set disorders and of Mo deficiency in a given growing season. Therefore, its essential for growers to consider and monitor factors which affect the Mo status of grapevines (as described in the recommendations section and the fact sheet in Appendix 1), to assist any decision to apply corrective Mo foliar sprays to grapevines.

Our research work has led to new Mo analysis procedures (refer to Research Strategy and Method section), which can now accurately detect very low concentrations of Mo in any plant tissue. This analysis is available as a commercial service to industry in several states including, SA and WA to assist in the monitoring of Mo status in grapevines.

Mo foliar sprays, applied pre-flowering to correct Mo deficiency for reproduction of grapevines are likely to facilitate achievement of normal, target yields and bunch quality and so help stabilise the supply and demand for quality wine grapes to wineries (Fact sheet, Appendix 1). The sustainability issues discussed in the Recommendations section and in the fact sheet in Appendix 1 should also be considered.

Recommendations

(a) Recommendations for Industry

Strategies to manage Mo in vineyards and for the optimal use of remedial Mo foliar sprays in viticulture nutrient management programs for grapevines are summarised below.

(i) Long Term Measures

Our results suggest that 110 Richter maybe the best rootstock for new Merlot plantings in vineyards/areas with a history of Mo deficiency and berry asynchrony ('hen and chickens') and millerandage (green seedless berries at harvest). This is provided Merlot on 110 Richter meets other key selection criteria such as, pest and disease resistance. Reasons for this are that Merlot on 110 Richter was always in the highest bunch yield group per site, and did not respond to or need applied Mo. This was presumably due to the greater ability for Mo uptake and the higher capacity of phloem mobility which in turn accounted for the higher Mo efficiency of 110 Richter.

(ii) Short Term Measures

If vineyards have a history of fruit set disorders, low Mo concentrations in tissue tests, consist of susceptible varieties, have climatic stress conditions pre-flowering (eg. cold, wet), are situated in cool climates on acid soils such grapevines are likely to be deficient in Mo; then remedial Mo foliar spray applications prior to flowering may benefit fruit set and yields.

If Mo deficiency for reproduction in wine grapes has been identified, the following corrective measures are suggested:

- Apply 250 to 500 mg/L of Mo to the point of canopy run-off before flowering at E-L 12 to 18 (10 cm shoot length and 5 leaf up to 50 cm shoot length with 14 leaves separating and flower caps still in place).
- Apply one spray only unless more than 2 mm of rainfall occurs within 48 hours of the spray. If >2 mm of rain occurs a reapplication of the Mo spray at the next fine break in the weather is recommended.
- Soluble sources of Mo for fertilizers include; sodium molybdate (39% Mo), ammonium molybdate (54% Mo). Molybdenum trioxide (66%) is insoluble in water, and future research is required to assess its use in vineyards.

<u>Caution:</u> Vineyard soils should be tested after 3 years of Mo spray regimes for total and extractable soil Mo. This is because Mo has the potential to accumulate in soil and lead to surface runoff /leaching of Mo to offsite water resources or possibly causing molybdenosis toxicity in ruminants grazing inter-vine row crops.

Soil applications of Mo may not be an effective short-term measure in the current season of application to overcome Mo deficiency for fruit set, since adequate proportions of soil applied Mo must reach the root hairs of the fibrous roots for uptake and transport to inflorescences

before flowering. It may be a longer-term solution on soils low in iron and aluminium, with low capacity to sorb and 'fix' the molybdate anion (unavailable for root uptake).

(iii) Sustainability issues from applying Mo foliar sprays

1. Molybdenosis

High concentrations of Mo in plant tissue (10 - 20 mg/kg on a dried oven basis) can induce copper (Cu) deficiency in ruminants that consume such forage, causing the disorder termed molybdenosis (Johansen *et al.* 1997). If pasture plants in the inter-vine rows are to be grazed when grapevines (after Mo fertilisation) are dormant, growers need to be aware of factors, which can affect molybdenosis in grazing ruminants. In general, plants can tolerate high amounts of Mo (100 to 500 mg/kg of oven-dried tissue) without showing yield loss or symptoms of phytotoxicity and molybdenosis toxicity rarely occurs under field conditions (Gupta 1997). However, concentrations in pasture plants of 10-20 mg/kg of Mo on a dried basis can induce molybdenosis in grazing ruminants (Johansen *et al.* 1997).

In vineyards, before and after 3 years of Mo foliar spray regimes, soils should be analysed for total and extractable Mo to monitor and minimise accumulation of high concentrations of Mo in inter-vine forages for grazing ruminants (see Appendix 1: Fact sheet).

2. Build-up of soil Mo reserves (Ch. 9)

The application of Mo fertilisers as foliar sprays pre-flowering to grapevines are effective measures to ameliorate Mo deficiency in grapevines in the current season. However, it is necessary to stress that correct use of foliar sprays of Mo should include the regular conduct of soil tests for Mo. Therefore, to minimise any potential risks, if any, of soil Mo accumulation and of subsequent leaching offsite, vineyard soils should be tested for total and extractable soil Mo concentrations after three consecutive seasons of Mo application and Mo fertiliser programs modified or reduced accordingly.

3. Annual carryover of Mo in the grapevine

Report results indicated that the grapevine has some capacity to store and carryover a proportion of foliar applied Mo from the previous growing season for redistribution and use in the next growing season. However, the amount of the carryover varied greatly from site to site.

This is a further reason to measure petiolar Mo concentrations at peak bloom as well as soil Mo reserves at least every 3 years after Mo spray regimes. This molybdenum audit information can then be used to adjust Mo fertilisation programs to meet grapevine needs and control soil Mo reserves.

(b) Recommendations for Future Research and Development

- Conduct research and adopt nutrient accounting as a means of auditing nutrient inputs and outputs for Mo and all essential nutrients on viticulture properties. An integrated approach can optimise fruit yield and quality at the vineyard level and minimise losses of nutrients to the environment, as well as being a useful educational tool for growers and advisers.
- New grapevine varieties especially if prone to berry asynchrony (millerandage) should be evaluated for Mo status and requirements.
- Other organs (eg leaf blades) need to be studied as potential, more sensitive diagnostic nutrient and prognostic tools to assess the Mo status of grapevines.
- There is also an urgency to develop petiole diagnostic standards for adequacy of sulphur, since none exist for grapevines. The development of such standards for different scion/rootstock combinations would be beneficial for industry.
- Diagnostic standards for other nutrients especially nitrogen and phosphorus need to be researched and revised for modern, scion/rootstock combinations grown in deficit irrigated vineyards, since many standards currently in use were based on work on grapevines in California by (Christensen *et al.* 1978).
- Define factors that may reduce the availability of the molybdate anion for leaf absorption such as sulphur deposits on leaves, compatibility of various combinations of (a) water quality (eg: acidity and contents of iron, aluminium, sulphur or copper), (b) interactions with pesticides and fungicides and (c) duration of mixing.
- Examine relationships between concentration of Mo and other nutrients in leaf blades and petioles of basal leaves at flowering and to that in berry juice at harvest for three scion/rootstock combinations, under defined management regimes
- Look at the effects of liming acid soils on the Mo status of a range of scion/rootstock combinations of wine grapes.
- Soil application of Mo based fertilisers and effects on the Mo status of grapevines and soil reserves.
- Assessments of Mo budgets and complete nutrient budgets for a range of vineyards, including the assessment of inputs in irrigation water and leaching losses could be studied further.
- Future work to define effective ultra low rates of Mo to overcome deficiency and to reduce build-up of soil Mo reserves after 3 years of consecutive Mo foliar sprays, especially at sites where there may be potential for surface erosion/leaching of Mo into offsite water resources or molybdenosis.
- Future research is needed to assess affects, if any, of low concentrations of Mo in berries at harvest from vines sprayed with Mo on fermentation for red wine making.

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Communication of Research

Chris Williams and Louise Chvyl

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(Number*= Number of participants)

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Intellectual Property

No 'commercial in confidence' intellectual property was produced from R&D in this project. However, information in this report is confidential to project stakeholders until it is published.

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References cited in this report are listed at the end of each chapter/section.

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Appendix 1: Molybdenum Fact Sheet

Role in grapevines

Molybdenum (Mo) is a micronutrient and is involved in the conversion of nitrate taken up by the roots, into a form that the vine can use. It acts in other molybdoenzymes and is essential for growth and reproduction in plants. Recent research has indicated that molybdenum also plays an important role in grapevine fruit set, seed formation, berry formation and development and bunch yield (Williams *et al.* 2004; Williams *et al.* 2007).

Symptoms of deficiency

Vegetative growth deficiency

Molybdenum deficiency may be involved in a growth disorder, often called the "Merlot problem", observed in Merlot in which newly planted vines on their own roots grow well initially and then exhibit symptoms including:

- Small leaves (size of a 50c coin or smaller),
- Leaf-edge burn, poor leaf colour, wood fails to mature,
- Rubbery feel to shoots, papery feel to leaves,
- Zig-zag or distorted growth habit of shoots.

Vines with these symptoms have excessive petiole nitrate-nitrogen concentrations and it is thought that the lack of molybdenum impacts on the metabolism of nitrate-nitrogen in the vine, leading to a build up of nitrate-nitrogen.

Molybdenum deficiency associated with poor fruit set ('hen and chickens')

Merlot grapevines in particular have a critical need for adequate molybdenum concentrations during flowering and reproduction for seed formation and bunch yield (Williams *et al.*, 2004). Wet and/or cold conditions leading up to flowering can also accentuate a temporary molybdenum deficiency leading to:

- 'Hen and chickens', (a form of berry asynchrony or millerandage = seedless berries) where the bunch at harvest consists of a mixture of a few large, normal berries (hens) and many small berries (chickens) of uneven ripeness (Figure 1).
- 'Shot berry' formation (a form of berry asynchrony) where the bunch has excessive numbers of small <5 mm diameter, green, seedless berries that may or may not ripen at harvest.
- Often there are no clear vegetative growth symptoms for molybdenum deficiency prior to flowering. After fruit set the only symptoms are 'hen and chickens' and 'shot berries'. Other indicators of Mo deficiency for reproduction are periods of cold wet conditions between bud burst and fruit set.
- Merlot on own roots is more susceptible to Mo deficiency during flowering and its subsequent effects on fruit set and bunch yield.



Figure 1. A Merlot bunch with 'hen and chickens' and shot berries

Other cultivars such as Cabernet Sauvignon, Chardonnay, Cabernet Franc, Ruby Cabernet and Sauvignon Blanc in Australia are also susceptible but are not as severely affected as Merlot.

Nutrient management

Molybdenum deficiency that affects growth (vegetative deficiency) is rare in mature vineyards. Vineyard treatments should only be applied if petiole analysis shows excessive nitrate levels (eg 10,000 mg/kg nitrate nitrogen) and molybdenum deficiency symptoms are persistent.

However, molybdenum deficiency that is only temporary during flowering may be a major cause of poor fruit set without any vegetative signs of deficiency. Other factors, such as periods of cold, wet conditions between bud burst and fruit set, zinc or boron deficiency can also cause poor fruit set.

Interpreting plant tests for molybdenum

(a) Petiole tests and diagnostic standards for Mo at peak bloom

A suggested scheme to assist in assessing the Mo status of irrigated Merlot vines is:

Deficient, vines whose petioles at peak flowering contain less than 0.09 mg/kg Mo (yield response to pre-flowering foliar Mo spray likely);

Marginal, vines with petiole Mo concentrations of 0.09-0.45 mg/kg (response to pre-flowering Mo sprays is uncertain);

Non-responsive, vines that have petiole Mo concentrations greater than 0.45 mg/kg (response to pre-flowering foliar sprays unlikely.

The calibrated petiole test at peak flowering (the standard time and tissue used for nutrient analysis in vines) can be used for diagnostic purposes but this will be too late for the most effective corrective measures to be taken in the current season. However, a scheme based on petiole sampling at flowering can still be used for troubleshooting (diagnostic testing), monitoring the vine Mo status on an annual basis (nutrient monitoring) and predictive testing.

A new Mo analysis procedure (using a mass spectrophotometer), which can now accurately detect very low concentrations of Mo in grapevine tissues is available as a commercial service to industry in several states including, SA and WA to assist in the monitoring of Mo status in grapevines.

(b) Vineyard history

Vineyards with a history of berry asynchrony ('hen and chickens') are likely to be affected in certain growing seasons with inconsistent, but recurrent, fruit set and berry asynchrony disorders. In other seasons, especially with warm, calm conditions leading up to flowering, no disorders are evident.

(c) Climatic factors

The onset of periods of climatic stress (eg. periods of cold, wet conditions between budburst and flowering) is likely to increase the incidence of both Mo deficiency and fruit set problems.

(d) Acid soils

Acid soils have greater ability to 'fix' molybdate anions onto iron and aluminium compounds. The majority of Mo in these complexes may not be available for root uptake by plants in the current growing season. Hence, Mo deficiencies in plants are likely to be more common on acid compared with alkaline soils.

Note: *In acid soils or soils low in molybdenum:*

- *Application of high rates of phosphorus fertilisers or lime increases molybdenum availability.*
- *Large applications of sulphate fertilisers, eg. gypsum, may induce molybdenum deficiency.*

Rootstock effects

Increased bunch yield responses from Mo application to Mo deficient grapevines were greatest for Merlot on own roots (1.8 to 3.2 fold). Significant, but smaller yield increases were recorded for Merlot on the rootstocks: SO4 (2136), 140 Ruggeri, Ramsey and Schwarzmann, (<1.8 fold) in SA by Williams *et al.* (2007). However, 110 Richter did not respond, but produced high yields. These findings suggest that 110 Richter should be considered as a rootstock for new Merlot plantings in vineyards with a history of berry asynchrony and Mo deficiency (provided it meets other selection criteria).

Molybdenum-containing fertilisers

Molybdenum as a soluble fertiliser is normally available as ammonium molybdate (54% Mo) or sodium molybdate (39% Mo).

Fertiliser application

(a) For vegetative deficiency of Mo in young grapevines

As molybdenum is only required in a small quantity, one annual foliar spray of 500 g/1000 L ammonium or sodium molybdate sprayed to the point of runoff should be adequate to overcome a vegetative growth deficiency where vegetative symptoms have been observed or petiole tests indicate high nitrate-nitrogen concentrations (Robinson and Burne 2000).

(b) Fruit set disorders and Mo deficiency in mature grapevines

When an effect on fruit set as a result of molybdenum deficiency is expected, growers can consider applying molybdenum foliar spray regimes (Williams *et al.* 2007) to improve fruit set and bunch yield as suggested below:

- Apply Mo before flowering at the growth stages in the (Coombe 1995) system, of E-L 12 to 18 (10 cm shoot length and 5 leaves up to 50 cm shoot length with 14 leaves separating and first flower caps still in place),
- Use a rate of 250 to 500 mg/L of Mo applied to the point of canopy run-off (c. 300g sodium molydate/ha),
- Apply one spray only unless more than 2 mm of rainfall occurs within 48 hours. Then reapply the Mo spray during the next dry period of weather.

- Monitor petiole Mo in grapevines at peak bloom (to assess annual carryover in vines) and if Mo sprays have been used for 3 years, measure soil Mo reserves (see the caution note below).

Sustainability issues

Caution: Vineyard soils should be tested after 3 years of Mo spray regimes for total and extractable soil Mo; as Mo can accumulate in soils and has the potential to lead to surface runoff/leaching of Mo to offsite water resources and/or molybdenosis toxicity in ruminants grazing inter-row cover crops. Such pasture plants can also be tested for Mo content (10-20 mg/kg of Mo in dried forage may pose a risk to ruminants, Johansen et al. 1997). If elevated levels of soil Mo are measured after 3 years of Mo sprays consider no application of Mo for a few years or use of ultra low rates of Mo.

Soil applications of Mo may not be an effective short-term measure in the current season of application to overcome Mo deficiency for fruit set, since adequate proportions of soil applied Mo may not reach the fibrous roots and/or conditions may not be suitable for uptake by the fibrous roots and transport to inflorescences before flowering. It may be a longer-term solution on soils low in iron and aluminium, with low capacity to 'fix' the molybdate anion.

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Appendix 2: Weather data

Kerry Porter and Chris Williams

Background

Weather data was obtained from the Bureau of Meteorology for weather stations located at Noarlunga and Kuitpo, from the McLaren Vale Grape, Wine and Tourism Association for weather station located in Hamilton Winery, McMurtrie Road, McLaren Vale, from the Lenswood Research Centre for the weather station located on its property at Swamp Road, Lenswood, and from Nepenthe Vineyards for the weather station located in a vineyard in Charleston, SA.

Six years of data, from July 2000 to June 2006, were obtained for Noarlunga and Kuitpo, almost four years data, from November 2002 to August 2006, for McLaren Vale, three years temperature data and four years rainfall data, from July 2002 to June 2006, for Lenswood, and four years soil temperature data, from September 2000 to December 2003, for Charleston.

Monthly averages were calculated for maximum and minimum air temperature for August through to January of the following year to show the major weather influences occurring during growth and flowering of grapevines in South Australia. Average soil temperature data was plotted for the months of September to December to correspond with grapevine flowering period.

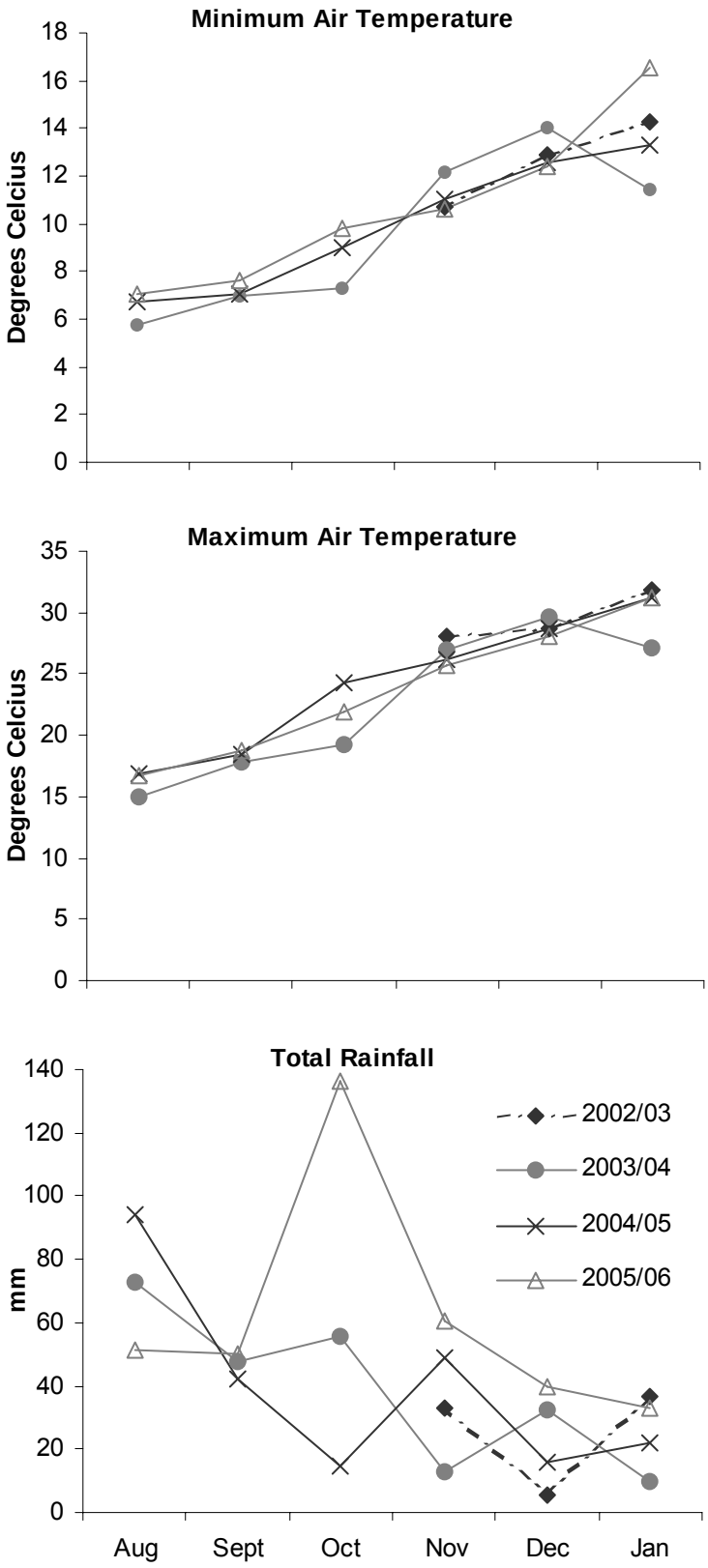


Figure 1. Monthly average minimum and maximum air temperatures, and total monthly rainfall for August to January for four years recorded at Hamilton Wines vineyard in McLaren Vale, SA.

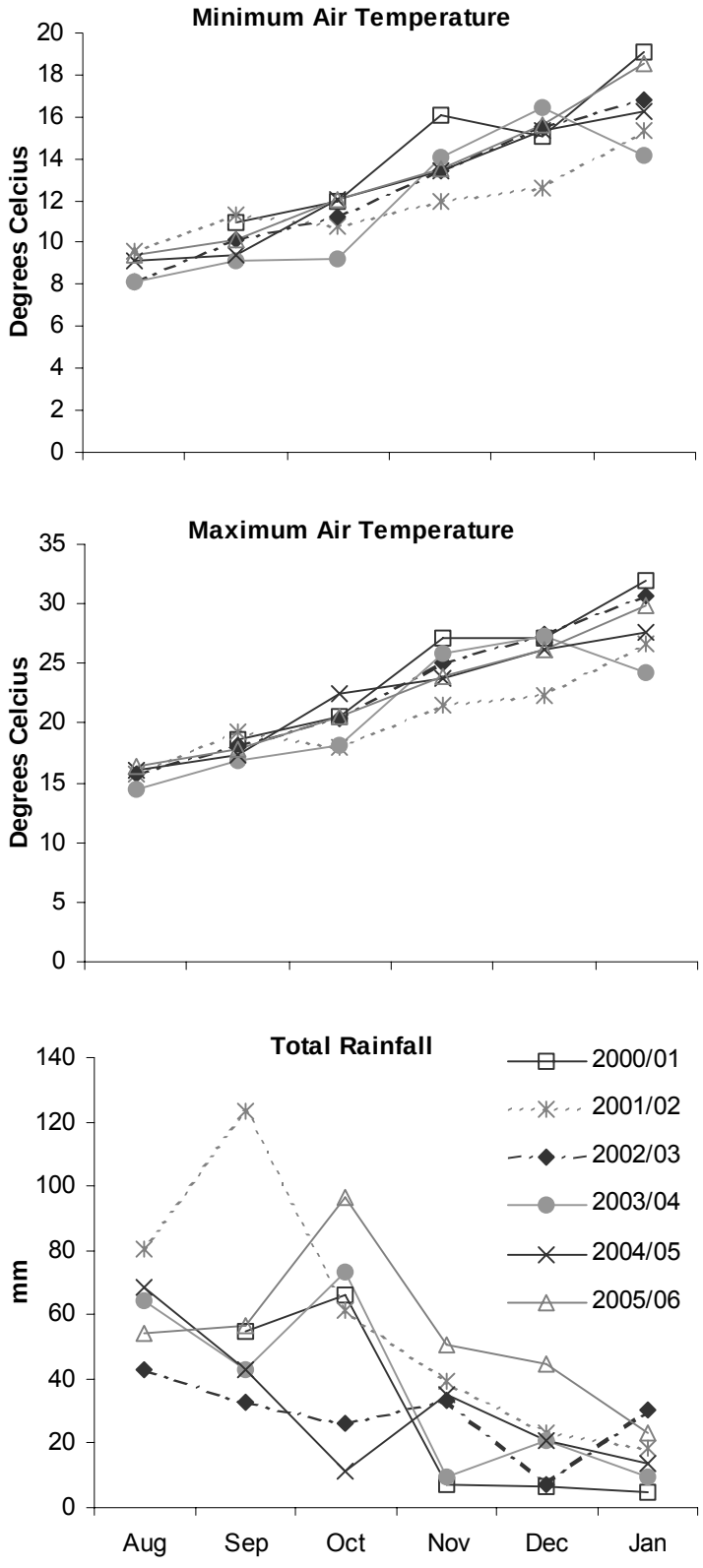


Figure 2. Monthly average minimum and maximum air temperatures, and total monthly rainfall for August to January for six years recorded at Bureau of Meteorolgy Weather Station in Noarlunga, SA.

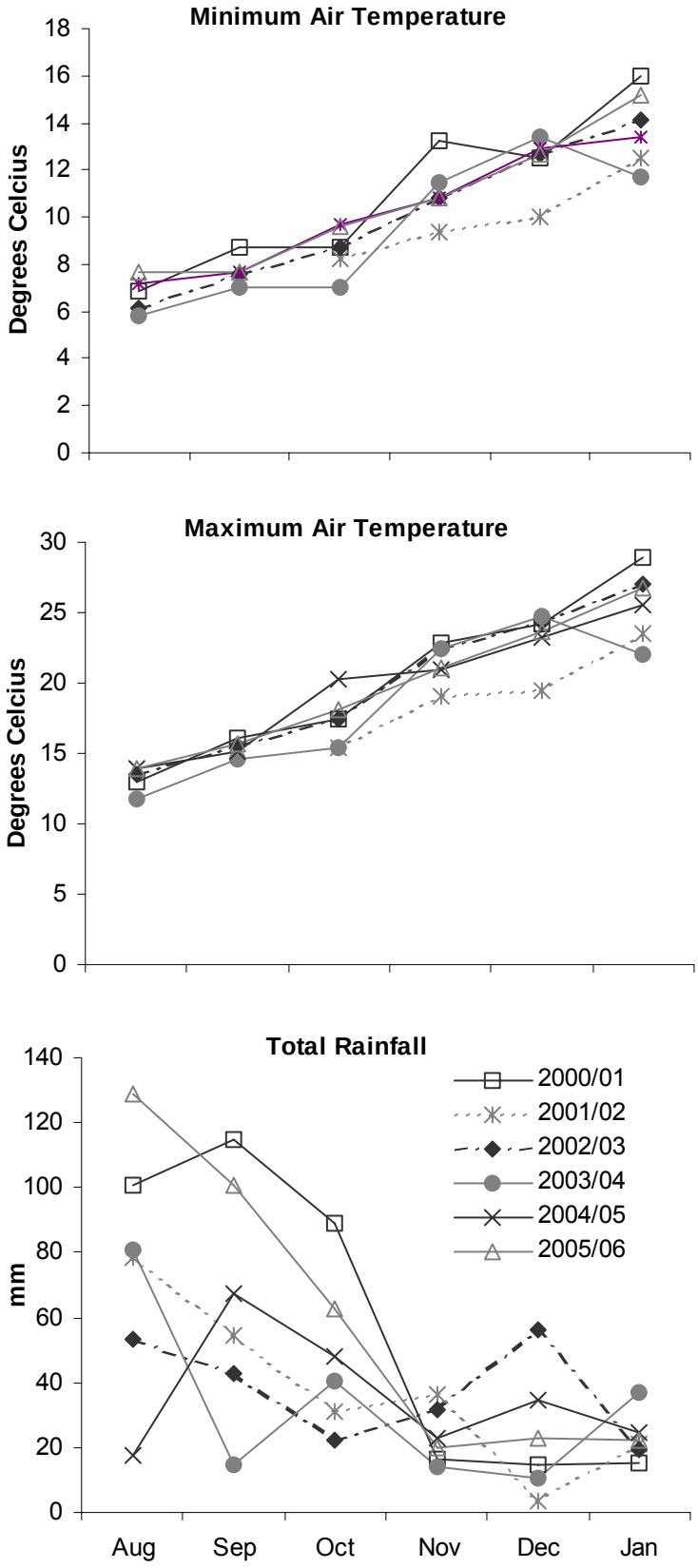


Figure 3. Monthly average minimum and maximum air temperatures, and total monthly rainfall for August to January for six years recorded at Bureau of Meteorolgy Weather Station in Kuitpo, SA.

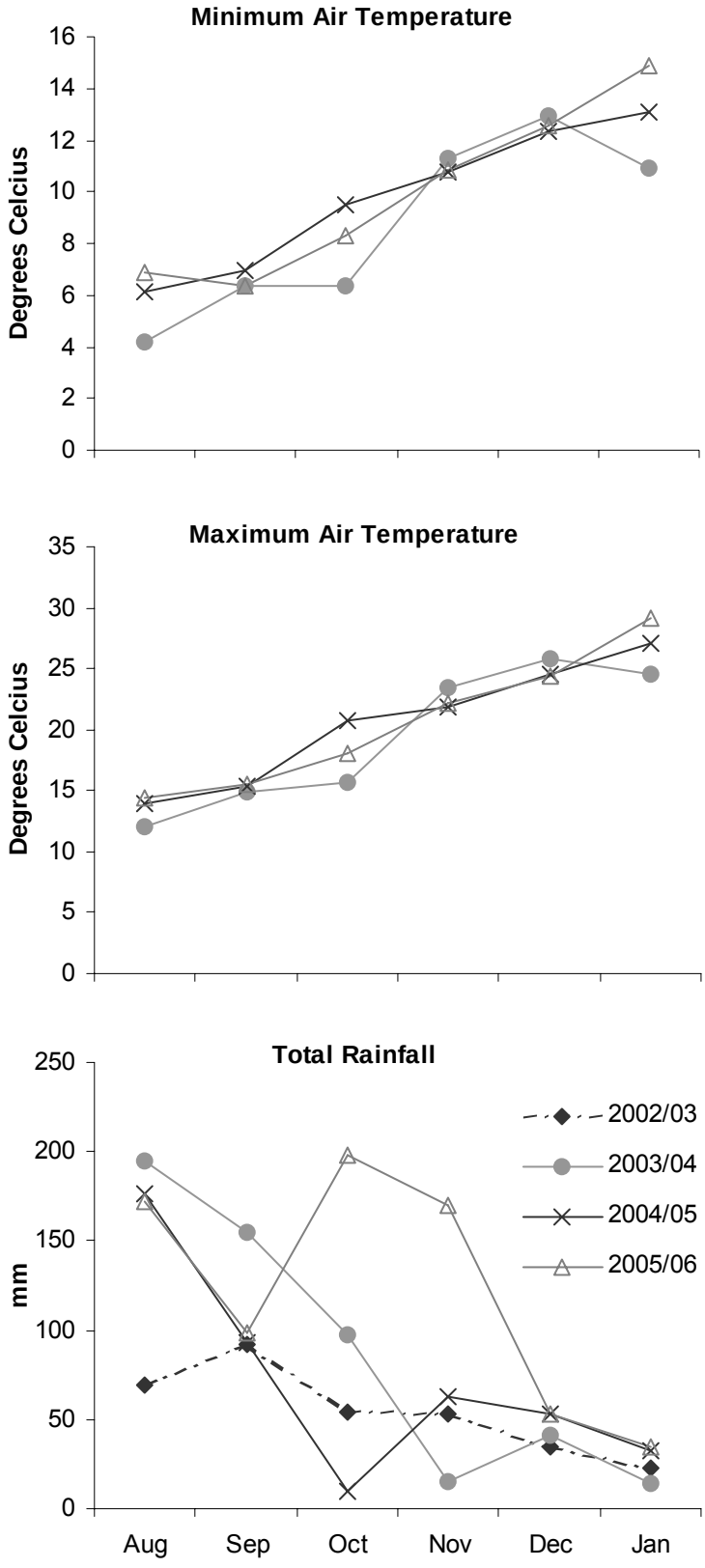


Figure 4. Monthly average minimum and maximum air temperatures, and total monthly rainfall for August to January for four years recorded at Lenswood Research Centre in Lenswood, SA.

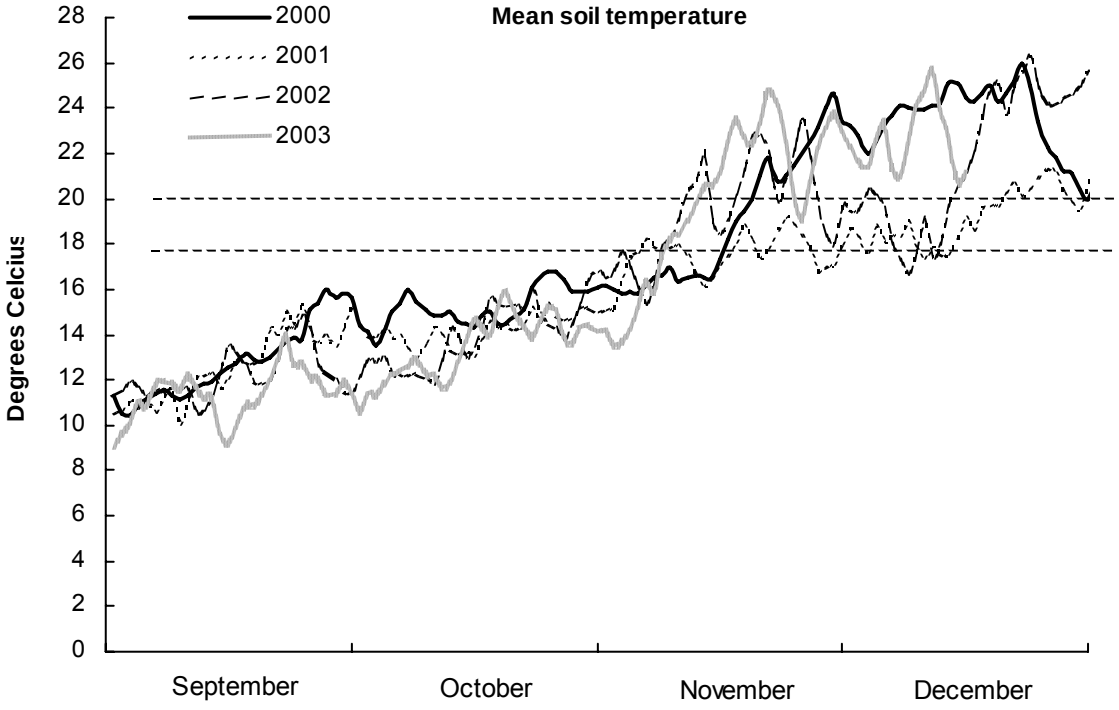


Figure 5. Mean daily soil temperature at depth of 30 cm from September to December for four years recorded at Nepenthe vineyards in Charleston, SA.

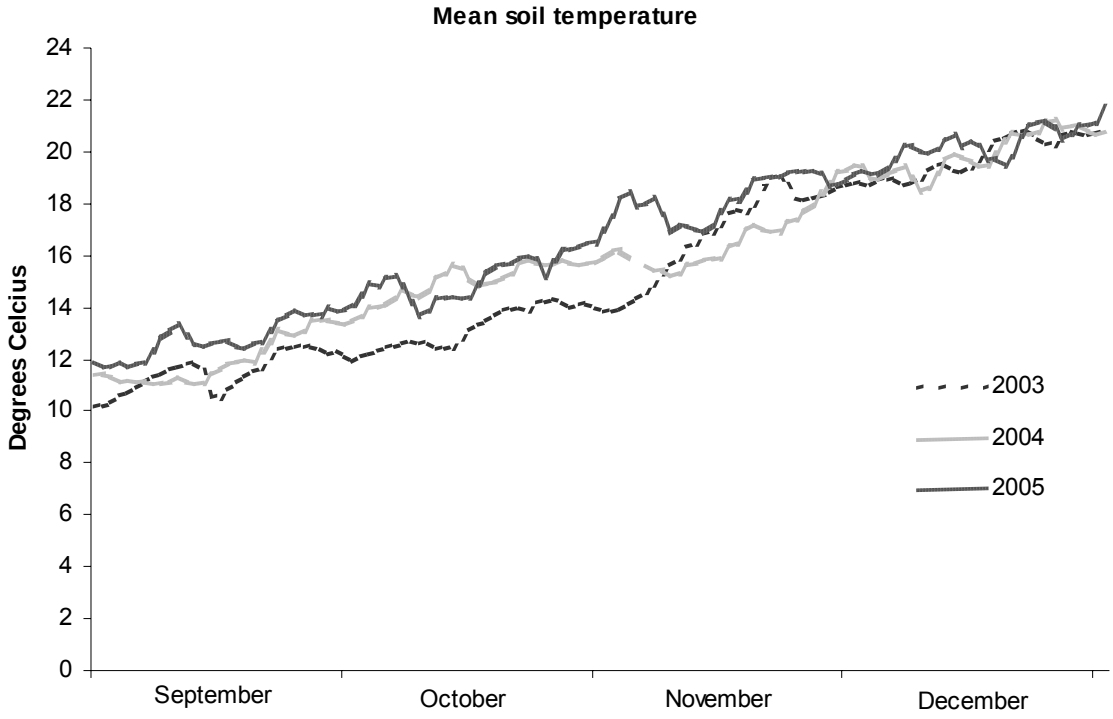


Figure 6. Mean daily soil temperature at depth of X cm from September to December for three years recorded at Lenswood Research Centre in Lenswood, SA.

Appendix 3: Soil test data for trial sites

Table 1: Soil pedology for SA experimental sites

Site	Sample depth (cm)	Description / Classification
Site 1	0-15	Dark brown (7.5YR3/2) firm massive sandy loam, pH = 5.0.
	15-30	Dark brown (7.5YR3/2) firm massive light sandy clay loam with 10-20% schist gravel (6-60 mm), pH = 4.5.
	30-40	Brown (7.5YR4/3) with a sporadic bleach (7.5YR7/2 dry) firm massive light sandy clay loam with 2-10% gneiss fragments, pH = 5.0.
	ASC	Insufficient data for ASC.
Site 2a	0-15	Brown (7.5YR4/2) hard loam with weak granular structure, pH = 6.0.
	15-30	Pinkish grey (7.5YR7/2dry) with brown (7.5YR5/3) mottles hard massive loam, pH = 6.0
	30-45	Light brown (7.5YR6/3, 7.5YR8/2dry) with strong brown (7.5YR4/6) mottles hard massive loam, pH = 6.0.
	ASC	Insufficient data for ASC
Site 2b	0-15	Dark brown (7.5YR3/2) hard massive fine sandy loam, pH = 6.0.
	15-30	Brown (7.5YR4/3, 7.5YR7/2dry) hard massive fine sandy loam, pH = 6.0.
	30-45	Strong brown (7.5YR5/6), light yellowish brown (2.5Y6/4) and red (2.5YR4/6) mottled very hard medium clay with strong medium angular blocky structure. PH = 6.5.
	ASC	Bleached-Mottled, Eutrophic, Brown Chromosol; thick, non-gravelly, loamy / clayey
Site 3	0-15	Brown (7.5YR4/3) hard massive loam with 10-20% ironstone (6-20 mm) and 10-20% quartz gravel (6-60 mm), pH = 6.5.
	15-30	Brown (7.5YR5/3), and pink (7.5R7/4 dry) hard massive loam with 20-50% ironstone (6-20 mm) and 10-20% quartz gravel (6-20 mm), pH = 4.5
	30-45	Yellowish red (5YR5/8) hard medium clay with strong fine polyhedral structure. pH = 6.0.
	ASC	Bleached-Ferric, Eutrophic, Red Chromosol; thick, gravelly, loamy / clayey
Site 4	0-15	Brown (7.5YR4/3) massive soft sandy loam, pH = 5.5.
	15-23	Pinkish grey (7.5YR6/2) soft massive sandy loam with 10-20% quartz fragments (20-60 mm), pH = 6.0.
	23-43	Pink (7.5YR7/3) soft massive sandy loam with 10-20% quartz fragments (20-60 mm), pH = 6.5.
	43-45	Yellowish brown (10YR5/4, dark red (2.5YR3/6) and strong brown (7.5YR5/6) mottled firm medium clay, pH = 7.0.
	Note: Inclusions of clods of clay in 23-45 cm sample indicate that the upper 1-2 cm of subsoil had been penetrated. Quartz fragments in overlying layer probably prevented deeper sampling.	
	Eutrophic, Brown Sodosol; thick, non-gravelly, loamy / clayey, deep	

Table 1 continued

Site	Sample depth (cm)	Description / Classification
5 a) western end of trial row	0-15	Dark reddish brown (5YR3/4) massive soft light sandy loam, pH = 7.0
	15-40	Reddish brown (5YR 5/4), bleached (5YR7/3) when dry massive soft light sandy loam, pH = 7.5.
	40-53	Red (2.5YR4/6) and strong brown (7.5YR4/6) mottled firm medium heavy clay with strong fine angular blocky structure, pH = 8.0. Coarse primary structure probably present, but not apparent in disturbed sample. Moderately to strongly dispersive.
	53-	Yellowish red (5YR4/6) and strong brown (7.5YR5/6) firm medium heavy clay with strong fine angular blocky structure, pH = 8.5.
	EHC[1], M-S[2], Red Sodosol[3]; thick, non-gravelly, loamy / clayey, deep	
[1] 'Eutrophic' if no carbonate at depth, 'Hypocalcic' if up to 2% carbonate, 'Calcic' if 2-20% carbonate at depth. [2] 'Mottled-Subnatric' if ESP 6-15, 'Mottled-Mesonatric' if ESP 15-25. [3] Assume 'Sodosol' (i.e. ESP of 40-60 cm layer is >6) from significant dispersion, bleached 15-40 cm layer and mottling in 40-53+ cm layer.		
5 b) eastern end of trial row	0-20	Dark reddish brown (5YR3/3) soft light fine sandy clay loam with weak granular structure. pH = 7.0.
	20-36	Reddish brown (5YR4/4) soft single grain massive light fine sandy clay loam. pH = 7.0.
	36-45	Dark red (2.5YR3/6) firm medium heavy clay with strong fine polyhedral structure, pH = 8.0. Weakly dispersive.
	45-	Red (2.5YR4/6) and yellowish red (5YR4/6) medium heavy clay with strong fine angular blocky structure, pH = 8.0.
	Sodic[4], ??[5], Red Chromosol[6]; thick, non gravelly, clay loamy / clayey, deep	
[4] Assume ESP > 6 at depth. [5] 'Eutrophic' if no carbonate at depth, 'Hypocalcic' if up to 2% carbonate, 'Calcic' if 2-20% carbonate at depth. [6] Assume Chromosol (i.e. ESP of 36-56 cm layer is <6) from low dispersion and lack of mottling & bleaching.		
Site 6	0-22	Reddish brown (5YR4/3) firm massive loam with 2-10% siltstone fragments (6-20 mm), pH = 6.5.
	22-44	Reddish brown (5YR4/4) firm massive loam with 2-10% siltstone fragments (6-20 mm), pH = 5.5.
	44-85	Red (2.5YR5/6) firm massive clay loam with 20-50% ferruginous siltstone fragments (6-60 mm), pH = 6.5.
	85-110	Yellowish red (5YR4/6) massive clay loam with minor pockets of yellowish red (5YR5/8) light clay and more than 50% siltstone fragments (20-200 mm).
	Basic, Inceptic, Red-Orthic Tenosol; medium, slightly gravelly, loamy / clay loamy, moderate	

Table 1 continued

Site	Sample depth (cm)	Description / Classification
Site 7, 8	0-26	Very dark greyish brown (10YR3/2) hard massive light sandy clay loam with 2-10% quartz fragments (6-20 mm), pH = 5.5.
	26-45	Very pale brown (10YR7/3) hard massive sandy clay loam with 2-10% ironstone gravel (6-20 mm), pH = 4.5.
	45-50	Yellowish brown (10YR5/6), pale brown (10YR6/3) and red (2.5YR4/6) mottled very hard medium clay with strong coarse angular blocky structure, pH = 5.0.
	Bleached-Mottled, Eutrophic, Brown Kurosol; thick, slightly gravelly, clay loamy / clayey, deep	
Site 9	0-18	Brown (7.5YR4/4) massive friable loam, pH = 6.0
	18-50	Reddish yellow (5YR6/6) massive firm clay loam, pH = 5.5
	50-63	Yellowish brown (10YR5/8), strong brown (7.5YR5/8) and red (2.5YR4/8) firm medium clay with strong medium polyhedral structure, pH = 7.0
	63-100	Yellowish brown (10YR5/8), reddish yellow (7.5YR6/8), yellow (10YR7/6) and red (2.5YR4/8) firm kaolinitic medium clay with 2-10% siltstone fragments (6-20 mm), pH = 7.0
	Mottled, Eutrophic, Brown Chromosol; thick, non-gravelly, loamy / clayey, deep	
Site 10a	0-13	Dark reddish brown (5YR3/3) friable loam with moderate granular structure, pH= 7.5
	13-28	Yellowish red (5YR4/6) friable massive clay loam with 10-20% shale fragments (2-6 mm), pH = 7.0
	28-60	Red (2.5YR4/6) and yellowish red (5YR5/6) firm light medium clay with strong polyhedral structure and 20-50% soft weathering shale fragments, pH = 6.0
	Haplic, Eutrophic, Red Dermosol; medium, non-gravelly, loamy / clayey, moderate	
Site 10b	0-25	Very dark greyish brown (10YR3/2) friable heavy fine sandy loam with moderate granular structure and 2-10% shale fragments (2-6 mm), pH = 6.5
	25-30	Yellowish brown (10YR5/4) friable massive fine sandy clay loam with 10-20% shale fragments (6-20 mm), pH = 6.0
	30-?	Yellowish red (5YR4/6) and red (2.5YR4/8) firm medium heavy clay with strong fine polyhedral structure, pH = 6.0
	Melanic, Eutrophic, Red Chromosol; thick, slightly gravely, loamy / clayey, moderate	

Table 2: Chemical properties of soils for SA field experiments

Site	Depth	Organic C	Total N	NO_3 N	NH_4 N	Iron	Extractable mg/kg			Conductivity	pH_w
	cm	%	%	mg/kg	mg/kg	mg/kg	P	K	S	DS/m	
1	0-15	1.38	0.14	10	3	1385	27	224	7.8	0.084	5.7
	15-30	1.12	0.11	5	1	1005	10	149	5.0	0.044	5.7
	30-45	0.74	0.09	4	1	1007	10	121	5.4	0.039	5.9
2a	0-15	2.55	0.25	13	4	2376	49	283	17	0.168	6
	15-30	1.96	0.18	8	3	2134	22	150	14.9	0.127	5.6
	30-45	1.18	0.09	7	2	1417	13	104	17.2	0.086	5.8
2b	0-15	3.02	0.21	8	2	1955	25	150	16.7	0.188	5.8
	15-30	1.22	0.11	6	1	1796	15	191	17.8	0.162	5.7
	30-45	0.86	0.08	4	2	1714	12	156	19.8	0.100	5.8
3	0-15	2.65	0.27	14	10	1674	22	90	14.7	0.081	5.2
	15-30	1.72	0.17	9	3	1360	12	70	14.3	0.064	5.3
	30-45	0.83	0.08	6	3	1012	7	63	27.4	0.061	5.4
4	0-15	1.3	0.1	25	1	986	140	166	41.3	0.134	6.3
	15-30	0.76	0.04	10	1	764	94	133	13.7	0.057	6.4
	30-45	0.49	0.02	5	4	874	60	142	29.5	0.065	6.4
5 a)	0-15	0.81	0.04	4	1	671	28	244	1.3	0.043	0.72
	15-30	0.42	0.03	3	1	644	14	224	1	0.039	0.76
	30-45	0.44	0.04	3	2	915	6	391	3.1	0.054	0.79
5 b)	0-15	0.43	0.03	3	2	751	18	241	1.2	0.037	7.7
	15-30	0.45	0.03	2	2	618	20	202	1.2	0.038	7.7
	30-45	0.57	0.03	3	3	810	9	278	4.1	0.068	8
6	0-15	2.46	0.24	4	2	2272	36	94	3.8	0.03	5.5
	15-30	1.63	0.08	1	1	2103	26	72	2.9	0.023	5.7
	30-45	0.87	0.03	1	1	1709	9	89	2.7	0.021	6
7	0-15	1.7	0.1	12	1	2981	224	206	3.8	0.041	6.4
	15-30	1.04	0.06	19	1	2783	294	534	4.5	0.058	5.9
	30-45	0.83	0.03	8	1	2559	84	105	4.4	0.031	6
8	0-15	1.59	NA	1	1	3255	263	184	3.9	0.035	6.3
	15-30	1.42	NA	1	1	3327	308	144	2.4	0.022	6.4
	30-45	0.94	NA	1	1	2377	229	164	2.4	0.017	6.3
9	0-15	3.54	0.29	19	1	4480	22	138	165	0.272	5.2
	15-30	1.44	0.1	9	1	2810	6	68	39.3	0.092	5.5
	30-45	1.09	0.08	8	1	2045	4	58	56.9	0.108	5.5
10 a)	0-15	2.78	0.22	4	3	2294	33	198	3.7	0.058	6.9
	15-30	0.89	0.06	1	2	1608	4	65	2.7	0.027	6
	30-45	0.44	0.04	1	1	1259	2	85	6.4	0.101	5.8
10 b)	0-15	3.63	0.24	4	3	1955	43	397	5.4	0.057	6.4
	15-30	1.92	0.12	2	2	1618	19	223	3.7	0.033	6
	30-45	0.79	0.06	1	2	841	17	150	3.9	0.024	5.7

5 a) western end of trial row
5 b) eastern end of trial row
10 a) Merlot
10 b) Cabernet Sauvignon
NA= Not Analysed

Appendix 4: Bunch assessment chart for berry asynchrony

For assessment of grape bunches in this project, both in the survey and in the interstate field trials, it was found there were no objective methods of assessment of berry asynchrony ('hen and chickens') for wine grape bunches. Therefore the rating chart in Figure 1 and Table 1 was assembled. This chart, laminated for use in the field, consists of 4 annotated colour photographs with written instructions on the back. The photographs of grape bunches grade from 1, a 'perfect bunch', through to 4, 'a bunch with very poor fruit set and berry development' (Figure 1). Where grade 4 was a bunch with very poor fruit, with very few fully sized coloured, mature berries (hens) and a majority of small green berries ('shot berries') and/or undersized, partly mature coloured berries (chickens) usually less than 5 mm in diameter.

BUNCH ASSESSMENT GRADES

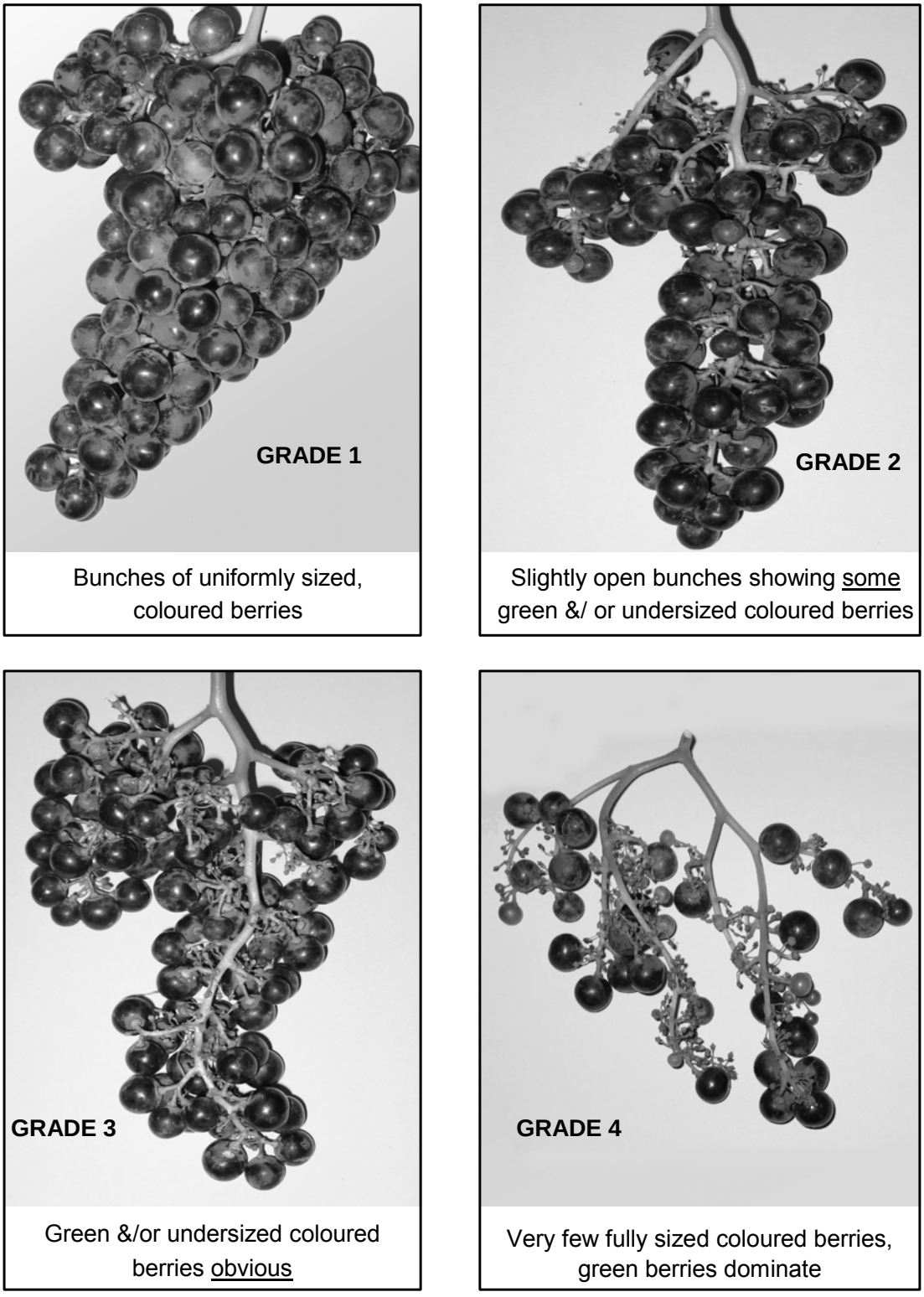


Figure 1. Bunch assessment grading chart for berry asynchrony

Table 1. Instructions for use of the bunch assessment grading chart for berry asynchrony

Bunch Assessment for 'Hen and Chickens' and Green Berries

For each variety &/or rootstock that you included in the survey please:

- Walk down the rows (at least 3 rows by 30 metres) in the area that you petiole sampled to assess the bunches.

- Select vines over this unsprayed area that are average & healthy, and assess their bunches by comparing them with the bunch grades shown overleaf.

Note: The grade pictures are of Merlot but should be used, with suitable interpretation, for other varieties being surveyed.

- Take care to look inside the bunches and at the under or sheltered side of bunches. Often the better side is the outward presentation.

- Rate the area either with one average grade or indicate the range of grades, or both.

- **DO NOT** include disease occurrence as part of the grading. Only assess the presence or absence of berries that are under 5 mm and green or partly coloured.

GRADE 1: consists of bunches where the **berries are uniformly sized** and either tightly bunched or slightly open. There may be a **negligible** number of green or undersized berries (under 5 mm in diameter) when the bunch is closely examined.

GRADE 2: consists of bunches that are **slightly open and** show **some small green or partly coloured berries** under 5 mm when examined. Bunches that are open but do **not** show any green or undersized berries should be included in grade 1.

GRADE 3: consists of bunches where the **small green or partly coloured, undersized berries** (under 5 mm) are **plentiful** and **obvious** without close examination.

GRADE 4: consists of bunches with **very few fully sized, coloured berries**, the majority being very small green, or undersized coloured berries (under 5 mm diameter).