Sunmuscat fruit set and bunch shatter

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SUNMUSCAT FRUIT SET AND BUNCH SHATTER

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CSIRO

HAL project number: DG05002

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This is the final report for the project "Sunmuscat fruit set and bunch shatter". This report describes the results of research into factors contributing to poor productivity of the drying variety Sunmuscat, and outlines management practices to moderate the effect of these factors in order to improve the variety's performance.

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June, 2009.

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CONTENTS

Table of Figures

Table of Tables

Media Summary

Sunmuscat is an emerging variety for the Australian dried grape industry. It is capable of producing high yields of high quality dried grapes but its yield performance—in terms of mature berries per bunch—has been variable. Management techniques have been identified to enable the Sunmuscat variety to more consistently perform to its potential.

This project has focussed on improving the efficiency of Sunmuscat production by identifying the causes of bunch shatter and poor fruit set. The aim was to develop management practices to effectively increase berry numbers per bunch at harvest.

A series of studies and trials were conducted over three seasons to investigate the factors contributing to poor berry numbers at harvest for this variety. The effects of cincturing and foliar application of minerals and Cycocel® (an inhibitor of gibberellic acid synthesis) on berry set, bunch shatter and fruit yield were assessed.

The data collected suggested that most of the loss of yield potential occurred during fruit set, but that the abscission of berries subsequent to fruit set also contributed. The latter was visually more dramatic than the former.

The evidence also suggested that flowers and berries competed poorly with the growing shoot tips for assimilate. Subsequently, treatments that ameliorated this competition, *i.e*. cincturing or application of Cycocel®, resulted in more berries per bunch at harvest. The application of some mineral nutrients known to be involved in plant reproductive biology or abscission (*viz*. boron, calcium, zinc), also resulted in more berries per bunch at harvest, but only if the competition for assimilate had been moderated to some extent.

Though effective, cincturing is not a practical means of improving berry numbers per bunch at harvest on a large scale.

But, application of Cycocel® was problematic because the timing of flowering was difficult to predict. This highlights a need for a framework to predict the flowering time of this variety to better schedule Cycocel® applications for maximum efficacy.

Future research also needs to quantify responses to Cycocel® rate.

Management practices with the potential to limit carbon assimilation and supply (*e.g.* water deficit pre-flowering and during flowering and fruit set) need to be avoided.

Technical Summary

Low berry numbers per bunch limit realisation of potentially high productivity levels from the highly fruitful variety Sunmuscat, a variety the Australian dried vine fruits industry would like to see grown by more dried vine fruit producers. It is not clear whether the low numbers of berries per bunch at harvest are due to poor fruit set or bunch shatter subsequent to fruit set.

Based on existing knowledge a series of studies and trials were conducted over three seasons to investigate the factors contributing to poor berry numbers at harvest for this variety and to develop management options to ameliorate the effect of those factors.

The data collected suggested that most of the problem lies in the fruit setting stage, but that the abscission of berries subsequent to set also contributed to a lesser extent. The evidence also suggested that the flowers and berries competed poorly with the growing shoot for assimilate. Subsequently, treatments that ameliorated this competition, *i.e*. cincturing or application of Cycocel® (an inhibitor of gibberellic acid synthesis) resulted in more berries remaining on the bunches at harvest. The application of some mineral nutrients known to be involved in plant reproductive biology (boron and zinc) or abscission (calcium), also resulted in more berries per bunch at harvest, but only if the competition for assimilate had been moderated to some extent.

Though effective, cincturing is clearly not a practical means of improving berry numbers per bunch at harvest on a large scale. On the other hand, application of Cycocel® was problematic because the timing of flowering was difficult to predict over the course of the project. This highlights a need for a predictive framework for flowering time to better time Cycocel® application for maximum efficacy.

The responses observed to the application of some mineral salts were not unexpected, but were not predictable on the basis of comparisons of petiole mineral nutrient levels in the standard tissue relative to the accepted standards for drying varieties. This suggests that the mineral nutrient standards for this variety may need to be revised to reflect a greater need by this variety for these mineral nutrients relative to the needs of the other major drying variety Sultana.

Introduction

Sunmuscat is an emerging variety for the Australian dried grape industry. While capable of producing high yields of high quality dried grapes, its yield has been variable. High bud fertility (*i.e.* bunches per shoot) has not always translated into high productivity because of poor fruit set and/or bunch shatter following fruit set (Figure 1). The basis for the inconsistent realization of the high yield potential of Sunmuscat is unknown. Poor productivity of Sunmuscat affects returns to producers. This problem, commonly known as “Sunmuscat fruit set and bunch shatter”, is likely to be related to poor pollen viability; competition between developing berries and rapidly growing shoots; competition between and within bunches; and may be influenced by mineral nutrient concentrations in key tissues at the time of flowering and fruit set.

Figure 1. Sunmuscat inflorescences at flowering (left) and after fruit set (right).

The overall aim was to develop management practice(s) to effectively increase berry numbers per bunch at harvest and hence improve yields of dried Sunmuscat grapes on a consistent basis.

What distinguishes sites that yield well from sites that don't?

To gain an insight into the basis for variation in vine performance anecdotally reported by industry, the components of yield (*i.e.* bearer numbers, bud fertility *etc.* – Figure 2) were quantified on six sites varying in productivity in the Sunraysia region of north west Victoria/south west NSW during the 2005-06 season.

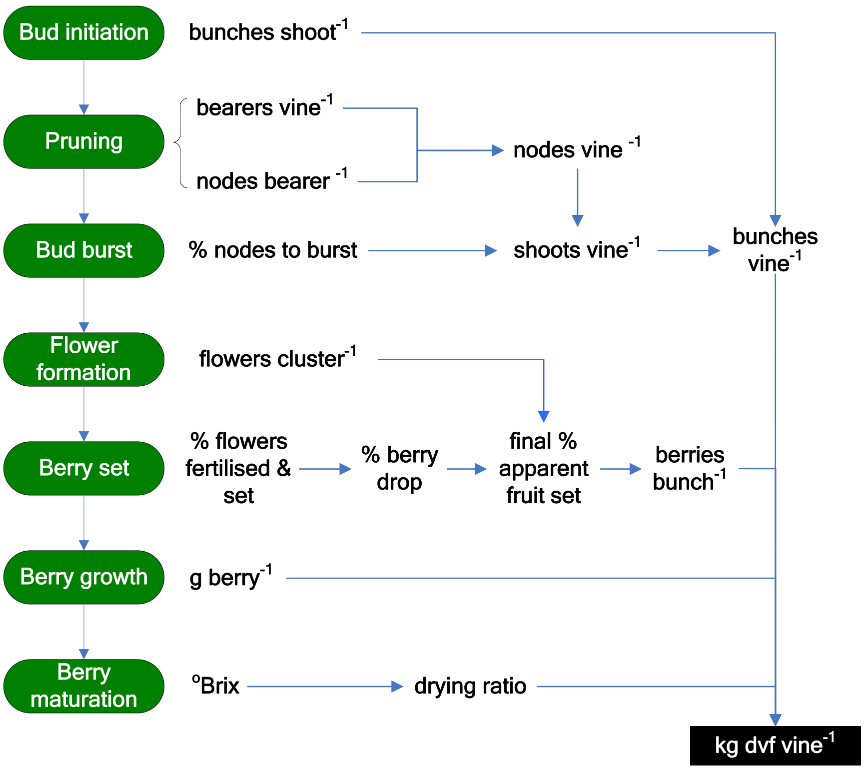


Figure 2. Processes contributing to final dvf per vine.

All vines used were growing on 1103 Paulsen rootstock. These vines were trained to a horizontal permanent cordon and managed using the "Shaw" swing arm trellis. Other details for each site are provided in Table 1. Measured yields of dried fruit (standardized to 13% moisture) for the season in which the study was conducted are presented on per vine and per hectare bases in Tables 3 and 4 respectively.

Vines used on each site were randomly selected. Bearer numbers, the number of shoots per bearer and bearer numbers, the number of shoots per vine and the number of inflorescences per shoot were determined respectively in September, early October and mid October. Flowers per inflorescence were also counted using a randomly selected inflorescence on each vine. Petioles opposite the basal cluster were sampled at 50% capfall for determination of nitrogen and the following minerals: P, K, Ca, Mg, S, Na, Al, B, Fe, Mn, Cu, Zn and Mo, as described in materials and methods.

Data for each site were tested for outliers [according to Grubbs test as described by Rohlf and Sokal (1981)], and each variate (across sites) was subjected to tests for normality and variance homogeneity and appropriate transformations applied to satisfy those tests if needed. The data were then analysed as a mixed model using the REML procedure in GenStat (11th Edition); site was the fixed variance component, and vine number (on each site) was the random component of the model. On the basis of a significant Wald statistic, means were separated using a least significant difference at P=0.05.

Table 1. Details of the six sites used to establish yield parameter variation for Sunmuscat and measured dvf (13% moisture) yields for 2005-06.

Site	Location	Spacing (row × vine) (m)	Vines ha^{-1}	m cordon ha^{-1}	Irrigation system	Reported yields*
A	Gol Gol	3.05 × 2.44	1,344	3,279	low levels	good
B	Gol Gol	3.05 × 2.44	1,344	3,279	low levels	poor
C	Merbein South	3.27 × 2.35	1,301	3,058	low levels	good
D	Stewart	3.35 × 2.44	1,223	2,985	overheads	poor
E	Merbein	3.20 × 2.70	1,157	3,125	low levels	average
F	Red Cliffs	3.66 × 4.00	683	2,732	drip	Poor

*Largely qualitative, undocumented and relative to industry "experience".

Specific petiole nutrient standards for this variety do not exist, but using the general standards used to interpret grapevine petiole nutrient concentrations at flowering (Robinson *et al.*, 1997), none of the sites used in the study were apparently deficient in any mineral nutrient (Table 2). Phosphorus (P) and potassium (K) tended to be lower on Site A relative to the other sites, and nitrogen (N) was higher in Site B relative to the other sites. Magnesium (Mg), iron (Fe), zinc (Zn) and copper (Cu) tended to be higher on the two Gol Gol sites (A and B) relative to the other sites. Manganese levels were higher on Site D at Merbein.

Table 2 Mineral nutrient concentrations in petioles opposite basal bunches sampled at 50% cap fall (November, 2005).
Different superscripts within rows indicate significant differences between site means (P=0.05).

	Site					
	A	B	C	D	E	F
			% of dry weight			
N	1.07^{b}	1.58^{a}	0.95^{b}	0.94^{b}	1.01^{b}	0.94^{b}
P	0.42^{d}	0.68^{c}	1.06^{a}	0.92^{b}	0.81^{bc}	0.82^{bc}
K	1.96^{c}	3.15^{b}	3.79^{a}	3.72^{a}	2.79^{b}	3.28^{b}
Ca	2.00	2.13	2.00	2.16	2.16	2.20
Mg	0.69^{a}	0.72^{a}	0.41^{c}	0.52^{b}	0.59^{b}	0.49^{b}
S	0.14^{a}	0.09^{c}	0.15^{a}	0.13^{ab}	0.11^{cb}	0.12^{b}
Na	0.09	0.04	0.03	0.05	0.03	0.03
			mg kg^{-1} dry weight			
Al	23^{a}	16^{b}	23^{a}	21^{a}	15^{b}	16^{ab}
B	49	48	48	50	42	41
Mn	59^{bc}	68^{ab}	69^{ab}	50^{c}	90^{a}	68^{b}
Fe	143^{a}	146^{ab}	108c	116^{c}	126^{bc}	118^{c}
Cu	23^{a}	21^{ab}	17^{cd}	19^{bc}	15^{d}	15^{d}
Zn	71^{a}	61^{ab}	40^{c}	49^{bc}	58^{b}	54^{b}
Mo	0.15	0.08	0.05	0.09	0.16	0.16

Across all sites about 10 bearers per vine (Table 3) were used in the 2005-2006 season when the study was conducted, but when scaled up to a per hectare basis to take account of differences in intra-row planting distances and row widths the number of bearers on Site C was a factor of two greater than the number of bearers on Site F (Table 4). Shoots per vine and bunches per vine were similar across the sites, but the bunch to shoot ratio was highest on Site B and lowest on Site E. When scaled up to take account of vine spacing however, the difference between the extremes in terms of shoots per hectare and bunches per hectare was a factor of two. The number of flowers per inflorescence in early November and the number of berries per cluster in late November were characterised by a high degree of variability such that the biometric procedure used could not identify significant site-related effects despite ostensibly large variation between the means for each site. Nonetheless, 27% of flowers set and remained on the cluster through to late November on Site D compared to 9-15% on Sites A, E and F.

Table 3. Mean vine features contributing to yield, and actual Sunmuscat dvf (13% moisture) yield on a per vine basis for 6 sites in the Sunraysia region in 2005-06. Different superscripted letters within columns indicate a significant (P=0.05) difference between means.

Site	Bearers $vine^{-1}$	Bearers m^{-1} cordon	Shoots $vine^{-1}$	Shoots $bearer^{-1}$	Inflo-res-cences $vine^{-1}$	Inflo-res-cences $shoot^{-1}$	Flowers inflores-$cence^{-1}$*	Berries $bunch^{-1}$	% "final" set	Kg dvf $vine^{-1}$
A	9.1	3.7^{b}	135	15^{a}	133	0.96^{bc}	$1,016^{ab}$	179	15^{b}	9.3^{ab}
B	8.1	3.3^{b}	117	14^{ab}	120	1.19^{a}	$1,218^{a}$	203	18^{ab}	10.9^{a}
C	10.8	4.6^{a}	165	15^{a}	160	0.97^{b}	$1,322^{a}$	200	16^{ab}	8.4^{b}
D	9.7	4.0^{ab}	127	13^{b}	144	1.16^{a}	675^{b}	150	27^{a}	9.5^{ab}
E	10.0	3.7^{b}	145	15^{a}	115	0.79^{c}	$1,367^{a}$	131	12^{b}	9.5^{ab}
F	9.9	2.5^{c}	161	16^{a}	139	0.97^{b}	$1,139^{a}$	137	12^{b}	11.0^{a}

*- On each vine inflorescences were randomly selected to count flower numbers.

Table 4. Mean vine features contributing to yield, and actual Sunmuscat dvf (13% moisture) yield on a per hectare basis for 6 sites around the Sunraysia region in 2005-06. Different superscripted letters within columns indicate a significant (P=0.05) difference between means.

Site	Bearers ha^{-1}	Shoots ha^{-1}	Bunches ha^{-1}	t dvf ha^{-1}
A	$12,300^{ab}$	$181,353^{ab}$	$178,296^{ab}$	12.1^{a}
B	$10,956^{b}$	$156,494^{b}$	$161,539^{b}$	14.0^{a}
C	$14,098^{a}$	$215,260^{a}$	$208,428^{a}$	11.6^{a}
D	$11,840^{b}$	$155,666^{b}$	$176,533^{ab}$	12.1^{a}
E	$11,678^{b}$	$167,306^{b}$	$133,604^{bc}$	7.9^{b}
F	$6,740^{c}$	$109,588^{c}$	$94,436^{c}$	7.5^{b}

Scatterplots of the site means versus yield on per vine and hectare bases were prepared to identify those components of yield contributing to differences in yield between sites (Figures 3 and 4), and the product moment correlation co-efficients calculated to identify significant relationships amongst the components of yield (Table 5).

The product moment correlation coefficients indicate that, across the 6 sites, a significant proportion of the variation in dvf yields was attributable to shoot fruitfulness, the number of bunches per hectare and the number of berries per cluster in late November. Variability in the number of bunches per hectare was significantly related to the bearers per hectare. In other words, much of the basis for the perceived, and measured, differences in yield across the 6 sites is attributable to the number of bearers laid down. The scatterplots give some indication of the variability in all the components of yield, and also suggest that there is a possibility that some significant product moment correlation coefficients may be due to significantly lower yield on a per vine basis at one site (Site F) and yield at Site F and another site (Site E) is lower than the other sites.

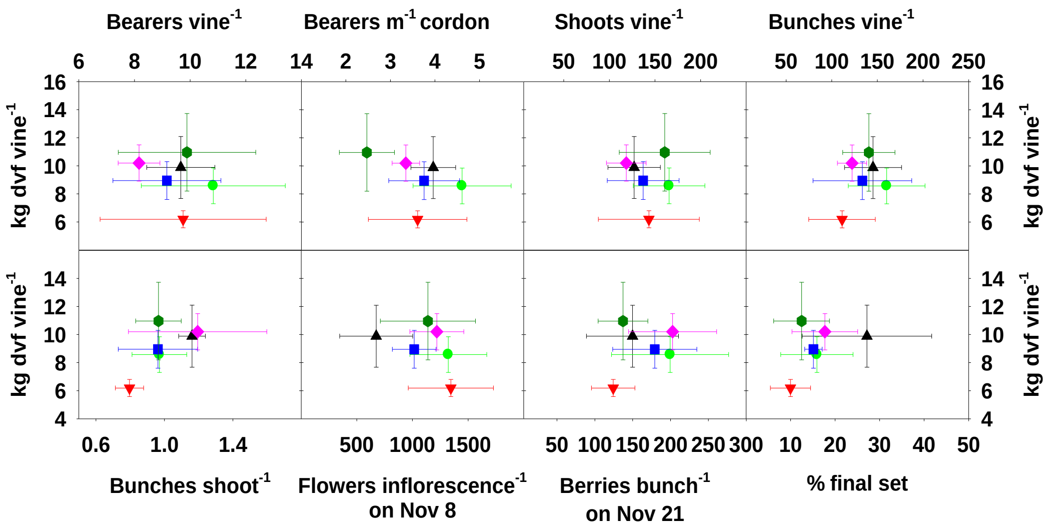


Figure 3. Scatterplots of components of Sunmuscat dvf yield on a per vine basis across 6 sites in the Sunraysia region in 2005-06.
Symbols represent site means, and the horizontal and vertical bars represent the standard deviations for the independent and dependent variables, respectively. Key to symbols: ▲, Site A; ▼, Site B; ●, Site C; ■, Site D; ◆, Site E; ⬢, Site F.

The product moment correlation coefficients indicate that, across the 6 sites, a significant proportion of the variation in dvf yields was attributable to shoot fruitfulness, the number of bunches per hectare and the number of berries per cluster in late November. Variability in the number of bunches per hectare was significantly related to the bearers per hectare. In other words, much of the basis for the perceived, and measured, differences in yield across the 6 sites is attributable to the number of bearers laid down. The scatterplots give some indication of the variability in all the components of yield, and also suggest that there is a possibility that some significant product moment correlation coefficients may be due to significantly lower yield on a per vine basis at one site (Site F) and yield at Site F and another site (Site E) is lower than the other sites.

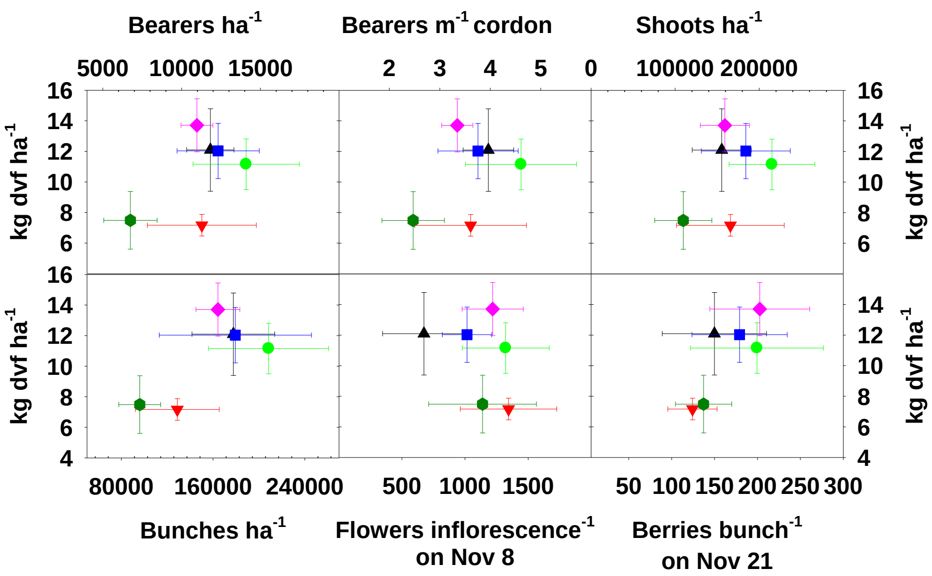


Figure 4. Scatterplots of components of Sunmuscat dvf yield on a per hectare basis across 6 sites in the Sunraysia region in 2005-06.
Solid dots represent site means, and the horizontal and vertical bars represent the standard deviations for the independent and dependent variables, respectively. Key to symbols: ▲, Site A; ▼, Site B; ●, Site C; ■, Site D; ◆, Site E; ⬢, Site F.

Table 5. Significant (P=0.05) product moment correlation coefficients for components of Sunmuscat dvf yield across 6 sites in the Sunraysia region in 2005-06.

	Bearers vine^{-1}	Bearers m^{-1} cordon	Bearers ha^{-1}	Shoots vine^{-1}	Shoots ha^{-1}	Bunches vine^{-1}	Bunches shoot^{-1}	Bunches ha^{-1}	Flowers inflorescence^{-1}	Berries cluster^{-}	% final set	Kg dvf vine^{-1}	T dvf ha^{-1}
Bearers vine^{-1}													
Bearers m^{-1} cordon	-												
Bearers ha^{-1}	-	0.97											
Shoots vine^{-1}	0.86	-	-										
Shoots ha^{-1}	-	0.93	0.96	-									
Bunches vine^{-1}	-	-	-	-	-								
Bunches shoot^{-1}	-	-	-	-	-	-							
Bunches ha^{-1}	-	0.91	0.92	-	0.87	-	-						
Flowers inflorescence^{-1}	-	-	-	-	-	-	-	-					
Berries cluster^{-1}	-	-	-	-	-	-	-	0.73	-				
% final set	-	-	-	-	-	-	0.80	-	-	-			
Kg dvf vine^{-1}	-	-	-	-	-	-	0.72	-	-	-	-		
T dvf ha^{-1}	-	-	-	-	-	-	0.80	0.74	-	0.81	-	-	

The set/shatter problem is mainly a berry set issue

Ten randomly selected inflorescences per vine were tagged in early October, 2005, on the Red Cliffs site refereed to as Site F in the previous section. The bunches were bagged in large brown paper bags, and the bags were removed and replaced every day until mid November, every 2-3 days from mid November to early December and replaced weekly till mid December. The numbers of flowers and berries were counted in each bag when it was removed.

The detailed counts of flowers per cluster before flowering, and of berries per bunch in late November, late December are presented as a Box plot in Figure 5. This representation of the data indicates that, across the board, Sunmuscat clusters had *ca*. 1,200 flowers, but 84% of those flowers failed to set a berry. Further losses only amounted to 4% of the original 1,200. Therefore, the poor productivity of Sunmuscat is most likely due to poor berry set.

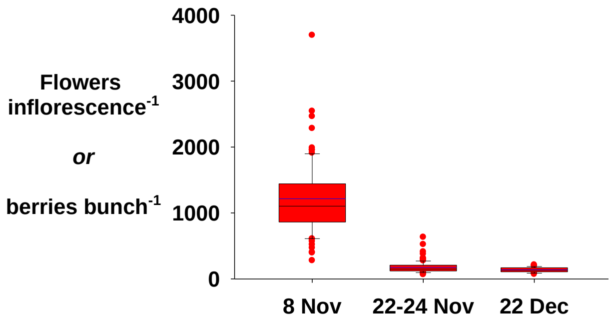


Figure 5. Box plots of flowers per inflorescence in early November and berries per cluster in late November and December 2005.

There appears to be two periods of significant flower/berry drop (Figure 6). The first period comprised mostly flowers and the second period comprised mostly small berries of 1-2 mm diameter. The loss of small berries is visually more dramatic than the loss of a large number of smaller individual flowers, but former is, in numerical terms, much less than the latter.

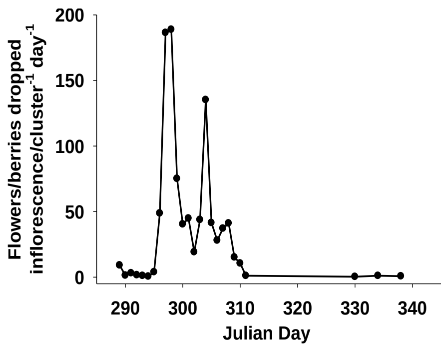
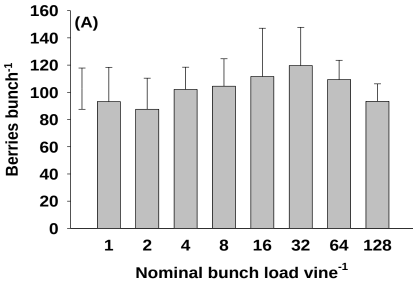


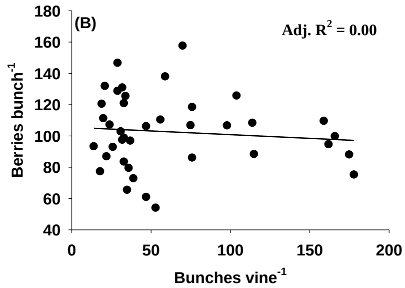
Figure 6 . Time course for Sunmuscat flower/berry drop for inflorescences-/clusters during 2005-2006 season.
Values presented are means (n=10).

Berries per bunch is unrelated to crop load

To investigate the competition for assimilate between inflorescences and the rest of the vine and within inflorescences, the number of inflorescences per vine was manipulated by systematically removing inflorescences to leave between 1 and 128 inflorescences per vine in a geometric series of power 2 (*i.e.* 1, 2, 4, 8, 16, 32, 64 and 128 inflorescences per vine). The experiment was carried out on a single row of vines at DPI Victoria's Koorlong Avenue site during the 2006-2007 season. There were five blocks of eight vines with buffer vines at each end of the row. The treatments were imposed by tagging bunches that were to remain, and then removing all others. At maturity all bunches were removed and the number of berries per bunch and total soluble solids were determined.

The actual number of bunches per vine at harvest varied between 14 and 178; a factor of greater than 10. The difference between the intended bunch load and the actual bunch load can probably be attributed to the difficulty of finding all the inflorescences prior to flowering and/or stimulation of fertile lateral buds induced by removal of a significant amount of the main crop.





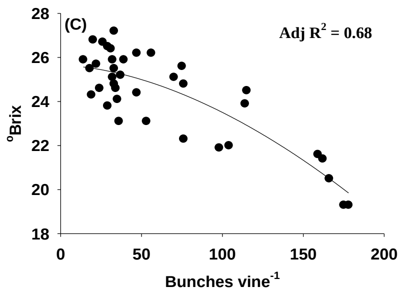


Figure 7. Crop load reduction effects on Sunmuscat bunches and maturity. (A), effect of reduction of inflorescence numbers to nominal levels prior to flowering (October, 2006) on mean berries per bunch at harvest (February, 2007); (B), bunches per vine at harvest versus berries per bunch at harvest (February, 2007); (C), mean bunches per vine versus mean total soluble solids (^{o}Brix) at harvest (February, 2007).

The imposition of a nominal load of inflorescences per vine prior to flowering was not a significant influence on the number of berries per bunch at harvest [Figure 7(A)]. Across whole vines, the average number of berries per bunch varied between 54 and 156 [Figure 7(B)]; a factor of less than 3. There was no relationship between the number of bunches per vine and the number of berries per bunch. In other words, competition for assimilate between bunches on a vine during flowering/fruit set/bunch shatter is not a factor in the problem of low berry numbers per bunch at harvest.

On the other hand, increasing bunch load was negatively correlated with berry maturity [Figure 7(C)]. The difference in maturity between grapes on vines with low bunch loads and grapes on vines with high bunch loads was almost 8°Brix, which amounts to almost 4 weeks in terms of the time taken to accumulate soluble solids at 2°Brix per week.

Clusters compete poorly with growing shoots for assimilate

Shoots grow rapidly at the time of fruit set, and growing shoots compete strongly with setting berries for assimilate. An observation trial was set up to determine competition between fruiting and non-fruiting shoots. Fruiting and non-fruiting shoots were sampled regularly throughout the season, separated into component parts and weights determined.

The presence of a cluster only marginally affected the growth of the fruiting shoot. Shoots grew exponentially between October and November (Figure 8). But the growth of a cluster is significantly slower than that of shoots. Clusters started growing only when shoot growth slowed down, *i.e.* during November, suggesting that competition for carbon was involved between a) set berries and shoots and b) clusters and shoots. This competition for assimilate between berries at the time of flowering/berry set and growing shoots may have a detrimental effect on final berry set and dvf yield at harvest.

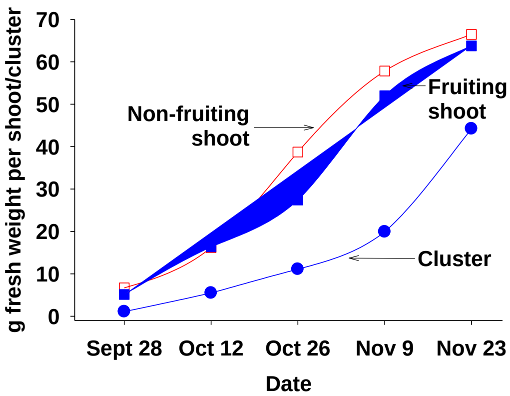


Figure 8. Growth of non-fruiting shoots, fruiting shoots and clusters during 2006-2007 season.
Values are means (n=12).

Assimilate partitioning management and mineral nutrients

Adequate vine nutrient status is essential for high levels of productivity for both (i) floral bud initiation and (ii) pollen viability/pollen tube growth (PradeepKumar et al., 2008). The bunch to shoot ratios across the six sites described previously suggest that floral bud initiation is not a limiting factor.

The mineral nutrients zinc, boron—classified as micronutrients—and calcium have well established roles in pollen viability, pollen tube growth and abscission zones (Beyer and Quebedeaux, 1974; Brewbacker and Kwack, 1963; Pandey et al., 2006; Sexton, 1998; Sogo and Tobe, 2005), respectively. Equally, insufficient supply of carbon (C) to setting flowers/berries is known to be a factor determining whether a fertilised flower persists through to maturity (Antcliff, 1961; Menzel and Paxton, 1986; Williams, 1980).

A number of approaches were used to determine whether poor productivity in Sunmuscat was due to deficiency of one or more mineral nutrients or limited carbon supply at the time of flowering/berry set.

A series of experiments investigating the impact of boron, calcium, zinc and selenium were conducted to investigate the possibility that one or more of these mineral nutrients were limiting in terms of fruit set and berry retention. Boron and zinc were included in the treatments because poor pollen viability or fertility, in other grapevine varieties, has been linked to deficiencies of these minerals (PradeepKumar et al., 2008). The scale of the experiments varied from dipping individual bunches to spraying whole rows of vines. Boron, calcium, molybdenum and zinc have all been linked to the reproductive biology of plants, but a role for selenium was still speculative.

Figure 9. Cincturing of Sunmuscat trunk using a cincturing tool.
The procedure involves the removal of a 3-6 mm wide ring of bark cutting through the phloem and cambium layers without damaging the xylem.

Cincturing (or girdling) prevents the flow of carbohydrates, minerals and hormones from leaves to the roots and lower trunk (Antcliff, 1961; Menzel and Paxton, 1986; Williams, 1980) (Figure 9).

Cincturing is carried out on mature, well established vines with the aim of enhancing availability of carbohydrates, minerals and hormones to the developing berries, rather than for export to the roots and lower trunk. Data collected over two seasons (2005-2006 and 2006-2007) suggest that cincturing vines at flowering was associated with a 30% increase in berries per bunch at harvest.

To investigate the role of mineral nutrients at the time of flowering/berry set, a trial was conducted that involved dipping developing Sunmuscat inflorescences in solutions of B (20 ppm), Ca (1,000 ppm), Mo (2 ppm) or Se (1 ppm) prior to flowering in conjunction with the first cincturing trial mentioned above. Inflorescences were also dipped in a 3,000 ppm solution of Zn, but this concentration desiccated the inflorescences rapidly, and a reduced concentration of 1,000 ppm also resulted in inflorescence desiccation. At this stage, the other mineral element treatments had already been applied twice, and so Zn was not included in the experiment conducted during the 2005-2006 season.

Counts of the number of berries per bunch at fruit maturity suggested that dipping inflorescences in any mineral prior to flowering did not result in more berries per bunch at maturity. Further analyses using the mineral content of the berries at harvest—as an index of the mineral nutrient status of the inflorescence at flowering—as covariates indicated significant effects attributable to dipping in specific mineral salts (Table 6). In addition, a significant interaction with cincturing suggested that cincturing was only effective if the inflorescence Se content was “adequate”, and the inflorescences had been dipped in either Ca, or B, or Se. This effect amounted to *ca*. 20-30 additional berries per bunch. Dipping inflorescences in a solution containing Mo had no effect, and, therefore, Mo was not considered further.

Table 6. Effect of cincturing whole vines and dipping individual inflorescences in solutions containing Ca, B, Mo or Se on berries per bunch at harvest during 2006-2007 season.
Different superscripts indicate a significant difference between means at P=0.05. Berry Se levels at harvest was used as a covariate.

	Treatment				
	Control	Mineral			
	(undipped)	Ca	B	Mo	Se
Control	100^{a}	101^{a}	104^{a}	103^{a}	107^{a}
Cinctured	118^{a}	149^{b}	140^{b}	114^{a}	145^{b}

Clearly competition for carbon was involved in the fruit set/bunch shatter problem, but modern methods to ameliorate the effects of this competition are based on the use of Cycocel®, a growth retardant that acts by inhibiting the synthesis of gibberellic acid (Ninnemann et al., 2005). To establish whether this chemical could be effective on this variety for this purpose, whole vines were sprayed with 100 mL Cycocel® $100L^{-1}$ spray mix in the last week of October or the first week in November, 2006. Another set of vines were cinctured at the same time, and another set of vines were maintained as control vines. The vines were chosen on the basis of similar bearer numbers. In January, 2007, 10 bunches per vine were sampled at random, and the number of berries per bunch determined. There were six replicate vines for each treatment. The data were subjected to outlier analysis and tests for normality and variance homogeneity, and the data analysed as described previously.

Irrespective of timing, cincturing resulted in 21-24 more berries per bunch in January compared to the control (Figure 10). The application of 100 mL Cycocel® 100L^{-1} in late October or early November did not result in more berries per bunch in January.

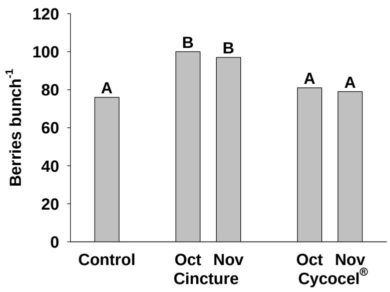


Figure 10. Effect of cincturing or Cycocel® applied at 100 mL 100L^{-1} in late October or early November, 2006 on the number of berries per bunch in January, 2007.
Values presented are means (n=6) and different letters above columns indicate significant differences between means at P=0.05.

The response to cincturing and dipping in mineral salts observed in 2005/06, and the response to cincturing in 2006/07 seasons served as the basis for the design of a large trial conducted in the 2007/08 season on a commercial vineyard property. The trial was designed to determine if a reduction in the competition for assimilates and nutrients between the growing shoots and bunches will improve berry set and if the application of Cycocel® is as effective as cincturing in improving berry set. It was also designed to assess potential for enhancement of berry set by application of mineral treatments.

The trial was established across 72 whole rows in a randomized block design (24 rows per block), and included 3 Cycocel® treatments (0 control, 40 mL/100L and 400 mL/100L) in each block, with all combinations of mineral treatments (B, Ca and Zn) applied to rows within each Cycocel® treatment in each block Figure 11). Mineral elements were applied as follows: 5% boron ($Na_2B_4O_7.10H_2O$), 16% Ca ($CaCl_2.H_2O$), 8% Zn ($ZnCl_2$), at rates of 5L/ha, 6L/ha and 2L/ha, respectively, prior to flowering in conjunction with cincturing as mentioned in the text below. The cincturing treatments were embedded in each row as subplots (3 replicates per row) using paired vines for comparative studies (*i.e.* cinctured versus uncinctured). Thus, the trial was a split-split plot design; the Cycocel® treatments comprised the main plots, the mineral spray treatments were the subplots, and the sub-subplots were cincturing comparisons. Selenium was not included in the trial because of the danger the element poses to human health in high concentrations.

The spray treatments were applied by a commercial contractor using a modern spray unit (Figure 12). The mineral treatments were applied 4 times and the Cycocel® treatments were applied twice before flowering. The number of berries per bunch was determined using a single bunch collected in January from each of the 6 vines in each row comprising the 3 pairs of cinctured and uncinctured vines in each row. Yields of dvf fruit were measured on the same vines in March, but it was recognized at that time that those yield estimates were prone to large degrees of error due to the difficulty of separating dried berries from dried leaf and rachis material and limited irrigation due to reduced water allocations, and for that reason are not considered further. Soil texture on the trial site varied from a heavier silty loam with limestone present at the surface to a sandy loam, and, thus, soil fertility could reasonably be expected to vary as well, and possibly affect the degree of response to the mineral nutrient treatments. To address this possibility, 20-30 petioles from opposite basal bunches were sampled at 50% capfall down each row and analysed for P, K, Mg, S, Na, B, Mn, Fe, Cu, Zn and Mo using inductively coupled plasma emission spectroscopy. All data were subjected to outlier analysis and tests for variance homogeneity and normality as described previously, and the analysis of variance was conducted using GenStat (11th Edition). Petiole nutrients at flowering were used as co-variates.

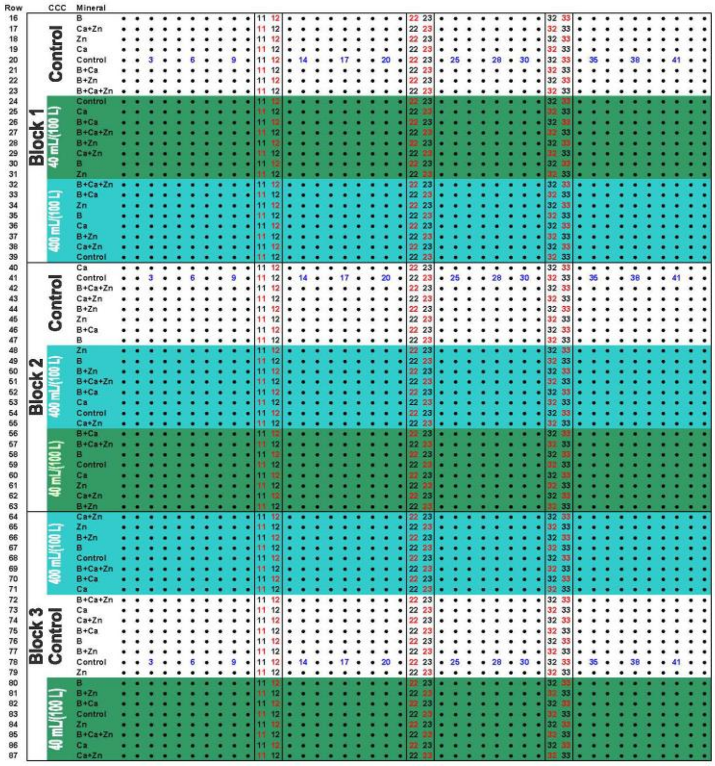


Figure 11. Site layout and experimental design and for Cycocel® and mineral nutrient applications and cincturing trial conducted in the 2007-08 season on DPI Victoria's Koorlong Avenue vineyard. Aerial image courtesy of GoogleEarth.

Analysis of the numbers of berries per bunch in January 2008 indicated that, across the site, the application of Cycocel® resulted in *ca.* 27 more berries per bunch in January, and that cincturing resulted in *ca* 54 more berries per bunch in January compared to bunches on unsprayed and uncinctured vines, respectively. The response to Cycocel® contained a strong linear component to increasing Cycocel® concentration; *viz* Control, 113^{A} *c.f.* 40 mL $100L^{-1}$, 135^{AB} *c.f.* 400mL $100L^{-1}$, 145^{B}, respectively, where different superscript letters indicate significantly (P=0.05) different means. The analysis also indicated a significant interaction between cincturing and the application of mineral sprays (Figure 13), but the mineral sprays main effect was not significant.

Figure 12. Commercial spray unit used to apply Cycocel® and mineral nutrient treatments the foliage to ensure thorough coverage under “real world” conditions.

The response to cincturing and the nature of the interaction is readily apparent: there was no response to any mineral spray unless the vines had been cinctured. The data presented in Figure 13 also suggest that any spray treatment containing Zn was more likely to result in an increase in berries per bunch. Significant responses to B and Ca were observed, but those responses were not as strong as the responses to Zn alone or Zn in combination with the other minerals. Thus, the data suggest that, on this site, there is a latent deficiency of Zn, and that possibly the vines were also marginal with respect to Ca and possibly B.

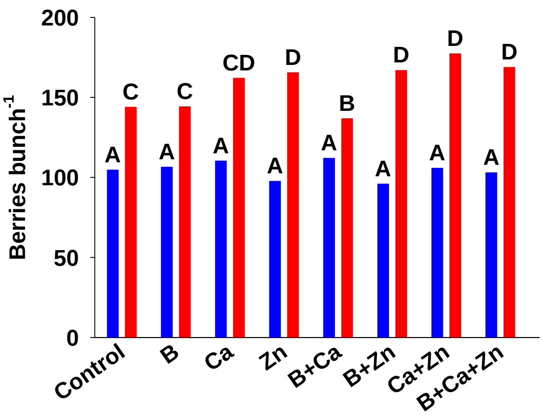


Figure 13. Interactive effects of cincturing and mineral spray applications prior to flowering on the number of berries per bunch in January.
■, bunches on uncinctured vines; ■, bunches on cinctured vines. Values presented are means (n=18) calculated from the untransformed data. Analysis and identification of significant differences between means conducted on transformed data. Different letters above bars indicate significantly different (P=0.05) means.

The covariance analysis indicated that the Cycocel® effect only remained significant when P and Na were used as covariates. This suggests that levels of the remaining minerals at flowering contributed in some manner to the Cycocel® response. The significance of the cincturing effect and the cincturing by spray interactive effect did not alter when levels of mineral nutrients in the petioles at flowering were used as covariates.

Conclusions and recommendations

The data collected over three seasons indicate that competition for assimilate is important in determining the number of berries per bunch in Sunmuscat. Management practices that have potential to limit carbon assimilation and supply, *e.g.* water deficit pre-flowering and during flowering and fruit set therefore need to be avoided. Trials conducted over three seasons indicated that cincturing can be used as a management practice to improve berry set by *ca*. 30-50%. If the carbon allocation problem is addressed then spraying B, Ca and/or Zn had a positive effect on berry numbers per bunch, amounting to an increase of *ca*. 20 berries/bunch. The response to CCC appears to be less than the response to cincturing indicating that there is considerable scope for improving the timing of CCC application in relation to obtaining increased berry set for this variety.

Future research to develop effective CCC spray should be based on

- developing a predictive model for Sunmuscat flowering behaviour, and
- quantifying the rate response when timing has been optimised.

The nature of the cincturing/CCC effects could be investigated by measuring assimilate supply to developing inflorescences and berries.

Technology transfer

Technology transfer has involved publication of results in industry journals, field demonstrations, reports; oral presentations at steering committee meetings; information sessions with industry stakeholders.

Field demonstration to growers

1. Singh, D.P. and Treeby, M. (2008). Labour saving in the vineyard. Growers' day at Red Cliffs,
2. Singh, D.P. (2008). Field day at DPI, Irymple vineyard.
3. Treeby, M. (2007). Field day at Cardross, Irymple.
4. Treeby, M. (2006). Field day at Irymple.

Oral presentations

1. Singh, D.P. 24th October, 2008. Sunmuscat fruitset and bunch shatter. Sunraysia dried fruit committee meeting.
2. Singh, D.P. 4th August, 2008. Sunmuscat fruitset and bunch shatter. Dried Grape Industry meeting.
3. Singh, D.P. November, 2007. Sunmuscat fruitset and bunch shatter. Dried Grape Steering committee meeting.
4. Treeby, M. 29th October, 2007. Sunmuscat fruitset and bunch shatter. Dried Grape Steering committee meeting.
5. Treeby, M. 19th October, 2006. Sunmuscat fruitset and bunch shatter. Dried Grape Steering committee meeting.
6. Treeby, M. 28th October, 2006. Sunmuscat fruitset and bunch shatter. Dried Grape Steering committee meeting.

Industry publications

1. Singh, D.P. (2009). Sunmuscat fruitset and bunch shatter. *Dried Grape Annual Industry Report (Horticulture Australia Ltd.)*.
2. Singh, D.P. (2008). Sunmuscat fruitset and bunch shatter. *Dried Grape Annual Industry Report (Horticulture Australia Ltd.)*.
3. Treeby, M.T., Swain, S.M. and Fitos, J.L. (2007). Solving poor fruit set of Sunmuscat. *The Vine* **3**, 28.
4. Treeby, M.T., Swain, S.M. and Fitos, J.L. (2006). Sunmuscat fruit set and bunch shatter. *The Vine* **2**, 23.
5. Treeby, M. and Swain, S. (2006). Sunmuscat fruit set and bunch shatter. *The Vine* **2**, 23.
6. Treeby, M.T. & Swain, S.M. (2006) Sunmuscat flowering and fruit set. *The Vine* **3**, 32-33.

Poster

Treeby, M.; Fitos, J. and Swain, S. May, 2007. Sunmuscat fruit set and bunch shatter. ADFA Horticultural Field Days, Mildura.

Acknowledgments

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