Leaf Canopy Structure and Vine Performance

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Leaf canopy structure of mature Pinot noir grapevines was manipulated during two consecutive seasons: shoot tipping at full bloom (yes or no), lateral shoot length (no laterals, laterals cut back to four leaves at full bloom, laterals allowed to grow undisturbed), and cluster zone leaf removal (leaf removal in the cluster zone or no leaf removal). Treatments were carried out in factorial combinations. Shoot tipping at bloom increased percent fruit set, berries per cluster, cluster weight, yield per shoot, and yield to pruning ratio. Shoot tip removal also increased main and lateral leaf size and the contribution of lateral leaves to total leaf area. Tipping decreased total yield per vine, juice pH, leaf area per vine, pruning weight, and cane weight and sugars in the trunk during dormancy. Increasing lateral shoot length increased juice soluble solids, juice pH, skin anthocyanin content, cane weight, and sugar and total non-structural carbohydrates in the trunk during dormancy. Percent fruit set increased in the absence of vegetative growing tips, on either the main or lateral shoots. Leaf removal in the cluster zone four weeks after bloom had no impact on yield components but reduced juice soluble solids.

KEY WORDS: canopy management, leaf age, vegetative growth, cluster zone leaf removal, shoot tipping, lateral shoot length, fruit set, yield components, fruit composition, skin anthocyanins, wood carbohydrate reserves

Achieving consistent yields of high quality grapes in cool climates is challenging. Yields tend to fluctuate from year to year and optimum maturity may not be reached every season. A short growing season, cool weather, and unfavorable precipitation patterns, are factors that may affect the yield and quality of the vintage. The success of wine grape production in cool climates can often be improved through proper canopy management. Canopy management provides a set of tools that allows grape growers to improve the canopy structure and microclimate.

One aspect of canopy structure that should not be underestimated is the age distribution of the leaf population. Grapevine leaves are net importers of carbohydrates until they reach 50% to 80% of their final size [18,36]. Photosynthetic rate increases until leaves attain full size (approximately 40 days after unfolding) and decreases steadily thereafter [22,23]. The most efficient leaves in the canopy, therefore, are those that are recently expanded. The age of the vine canopy can be manipulated with selective leaf removal and shoot tipping at appropriate growth stages.

Removing shoot tips promotes lateral shoot growth at the nodes closer to the excised tip [13,37]. Lateral shoots developed during the period of active shoot growth will provide additional photo-assimilating surface during fruit ripening. Lateral shoots become net exporters of carbohydrates as soon as they have two fully expanded leaves [12]. They provide assimilates to support their own growth and export the surplus to the main shoot, contributing to fruit ripening [19]. Candolfi-Vasconcelos *et al.* [6] found that during ripening, the most efficient leaves are those located at the top of the canopy and those arising from lateral shoots.

To retain, hedge, or remove lateral shoots in grapevine canopies has been a matter of controversy in many wine grape production zones in the Old and New World. Lateral shoots are undesirable in vigorous vineyards because they lead to crowded canopies, with excessive shading and humidity, and poor air circulation, resulting in an imbalance favoring vegetative growth over fruit production and increased disease incidence [9,11,30,31]. In moderate vigor vineyards, lateral leaves improve fruit quality and are the most important contributors to sugar accumulation in the fruit during ripening, and to starch accumulation in the parent vine [4].

The objective of this study was to determine how different canopy management practices and combinations of these practices affect yield, fruit composition, vegetative growth, and carbohydrate reserves in the permanent vine structure. Ultimately, the goal was to provide growers with tools to optimize wine grape production using these practices.

Materials and Methods

Experimental design: The experiment was carried out on 180, 17-year-old, own-rooted Pinot noir grapevines during two consecutive seasons. Vines were spaced 1.83 m × 2.74 m and were cane-pruned to four buds/m^2 (11 buds/m row) in the first season and were balanced pruned to 28 buds/kg of one-year-old pruning wood in the second season. The following treatments were applied in factorial combinations:

Shoot tipping: removal of 3 to 4 apical leaves) at full bloom, or no shoot tipping.

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Lateral shoot length: *(1)* no laterals (laterals removed weekly as they arose, starting at full bloom); *(2)* short laterals (laterals cut back to four leaves at full bloom, and subsequent lateral growth removed weekly); *(3)* long laterals (laterals allowed to grow undisturbed).

Leaf removal in the cluster zone four weeks after bloom or no leaf removal: This treatment consisted of removing the leaves and lateral shoots opposite the clusters in addition to one leaf immediately above and below the cluster.

Each treatment combination was replicated five times with three vines per plot in a completely randomized design.

Fruit set: Prior to bloom, one inflorescence per vine was enclosed in a mesh bag to retain all shed flowers. The bags were removed at the end of July, four weeks after full boom, and all abscised flowers and fruitlets counted. At harvest, these clusters were picked separately, frozen at -20°C, and the number of berries was later counted. The number of flowers was calculated as the sum of shed flowers and berries. Percent fruit set was calculated as the quotient of the number of berries at harvest and the total number of flowers per inflorescence.

Yield and yield components: The crop was harvested on 1 October in 1995 and on 17 October in 1996. The number of clusters per plant was recorded. One hundred berries from each plot were chosen randomly to determine mean berry weight. Cluster weight was obtained by dividing total yield by the number of clusters. The number of berries per cluster was calculated by dividing cluster weight by the mean berry weight.

Fruit composition: A sample of 25 clusters per experimental unit was crushed for determination of soluble solids, pH, and titratable acidity.

Skin anthocyanin content was determined on a 100-berry sample from each experimental unit as described by Candolfi-Vasconcelos and Koblet [4]. An extinction coefficient of E 1% = 380 was used in the calculations [29].

Canopy development and vine vigor: Trunk volume (V) was estimated during pruning in February 1996 and 1997. For this purpose, the trunks were divided into a varying (n) number of sections that were approximately cylindrical shape and the following formula was used:

$$V = \sum_{i=1}^{n} \left(\frac{d_i}{2}\right)^2 \cdot \pi \cdot L_i$$

n: number of cylindrical sections. $1 \leq n \leq 3$
d_i: diameter of the trunk section i
L_i: length of the trunk section i

The weight of the one-year-old prunings, including woody laterals, was recorded in 1996 and 1997. Cane weight was obtained by dividing pruning weight by the number of canes.

Three shoots per replicate were collected on 9 September 1996 for growth analysis. The number of main and lateral leaves were counted. Shoot length and diameter, and primary and lateral leaf area were measured.

The Ravaz index [27] was calculated by dividing total yield per vine by the pruning weight recorded during the winter following each season.

Wood carbohydrate reserves: During pruning, wood samples from the trunk were collected and carbohydrates were extracted and analyzed using the method described by Candolfi-Vasconcelos and Koblet [4].

Statistical analysis: The Statview statistical package was used for statistical analysis of data. Results were subjected to correlation analysis and to a 4-way analysis of variance (shoot tipping × lateral length × leaf removal × season). The Waller-Duncan k-ratio test was used to compare means. Interactions between factors were rare, and the contribution of the interactions to the total variance was very small relative to the main effects. For this reason, we chose to present only the means of the main effects. For completeness, all significant interactions found are reported in the text. The effect of cluster zone leaf removal was omitted from the tables when there was no significant response (Tables 1, 4, and 5).

Results and Discussion

Yield and yield components: Shoot tipping at bloom improved fruit set by 25% (Table 1). Additionally, fruit set was favored by lateral shoot removal with a trend toward higher percent fruit set in response to complete removal of lateral shoots. The positive effect of tipping on fruit set has been established in previous studies [4,8,17,34]. Actively growing shoot tips compete with the developing inflorescences for assimilates. During bloom, the leaves in the mid- and upper-shoot section export carbohydrates to the shoot tip [12,18,26]. After hedging, the direction of translocation is reversed; instead of moving acropetally to the shoot tip, assimilates are diverted basipetally [26] and made available to the developing inflorescences. This is thought to improve fruit set. During early stages of development, lateral shoots depend on assimilates provided by the main shoot for growth, competing with other vegetative and reproductive sinks [20]. Elimination of all competing vegetative growing tips, either on the main or lateral shoots, increases the pool of available carbohydrates for floral development, which may result in improved fruit set.

Cluster zone leaf removal had no measurable effect on fruit set or any other yield component (data not shown). We chose to apply this treatment four weeks after full bloom based on prior research. Candolfi-Vasconcelos and Koblet [4] found that leaf removal in the cluster zone in the early stages of berry development can reduce fruit yield, because flower and fruitlet

Table 1. Effect of canopy manipulations on fruit yield and yield components of Pinot noir grapevines during two consecutive seasons.

	Fruit set %	Berry wt (g)	Berries/ cluster	Cluster wt (g)	Clusters/ shoot	Shoots/ vine	Yield/ shoot (g)	Total yield/ vine
***(A)* Tipping**								
No	35.4	1.20	92	107	1.71	21.5	186	4.20
Yes	44.3	1.18	104	11:	1.70	17.5	204	3.55
Significance (*p*)	0.0001	ns*	0.0002	0.0002	ns	<0.0001	0.0475	0.0201
***(B)* Laterals**								
Absent	44.9 a*	1.19	100	116	1.65	19.2	192	3.71
Short	37.0 b	1.19	98	115	1.78	19.2	206	4.07
Long	36.6 b	1.19	94	109	1.69	20.1	188	3.84
Significance (P)	0.0177	ns	ns	ns	ns	ns	ns	ns
***(C)* Season**								
Year 1	42.9	1.28	82	104	1.49	18.6	154	2.86
Year 2	36.7	1.10	113	123	1.92	20.4	236	4.89
Significance (*p*)	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0096	<0.0001	<0.0001

* Values followed by the same letters within main factors and columns do not differ significantly; ns: not significant at the 5% level

abscission may occur. During bloom, shoots of *V. vinifera* have an average of 16 to 19 unfolded leaves [24]. Under non-stressing conditions at this stage of development, retranslocation of assimilates from the reserves stored in the permanent structure has ceased [35]. The basal leaves are fully expanded and are net exporters of carbohydrates [12,18]. Removal of basal leaves at full bloom equates to the elimination of a significant proportion of the primary source of photoassimilates. Four weeks after full bloom, the main shoot has 25-27 unfolded leaves [M. C. Vasconcelos, unpublished data, 1997]. Elimination of basal leaves at this stage does not affect fruit set [3,4].

The final number of berries per cluster, cluster weight and yield per shoot were increased by shoot tip removal, but not by other treatment factors (Table 1). These increases largely reflect those observed in fruit set with similar trends in response to lateral shoot removal.

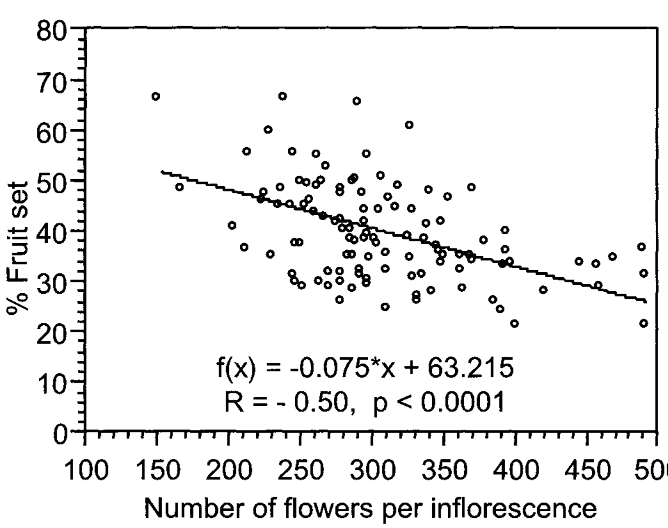

Fig. 1. Relationship between number of flowers and percent fruit set of Pinot noir grapevines subjected to different canopy management treatments. Data were pooled across all treatment factors.

There was no treatment effect on berry weight or bud fertility (clusters/shoot), but there was a significant effect of season (Table 1). Candolfi-Vasconcelos and Koblet (4) found that removal of mature leaves during the two-week period following bloom reduces bud fertility in the following season. Carbohydrate shortage during this period is critical for fruit production in both the current and following seasons.

Season affected yield/vine (Table 1) mainly due to the number of buds left per vine after pruning, but also through increased bud fertility and heavier clusters (Table 1). Shoot tip removal considerably reduced cane and pruning weights after the first season of implementation of the treatments (as will be discussed below), affecting the number of buds left after balanced pruning. There was a significant interaction between the shoot tipping treatment and the season (p = 0.0017). Yields per vine were 2.7 and 3 kg/vine for the non-tipped and tipped vines in the first season, respectively. These differences were not significant. In the second season, however, non-tipped vines had more shoots and clusters per vine which resulted in higher yields (5.7 and 4.1 kg/vine for non-tipped and tipped vines, respectively).

Across all treatments, total yield per vine was closely related to number of shoots per vine ($r = 0.743, p < 0.0001$), number of clusters per shoot ($r = 0.673, p < 0.0001$), and berries per cluster ($r = 0.457, p < 0.0001$). Percent fruit set was inversely related to number of flowers per inflorescence (Fig. 1). This compensation mechanism is an interesting phenomenon and seems to indicate that even after the number of clusters and flowers are determined, fruit set provides an additional opportunity to regulate the crop, by adjusting it to the available resources.

Fruit composition: Juice soluble solids concentration was reduced by shoot tipping (Table 2). Brix

Table 2. Effect of canopy manipulations on fruit composition of Pinot noir grapevines during two consecutive seasons.

	Soluble solids °Brix	Juice pH	Titratable acidity (g/L)	Skin anthocyanins (mg/berry)	Skin anthocyanins (mg/g fruit)
***(A)* Tipping**					
No	22.5	3.23	7.24	0.933	0.791
Yes	21.9	3.19	7.52	0.885	0.757
Significance (*p*)	<0.0001	0.0192	ns*	ns	ns
***(B)* Laterals**					
Absent	21.7 c*	3.17 b	7.62	0.849 b	0.722 b
Short	22.2 b	3.22 ab	7.30	0.912 ab	0.772 ab
Long	22.7 a	3.24 a	7.21	0.966 a	0.828 a
Significance (*p*)	<0.0001	0.0045	ns	0.0076	0.0149
***(C)* Leaf Removal**					
No	22.5	3.22	7.50	0.924	0.789
Yes	21.9	3.20	7.26	0.894	0.760
Significance (*p*)	0.0001	ns	ns	ns	ns
***(D)* Season**					
Year 1	22.8	3.27	7.07	0.938	0.741
Year 2	21.6	3.15	7.69	0.880	0.807
Significance (*p*)	<0.0001	<0.0001	0.0006	ns	0.0270

* Values followed by the same letters within main factors and columns do not differ significantly; ns: not significant at the 5% level. Interactions between main factors were not significant.

increased, however, with increasing lateral shoot length. These two responses can be explained if the corresponding leaf age distribution and photosynthetic activity of different aged leaves are considered. Photosynthetic activity is higher in recently formed leaves, with the peak of photosynthesis occurring when leaves attain full size, followed by a gradual decrease with increasing leaf age [1,21,22,33]. Young leaves were present on non-tipped vines and those with lateral shoots. Thus, non-tipped vines or those with lateral shoots should have higher overall canopy photosynthesis, resulting in a larger pool of photoassimilates available for accumulation of sugars in the fruit. Furthermore, it has been shown that the presence of fully expanded young leaves is advantageous for sugar accumulation in the fruit [4].

Removing four basal leaves four weeks after bloom reduced juice soluble solids at harvest (Table 2). It has to be noted that under western Oregon climatic conditions, vegetative growth stops relatively early compared to that of wine grape growing regions in central Europe that receive precipitation during the summer months. In eastern Switzerland, where leaf growth does not stop until veraison, there was no significant decrease in juice soluble solids on vines where all the leaves in the primary shoot had been removed [3]. In that study, lateral shoots were able to reconstruct an adequate assimilating surface and compensate for the absence of main leaves. In the present experiment, basal leaf removal was not compensated for by increased lateral shoot growth; there was no interaction between the leaf removal and the lateral shoot length treatments for leaf area (Table 3). Lower juice soluble solids in response to basal leaf removal can be explained by the reduction of the leaf to fruit ratio from 15 to 10 cm^2/g fruit (Table 3).

Jackson and Lombard [14] warned against excessive fruit exposure due to leaf removal and recommended considering this practice vineyard by vineyard using historical data on canopy exposure and previous wine quality. If foliage or fruit already receive adequate exposure, leaf removal may cause a reduction in berry weight and soluble solids, probably because too much leaf area has been removed [2].

There were no significant differences in titratable acidity among treatments but juice pH responded similarly to juice soluble solids, indicating that "younger" canopies hasten fruit ripening (Table 2). In contrast with our results, it is generally accepted that increased cluster exposure to sunlight decreases juice acid content [15,16,28,31,32,37].

Table 3. Effect of canopy manipulations on canopy architecture of Pinot noir grapevines during the second season of application of the treatments.

	Main leaves size (cm^2)	Lateral leaves size (cm^2)	Main leaf area/ vine (m^2)	Lateral leaf area/ vine (m^2)	Total leaf area/ vine (m^2)	Lateral leaf area percent of total	Leaf:fruit ratio cm^2/g fruit
(A) Tipping							
No	99	31	5.69	2.13	7.82	24	15
Yes	113	38	2.47	1.73	4.18	32	11
Significance (*p*)	0.0067	0.0103	<0.0001	ns*	<0.0001	0.0049	0.0031
(B) Laterals							
Absent	98	—	4.17	—	3.89 b*	—	9 b
Short	109	33	4.24	2.57	6.81 a	39 b	14 a
Long	112	35	3.80	3.22	7.02 a	46 a	15 a
Significance (*p*)	ns	ns	ns	<0.0001	0.0019	<0.001	0.0005
(C) Leaf Removal							
No	109	37	4.50	2.19	6.68	29	15
Yes	103	32	3.64	1.68	5.32	28	10
Significance (*p*)	ns	ns	ns	ns	ns	ns	0.0012

* Values followed by the same letters within main factors and columns do not differ significantly; ns: not significant at the 5% level. Interactions between main factors were not significant.

Table 4. Effect of canopy manipulations on vine vigor and Ravaz Index of Pinot noir grapevines during two consecutive seasons.

	Cane wt (g)	Pruning wt (kg/vine)	Trunk volume (cm³)	Ravaz index (kg fruit/kg prunings)
(A) Tipping				
No	61	1.209	2394	4.0
Yes	43	0.678	2254	6.0
Significance (*p*)	<0.0001	<0.0001	ns*	<0.0001
(B) Laterals				
Absent	46 b*	0.839	2282	5.6 a
Short	53 ab	0.953	2260	5.1 ab
Long	56 ab	1.038	2430	4.3 b
Significance (*p*)	0.0251	ns	ns	0.0158
(C) Season				
Year 1	58	1.081	2458	3.2
Year 2	46	0.805	2190	6.8
Significance (*p*)	0.0001	0.0001	0.0004	<0.0001

* Values followed by the same letters within main factors and columns do not differ significantly; ns: not significant at the 5% level.

Skin anthocyanin content was not affected by increased exposure resulting from leaf removal in the cluster zone (Table 2). Reports on the effect of sun exposure on anthocyanin content are inconsistent. Increasing sun-exposure of berries did not change anthocyanin content in Pinot noir [25], but increased color of Cabernet Franc [10] and Cabernet Sauvignon [7].

The presence of more lateral leaves improved skin anthocyanin content both per berry and per amount of fruit (Table 2). Candolfi-Vasconcelos and Koblet [4] showed that canopies composed only of lateral leaves generated fruit with higher soluble solids and anthocyanin content as compared to non-defoliated controls. They hypothesized that lateral leaves, being the youngest leaves in the canopy, played a major role in metabolic processes occurring during fruit ripening.

Canopy development and vine vigor: Average leaf size (main and lateral leaves) increased with shoot tip removal but did not respond to other treatments (Table 3). It has been shown that one of the compensation mechanisms for defoliation is the increase in the size of the remaining leaves [4]; however, we did not observe this compensation in response to basal leaf removal and lateral shoot shortening. Removal of shoot tips decreased total leaf area by 47%, mainly because of reduced main leaf area (Table 3). Complete removal of lateral shoots decreased total leaf area by 43% and 45% as compared to the treatments with trimmed laterals and long laterals, respectively (Table 3). Vines with laterals cut back to four leaves had 20% less lateral leaf area than vines with untrimmed lateral shoots but there was no significant difference in total leaf area between these treatments. Total leaf area per vine was not significantly reduced by leaf removal in the cluster zone (Table 3).

Shoot tip removal increased the proportion of leaf area arising from lateral shoots but leaf removal in the cluster zone did not change this ratio (Table 3).

Shoot diameter during mid-ripening did not respond to shoot tip removal, even though the hedged shoots were 76% shorter (data not shown).

Trunk volume measured in the winter during dormancy was not affected by any of the treatments (Table 4) but decreased after the second season. This could not be accounted for with changes in water content (data not shown). The decrease in trunk volume may be the result of the increased yields in response to balanced pruning in the winter prior to the second season. The fruit is the primary sink for assimilates during the six weeks post veraison [5]. After that, the roots become the most powerful sink [5]. During ripening and under non-stressing conditions, leaf photosynthesis is the only source of carbohydrates for fruit development [5]. However, carbon reserves in the trunk and roots can complement current photosynthesis to support fruit maturation in cases of photosynthate shortage [5]. The

Table 5. Effect of canopy manipulations on trunk carbohydrate reserves of Pinot noir grapevines during dormancy.

	Starch concentration	Sugar concentration	TNSC concentration	Starch g/ trunk	Sugar g/ runk	TNSC g/trunk
(A) Tipping						
No	9.3	3.9 a*	13.2	172.0	71.9 a	244.0
Yes	9.7	3.5 b	13.1	170.4	59.4 b	226.9
Significance (*p*)	ns*	0.0034	ns	ns	0.0011	ns
(B) Laterals						
Absent	9.0	3.5	12.5	156.0	59.0 b	210.7 b
Short	9.4	3.6	13.1	170.1	64.9 ab	235.0 ab
Long	10.0	4.0	13.9	187.6	73.1 a	260.7 a
Significance (*p*)	ns	ns	ns	ns	0.0105	0.0186
(C) Season						
Year 1	11.9 a	3.7	15.7 a	225.5 a	69.6 a	292.2 a
Year 2	7.0 b	3.7	10.7 b	117.0 b	61.7 b	178.7 b
Significance (*p*)	<0.0001	ns	<0.0001	<0.0001	0.0362	<0.0001

* Values followed by the same letters within main factors and columns do not differ significantly; ns: not significant at the 5% level.
Interactions between main factors were not significant.

higher crop load during the second season may have limited the replenishment of carbohydrate reserves in the trunk (Table 5) as well as caused the lower trunk volumes.

Pruning weights were not affected by lateral shoot length (Table 4) or leaf removal (data not shown) but decreased greatly with shoot tipping (Table 4). Pruning weights and average cane weight were lower following the second season, possibly in response to balance pruning (Table 4). There was a significant interaction between the shoot tipping treatment and the season: shoot tipping decreased cane weights from 73 g to 42 g after the first season and from 49 to 43 g after the second season. Vines in balance should have canes in the 30 to 40 g range, 40 g being preferred in cool climates (R. E. Smart, personal communication, 1995). Vines without lateral shoots had the lowest cane weights (Table 4).

The Ravaz index represents the ratio of reproductive to vegetative growth and balanced vines should remain between 5 and 7 [27]. Shoot tipping increased the Ravaz index from 4 to 6 (Table 4). Trimming or eliminating lateral shoots also increased the Ravaz index (Table 4). Leaf removal did not change this ratio and did not affect cane or pruning weight (data not shown). The Ravaz index increased more than two-fold from the first to the second season (Table 4). This is probably a response to balance pruning prior to the second season. This supports the general belief that appropriate pruning levels, matching the vine capacity with the cropping level, are extremely important to achieving a balance between vegetative and reproductive growth.

Carbohydrate reserves in the wood: The concentration and total amount of starch in the trunk during dormancy were not significantly affected by any of the canopy management treatments (Table 5). There was a trend, however, toward increased concentration and total amount of starch in response to shoot tipping, lateral shoot length (Table 5), and leaf removal (data not shown). Sugar concentration and total amount per trunk decreased with shoot tipping (Table 5). The total amount and concentration of non-structural carbohydrates were not significantly affected by shoot tipping (Table 5) or leaf removal (data not shown). Total carbohydrate reserves stored in the trunk increased, however, with lateral shoot length, in agreement with prior research by Candolfi-Vasconcelos [3].

Starch content in the permanent vine frame was related to juice soluble solids during the preceding season (year 1: $r = 0.326$, $p = 0.011$; year 2: $r = 0.411$, $p = 0.001$), suggesting that sugar accumulation in the fruit and starch accumulation in the reserve organs occur simultaneously. This is in agreement with results reported previously [4,5].

Conclusions

The canopy management techniques used in this experiment were targeted at changing the leaf age distribution of the vine canopy at critical times during the growing season. They should only be implemented with full understanding of their impact on the carbohydrate translocation patterns and leaf photosynthetic response to aging.

Canopy management practices can be used to maximize the amount of carbohydrates partitioned to inflorescences during bloom to improve fruit set, or to reduce partitioning to reduce fruit set. Results obtained in this study indicate that eliminating immature leaves during bloom increases fruit set and promoting vegetative growth during this period reduces fruit set. Therefore, by manipulating the number of competing sinks for carbohydrates during early stages of berry development, it is possible to increase fruit set in poor set varieties or decrease cluster compactness in varieties prone to bunch rot.

Canopy management can be used to maximize carbohydrate partitioning to fruit during ripening; this can be achieved by actively promoting the availability of young, fully expanded leaves during fruit ripening. Retaining lateral shoots hastened fruit ripening, improved fruit color, and increased the level of carbohydrate reserves in the trunk. This is a valuable technique and can be used to improve fruit composition and vine survival in short-season winegrape regions.

Removal of leaves in the cluster zone four weeks post-bloom did not affect yield or yield components but decreased juice soluble solids and did not improve skin anthocyanins. Our experiment was conducted in a moderate vigor vineyard and removal of three to four leaves in the cluster zone seemed to be excessive. This cultural practice should be reserved for vigorous vineyards with crowded canopies.

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