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Reduced grapevine canopy size post-flowering *via* mechanical trimming alters ripening and yield of 'Pinot noir'

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Summary

The degree and time of canopy trimming can alter phenology, rates of increase or decrease in berry components during grape ripening, and may influence yield and its components. The objective of this study was to investigate the extent to which reducing canopy size, by mechanical trimming post-flowering, changed *Vitis vinifera* L. 'Pinot noir' fruit yield and composition.

Vines were mechanically trimmed to three different canopy heights at fruitset: 1000 mm (100 % canopy height), 600 mm (60 % canopy height relative to the control treatment) and 300 mm (30 % canopy height relative to the control treatment). Total soluble solids concentration and content, titratable acidity, pH and fresh berry mass were measured throughout ripening, and yield and leaf area were measured at harvest.

Reduced canopy size via trimming to 30 and 60 % of the control treatment height slowed total soluble solids accumulation and in some cases increased titratable acidity and increased pH. The total soluble solids-titratable acidity ratio was therefore reduced throughout ripening by these trimming treatments relative to the full canopy height. Trimming to reduce canopy size had two effects on the source-sink ratio; it reduced the source (canopy) but increased fruit yield, an important sink. Therefore, the time of trimming is an important management consideration because it can delay and slow ripening due to reduced source leaves but could potentially accentuate the delay via increasing yield (sink). This technique may represent a way to offset the acceleration of phenology and grape ripening that has been observed to occur as a result of warmer seasons.

K e y w o r d s : source-sink ratio; ripening; fruit synchrony; 'Pinot noir'; canopy trimming.

Introduction

While temperature is a key driver of development processes in the grapevine, manipulations of the source-sink ratio of field and pot-grown vines can modify temperature-dependent growth processes and affect phenology and associated berry components such as total soluble solids (TSS) (Ollat *et al.* 1998, Petrie *et al.* 2000, Poni and Giachino 2000, Kliewer and Dokoozlian 2005, Petrie and Clingeleffer 2006, Nuzzo and Matthews 2006, Stoll *et al.* 2011, Greven *et al.* 2014, Parker *et al.* 2014, Parker *et al.* 2015). The date at which a target total soluble solids concentration is achieved is delayed when the source component of the source-sink ratio is limited, such as by reducing canopy size and therefore source size through trimming vines (Poni and Giachino 2000, Stoll *et al.* 2011, Parker *et al.* 2014, Parker *et al.* 2015). This delay to reach target total soluble solids concentration may be due to a delay in the date of véraison (and therefore start or ripening) (Parker *et al.* 2014) and/or slower rates of total soluble solids accumulation from véraison to harvest or to a target total soluble solids concentration (Poni and Giachino 2000, Parker *et al.* 2015). In potted vines, trimming shortly after flowering has also been shown to increase titratable acidity (Poni and Giachino 2000), although no differences in these measurements were observed in the field-grown vines trimmed at fruitset (Stoll *et al.* 2011, Parker *et al*. 2015).

While trimming shoots reduces leaf area, it also removes the growing tip and younger leaves which are important sinks for metabolites. This means assimilates from source leaves can be redirected towards alternate sinks, including developing inflorescences (Coombe 1959, 1962, Vasconcelos and Castagnoli 2000). As a result, the time of trimming can have different effects on fruitset, yield and its components (berry number per bunch and berry size). Trimming pre-flowering has been found to have little effect on fruitset or yield (Coombe 1959) although leaf removal has been found to increase berry abscission and reduce yield (Candolfi-Vasconcelos and Koblet 1990, Bennett *et al.* 2005, Poni *et al.* 2006, Lohitnavy *et al.* 2010). Trimming during flowering but prior to fruitset has been found to be the most effective time to increase fruitset and subsequent yield *via* assimilate redirection (Coombe 1959, 1962, Vasconcelos and Castagnoli 2000, Collins and Dry 2009) although Poni and Giachino (2000) found trimming at this time had no overall effect on yield components except a reduction in berry size. Trimming at fruitset or shortly after has produced no or few differences in yield with reports of no effect on total berries per cluster (Stoll *et al.* 2011), no change in overall yield for field grown vines (Parker *et al.*

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2014), but a small increase in percentage fruitset but still no influence on yield or yield components (bunch or berry mass) (Collins and Dry 2009). One study found yield and berry weight increased in one of two seasons when trimmed 6 weeks post-bloom (Candolfi-Vasconcelos and Koblet 1990) but Collins and Dry (2009) found that once bunch closure had occurred, trimming did not affect yield. Therefore the degree of trimming, its timing (and relation to the season) are important factors to consider when using this method to reduce canopy size and consequently leaf area. If trimming alters yield then both components of the source-sink ratio are altered, furthering the reduction in the source-sink ratio. This is an important consideration because reducing leaf area delays veraison and slows total soluble solids accumulation but higher yields also slow total soluble solids accumulation (Parker *et al.* 2014, 2015).

The delay in véraison and the slower rates of total soluble solids accumulation might represent one way in which to counter the acceleration of phenology and grape ripening that has been observed to be occurring as a result of climate change (Duchêne and Schneider 2005, Jones 2006, Webb et al. 2007, Petrie and Sadras 2008, Duchêne *et al.* 2010, Tomasi *et al.* 2011, Trought *et al.* 2015). Although trimming may represent additional mechanisation in the vineyard the potential practical application and benefits of this practice to mitigate some of the effects of climate change need to be considered (Trought *et al.* 2015). Therefore, a detailed understanding of the magnitude of change generated by trimming for different varieties and climates as well as the practical application (mechanical trimming) warrant further investigation. The aim of this study was to reduce canopy size by mechanical trimming to different heights and to assess the magnitude of changes to primary berry components - soluble solids, titratable acidity, pH, berry weight and yield of 'Pinot noir'.

Material and Methods

Two adjacent rows of *Vitis vinifera* L. 'Pinot noir' vines (clone 777, rootstock 3309) located in a commercial vineyard in Marlborough, New Zealand (41°27’46.60”S, 173°54’6.42”E) were used during the 2010-2011 growing season. In 2011-2012, two new rows were used adjacent to those used in 2010-2011. This enabled the treatments to be repeated without any carry over effects of the treatments from 2009-2010 confounding responses for 2010-2011. Vines were planted in 2007 in rows orientated north to south and at a 3 m row and a 1.8 m vine spacing. The training system was Double Guyôt with two 12-node canes lightly wrapped to the fruiting wire at 900 mm from the ground surface. The canopy was trained using foliage wires to vertical shoot positioning (VSP) and was approximately 300 mm in width. Vines were drip irrigated as necessary and vineyard management was undertaken by the grower, using current commercial practices of Sustainable Winegrowing New Zealand (2014). Eighty percent flowering occurred on December 4, 2010 and December 10, 2011. Three canopy size treatments were applied post-flowering to each block in a randomised block design (blocked along the rows by spatial position) across the two rows per season, with 10 replicates per treatment (one per block), where a replicate consisted of four adjacent vines (in one vineyard bay).

Vines were shoot-positioned and trimmed by the grower to a standard industry canopy height of 1000 mm measured from the fruiting wire to the top of the canopy (“control treatment”) with a tractor-mounted ELITE ‘Double-sided L’ trimmer (ERO-Gerätebau GmbH, Germany). Shortly after this, on 23 December 2010 and 23 December 2011, vines were trimmed with a hand-held hedge trimmer (Stihl™ HS 45, STIHL Holding AG & Co. KG, Germany) to final canopy heights of 600 mm (60 % canopy height relative to the control treatment) and 300 mm (30 % canopy height relative to the control treatment) (Fig. 1). All trims heights were above the fruiting zone. Re-growth (laterals and leaves) was removed each week from mid-January for all three trim heights until harvest.

Weekly samples were collected randomly from both sides of the row of each replicate from pre-véraison until harvest (total sample size of 34 berries taken across the four vines in each replicate). Samples were weighed, crushed by hand in polyethene bags and coarsely filtered. The juice was analysed for total soluble solids concentration (°Brix) determined by refractometry with an Atago Pocket PAL-1 refractometer (Atago Co., Ltd, Japan), pH using a Metrohm 744 pH meter (Metrohm AG, Switzerland), and for titratable acidity (TA) by endpoint titration

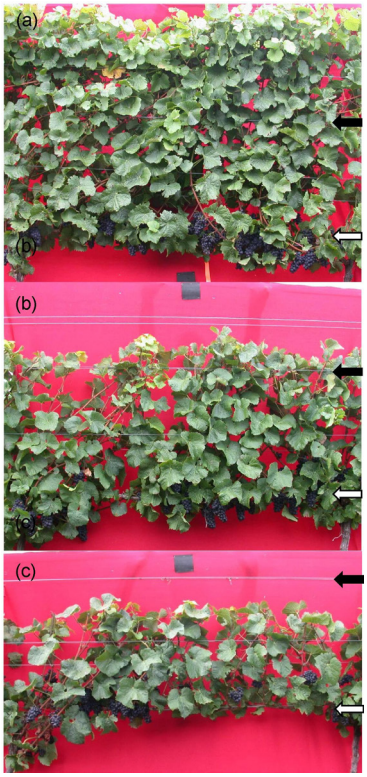

Fig. 1: Canopy heights in 'Pinot noir' grapes. (**a**) Control treatment canopy height at 1000 mm (**b**) 60 % canopy height relative to the control treatment at 600 mm (**c**) 30 % canopy height relative to the control treatment at 300 mm. Photographs taken from the 2010-2011 season. The lower arrow (white with black outline) indicate the fruiting wire and the upper arrow (black) indicate the second foliage wire above the fruiting wire.

(tartaric acid equivalents in $g \cdot L^{-1}$) using 0.1 M NaOH to pH 8.4 at 20 °C with a Mettler Toledo DL 50 Graphix titrator (Mettler Toldeo GmbH, Analytical, Switzerland). Berry total soluble solids content was calculated from the average berry fresh mass (g) and the corresponding total soluble solids concentration (°Brix). A three–parameter exponential parameter function was fitted to total soluble solids:

$$y = a + br^x \qquad (1)$$

where a is the y asymptote (in °Brix), $b < 0$, $0 < r < 1$ and x is the day of the year (DOY). The following measures were interpolated from the curve fits: DOY of 8 °Brix used as a proxy measure for véraison (Parker *et al.* 2014), DOY of 20 °Brix, and duration of total soluble solids accumulation that was comparable across all curve fits, starting at 8 °Brix up to the lowest total soluble solids concentration that was measured at harvest for one replicate, treatment and season (20 °Brix). To further estimate the rate of accumulation of total soluble solids at different stages of the ripening period, the curves were divided into 2 °Brix increments and the time (d) estimated for each replicate. For TA, a general logistic function was fitted to each replicate:

$$y = a + \frac{c}{1+te^{(-b(x-m))^{1/t}}} \qquad (2)$$

TA values on the DOY 8 °Brix and DOY of 20 °Brix were interpolated from these fits.

The thermal summation on the DOY 8 °Brix and DOY of 20 °Brix were calculated using the Grapevine Flowering Véraison (GFV) model (Parker *et al.* 2011), where a phenological stage occurs when a critical state of forcing is reached (thermal summation value, F^*), defined as a sum of the average daily minimum and maximum temperatures divided by two, from a starting date t_0 = 60th DOY in the northern hemisphere (in the southern hemisphere this corresponded to 29 August calculated from 1 July).

All the vines in each replicate were harvested on April 6, 2011 or April 16, 2012. Total bunch number and yield (fresh mass) per replicate were recorded, with the average number of bunches per vine (total bunch number/four vines per replicate) and average bunch fresh mass (total fresh mass per replicate/total bunch number) calculated. Results were analysed by ANOVA or REML (where there were missing data), using Genstat 14 (VSN International Ltd, Hemel Hempstead, United Kingdom). Comparison of means was determined by least significant difference (LSD) method at the 5 % level of significance. Non-linear regression was used to analyse the relationship between total soluble solids concentration and duration (d) as well as the relationship between total soluble solids accumulation and TA concentration in 2011-2012 (data were transformed using the natural log for analysis in 2010-2011 for 2 °Brix increments). Figures were plotted using Sigmaplot 12 (Systat Software, Inc., San Jose, CA, USA).

Table 1

Time and thermal time using the Grapevine Flowering Véraison (GFV) model to reach total soluble solids concentrations of 8 and 20 °Brix at different canopy heights in 'Pinot noir' grapes

Canopy trim height†	8 °Brix		20 °Brix		Duration 8-20 °Brix (d)		GFV at 8 °Brix (°C·d^{-1})§		GFV at 20 °Brix (°C·d^{-1})§		Duration 8-20 °Brix (GFV) (°C·d^{-1})§	
	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012
Control treatment	30 Jan (30)	11 Feb (42)	12 Mar (72)	24 Mar (84)	42	42	2290	2352	3021	3230	731	879
60 % canopy height	31 Jan (31)	12 Feb (43)	19 Mar (78)	30 Mar (91)	47	47	2312	2370	3137	3318	825	948
30 % canopy height	3 Feb (34)	13 Feb (44)	27 Mar (87)	4 April (95)	53	51	2373	2383	3270	3369	897	987
LSD	0.88	0.58	2.17	2.15	2.28	2.19	16.9	9.5	32.6	25.7	33.0	26.2

† Control treatment at 1000 mm, 60 % canopy height relative to the control treatment at 600 mm, 30 % canopy height relative to the control treatment at 300 mm. Total soluble solids concentrations (°Brix) were measured for a 34-berry sample. Day of the year (DOY) to target total soluble solids concentration (°Brix) in brackets.§ °C·d^{-1} are degree-days from 29 August until the target total soluble solids concentration of 8 or 20 °Brix, or the degree-days for the duration from 8 or 20 °Brix.

Results

In both seasons, reduced canopy size via trimming (60 % canopy height and 30 % canopy height treatment) increased the time taken for fruit to reach 20 °Brix by up to 15 days (Tab. 1). This was partly a reflection of a delay of up to four days in the onset of total soluble solids accumulation (measured at 8 °Brix), and partly an increase in time taken for fruit to accumulate total soluble solids from 8 to 20 °Brix ($\alpha = 0.05$, Tab. 1; Fig. 2). The slight differences in the DOY to reach 8 °Brix, and the increase in chronological time taken to accumulate total soluble solids, caused by

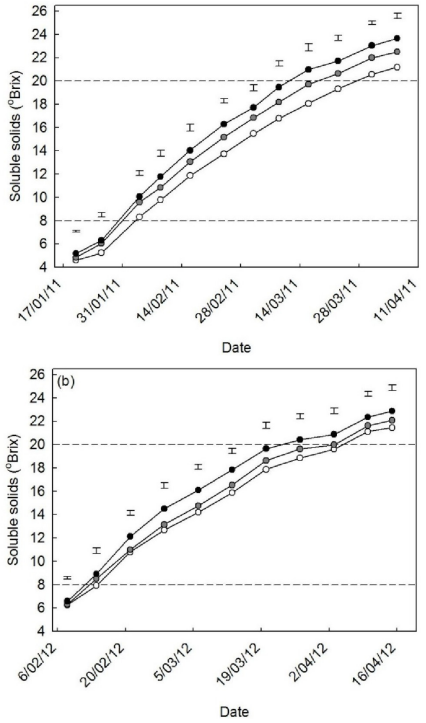

Fig. 2: Total soluble solids (°Brix) accumulation in response to different canopy heights in 'Pinot noir' grapes. (**a**) 2010-2011 and (**b**) 2011-2012. Treatments: (●) Control treatment canopy height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. Error bars indicate least significant difference values (LSD) at α = 0.05. Horizontal dashed line (– – –) indicates 8 and 20 °Brix respectively (onset of ripening and common target total soluble solids concentration for all replicates).

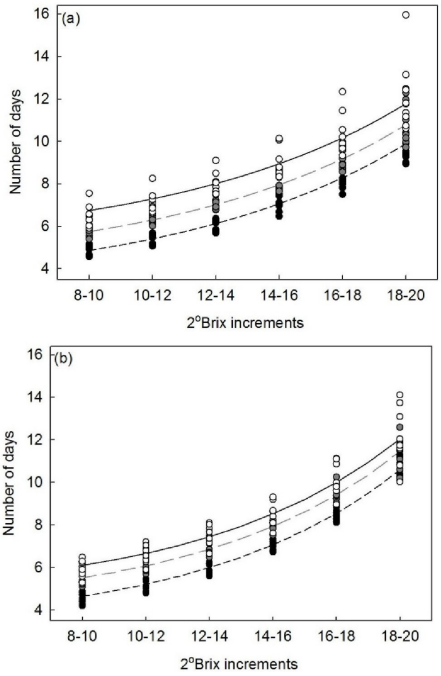

Fig. 3: Regression between the number of days to increase total soluble solids concentration at 2 °Brix increments in 'Pinot noir' grapes. Data was transformed (ln) for 2010-2011 regression analysis. Treatments: (●) Control treatment canopy height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. (**a**) 2010-2011, where $y = a + 0.469\ (1.143^x)$, and $a = 3.07$ for the control treatment canopy height, $a = 3.962$ for the 60 % canopy height, and $a = 4.953$ for the 30 % canopy height, (**b**) 2011-2012, where $y = a + 0.30\ (1.17^x)$, and $a = 3.138$ for control treatment canopy height, $a = 4.00$ for 60 % canopy height and $a = 4.59$ for 30 % canopy height.

the reduced canopy height *via* trimming, was also reflected in the thermal time requirements ($°C \cdot d^{-1}$) as calculated by the GFV model (Tab. 1).

In 2010-2011, rates of total soluble solids accumulation between two sample points differed for January 20-26, January 26 to February 4 (α = 0.05, where control treatment rates were greater than the rates in the 60 % and 30 % canopy height treatments), and February 4-9 (α = 0.05) where control treatment and 60 % canopy height treatment rates were greater than the rates in the 30 % canopy height treatment (Fig. 2). In 2011-12, rates differed on February 8-14 (α = 0.05, control treatment and 60 % canopy height treatments were greater than the rate in the 30 % canopy height treatment) (Fig. 2). The lag in the rate of accumulating fruit total soluble solids between vines in the control treatment and 60 % trim height treatments, or control treatment and 30 % trim height treatments, was consistent (*i.e.* they differed by the same number of days) at all 2 °Brix increments ($p < 0.05$, Fig. 3a, b). As fruit ripened, the time taken to increase total soluble solids concentration by 2 °Brix increased consistently across the three treatments ($p < 0.05$, Fig. 3a, b).

There were few differences in TA through the ripening period, particularly for the last four sampling points (Fig. 4). The only notable differences with respect to decreased canopy height were that 1) the fruit in the 60 % and 30 % canopy height treatments had lower maximum TA in 2011-2012 (α = 0.05, Fig. 4a, start of the TA measurements) and 2) the fruit in the 30 % canopy height treatments in 2010-2011 and in the 30 % and 60 % canopy height treatments 2011-2012 had higher TA in the earlier stages of ripening (up until March 21, 2011 and March 20, 2012, Fig. 4a, b, α = 0.05), including the interpolated TA concentration at 20 °Brix (Tab. 2). This was reflected in consistent rate values (r) for the regression between total soluble solids and TA but a reduced total soluble solids-TA ratio with reduced canopy size (in 2010-2011, a and b differed for all three treatments, consistent r (rate) value, $p < 0.05$, Fig. 5a; in 2011-2012, a and b differed for all three treatments, consistent r (rate) value for the 30 % and 60 % canopy height treatments, $p < 0.05$, Fig. 5b).

In 2010-2011, the 30 % canopy height treatment resulted in a reduced berry fresh mass compared with those of the 60 % canopy height or control treatments at most time points (Fig. 6a). In 2011-2012, berry fresh mass for the 30 % canopy height treatment vines were less than for the 60 % canopy height or control treatments on four occasions, including harvest (Fig. 6b) (α = 0.05).

The reduction in overall berry fresh mass due to a reduced canopy height generally resulted in lower berry total soluble solids content (α = 0.05, Fig. 7). In 2010-2011, the total soluble solids content of the fruit in the 30 % canopy height treatment was repeatedly less than those of the fruit

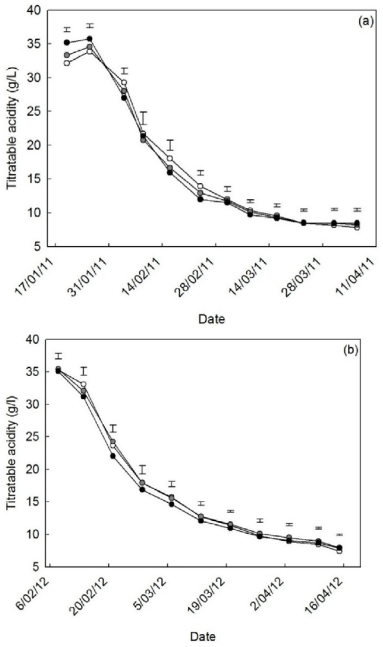

Fig. 4: Titratable acidity (g·L^{-1}) decrease over time in response to different canopy heights in 'Pinot noir' grapes. (**a**) 2010-2011 and (**b**) 2011-2012. Treatments: (●) Control treatment canopy height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. Error bars indicate least significant difference values (LSD) at α = 0.05.

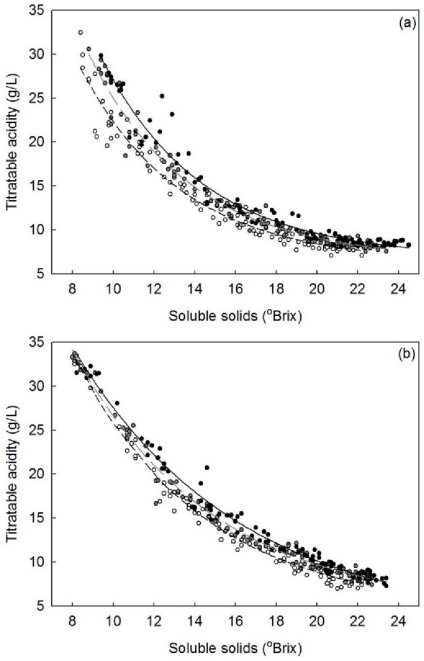

Fig. 5: Regression of total soluble solids concentration in 'Pinot noir' grapes with titratable acidity, for data points where total soluble solids concentrations were ≥ 8 °Brix. Treatments: (●) control treatment canopy height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. (**a**) 2010-2011, where $y = a + b\ (0.82^x)$, where a = 6.8, b = 149 for the control treatment canopy height, a = 6.6, b = 136 for the 60 % canopy height and a = 6.2, b = 119 for the 30 % canopy height. (**b**) 2011-2012, where $y = a + 0.30\ (r^x)$, and a = 3.0, b = 84, r = 0.88 for the control treatment canopy height a = 4.7, b = 95, r = 0.86 for the 60 % canopy height and a = 4.5, b = 104, r = 0.85 for the 30 % canopy height.

in the 60 % canopy height or control treatments (α = 0.05, Fig. 7a). However, in 2011-2012, there was less difference between the canopy height treatments (α = 0.05, Fig. 7b). The reduced total soluble solids content calculated for the final sample was an artefact of the reduced berry weight used for the calculation (α = 0.05, Fig. 6 and 7).

The only differences measured for juice pH in 2010-2011 were on February 9 and 24 and April 6, 2011, where the fruit in the 30 % canopy height treatment had lower pH values than those in the 60 % canopy height or control treatments (α = 0.05, Fig. 8a). However, in 2011-2012, the pH of the 30 % canopy height treatment fruit was progressively greater than those of fruit in the 60 % canopy height or control treatments (up to a difference of 0.09, α = 0.05) (Fig. 8b).

The reduced canopy height treatments generally resulted in higher yields per vine compared with the untrimmed control treatment (Tab. 3, α = 0.05). There were no differences in bunch fresh mass or bunch numbers across the fruit from the three trim height treatments (Tab. 3, α = 0.05, exception was a reduction in bunch fresh mass for the control treatment in 2011-2012).

Discussion

When the canopy height was reduced post-flowering via mechanical trimming, total soluble solids accumulation was delayed and the time taken to reach a target total solu-

Table 2

Titratable acidity (tartaric acid equivalents g·L^{-1}) at different canopy heights on the day at which 8 and 20 °Brix was reached in 'Pinot noir' grapes

Canopy trim height†	Titratable acidity on DOY 8 °Brix		Titratable acidity on DOY 20 °Brix	
	2010-2011	2011-2012	2010-2011	2011-2012
Control treatment	32.9	34.0	9.3	9.9
60 % canopy height	32.7	33.5	9.0	9.6
30 % canopy height	29.7	33.4	8.4	8.9
LSD	1.15	0.69	0.19	0.26

† Control treatment at 1000 mm, 60 % canopy height relative to the control treatment at 600 mm, 30 % canopy height relative to the control treatment at 300 mm. Day of the year (DOY).

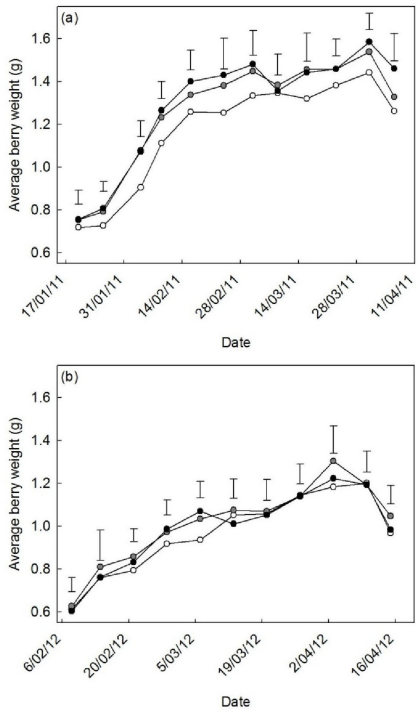

Fig. 6: Berry fresh mass (g) in response to different canopy heights in 'Pinot noir' grapes. (**a**) 2010-2011 and 2011-2012. Treatments: (●) control treatment canopy height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. Error bars indicate least significant difference values (LSD) at α = 0.05. For 14 February 2012, the number of blocks was reduced to five and all treatments were evenly represented across the blocks (n = 15). For 10 April 2012, REML was used for analysis because of missing data, n = 19).

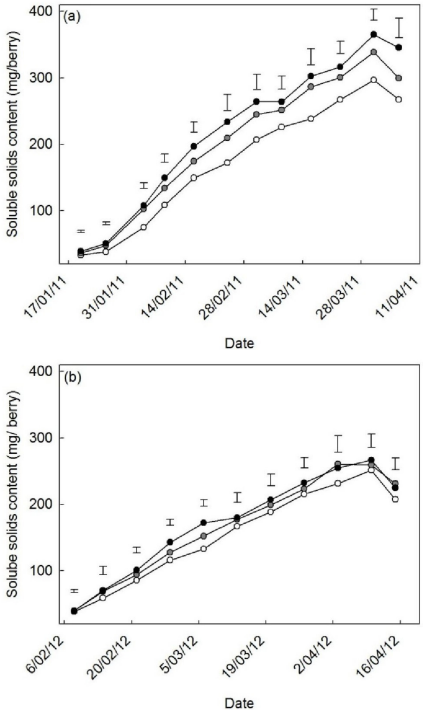

Fig. 7: Total soluble solids content (mg·berry^{-1}) in response to different canopy heights in 'Pinot noir' grapes. (**a**) 2010-2011 and (**b**) 2011-2012. Treatments: (●) Control treatment canopy height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. Error bars indicate least significant difference values (LSD) at α = 0.05. For 14 February 2012, the number of blocks was reduced to five and all treatments were evenly represented across the blocks (n = 15). For 10 April 2012, REML was used for analysis because of missing data (n = 19).

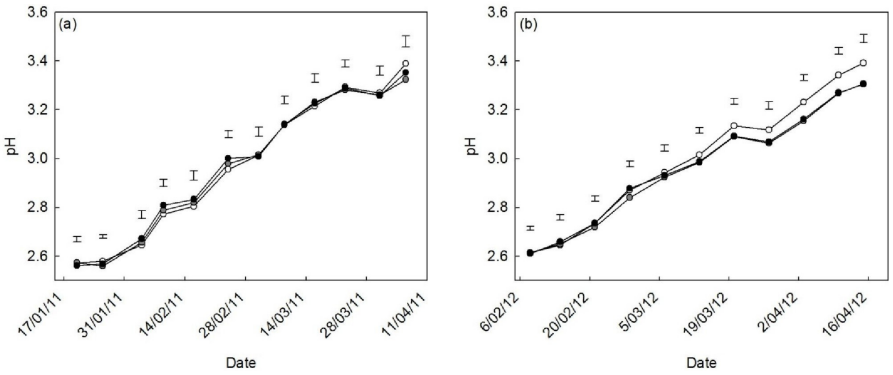

Fig. 8: pH in response to different canopy heights in 'Pinot noir' grapes. (**a**) 2010-2011 and (**b**) 2011-2012. Treatments: (●) Control treatment trim height at 1000 mm (●) 60 % canopy height relative to the control treatment at 600 mm and (○) 30 % canopy height relative to the control treatment at 300 mm. Error bars indicate least significant difference values (LSD) at α = 0.05.

ble solids concentration increased (Tab. 1 and Fig. 2), confirming results from previous studies (Ollat *et al.* 1998, Petrie *et al.* 2000, Poni and Giachino 2000, Stoll *et al.* 2011, Parker *et al.* 2014, Parker *et al.* 2015). The delay in the onset of ripening (defined as DOY 8 °Brix) was similar to that observed by Parker *et al.* (2014), where DOY for 8 °Brix for 'Pinot noir' was delayed up to 5 d when the main leaf area per vine was halved (12 to six leaves per shoot). The slower rates of total soluble solids accumulation at 2 °Brix increments (Fig. 2) and the larger GFV values for the duration to 20 °Brix (Tab. 1) in response to reduced canopy height indicated that total soluble solids accumulation rates were consistently reduced by mid/late March when days were shorter and cooler. The reduced canopy size resulted in a consistent total soluble solids accumulation rate difference relative to the control treatment throughout the ripening period (Fig. 3).

In 2010-2011, fruit total soluble solids content was reduced with trimming but in 2011-2012, the decrease in canopy height resulted in fewer differences between treatments in fruit total soluble solids content as a result of few differences in berry fresh mass (Figs 6 and 7). Total solu-

Table 3

Yield parameters at different canopy heights in 'Pinot noir' grapes

Canopy trim height†	Average number of bunches per vine		Calculated average bunch fresh mass (g) §		Yield ($kg \cdot vine^{-1}$)		Yield ($t \cdot ha^{-1}$)	
	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012
Control treatment	43	44	111	69	4.76	3.01	11.0	7.0
60 % canopy height	45	47	118	87	5.37	4.11	12.4	9.5
30 % canopy height	45	44	116	89	5.21	3.94	12.1	9.1
LSD	1.88	4.86	9.18	8.16	0.64	0.64	1.48	1.47

† Control treatment at 1000 mm, 60 % canopy height relative to the control treatment at 600 mm, 30 % canopy height relative to the control treatment at 300 mm.
§The calculated average bunch fresh mass was the yield divided by the number of bunches.

ble solids content also decreased for harvest fruit samples in both seasons (Fig. 7); it is unlikely this is an effect of late total soluble solids export from the berry, and therefore sampling error and potentially shrivel contributed to these differences.

At the time of maximum TA, lower TA was measured for fruit from the trimmed vines (Fig. 4). The decrease in TA has been measured to correspond to a reduction in malate: malate is dependent on carbon source and glucose for its production and storage in the berry and is therefore reduced when the carbon source is reduced via leaf removal (Ollat and Gaudillere 1998). In this present experiment, malate was not measured but this could be a plausible explanation. Differences in TA were reduced by harvest time, suggesting that even if malate concentrations resulted in a lower maximum TA, the big differences observed early during the ripening phase were reduced by harvest. However, the juice from fruit in the 30 % canopy height treatment had higher pH values in 2011-2012 (Fig. 8), indicating that the source-sink manipulations under certain circumstances can alter the acid composition and free hydrogen ions in the berries separately from the TA measurement of tartaric acid equivalents. Therefore, further research is required to determine the interplay of pH and acidity in response to reducing canopy size by trimming at fruitset.

The total soluble solids-TA ratio decreased when canopy height was reduced predominantly as a result of a reduction of total soluble solids concentrations (Fig. 5a, b) which supports the findings of Parker *et al.* (2015). Although TA was also reduced as a result of a decrease in canopy height (Fig. 4a, b and Tab. 2 at 20 °Brix), this reduction was insufficient to counter the reduction of total soluble solids and to therefore maintain the same total soluble solids-TA ratio (Fig. 5a, b).

Although this study was concerned with the measurement of primary components of berry composition, it would be important to consider other berry components such as amino acids or compounds that contribute to flavour and aroma profiles important for 'Pinot noir'. Given that the soluble solids-TA relationship was altered due to the trimming treatments, it would be of interest to examine which other compounds are affected by the trimming. It is plausible that the trimming could desynchronise the accumulation of primary and secondary metabolites resulting in changes in the relative proportions of compounds at harvest.

No differences in yield were measured in 2010-2011 but in 2011-2012, the yield of the 30 % and 60 % canopy height treatments were greater than that of the control treatment (Tab. 3, $p < 0.05$); this confirms the findings of earlier studies where trimming shortly after flowering resulted in an increased in fruitset and/or yield (Coombe 1957, 1962, Candolfi-Vasconcelos and Koblet 1990, Vasconcelos and Castagnoli 2000, Collins and Dry 2009). Severe trimming (30 % and 60 % canopy height relative to the control height) reduced canopy size and the source assimilates, and increased yield increased the sink demand. Consequently the increased yield from trimming post-flowering and pre-bunch closure may have accentuated the differences observed in total soluble solids concentrations and rates of accumulation.

At most sampling times before harvest in both seasons, vines in the 60 % canopy height treatment and the control treatment had a greater berry fresh mass (Fig. 6), confirming earlier findings (Stoll *et al.* 2011, Parker *et al.* 2014, 2015). However, the average fresh berry mass at harvest decreased for all samples (Fig. 6) because of shrivel and/or sample error.

Interestingly, the calculated bunch fresh mass as calculated by the yield divided by the number of bunches increased in both seasons for the 30 % and 60 % canopy height treatments (Tab. 3); this may have been due either to an increase in berry number per bunch or to an increase in average berry weight. The differences in berry fresh mass trends and yield responses to canopy height manipulations further highlight the need to understand the effects on individual yield components in response to the degree and timing of trimming. Collins and Dry (2009) found the most effective time to increase fruitset (as measured by counting flowers and then berries) via trimming was from the start of flowering until capfall was complete, confirming the increased fruitset observed in earlier studies where trimming only occurred at flowering (Coombe 1959, Vasconcelos and Castagnoli 2000). Collins and Dry (2009) found yield was increased as a consequence of increased fruitset and that there was an increase in berry number due

to an increase of seeded berries rather than any change in berry weight. In this experiment, it is not possible to determine without further experimentation the relative contribution of increased berry number versus increased berry mass that resulted in increased fresh bunch mass and yield in response to trimming. Measurement of flower number, berry fresh mass and berry number per bunch on harvest bunch samples is required to elucidate the importance of these two components on increased yield at harvest in future studies.

Higher yields can also influence the rate of total soluble solids accumulation (Nuzzo and Matthews 2006, Petrie and Clingeleffer 2006, Greven *et al.* 2014, Parker *et al.* 2014) so trimming during this time period may have had a confounding effect on the rate of total soluble solids accumulation *via* reducing source leaves and increasing sink size. Therefore it is important to also consider the effect of the time of trimming on yield components and the subsequent influence of the source-sink ratio on berry maturation.

New rows were used each season so that the impact of trimming by season could be investigated. From the two seasons of data presented here, it can be observed that within a season trimming can not only alter soluble solids accumulation, but if conducted at the right period, it can also increase yield, The limitation of this approach is that the application of repetitive trimming was not investigated. Continuous trimming - season after season - on the same vines may impact on carbohydrate reserves and potentially modify the magnitude of these dynamics. Severe defoliation or trimming has been observed to reduce carbohydrate reserves and/ or reduce yield components in the subsequent season (reduced inflorescence or berry number per bunch or reduced bunch size (Candolfi-Vasconcelos and Koblet 1990, Duchêne *et al.* 2003, Bennett *et al.* 2005, Poni *et al.* 2006, Lohitnavy *et al.* 2010, Zufferey *et al.* 2012). Further studies to establish how these trends continue over several seasons on the same vines would be informative to understand the longer term implications of applying mechanical trimming to altering ripening and yield within a season.

Conclusions

Reduced canopy size and consequently source limitation via mechanical trimming of 'Pinot noir' vines shortly after flowering can result in a delayed ripening period, slower total soluble solids accumulation, and in small differences in titratable acidity and pH (the last two depending on the season). The reduction in total soluble solids concentration alters the total soluble solids: TA ratio. The effects of reduced canopy height during the flowering to bunch closure period can therefore not only create source limitations by reducing the amount of leaves but may also alter sink components by increasing yield. Therefore trimming can be of benefit in controlling the ripening phase particularly by delaying soluble solids accumulation, and the additional benefit of increasing yield if trimmed shortly after flowering, may also intensify the delay. Further work on other metabolites will help elucidate if trimming can lead to benefits in grape quality. Since TA was not affected by trimming, it is likely the balance of berry components may differ depending on which are modified and this would be worthy of further investigation. If trimming can be used to delay the ripening period without negating quality, it would a potential method to counter advanced phenology and ripening due to warmer climate conditions.

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