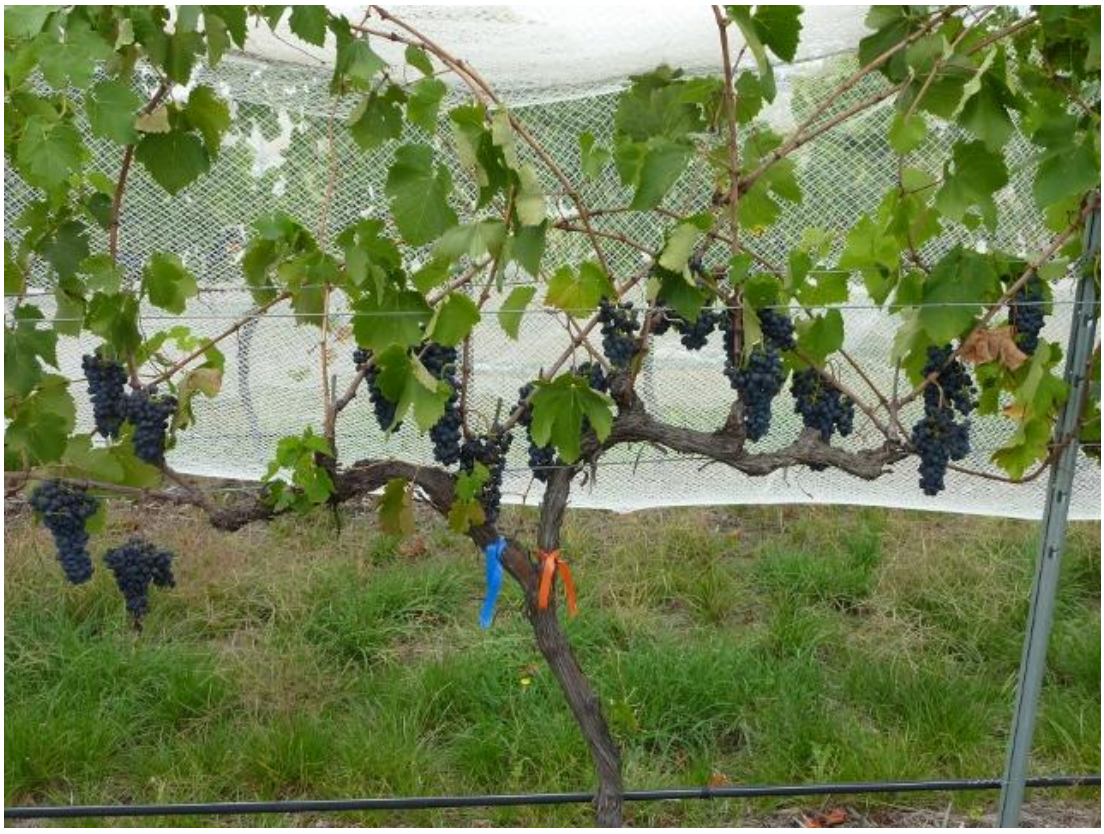
Regulating sugar accumulation through canopy management



FINAL REPORT to
GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

Project Number: RT 08/03-3

Principal Investigator: John Whiting

Research Organisation: Bendigo Winegrowers Association

Date: June 2011

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Author: John Whiting

For Bendigo Winegrowers Association

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1. Abstract

Leaf removal was investigated as a means of slowing the accumulation of sugars into grapes. This was undertaken in response to warmer seasons where grapes were reaching the optimum sugar maturity three to four weeks earlier than average and during a hotter part of the season. In the first season, two timings (4 and 11/2 weeks before veraison), and three target levels of leaf removal (50%, 67% and 75%) were investigated. Timing of leaf removal did not significantly impact on sugar accumulation in the grapes. The delay in reaching a target sugar concentration of 25º Brix (13.9 Baume) compared with the control treatment were 7, 19 and 22 days respectively for the 50%, 67% and 75% leaf removal treatments. Leaf removal reduced anthocyanin concentrations in the berries but not phenolic or tannin concentrations. In the second season the removal of 75% of the leaves just before veraison was compared with no leaf removal and grapes were harvested at three target sugar concentrations. Leaf removal delayed sugar accumulation at all three stages of harvest. Wines made from leaf thinned treatments at each target sugar concentration showed less colour than wines from control vines but there were no differences in tannin concentrations. Wine tastings rated the leaf removal treatments below that of no leaf removal and substantial variations in wine score were evident between the three target sugar concentrations. This experiment has demonstrated that sugar accumulation into the grapes can be regulated by leaf removal and there may be a reduction in colour but not tannins in red grapes and wine. Further investigation is required to ascertain the cause of the reduction in colour and possible remedies.

2. Executive summary

Changes in climatic conditions, principally increased temperatures, have resulted in significant increases in the rate of sugar accumulation into the berries. This has led to increased wine alcohol concentrations and unbalanced wines that have elicited negative responses from some consumers and wine judges. The Bendigo Winegrowers Association obtained GWRDC RITA funding to examine aspects of premature ripening. Part of the project looked at slowing down ripening in a field demonstration and the other part provided information back to the growers through seminars and industry journal articles.

In the first season in 2008-09 the field demonstration involved removing leaves to slow down sugar accumulation in the berries. The first year of the trial showed that there were no differences in ripening between the timing of leaf removal either at the end of rapid shoot growth or just before veraison. The degree of leaf removal had an impact on ripening with 50% leaf removal delaying ripening by around 7 days and 75% leaf removal producing a delay of up to 29 days to reach a target sugar concentration of 25° Brix (13.9 Baume). In the berries, leaf removal produced lower berry weights, higher phenolic and tannin concentrations and lower anthocyanin concentrations compared with control vines. These results and other related topics were discussed in a seminar in November 2009.

In the second season in 2009-10 only one leaf removal treatment was tested in the field (75% leaf removal just prior to veraison) and sufficient grapes were produced to harvest at three sugar concentrations to make small batches of wine. Leaf removal delayed ripening by 20 to 42 days depending on the target sugar concentration, although in the 2009-10 season substantial rainfall occurred from March onwards and this contributed to delaying sugar accumulation. Harvesting at successively higher sugar concentrations produced lower weight berries, lower titratable acidity and higher pH in the berries, along with greater colour density, total phenolics and tannin concentrations in the wines.

Leaf thinning produced lower berry weights, lower titratable acidity and higher pH in the berries. In the wines, leaf thinning produced lower colour density, total phenolics and anthocyanin concentrations, but there were no differences in tannin concentration compared with control treatments. Wine tasting assessments showed differences in wine colour, aroma and the palate between harvesting at the different sugar concentrations and between leaf thinning and control. The primary impact of the leaf thinning in the wine was reduced colour but the aroma and taste were also less intense to some tasters. The latest harvested grapes (mid April) had developed eucalypt characters. A seminar in June 2011 discussed the trial results and addressed other related topics was delayed due to growers being preoccupied with a very wet season (conducted in June 2011).

In summary leaf removal will delay sugar accumulation and it needs to be around two thirds leaf removal to provide a significant delay. Whilst leaf removal seems to have minimal impact on tannins in the fruit and wine, grape and wine colour is reduced by leaf thinning (despite leaf thinning producing smaller berries) and the reduced colour may be due to higher berry temperatures from greater fruit exposure. These results may also have application for seasons where extensive leaf loss occurs due to extreme events, e.g. the 2010-11 season where downy mildew depleted the leaf area on many vines.

3. Background

The Bendigo wine region has an esteemed history of producing wines of quality and style. From the genesis of the industry in the 1850s, the region achieved national and international acclaim in the 1880s. The wine industry suffered a decline in the 1890s due to the destructive pest grape phylloxera along with tough economic times. Since the re-establishment of the industry in the 1970s the region has once again been well recognised for the quality of the wines. The Bendigo region now encompasses some 890ha (DPI Victoria, Phylloxera Exclusion Zone survey) capable of producing an estimated 6,000 tonnes.

In recent years the Bendigo Winegrowers Association (BWA) has focused on a strategic direction for the region. Activities have included developing a regional marketing strategic plan, branding of the region (Rich Ripe Reds), critically reviewing their wine styles with an independent consultant and conducting a seminar on improving wine quality in the vineyard and winery.

Following a seminar on improving wine quality (see report on seminar - Whiting 2008), the BWA reviewed the outcomes of the seminar and outlined further issues to be addressed. One of the major issues was of rapid ripening and high sugar concentrations at harvest and consequent flavour imbalances in the wine. The issue has become more pronounced in recent years and appears to be associated with drought and climate change.

Some techniques to address high fruit sugar levels and resultant alcohol concentrations in the winery are being explored by the Australian Wine Research Institute, such as lower alcohol yielding yeasts. Whilst increasing the water supply and the yield will delay ripening, during drought conditions and with above average seasonal temperatures, these techniques to reduce sugar concentrations are not feasible. Little research and extension into vineyard management practices to delay sugar accumulation under warmer climatic conditions has appeared.

An option to delay sugar accumulation is through adjusting the leaf to crop ratio (Petrie *et al*. 2000). Research by many workers has shown a significant reduction in sugar accumulation when the leaf area to crop weight ratio gets below around 10 cm^2 g^{-1} of fruit (Smart and Robinson 1991, Kliewer and Dokoozlian 2001, Intrieri and Filipetti 2001), although this value is variety and location dependent. Previously this relationship has been investigated in relation to optimising grape ripening but in the current context the relationship could also be used to limit sugar accumulation. The relationship is also quite robust and consistent so the likelihood of this being a successful technique is high.

The outcomes of previous research now need to be applied in a commercial situation under local climate and management conditions. Hence a field demonstration of the technique is a critical step in evaluating its effectiveness as a management technique. Practical and inexpensive techniques to reduce leaf area are available, e.g. mechanical leaf pluckers. Whilst the relationship between the leaf area to crop weight ratio on ripening is clear, it is less well known what the impact may be on grape quality components or the longer term effects of leaf removal on vine carbohydrate storage. The timing of leaf defoliation can have a significant impact on the vine response with earlier leaf removal (4 weeks after flowering) having greater negative impacts than later timings of leaf removal (Bennett *et al*. 2005).

Adoption processes in farming show that farmers do not necessarily embrace the complete application of a new innovation (Pannell *et al*. 2006). Regulated Deficit Irrigation is a good example where not many growers currently use the technique as defined during the research stage, but rather they use bits and pieces of it that suit their vineyard context. In this project, a good outcome would be to encourage growers to experiment with the

technique and improve its applicability to a range of commercial situations. The BWA have identified rapid sugar ripening as an issue and have been motivated to seek a solution to the issue by commissioning the project. This approach is consistent with a series of steps growers need to go through in order to adopt new innovations (Nicholson *et al*. 2003).

The outcomes of the project are likely to have impact because it has been identified as a high priority issue by the BWA. The impact would be measurable in monitoring the future alcohol content of Bendigo wines along with quality assessments. The approach also has application across a broader number of regions in central Victoria. Co-investment will be provided by cooperating vineyards, the BWA and the Department of Primary Industries (DPI), Victoria.

The first year of the project will determine the approximate leaf area to crop weight ratio for the Shiraz variety in the Bendigo region. A pilot trial will be established by John Whiting Viticulture at Balgownie Estate and funds are required to undertake periodic sampling and analysis of berry samples. Measurements of grape anthocyanin and tannin concentrations will be provided by DPI Mildura. Progress results will be reported at a seminar after the season is completed. The seminar will also include invited speakers on other aspects of grape and wine quality identified by the BWA during their review of future R&D activities.

The second year will utilise results from the first season and focus on the application of leaf removal on larger blocks of vines under commercial production systems. Ripening will be monitored and, if appropriate arrangements can be made within the limited RITA budget, wine samples will be prepared for analysis and organoleptic assessment. A second seminar will be held to relay the results to growers and provide an opportunity to assess the wines.

4. Project Aims and Performance Targets

1. To delay sugar accumulation in red grapes through canopy manipulation.

2. To demonstrate a practical method of canopy manipulation under commercial conditions.

Outputs will include two seminars at two stages of the project and associated seminar proceedings. Two general extension articles will also be produced and a final report.

Performance targets

1. To delay sugar ripeness by 2-4 weeks while maintaining yield and quality.
2. To demonstrate the feasibility of using canopy manipulation on a commercial scale.
3. To run two seminars with attendance of 40 people at each seminar.
4. To prepare two extension articles during the project and a final report within GWRDC timeframes.

5. Method

The project had a field demonstration component and an extension component. The field demonstration aspect applied basic research outcomes to help refine the application of the proposed technique to a field situation in the Bendigo region. The first year investigated the appropriate timing and extent of leaf removal, whilst the second year focused on the impact of leaf removal on wine composition and organoleptic assessment. The extension component provided updates on progress with the field demonstration along with other information relevant to grape ripening and handling high sugar musts in the winery.

The original intention of the project in the second year was to apply leaf plucking on a larger scale using mechanised means. However feedback from the BWA indicated they would need to see the impact of leaf plucking on wine quality before they committed to larger scale applications of the technique. Thus the focus in the second year changed to examine wine quality.

Year 1

A field demonstration was established in Shiraz at Balgownie Vineyards, Maiden Gully, Victoria (S36.735787, E144.189870). Rows were orientated east-west and vines trained to a vertical shoot positioned system with movable foliage wires. The mean yield for the experimental block was equivalent to 7.5 t ha^{-1} and 0.6 Ml ha^{-1} of irrigation was applied during the season.

The main aim of the experimental treatments was to determine the optimum timing and degree of leaf removal to induce a delay in sugar accumulation. There were two timings of leaf removal, one at the end of rapid shoot growth (early) and the other just prior to veraison (late). Three levels of leaf removal were assessed aiming for 50, 67 and 75% leaf removal applied by removing leaves alternatively along the shoot. An additional treatment was added examining 75% leaf removal above the bunch zone at the later timing to provide leaf protection around the bunches. The control vines were untreated. The treatments were applied in a factorial design to single vine plots in a randomised complete block with six replications.

Assessments included the estimation of canopy leaf area using a relationship between leaf length and area, regular sampling for berry weight and composition, sampling at a target sugar concentration for berry weight and composition, including berry tannins, phenolics and anthocyanins at harvest, and yield and components of yield. Leaf area per vine was assessed non-destructively at veraison by using a relationship between leaf length and leaf area (Area = aL^b , where L is leaf length – see Williams and Martinson 2003). The average leaf area on four randomly selected shoots per vine was calculated and multiplied by the number of shoots per vine to calculate total leaf area per vine.

Weekly berry samples were collected and frozen, then thawed and juiced and analysed after the season had finished. At a predetermined target harvest sugar concentration (26° Brix, 14.4 Baume)vines were harvested and extra berry samples were collected and frozen for berry phenolic, tannin and anthocyanin measurements (Habertson *et al.* 2003)) by Dr Mark Downey's laboratory at the Victorian Department of Primary Industries, Irymple. The weekly and final harvest juice samples were analysed for sugar concentration, titratable acidity and pH by a OenoFoss™ interferometer maintained and calibrated by Balgownie Wines.

In the following season a Merbein Bunch Count was conducted on the trial vines at around flowering to assess the potential impacts of leaf removal on aspects of budburst and fruitfulness. Data was analysed by analysis of variance as well as linear and non-linear regression.

Year 2

The experiment was established on Shiraz vines also at Balgownie Vineyards on another block with the same row orientation and trellis system as in year 1. In this experiment the removal of 75% of the leaves by sequential removal along the shoot was applied just prior to veraison and was compared with untreated control vines. Each treatment was applied to panels of four vines with 18 panels of each treatment randomly allocated across the block. Each treatment was harvested at three target sugar concentrations (12.5, 13.5 and 14.5 Baume). An additional treatment of simulated mechanical removal of all shoot growth above the bunch zone (approximately 75% of the shoot) was applied to four adjacent panels and this was only harvested at a target sugar concentration of 13.5 Baume. This treatment was added to evaluate one of the methods used by Stoll *et al*. (2009) to slow down the ripening of Riesling.

Each panel was sampled weekly for sugar concentration and when the target sugar concentrations were reached, the grapes on three panels were harvested (data on yield and bunch number per vine collected, and berry samples for composition collected) and processed for wine making. The grapes were pooled and then split evenly for two winemaking replications. Grapes were crushed and destemmed, SO_2 added at 75 mg L^{-1}, DAP added at 400 mg L^{-1}, and yeast (Lalvin® 2226) at 250 mg L^{-1}. Fermenting musts were pressed after seven days and malolactic culture Viniflora® CH16 added at recommended rates.

Wines were maintained at approximately 20°C until testing for malic acid indicated that malolactic fermentation was complete or had stabilised. Wines were then adjusted for pH, cold stabilised and bottled with Stelvin screw caps. The post primary fermentation processes were completed at the CSIRO Wine Laboratory, Merbein. Basic pre-bottling wine data of the wines (alcohol, volatile acidity, pH, titratable acidity) was supplied by CSIRO Merbein. The wines were also analysed spectrophotmetrically (Iland *et al*. 2004) and the protein precipitation tannin assay technique (Habertson *et al*. 2003) by Dr Mark Downey's laboratory at the Victorian Department of Primary Industries, Irymple.

The berry samples collected weekly and at harvest were frozen and then thawed, juiced and analysed after harvest was completed. The juice samples were measured using the same OenoFoss™ equipment as in year 1. Data to compare treatment means was analysed using REML due to uneven numbers of replications, as well as linear and non-linear regression.

6. Results and Discussion

Climatic data

Temperature and rainfall data were collected from the Bendigo weather station (Station Number 81123) over the 2 years of the trial and compared with short and long term averages. Temperature data was converted to Heat Degree Days (HDDs) and plotted as a cumulative total through the season (Figure 1). The longer term (50 year) mean had the lowest cumulative HDDs (1736°C) compared with recent seasons. The mean cumulative HDDs going back 5 years from the end of the project were substantially higher (1888°C) and this was the period over which concerns were raised about early ripening. The 2008-09 season was only slightly above the long term average (1778°C) whilst 2009-10 was much hotter than even the short term average (2022°C). The 2009-10 season was characterised by a very hot November which pushed the cumulative HDDs up right at the start of the season.

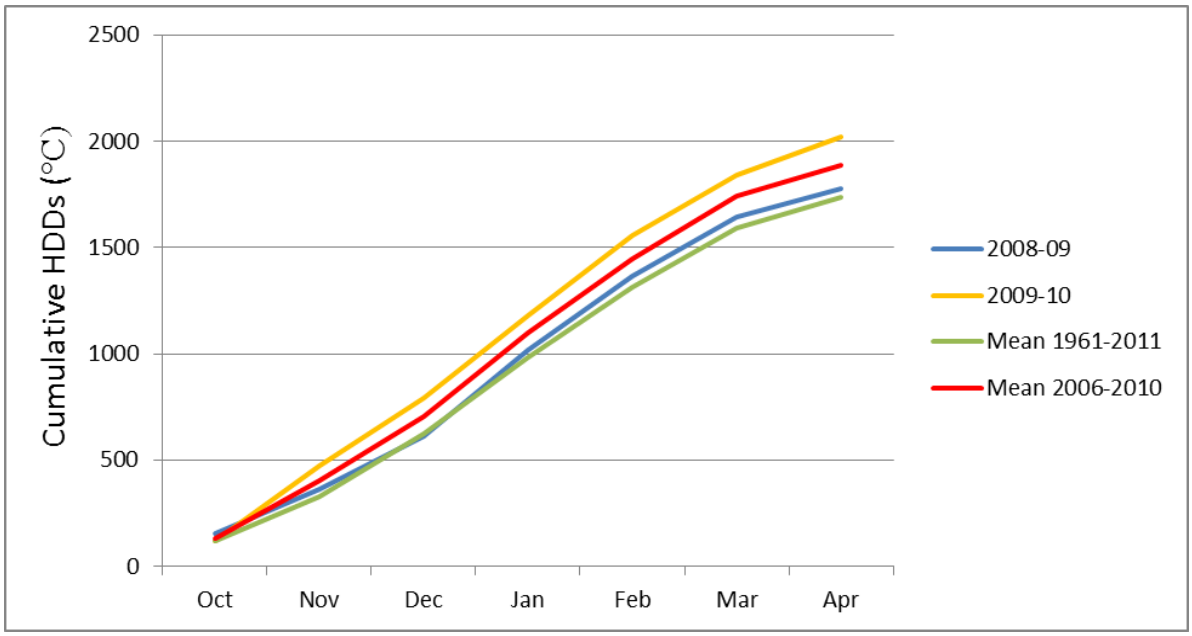


Figure 1. Cumulative Heat Degree Days (HDDs) for the two trial seasons compared with short and longer term averages.

Rainfall data showed variations from the long term mean (150 years) (Figure 2). The 2008-09 season started with reasonable winter rainfall, a dry September and October, a wet November and December, no rain in January and February, and below average rain for the remainder of the season. In 2009-10, rainfall was near average during winter and spring, then drying off in December and January. Rainfall was above average in February and substantially above average from March onwards. Whilst the control treatment was ripe by the time the rain came, the frequent rain slowed the ripening of the leaf thinned treatment which was well behind the ripening of the control treatment.

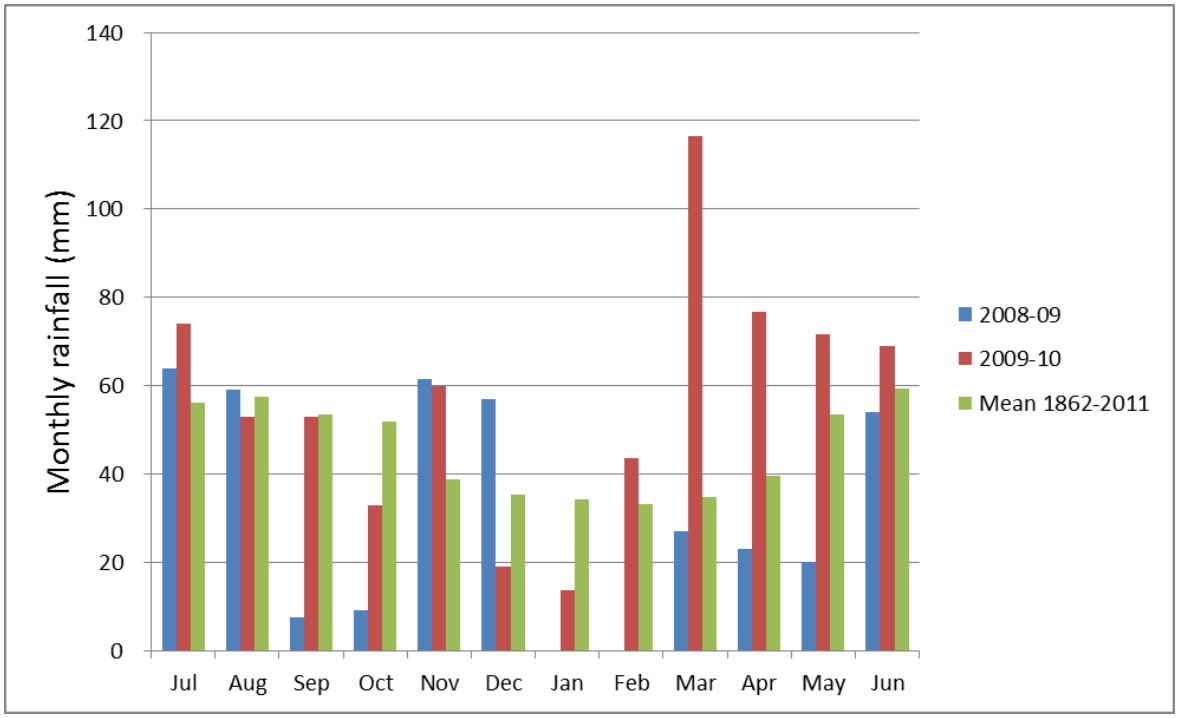


Figure 2. Mean monthly rainfall for the two seasons of the trial compared with the long term mean.

a) Year 1

Leaf area

The relationship between leaf length and individual leaf area was $A = 0.0193L^{1.9105}$, where A is leaf area and L is leaf length, with $R^2 = 0.9591$. Leaf area was calculated on one surface only to reflect the main part exposed to sunlight for photosynthesis. There were no significant differences in shoot numbers per vine across the treatments but there were significant differences in mean leaf area per shoot in line with the degree of leaf removal (Table 1). This resulted in significant differences in total leaf area per vine due to the degree of leaf removal although there was no significant difference between the 67% and 75% leaf removal treatments with leaf area per vine. The actual proportions of leaf removal for the intended 50%, 67% and 75% leaf removal treatments were 42.3%, 66.7% and 70.6% respectively. Where 75% of the leaves were removed above the bunch zone at the late timing, the total leaf removal was 44.7%. Timing of leaf removal had no effect on total leaf area per vine but the late leaf removal treatment resulted in a greater mean area per leaf than early leaf removal (82.7cm^2 vs. 75.3cm^2 respectively, P=0.05). Removing leaves at these stages (end of rapid shoot growth onwards) only produced small amounts of regrowth at the tip of the shoots and no growth of laterals.

Table 1. Leaf area data

	Proportion of leaves removed					LSD 5%
	Control	50%	67%	75%	75% above fruit zone	
Shoots per vine	14.7	15.4	14.8	16.1	15.5	NS*
Mean area per leaf (cm^2)	81.8	82.8	78.1	76.0	84.5	NS
Total leaf area per shoot (cm^2)	3525	1946	1164	948	1866	500
Total leaf area per vine (m^2)	5.16	2.93	1.72	1.51	2.85	0.74

* NS = not significant.

Veraison

Berry sampling commenced before veraison and continued until each treatment was harvested. There was a visual delay in veraison with the leaf thinned treatments (Figure 1) and this was substantiated by counting the proportion of coloured berries at several stages through veraison. Early leaf removal delayed veraison more than late leaf removal (Figure 2a) and a greater degree of leaf removal progressively delayed veraison (Figure 2b). In each case early leaf removal and 75% leaf removal delayed the estimated date of 50% veraison by around 6 days compared with no leaf removal.



Figure 1. Visual delay in veraison with 66% of leaves removed early (L) and control (R) (12 January 2009).

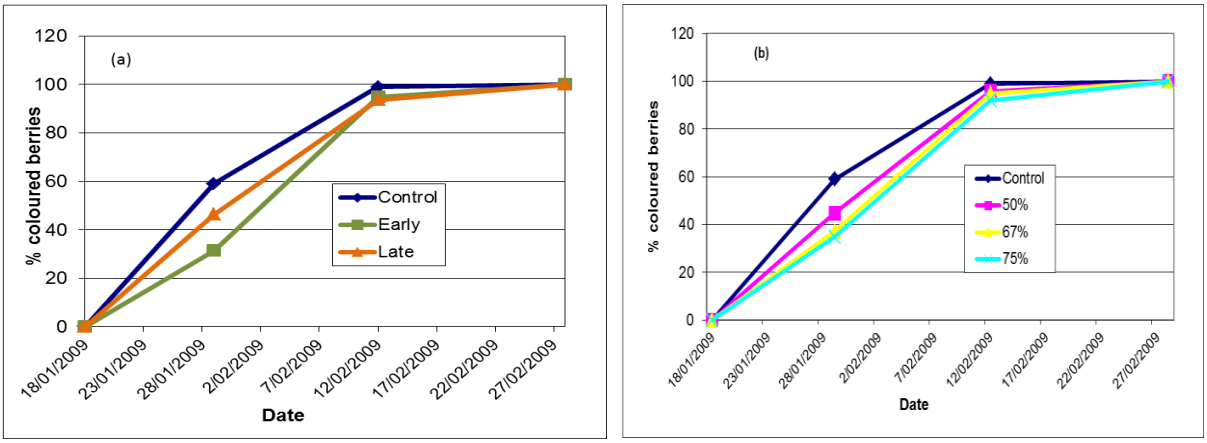


Figure 2. (a) Effect of timing of leaf removal on veraison, and (b) effect of the degree of leaf removal on veraison.

Timing of leaf removal

The timing of leaf removal, either at the end of rapid shoot growth (early) or just prior to veraison (late), showed very few differences between the two treatments. Early leaf removal produced a lower bunch weight, lower final berry weight, more fruitful watershoots and more bunches per watershoot than the late leaf removal timing. The latter effects may relate to better light exposure of the cordon where epicormic buds are present with leaf removal increasing fruitfulness of the resultant watershoots at a later stage (pre-veraison) compared with shoots from spurs where fruitfulness is determined much earlier (around flowering).

Whilst early leaf removal delayed veraison compared with late leaf removal, there were no significant differences in sugar concentration during the remainder of ripening. Hence the timing of leaf removal between the end of rapid shoot growth and just before veraison is not critical, so there is a window of opportunity to conduct leaf removal. Leaf removal before the end of rapid shoot growth increases the potential for shoot regrowth and growth of laterals which may require further leaf removal inputs, and leaf removal at around flowering has quite negative effects on fruitfulness in the following season.

75% leaf removal above the bunch zone

This treatment responded in a very similar manner to the 50% leaf removal along the whole shoot treatment since they both had similar total leaf area per vine. The only significant differences between the two treatments were in anthocyanin content (mg berry^{-1}), anthocyanin concentration (mg g^{-1} FW) and phenolic concentration (mg g^{-1} FW) in the berries at harvest. In these instances values were lower in the 75% leaf removal above the bunch zone compared with 50% leaf removal along the full shoot.

Progressive berry sampling

The remainder of the results and discussion will focus on the degree of leaf removal since that is what produced the greatest delays in ripening. The greater the degree of leaf removal, the slower the ripening of the grapes (Figure 3). The estimated delay in reaching 25° Brix compared with control were 7, 19 and 22 days respectively for the 50%, 67% and 75% leaf removal treatments. The small difference between the 67 and 75% leaf removal treatments reflects the leaf area measurements where there was no significant difference between these two treatments (Table 1). Removing 75% of the leaves above the fruit zone at the late timing delayed ripening to 25° Brix by 9 days (data not shown).

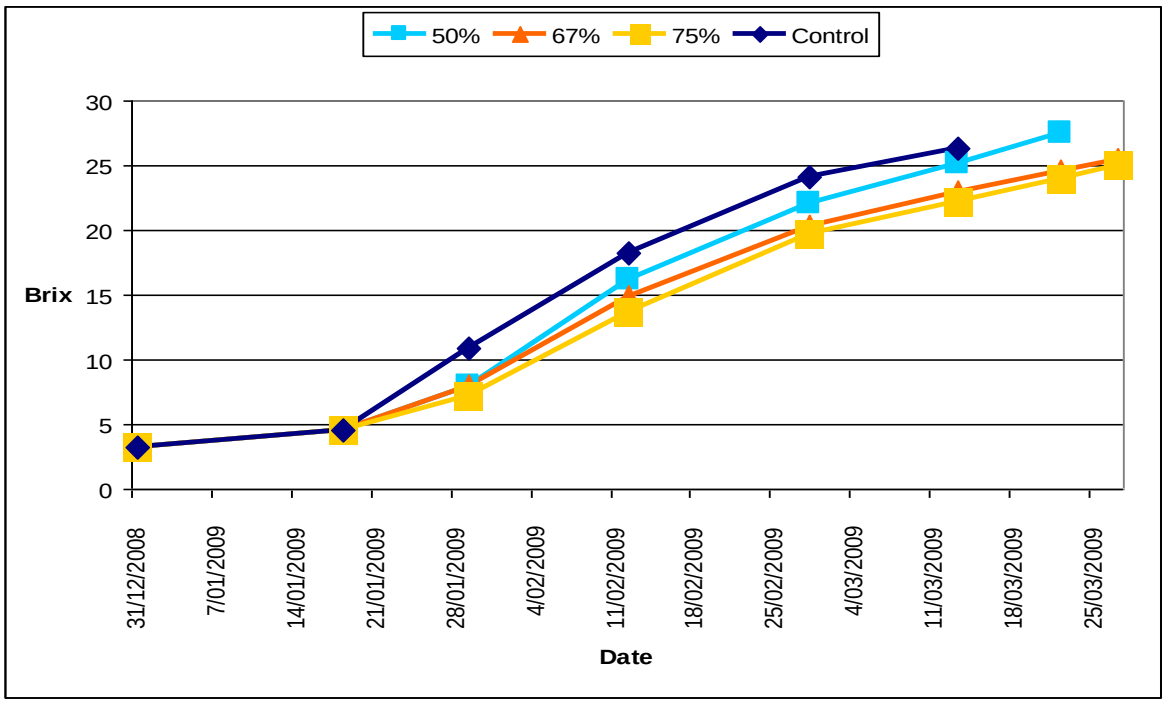


Figure 3. Effect of degree of leaf removal on sugar concentration in the berries during the ripening period.

Berry weight showed the typical trend for Shiraz reaching a peak and thereafter declining (Figure 4). The treatments all appeared to peak at the same time so the degree of leaf removal did not influence the timing of berry weight decline. The longer the berries remained in the field the greater the berry weight reduction. Since sugar concentration was increasing and total sugar content per berry had stabilised during this time the loss of berry weight was due to loss of water. During this dry season, vines were watered sparingly due to limitations on water supply. There were significant differences in final berry weight when treatments were harvested at a target sugar concentration due to greater water loss during the longer period the treatments remained on the vine (Table 2).

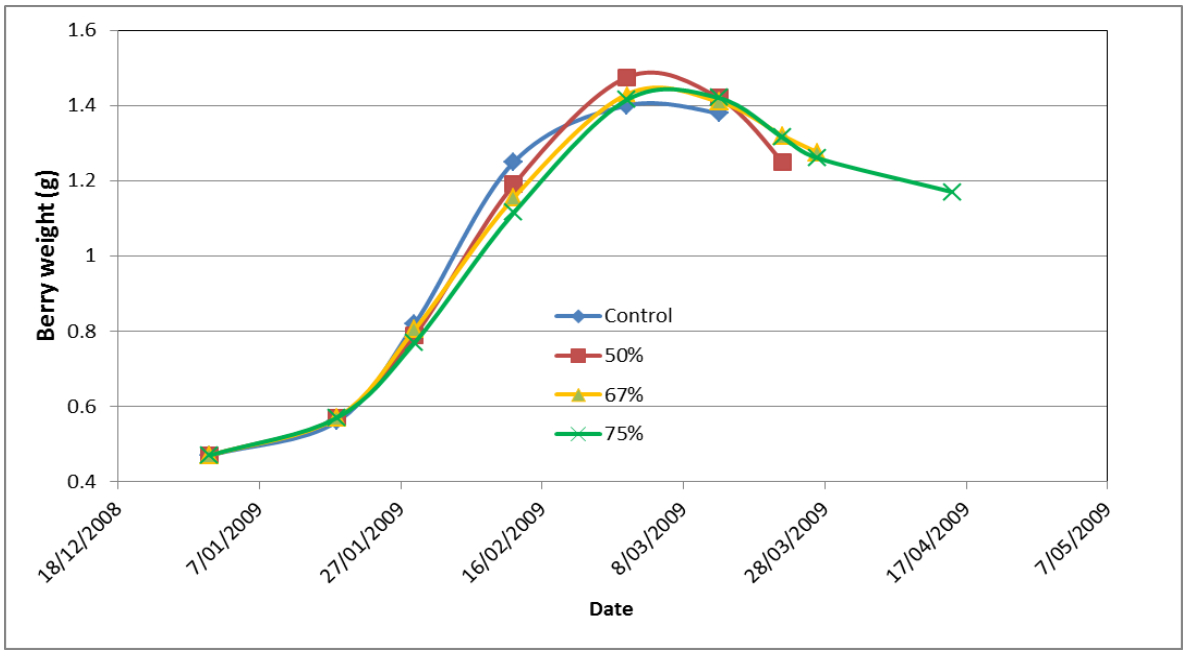


Figure 4. Berry weight changes during ripening of leaf removal treatments and control.

Most treatments were harvested close to the target sugar concentration of 26.0° Brix (±0.5° Brix) but the 50% leaf removal treatment was comparatively over-ripe when harvested (Table 2). There were no differences in titratable acidity between treatments but juice pH was lower on the 67% leaf removal treatment than the control treatment.

Table 2. Berry analysis of leaf removal treatments at harvest.

	Proportion of leaves removed				LSD 5%
	Control	50%	67%	75%	
Berry weight (g)	1.38	1.25	1.27	1.17	0.10
Sugar concentration (° Brix)	26.3	27.5	25.5	26.5	1.1
Titratable acidity (g L^{-1})	3.13	2.99	3.17	3.26	NS
pH	3.89	3.90	3.80	3.83	0.08

Yield and components of yield

Whilst some components of yield showed a significant decrease due to leaf removal compared with control (Tables 2 and 3), yield was not significantly lower on leaf removal treatments. There is a trend for lower yields with leaf removal treatments but perhaps vine to vine variability confounded the statistical analysis. Bunch weights were certainly lower on the 50 and 75% leaf removal treatments compared with control due to a combination of berry weight loss (discussed above) and lower berry numbers per bunch. Given the extra time fruit is left on the vine to achieve ripening it would be expected the leaf removal treatments would make the vine more vulnerable to yield loss through a range of mechanisms (dehydration, bird damage, bunch necrosis, berry rots).

Table 3. Yield and components of yield for leaf removal treatments

	Proportion of leaves removed				LSD 5%
	Control	50%	67%	75%	
Yield (kg $vine^{-1}$)	4.12	3.16	3.59	3.02	NS
Bunch number per vine	25.7	22.8	24.9	26.1	NS
Mean bunch weight (g)	145.9	119.9	124.7	97.6	22.9
Mean berry number per bunch	105.9	96.1	97.9	82.5	18.7

Leaf to crop ratio and sugar per vine and per leaf

The total soluble solids (TSS) per vine and berry were calculated by multiplying crop and berry weight by the concentration of TSS (°Brix). On a per vine basis there were no significant differences between the treatments due to high vine to vine variability (Table 4). On a per berry basis the control treatment had more TSS per berry than the 67% and 75% leaf removal treatments and the 50% leaf removal treatment had more TSS than the 75%

leaf removal treatment. Thus leaf removal reduced the amount of sugar in the berry but not greatly.

The 67% and 75% leaf removal treatments substantially increased the amount of TSS (sugar) in the crop per area of leaf, indicating that the leaves in the control and 50% leaf removal treatments were on average operating below full capacity (Table 4). This is likely due to shading of many leaves in the control and 50% leaf removal treatments and the lower intensity of light reaching internal leaves. The standard leaf area to crop ratio measurement also revealed significant differences between the treatments with control having a reasonably typical value of 13.6 cm^2 of leaf area per g of crop. Reducing the leaf area in the 50% treatment significantly reduced the leaf to crop ratio as expected and further leaf removal (67 and 75% treatments) produced a significantly lower again leaf to crop ratio.

Table 4. TSS per crop and berry and two indicators of leaf area and crop ratios.

	Proportion of leaves removed				LSD 5%
	Control	50%	67%	75%	
TSS per vine (kg)	1.08	0.87	0.91	0.80	NS
TSS per berry (g)	0.36	0.34	0.32	0.31	0.02
TSS per total leaf area (mg cm^{-2})	23.9	31.1	56.2	54.2	15.2
Leaf area to yield ratio(cm^2 g^{-1})	13.6	9.8	5.1	5.5	3.3

Typical relationships between the leaf to crop ratio and various crop measurements show a steepening decline in the crop measurement as the leaf to crop ratio decreases. In the current experiment the ratio of leaf area to crop was compared with sugar concentration on the 13 March (after that date harvesting of some treatments commenced). Comparing the leaf area to crop ratio with sugar concentration data at other times, e.g. at harvest, is not valid because later harvested vines had extra time for sugar accumulation to occur and all vines approached a target sugar concentration of 26° Brix.

Previous research has suggested a hyperbolic relationship between the two parameters ($y = a-(b/x)$ where y = sugar concentration and x = leaf area to crop ratio) and this relationship was used with the current data. Across all vines there was a significant relationship ($P<0.001$; $y=26.77-(17.77/x)$; $r=0.750$) between the leaf area to crop ratio and sugar concentration on a specific date (Figure 5). There would appear to be a cut-off point around 10 cm^2 g^{-1}, above which none of the sugar concentrations were below 25 °Brix. Below 10 cm^2 g^{-1} the concentration of sugar in the crop steadily declined. The value of 10 cm^2 g^{-1} has been determined in a number of other experiments as a critical value for ripening grapes adequately (e.g. Kliewer and Dokoozlian 2001).

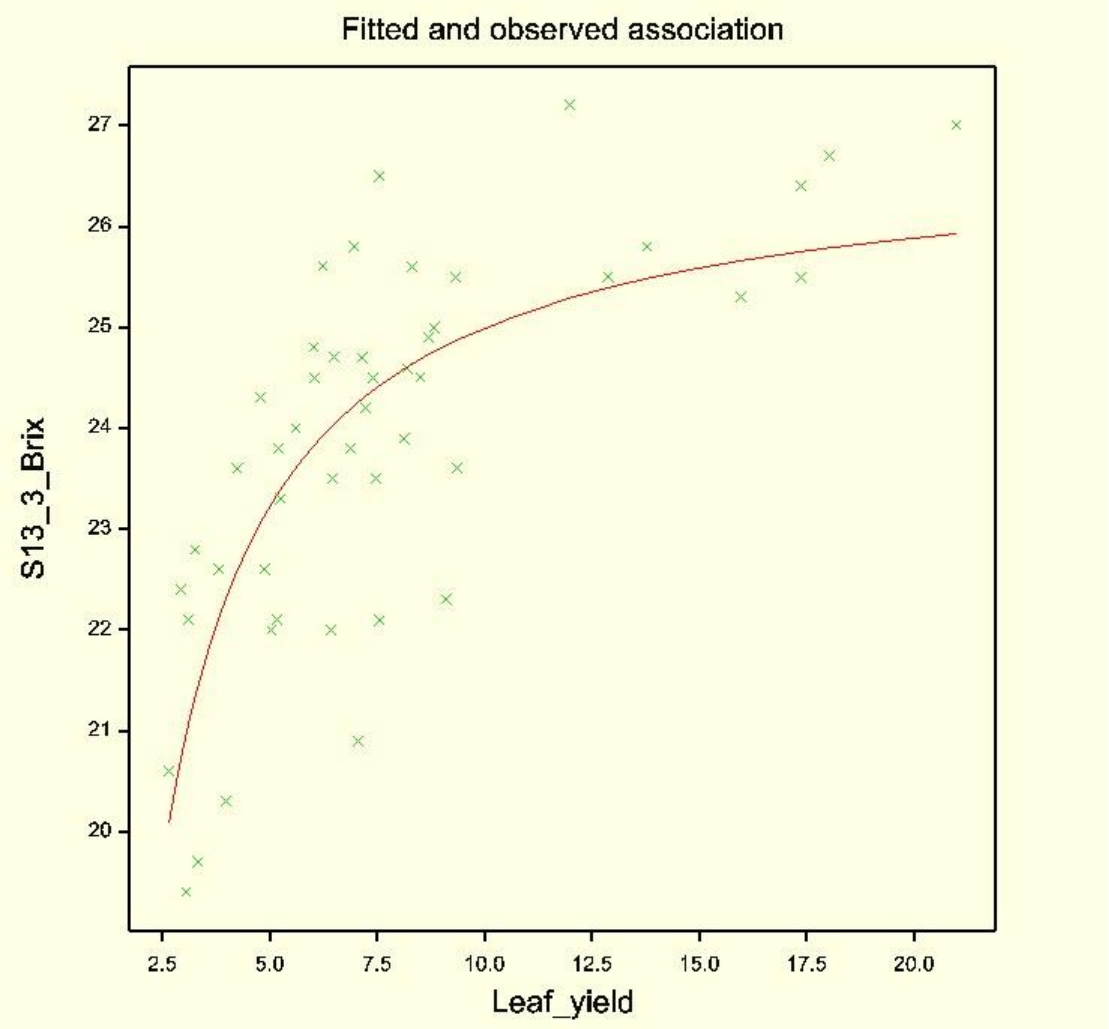


Figure 5. Leaf to crop ratio and impact on °Brix on one sample date.

Several reports have indicated similar hyperbolic relationships between the leaf area to crop ratio and other measurements (e.g. yield, berry weight, proline concentration, and skin colour). At the same sample date there was a significant relationship with juice pH (P=0.001; y=3.89-(0.85/x); r=0.603) but not titratable acidity or berry weight.

Berry anthocyanins, phenolics and tannins

Berries were sampled at the target harvest sugar concentration for phenolic, anthocyanin and tannin analysis. Treatment had no significant effect on total phenolics and tannins per berry, but total anthocyanin per berry was significantly greater in the control and 50% leaf removal treatment than the 67% and 75% leaf removal treatments (data not presented).

The concentration of phenolics, anthocyanins and tannins in the berries were significantly affected by treatment. The concentrations of phenolics and tannins were lowest in the control treatments and significantly so compared with some of the leaf removal treatments (Figure 5). This is probably due to the lower berry weights on some of the leaf removal treatments. This is affirmed by significant negative correlations between final berry weight and phenolic (P=0.05) and tannin (P=0.001) concentrations. Given that the total amount of phenolics and tannins were unaffected by treatment the primary reason for the increase in concentration of phenolics and tannins in some treatments appears to be berry shrivel through loss of water.

The concentration of anthocyanin in the berries was affected by treatment. The control treatment was significantly greater than the 67% leaf removal treatment (Figure 6). There was no significant correlation between berry weight and the total amount or concentration of anthocyanins. Thus the berry shrivel seen in the leaf removal treatments did not concentrate the colour in the berries. There would appear to be other factors influencing anthocyanin development in the berry.

Leaf area per shoot or vine and the leaf to crop ratio were all positively correlated with the total anthocyanins per berry (P=0.001). Sugar concentration and sugar per berry were also positively correlated with total anthocyanin per berry. With the concentration of anthocyanin per berry only the leaf to crop ratio, sugar concentration and berry tannin concentration were positively correlated. Correlation does not imply a causal relationship but it does imply that some factor related to the canopy is impacting on anthocyanin development. It is likely that the reduced anthocyanin in berries in the leaf removal treatments is due to greater exposure of the fruit inducing higher temperatures in the berries which will depress anthocyanin production (Mark Downey, pers. com., Koshita *et al*. 2011).

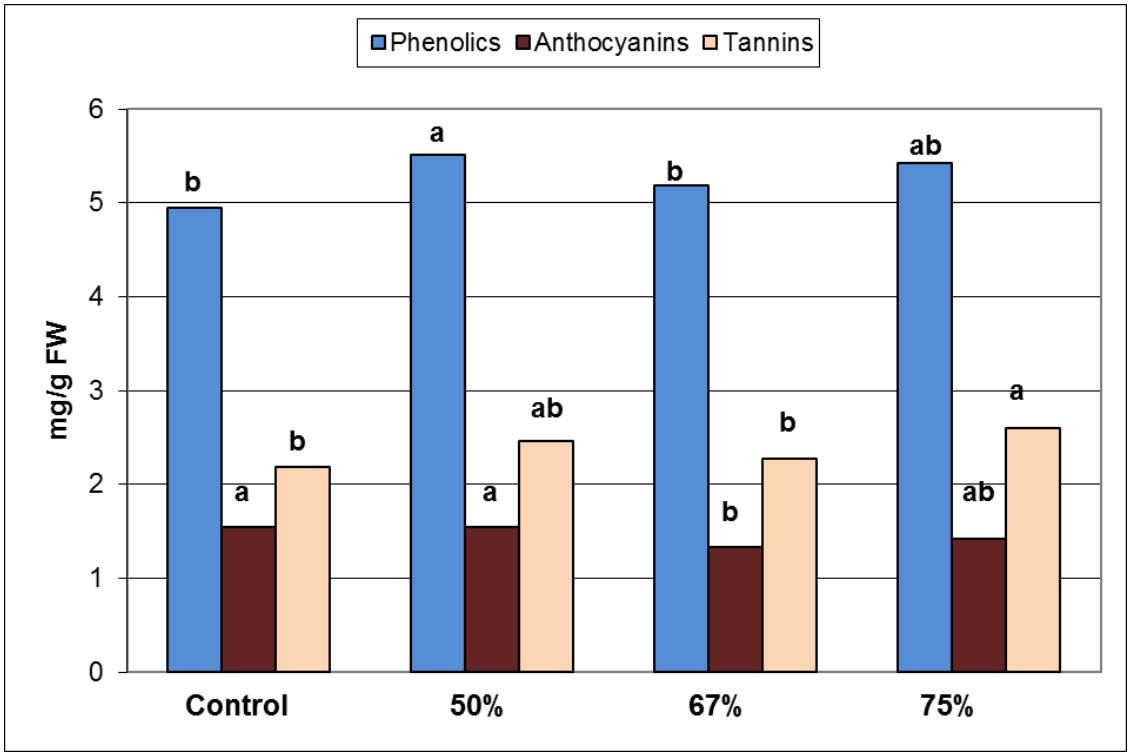


Figure 6. Concentrations of anthocyanins, phenolics and tannins in berries at harvest from three leaf removal treatments and a control.

Merbein Bunch Count results

Very few differences were observed between the treatments in the following season. Bunch number per count node was lower on the 67% leaf removal treatment compared with the 76% leaf removal treatment, bunch numbers per fruitful shoot were lower on the 67% leaf removal treatment compared with the 50% leaf removal, and bunches per shoot were lower on the 75% leaf removal treatment compared with the 50% leaf removal (data not presented). Overall, the control treatment did not differ from the leaf removal treatments. Thus there were no clear impacts on bud burst or fruitfulness in the season following leaf removal.

Seminar

A seminar attended by 35 people from across the Grampians, Pyrenees, Bendigo and Heathcote regions was held on the 18 November 2009 at the Bendigo Regional Institute of TAFE (BRIT). The topics and speakers were:

"Overview of the impact of high grape sugar" – Geoff Cowey, AWRI
"General principles of delaying ripening" – John Whiting
"Results from trial at Balgownie" – John Whiting
"Importance of stored carbohydrate for grape production" – Dr Jason Smith, CSU
Grower experiences – John Monteath, Balgownie Estate
- Jamie Hewet, Fosters Wine Group
- Paul Greblo, Sandhurst Ridge

"Working with high sugars in the winery" – Geoff Cowey, AWRI
"Impacts of heat on vine performance and alleviating heat damage" – John Whiting

b) Year 2

Leaf area

The relationship between leaf length and individual leaf area was $A = 0.0127L^{1.9856}$, where A is leaf area and L is leaf length, with $R^2 = 0.989$. There were no significant differences in shoot numbers per vine across the two treatments or the three harvest timings. There were significant differences in total leaf area per vine in line with the degree of leaf removal but no differences between the three harvest timings. The target 75% leaf removal treatment resulted in an actual leaf removal of 66% compared with control. There were no significant interactions between target Baume and the canopy treatments (control and leaf removal) for any parameter assessed, so data for the two factors is presented separately.

Shoot removal above the bunch zone treatment on adjacent panels

Since this treatment was only applied to adjacent panels and not part of the replicated trial, the results cannot be analysed as part of the main trial. Some general observations were made in comparison with the comparable treatment in the main trial (leaf thinning, harvested at target of 13.5 Baume). Cutting the shoots just above the bunch zone ('shoot removal') resulted in the removal of 61% of the leaf area, slightly less than the leaf removal treatment ('leaf removal') in the main trial (66%). The main difference between the two treatments was 40% lower bunch numbers on the shoot removal treatment and that produced a lower yield and earlier ripening pattern compared with leaf removal. The reduced bunch number was a result of earlier thinning conducted on the vineyard and not due to the shoot removal treatment. Despite this the leaf area to crop ratios were similar between shoot removal (5.8 $cm^2\ g^{-1}$) and leaf removal (4.0 $cm^2\ g^{-1}$), but much lower than those of Stoll *et al*. (2009) of 8 $cm^2\ g^{-1}$.

Shoot removal produced a delay in ripening of 21 days (at 13.5 Baume) compared with adjacent non-leaf plucked control and, due to the low crop, it was harvested 9 days earlier than the leaf removal treatment. This period of delay was similar to that reported by Stoll *et al*. (2009). Spectral analysis of the wine showed wine colour density was higher in the leaf removal treatment (8.1au) compared with shoot removal (6.7au). The HPLC tannin assay analysis showed free anthocyanins to be higher in the shoot removal treatment (462 mg L^{-1} vs. 347 mg L^{-1}) but the LPP+SPP was lower in shoot removal (1.94au vs. 2.84au) suggesting that more of the anthocyanins were polymerised in the leaf removal treatment. Tannin concentrations were lower in the shoot removal treatment (178 mg L^{-1}) than in the leaf removal treatment (286 mg L^{-1}).

Shoot removal above the bunch zone is an easier treatment to implement in the field than leaf plucking, and in this limited comparison it has produced a comparable delay in maturity. Compared with the control treatment, shoot removal has produced similar responses to leaf plucking in the wine samples (less anthocyanin, similar phenolic and tannin concentrations). Comparisons with an equivalent leaf removal treatment have shown some differences in the wine analysis but this may have been compounded by the large difference in yield. Further evaluation of the shoot removal treatment on larger scale blocks is suggested before implementation.

Progressive berry sampling

The period between veraison (67% coloured berries) on 17 January and 12 February produced the greatest differences in the rate of sugar accumulation between control and leaf removal (Figure 7). After the 12th February the rates of sugar accumulation were similar with both treatments. The shoot topping treatment was riper than the leaf thinned treatment due to 40% less yield (see above). The approximate time differences between the 75% leaf

removal treatment and the control were 20, 26 and 42 days to reach the target Baumes of 12.5, 13.5 and 14.5 respectively. Well above average rainfall in March (116mm) significantly slowed ripening which increased the time period for grapes to reach the higher target Baumes.

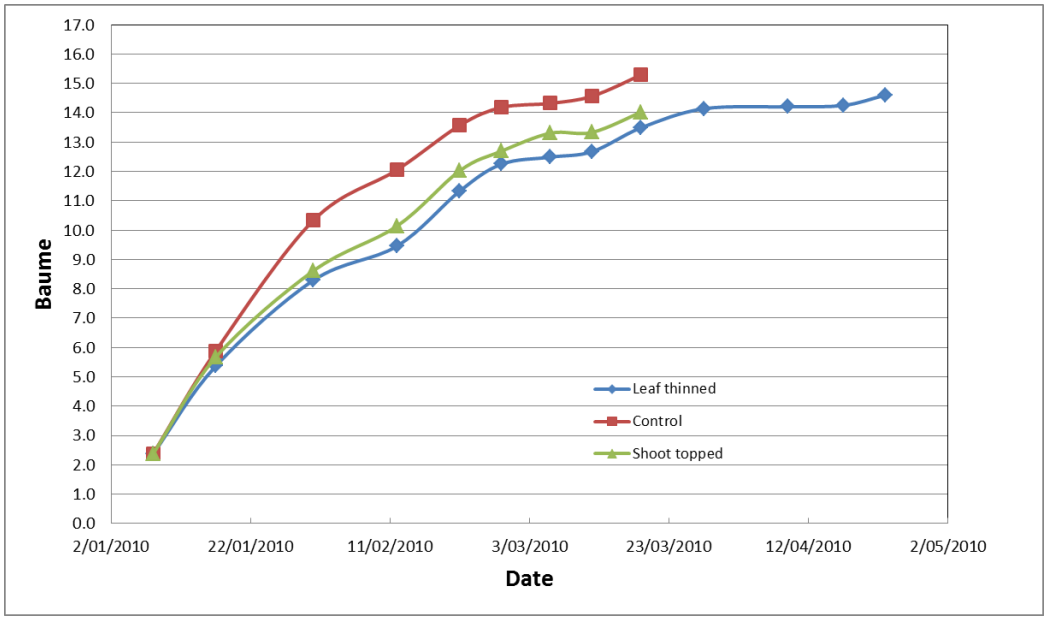


Figure 7. Progressive sugar concentration for vines with 75% leaf removal treatment compared with control.

Progressive berry weight data showed a typical peak in berry weight and decline thereafter described for Shiraz (Figure 8). This occurred even though rainfall was high and regular from March onwards and the pattern was similar to the previous season which was much drier during this period. The peak berry weight was also independent of sugar concentration with the peak berry weight for control occurring at around 12.1 Baume and for leaf removal at around 9.5 Baume.

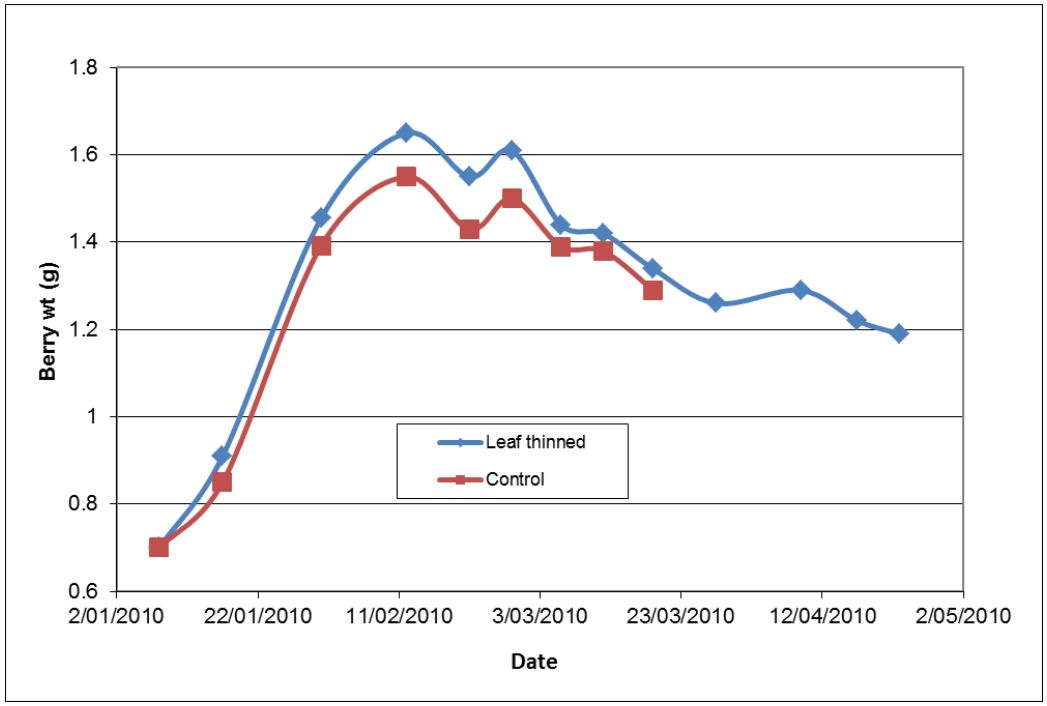


Figure 8. Progressive berry weights for vines with 75% leaf removal compared with control.

Analysis of berry samples at harvest showed significant differences between the three target Baumes and between the two main treatments (control and leaf thinned) (Table 5). Whilst the berry sampling Baume results at harvest showed some differences to the target Baume, after harvest and crushing the Baume of the must was much closer to the target sugar concentration. Berry pH increased with the later harvesting and titratable acidity and berry weight decreased. Leaf thinned treatments had a lower sugar concentration, higher pH, lower titratable acidity and lower berry weight at harvest.

Table 5. Berry sample data at harvest for three target Baumes and two canopy treatments.

Treatment	Berry sugar concentration (Baume)	pH	Titratable acid (g/L)	Berry weight (g)
Target 12.5 Ba	13.5c	3.71c	4.7a	1.35a
Target 13.5 Ba	14.1b	3.81b	4.4b	1.35a
Target 14.5 Ba	15.0a	4.03a	3.9c	1.24b
F probability	<0.001	<0.001	<0.001	0.005
Control	14.4a	3.69b	4.8a	1.35a
Leaf thinned	14.0b	4.00a	3.8b	1.28b
F probability	0.009	<0.001	<0.001	0.044

Yield and components

When grapes were harvested at the three target sugar concentrations there was a reduction in yield with the two later harvests compared with harvesting at a target of 12.5 Baume (Table 6). There were no significant effects of target Baume on bunch number per vine, bunch weight or berry number per vine. With the two canopy treatments leaf thinning significantly increased the berry number per bunch over control but there were no differences between them for yield, bunch number per vine and bunch weight.

Table 6. Yield and components of yield for three harvest timings and two canopy treatments.

Treatment	Yield (kg vine^{-1})	Bunch number per vine	Bunch weight (g)	Berry number per bunch
Target 12.5 Ba	4.3a	24.9	166.1	128.7
Target 13.5 Ba	3.5b	22.8	153.8	114.2
Target 14.5 Ba	3.3b	21.2	154.9	125.2
F probability	0.045	NS	NS	NS
Control	3.7	23.2	154.4	117.6b
Leaf thinned	3.7	22.7	162.2	127.8a
F probability	NS	NS	NS	0.044

Leaf to crop ratio and sugar per vine and per leaf

Harvesting the grapes at three harvest timings had no significant impact on total soluble solids (TSS) in the berry, per vine or as a proportion of the leaf area (Table 7). The three harvest timings had an effect on the leaf area to crop ratio due to the lower crop on the later picked vines since leaf area per vine was similar for the three harvest timings. The leaf thinning treatment reduced the total soluble solids per berry although on a per vine basis there was no effect. The TSS per leaf area was substantially higher in the leaf thinned

treatment, a result similar to year 1 of the project. The leaf to crop ratio was significantly lower on the leaf thinned treatment and similar to the first year of the project.

Table 7. Total soluble solids and leaf to crop ratios for three harvest timings and two canopy treatments.

Treatment	TSS per berry (mg)	TSS per vine (kg)	TSS per total leaf area (mg cm^{-2})	Leaf area to crop weight ratio (cm^2 g^{-1})
Target 12.5 Ba	0.33	1.05	43.3	7.0b
Target 13.5 Ba	0.34	0.89	42.6	8.2ab
Target 14.5 Ba	0.33	0.89	43.0	9.5a
F probability	NS	NS	NS	0.037
Control	0.35a	0.95	21.9b	12.5a
Leaf thinned	0.32b	0.94	64.1a	4.0b
F probability	0.013	NS	<0.001	<0.001

The results suggest that with around 66% of the leaves removed, the remaining leaves became more active and maintained the sugar going into the berry. Any yield loss would be due to moisture loss from the berries, and Shiraz commonly reacts that way.

The 2010 data showed a typical hyperbolic relationship between the leaf to crop ratio (x) and sugar concentration (y). In the current experiment the ratio of leaf area to crop was compared with sugar concentration on the 6 March (after that date harvesting of some treatments commenced). Across all vines there was a significant relationship ($P<0.001$, $y=26.78-(17.65/x)$; $r=0.902$) between the leaf area to crop ratio and sugar concentration on a specific date (Figure 9). There would appear to be a cut-off point around 8-9 cm^2 g^{-1}, above which none of the sugar concentrations were below 24 °Brix. Below 8-9 cm^2 g^{-1} the concentration of sugar in the crop steadily declined. This result is almost exactly the same as in the previous season (see above) which suggests the relationship is quite robust despite the trials being conducted in different blocks and seasons. There were no significant hyperbolic relationships between the leaf area to crop ratio with other berry characteristics measured at the one time.

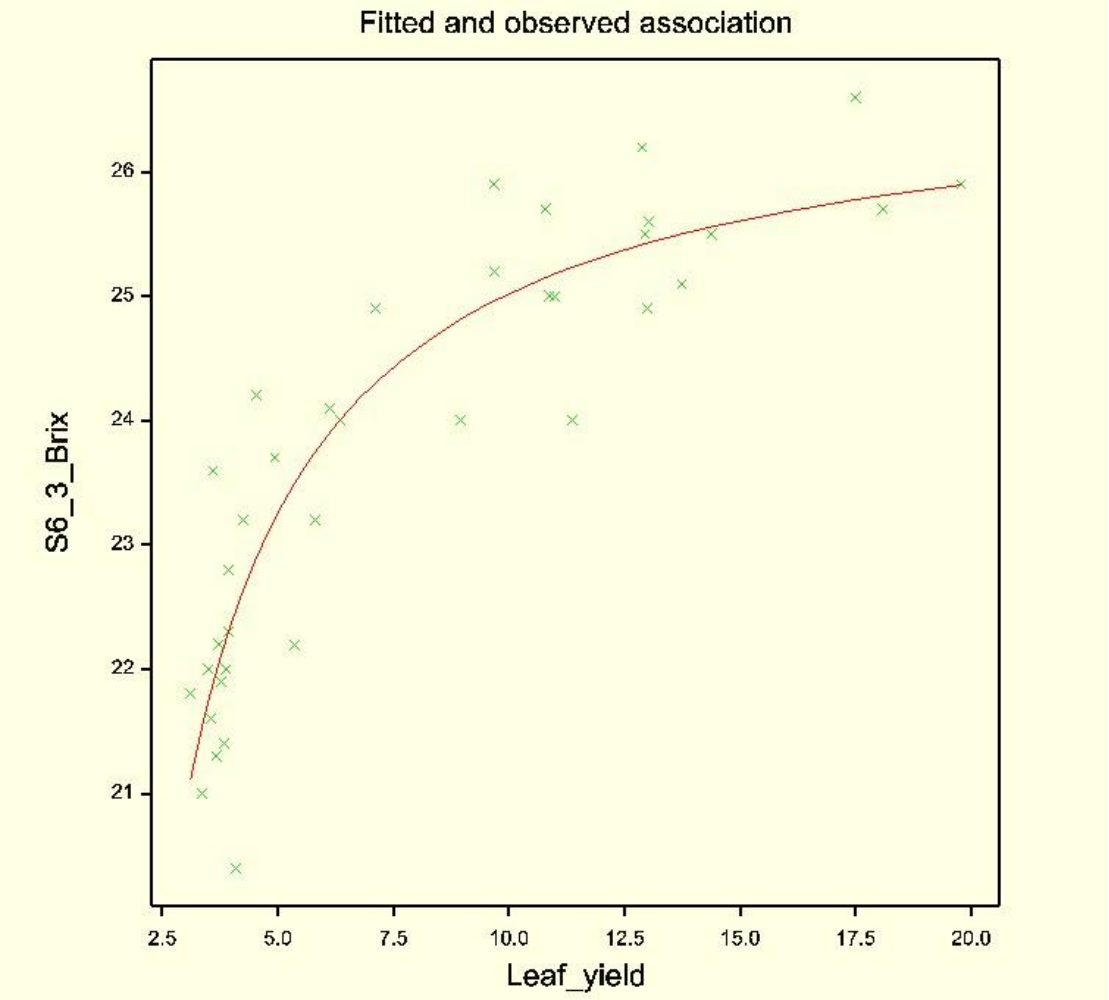


Figure 9. Impact of leaf to crop ratio on sugar concentration in the berries at one sample date.

Final composition of must

There appeared to be a difference between the field refractometer and the OenoFoss™ readings for sugar concentration. Comparing readings of two samples from the same vines, one being read by the refractometer and the other on frozen then re-thawed juice on the OenoFoss™ instrument, showed the refractometer reading averaged 0.7 Baume lower. The decision to harvest was based on the refractometer readings but full juice analysis was undertaken using the OenoFoss™ machine. Thus pre-harvest samples were close to the target Baume but subsequent analysis of frozen and thawed juice indicated they were over the intended target.

The variability between the must in the ferments was low. Initially each duplicate wine was fermented in two containers and the variability in must Baume and pH between the four containers of each treatment (expressed as coefficient of variation (CV)) was low (maximum treatment values were 2.7% CV and 1.6% CV respectively), and a little higher for titratable acidity (6.4% CV).

The must Baume was within 3.5% of the target Baume on average and the treatments paired for target Baume were within 0.5 Baume or less (Table 8). The desired spread of berry ripeness was achieved. Must pH was substantially higher and must titratable acidity was lower in the leaf thinned treatments compared with control treatments at similar Baume levels. Differences in pH could be due to differences in acid concentration and/or cations,

primarily potassium. Neither were measured but the grapes in the leaf thinned treatments were more exposed to the sun and hence were presumably warmer than control grapes. That may have resulted in a greater loss of malic acid and/or greater transpiration of water and hence mass flow of potassium into the berry.

Table 8. Must composition for two canopy treatments and three harvest times.

Canopy treatment	Target harvest Baume	Must Baume	Must pH	Must titratable acidity (g L^{-1})
Control	12.5	12.8 (0.2)[1]	3.66 (0.02)	4.6 (0.1)
	13.5	14.0 (0.2)	3.71 (0.01)	4.6 (0.2)
	14.5	15.3 (0.1)	4.00 (0.02)	4.5 (0.3)
Leaf thinned	12.5	13.1 (0.3)	3.97 (0.06)	4.2 (0.2)
	13.5	13.8 (0.2)	4.05 (0.04)	4.0 (0.1)
	14.5	14.8 (0.1)	4.33 (0.02)	4.1 (0.2)

[1] Standard deviation of mean

Basic wine analysis

During the wine making process various adjustments were made to acidity to maintain pH at an acceptable level. After pressing, wines were maintained in duplicates for each treatment. Some measures of wine chemistry suggested low variability between the duplicate wines (maximum value across all treatments - pH CV 1.0%, alcohol CV was 3.5% and volatile acidity 5.0%) but other measures were higher (maximum value across all treatments – titratable acidity 17.4% CV and residual sugar 23.0% CV).

Adjustments to acidity resulted in wine pHs of around 3.5 with titratable acidity of around 8 g L^{-1} (Table 9). Wine alcohols varied in line with the harvest timings and leaf thinned treatments tended to have lower wine alcohols than control vines. Volatile acidity was below 0.5 g L^{-1} and residual sugars were below 2.6 g L^{-1}.

Table 9. Wine acidity and alcohol for two canopy treatments and three harvest timings.

Canopy treatment	Target harvest Baume	Wine pH	Wine titratable acidity (g L^{-1})	Wine alcohol (%)
Control	12.5	3.51 (0.02)[1]	7.3 (0.9)	12.9 (0.1)
	13.5	3.47 (0.03)	8.6 (1.5)	15.1 (0.3)
	14.5	3.39 (0.01)	8.6 (0.1)	16.4 (0.3)
Leaf thinned	12.5	3.54 (0.01)	8.6 (0.1)	12.7 (0.0)
	13.5	3.47 (0.03)	7.8 (0.3)	14.5 (0.1)
	14.5	3.44 (0.01)	7.7 (0.3)	14.7 (0.5)

[1] Standard deviation of mean

Colour and tannin analysis

Spectral analysis of the wines showed significant differences between the harvest timing and canopy treatments. Wine colour density (absorbance units) showed greater wine colour density at higher degrees of ripeness (Figure 10). Leaf thinned treatments had substantially lower wine colour density than control treatments. This correlates with the results in the first year where grapes from leaf thinned vines had substantially less colour the control vines.

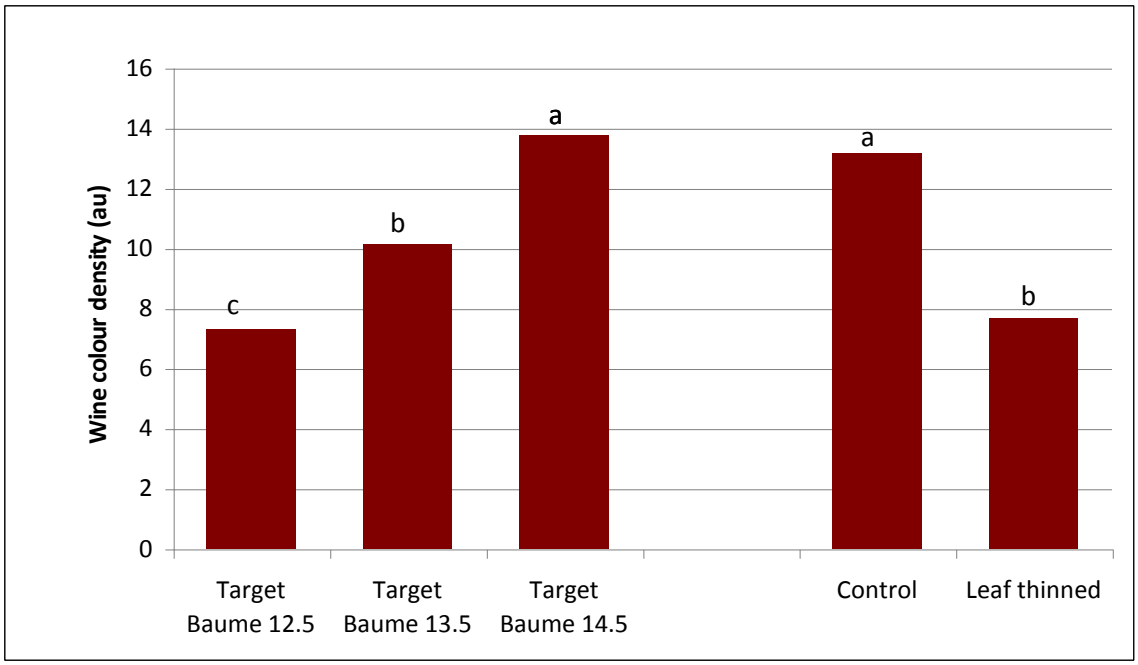


Figure 10. Wine colour density for three harvest timings and two canopy treatments (values with different letters were significantly different at <0.001).

With the timing of the harvest, wines made from riper grapes showed significant increases in the % red pigments, % SO_2 resistant pigments, total red pigments and total phenolics (Table 10). There were no significant differences in hue. For the canopy treatments control had lower mean hue values, % SO_2 resistant pigments, total red pigments and total phenolics. There was no significant difference between control and leaf thinning for the % red pigments.

Table 10. Spectral analysis of wines for three harvest timings and two canopy treatments.

Treatment	Hue	% red pigments	% SO_2 resistant pigments	Total red pigments (mg L^{-1})	Total phenolics (mg L^{-1})
Target 12.5 Ba	0.68	25.2b	2.0c	17.1b	30.2c
Target 13.5 Ba	0.72	30.8ab	3.1b	19.3b	35.4b
Target 14.5 Ba	0.65	33.7a	3.8a	24.5a	47.4a
F probability	NS	0.019	<0.001	0.002	<0.001
Control	0.64b	31.6	3.6a	25.0a	42.3a
Leaf thinned	0.73a	28.2	2.4b	15.6b	33.1b
F probability	0.003	NS	<0.001	<0.001	<0.001

With the protein precipitation tannin assay analysis, free anthocyanin values were significantly lower in the late harvested wines, but there was no difference between the two earlier harvests (Figure 11). With both phenolics and tannins, late harvest was greater than the middle harvest, which in turn was greater than the early harvest. With anthocyanin and phenolics, control wines were higher than wines from leaf thinned vines, but there was no difference between the two main treatments for tannin concentration.

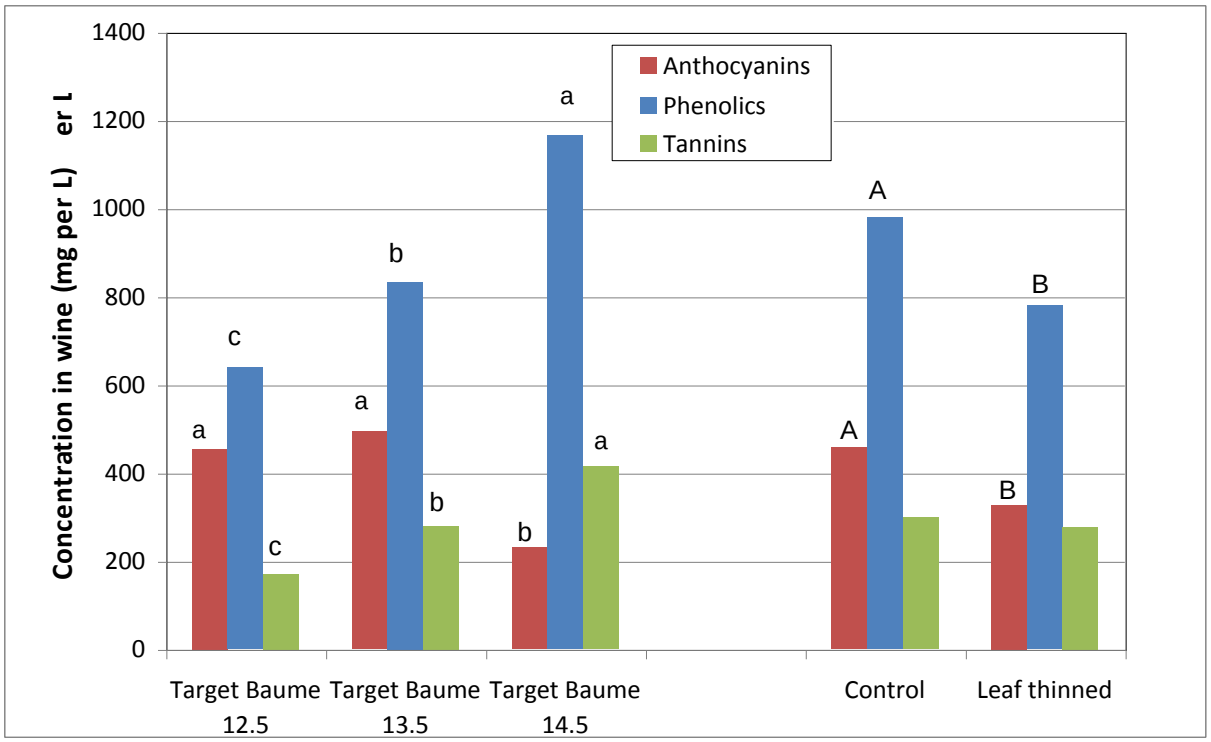


Figure 11. Tannin assay results in wines from three harvest timings and two canopy treatments (within each measure, values with different letters were significantly different at <0.001 (lower case) and <0.01 (upper case)).

For the remaining tannin assay measurements there were significant differences between all treatments. Wine made from the riper grapes had more short (SPP) and long (LPP) polymeric pigments as well as non tannin pigments (NTP) (Table 11). Whilst the harvest timing of 14.5 Baume had reduced 'free' anthocyanin (Figure 10) the overall colour was high because the anthocyanins were polymerised with tannins, and thus would be expected to be more stable over the longer term. With the canopy treatments wines from the leaf thinned vines had significantly lower values of SPPs, LPPs and NTPs.

Table 11. Tannin assay results on wines for three harvest timings and two canopy treatments.

Treatment	Short polymeric pigments (au)	Long polymeric pigments (au)	SPP + LPP (au)	Non tannin pigments (mg $L^{-1)}$
Target 12.5 Ba	1.18	0.95	2.13	469
Target 13.5 Ba	1.58	1.51	3.09	554
Target 14.5 Ba	2.08	2.04	4.12	751
F probability	<0.001	0.001	<0.001	0.001
Control	1.94	1.74	3.68	681
Leaf thinned	1.29	1.26	2.55	502
F probability	<0.001	0.006	<0.001	0.002

Tasting panel

Wines were assessed by three Bendigo winemakers and the author. It is difficult to be definitive about the description of the wines because of variability in perceptions between the tasters – no training or standardisation was conducted before the tasting. Generally the

colour was noted as red-purple ranging from light (in the early harvested, leaf thinned treatment) to medium-deep (in the late harvested, control treatment) (Table 12). The aromas were predominantly plum, herbal, spicy and clean although some wines showed reductive characters. The late harvested, leaf thinned treatment showed clear eucalypt characters, perhaps due to the extended time period these grapes remained in the field before harvest and an accumulation of eucalypt volatiles from nearby gum trees.

On the palate, the predominant characters were plum and herbal, with some wines showing raspberry, greenness, cherry and sappy characters. Weight on the palate ranged from 'light, simple, short' in early harvested leaf thinned treatments, to 'good body and tannin, good length, soft tannins' with the mid and late harvested control wines – these were the preferred wines of the panel. The late harvested control wines were noted as 'warm' reflecting the higher alcohol with these wines.

Wine scores from three of the tasters on the Bendigo panel were collated and pooled across wine replication (difference tasting revealed no significant differences between wine replications of four treatments – see below). Tasting panel scores for the control wines were reasonably consistent (low standard deviation) but there were greater differences in scores for the leaf thinned and shoot trimmed treatments (higher standard deviations) (Table 13). The control middle and late harvest treatments received the highest scores and the leaf thinned, early harvest the lowest score. The other treatments ranged in between with not great differences between them. At all harvest timings the control wines had higher scores than leaf thinned wines, and within each canopy treatment, wine score increased with progressively later harvested grapes.

Table 13. Wine scores from Bendigo tasting panel

Treatment	Mean wine score	Standard deviation
Control, early harvest	14.0	0
Control, middle harvest	15.4	0.2
Control, late harvest	16.6	0.6
Leaf thinned, early harvest	12.6	1.9
Leaf thinned, middle harvest	14.2	2.0
Leaf thinned, late harvest	14.5	1.1
Shoot trimmed, middle harvest	13.7	1.4

A selection of wines were compared using difference testing at the National Wine and Grape Industry Centre, Wagga Wagga by Dr Anthony Saliba. Of the wines provided representing four treatments there were no significant differences between the wine replicates. For the early and late harvest, there were significant differences between the control and leaf thinned treatments. For the middle harvest there was no reported difference between control and leaf thinned wines which is a surprising result given the clear differences observed by the Bendigo wine tasting panel. Lack of resources precluded investigating these differences further with descriptive analysis.

Grower tasting

The second seminar included a tasting of six of the experimental wines. Only one wine replication was assessed as earlier work had shown no significant differences between wine replication for four of the treatments. The shoot topped treatment was also excluded from the tasting since the fruit was not part of the replicated trial. The six wines were presented in XL5 glasses in the wine tasting room at the Bendigo Regional Institute of TAFE (BRIT). Attendees were asked to assess the wines independently by making comments on the

Table 12. Wine tasting notes for canopy treatments and ripeness levels

Wine	Appearance	Aroma	Mouth	Comments
Control, 12.5Ba, rep 1	Medium red-purple, bright Intensity	Plum, sl herbal, clean, spicy	Mid weight plum, good mid palate, short and herbal finish, green and sour	
Control, 12.5Ba, rep 2	Medium red-purple, bright Intensity	Plum, closed fruit, clean, spicy	Plum, mid weight, short, green, sl reductive	
Control, 13.5Ba, rep 1	Medium red-purple, bright Intensity	Simple plum, clean, spicy	Rich plummy fruit more mid palate, medium weight, length, sl heat, good body and tannin, tannins soft with length	Best balance (1 taster)
Control, 13.5Ba, rep 2	Medium deep red –purple, bright Intensity	Gentle plum, clean, spicy	Mid weight plummy fruit, good mid palate, herbal finish, good length, subdued tannins	Best balance (1 taster)
Control, 14.5Ba, rep 1	Medium deep red-purple, bright Intensity	Ripe plum, raspberry, reductive (but it blows off)	Good intensity, mid weight plum and raspberry, some length, sl bitter, raspberry leaf, good tight structure, warm.	Good balance and structure (3 tasters)
Control, 14.5Ba, rep 2	Medium deep red-purple, bright Intensity	Plum, sl leesy, clean, spicy	Soft mid weight, plummy fruit, some mid palate sweetness, sl bitter, firm persistent tannins, slightly warm	Best structure & balance (3 tasters)
Leaf thinned, 12.5Ba, rep 1	Light red-purple, bright Intensity	Rose hip, herbs, clean, spicy	Light and simple, short, herbal flavours, simple, cherry, berry	
Leaf thinned, 12.5Ba, rep 2	Light red-purple, bright Intensity	Closed red plum, clean, spicy	Light and thin, short, sl reductive, simple, light, elegant	
Leaf thinned, 13.5Ba, rep 1	Medium red-purple, bright Intensity	Ripe plum, clean, spicy	Persistent licorice with warm soft tannins, light body, some upfront intensity but short	
Leaf thinned, 13.5Ba, rep 2	Medium red-purple, bright Intensity	Red plum, herbal, clean, spicy	Light and simple, short and sl bitter, good tight with softer tannins	
Leaf thinned, 14.5Ba, rep 1	Medium red-purple, bright Intensity	Plum, eucalypt, herbal	Light weight, short, sl sappy	
Leaf thinned, 14.5Ba, rep 2	Medium red-purple, bright Intensity	Plum, eucalyptus	Medium weight, some mid palate intensity, short	
Shoot trimmed, 13.5Ba, rep 1	Medium-light red-purple, bright Intensity	Closed red plum, herbal, reductive	Light, simple, short plum fruit, some reduction	
Shoot trimmed, 13.5Ba, rep 2	Medium-light, red-purple, bright Intensity	Closed red plum, herbal, reductive	Med-light, sl sappy fruit, sl reductive	

wines, scoring them using the 20 point wine show system and/or ranking the wines. A general discussion of the wines was led by winemaker Greg Dedman of BRIT. Score sheets were collected and results summarised. Some slight changes in the wines were noted between this tasting and the previous one in mid November 2010. In one wine that was particularly strong in eucalypt character in the earlier tasting, that character was now more subdued. There also appeared to be some stabilisation of colour in the leaf thinned wines such that they did not appear as light as previously assessed. Few wine faults were mentioned by the tasters apart from a couple of tasters describing sulphidic (reductive) characters in two of wines. Some tasters perceived some of the wines to be too acidic.

The tasters used similar descriptors to those presented in Table 12, although with the greater number of tasters the range of descriptors increased. The tasters noted similar colour differences to those in the table. The predominant aroma descriptors used were plum and berry, but additional descriptors of meaty and leafy/green were noted in some wines. On the palate there was a greater range of perceptions such that one wine was described variously as too astringent and nice tannins. The tasters were fairly consistent in picking the high alcohol in the late harvested control treatment and the much leaner and thin characters in the early harvested leaf thinned treatments.

The wine taster scores showed an overall preference for the control treatment over the leaf thinned treatments at each harvest timing, and within each treatment there was an increased score with increasing ripeness (Table 14). These trends were similar to the earlier tasting. It was again noted that the variation in scoring was higher in the leaf thinned treatments (higher standard deviations) indicating a greater divergence of opinion about those wines.

Table 14. Wine scores from Bendigo seminar tasting

Treatment	Mean wine score (n=8)	Standard deviation
Control, early harvest	14.1	0.7
Control, middle harvest	15.1	1.2
Control, late harvest	15.5	0.8
Leaf thinned, early harvest	12.8	1.4
Leaf thinned, middle harvest	13.3	2.1
Leaf thinned, late harvest	13.9	3.1

The wine tasters were also given the option of ranking the wines and fourteen tasters provided ranking data. The rankings showed a wide range of preferences with three of the wines ranked at all levels (1 to 6) and the other three ranked at four out of six levels (Figure 12). For example, with the leaf thinned treatment harvested at a target of 12.5 Baume, over 50% of the tasters ranked the wine number 6 (lowest rank) but it was also ranked third, fourth and fifth by some tasters. The control 13.5 and 14.5 target Baume treatments received the highest rankings although over 20% of the tasters rated control 12.5 target Baume and leaf thinned 14.5 target Baume as their second ranked wine, a similar proportion to those ranked control 13.5 Baume as their second ranked wine.

Whilst many tasters preferred the riper harvested treatments from the control vines it was not universal with some preferring the leaner, lower alcohol, less tannic, more elegant characters of the leaf thinned treatments. Some likened the latter style to that of some wineries in the 2007 vintage in the Bendigo region. Samples of the wines will be retained with the possibility of reassessing them at a later date.

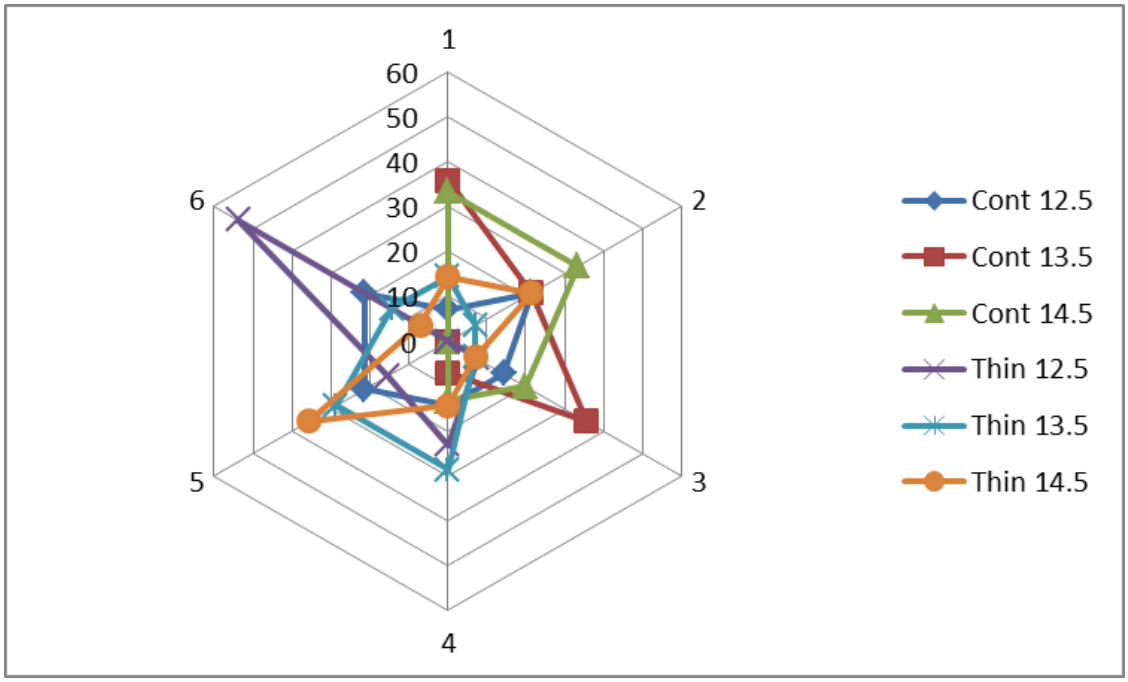


Figure 12. Percentage of scorers (0-60 scale from the centre) in each ranking (1-6 around the outside) of six wines (coloured lines).

Seminar

The second seminar associated with the project was attended by 22 people from across the Grampians, Pyrenees, Bendigo and Heathcote regions on 10 June 2011 at the Bendigo Regional Institute of TAFE. The topics and speakers were:

"What's driving our climate variability?" – Dale Grey, DPI
"Regulating grape ripening trial results from 2009-10 season" – John Whiting
Tasting of regulating grape ripening trial wines
"Sensory effects of extended ripening of Cabernet Sauvignon" – Prof Hildegarde Heymann, University of California, Davis.
"R&D at the National Wine and Grape Industry Centre" – Prof Jim Hardie, Director NWGIC.

7. Conclusions

1. Leaf removal is a practice that can delay sugar accumulation into the berries.
2. There is a window of at least 3-4 weeks in which leaf removal can be conducted prior to veraison.
3. The greater the degree of leaf removal, the bigger the delay in ripening. Removal of 40-50% of the leaves delays ripening by around one week and removing 65-70% of the leaves can delay ripening by three to seven weeks.
4. With Shiraz, leaving the fruit longer on the vine increases the degree of berry shrivel and creates potential losses in crop weight and impacts on juice composition, e.g. lower acidity and higher pH. This may be less of an issue with other varieties.
5. Leaf removal decreased the colour in the grapes (year 1) and wine (year 2), perhaps due to the increased fruit exposure leading to higher berry temperatures and depressed anthocyanin development. This would not be an issue with white grapes although other impacts of increased fruit exposure (e.g. increased sunburn) need to be considered. If increased fruit exposure is causing the decrease in colour, then there may be ways to reconfigure the trellis or canopy to provide more shade on the fruit.
6. Leaf removal had virtually no impact on tannin concentrations in the grapes and wine.
7. Assessments of wine quality showed on average leaf thinned wines rated lower than control wines at each stage of harvest, although leaf thinned wines harvested at 13.5 and 14.5 target Baumes were equivalent to control wines harvested at 12.5 Baume. A small number of people preferred the leaf thinned wines for their lighter, more elegant style.
8. The classic hyperbolic relationship between the leaf area to crop weight ratio and the sugar concentration described in other reports also applied in this work. The relationship was highly significant and very constant between the two seasons which were conducted on different blocks of Shiraz.
9. The trial also provided some insights into wine quality of grapes harvested at progressively riper stages. Differences between harvesting at 12.5 and 14.5 Baume were sometimes greater than the differences attributed to leaf removal (e.g. wine colour, phenolics and tannin).
10. The decreased wine colour may limit adoption in red grapes and the return to a cooler season will have diminished grower and winemaker concerns about early ripening. There are risks associated with adopting the leaf thinning practice because a decision to thin leaves has to be made by veraison and this has to be weighed up against the possibility of the weather turning cold and the grapes not ripening adequately.
11. Growers have shown an interest in the work, not so much by directly adopting the practices trialled here, but more by re-examining the way they produce their grapes. They are also keen to conduct more events to broaden their knowledge and skills.
12. There has been interest in this work elsewhere, with contact with a student from the University of Melbourne undertaking a project on this issue, along with some contact from overseas. Similar work is being conducted in Germany (Stoll *et al*. 2009) and New Zealand (Kemp *et al*. 2010, Pan *et al*. 2010).

8. Recommendations

This project has demonstrated that reducing leaf area is an approach that can reduce the rate of sugar accumulation into the grapes during periods where early ripening is deemed undesirable. Some uncertainties with the technique as it was applied (lower colour in red grapes and wine and uncertainty about the seasonal weather) may limit adoption of the technique however there are still opportunities to work on the technique and improve the likelihood of adoption of some form of the technique.

Further research to better understand the development of anthocyanins in the berries of red grapes would impact on the useability of the technique. It has been proposed that increased fruit exposure and increased berry temperatures is the cause of lower anthocyanin development but it is not clear whether reduced carbohydrate production arising from less leaves per vine is implicated. Some clarification would be useful.

Future work could look at mitigating the negative impacts of fruit exposure on anthocyanin development through trellis or canopy manipulation. Recent surveys of the impacts of heat damage highlighted aspects of row orientation, trellis system and canopy manipulation through the use of foliage wires, among other potential practices, to ameliorate the impacts of heat on grape berries. Results of further studies in that area could be applied to the leaf removal technique.

The method could be trialled on white varieties where there is no colour development in the berry but other aspects of bunch exposure (sunburn browning) need to be considered. Some promising results on leaf removal to slow the ripening of Riesling have been published from Germany but the full impact on white grapes in a hotter climate won't be known until it is evaluated in Australia.

For growers to have confidence in applying the method they need some assurity that the season will lead to early ripening. The decision to remove leaves needs to be made by veraison stage and if the weather turns decidedly cool after that then the delay in ripening from leaf removal may be excessive and the grapes not reach optimum maturity. For example, 2010-11 would not be a season where the technique should be used and many growers that lost leaves due to downy mildew reported sugar accumulation stalled, sometimes as low as 11.5 Baume. Any work to improve seasonal temperature forecasting would be very useful in determining when to apply the leaf removal technique and when not to.

Research on leaf area to crop balance is continuing overseas so there is some confidence that the technique is useful in delaying grape maturity. Researchers in Australia need to keep abreast of developments in this area. A modification of the technique may arise that will prove more useful than the practice applied in this project.

Small field demonstrations should continue to be supported by GWRDC and expanded where results arising from more fundamental research projects funded by GWRDC could be tested in a broader range of field situations.

9. Appendix 1: Communications

Whiting, J. (2009) Local trial results from 2008-09 season. Presented at a seminar on 'Handling High Sugars', Bendigo Regional Institute of TAFE, 18 November 2009.

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Whiting, J (2011) Leaf removal impacts on wine. Wine and Viticulture Journal (in preparation).

10. Appendix 2: Intellectual Property

Information generated by this project has been made available in the public domain and accessible for others to utilise.

11. Appendix 3: References

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12. Appendix 4: Staff

This project was conducted on behalf of the Bendigo Winegrowers Association by John Whiting Viticulture.

13. Appendix 5 Acknowledgements

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