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Impact of early fruit-zone leaf removal on grapevine development and fruit quality in *Vitis vinifera* ‘Merlot’

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Dedication

This is dedicated to my lovely wife, Julie. Without her unwavering love and support, this would not be possible.

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Abstract

The objective of this study was to determine the optimal timing of fruit-zone leaf removal for red wine grape cultivars, specifically *Vitis vinifera* ‘Merlot’, in the Yakima Valley, Washington using four different timings of fruit-zone leaf removal, (i) pre-bloom, (ii) full-bloom, (iii) 3 weeks post-bloom and (iv) no leaf removal (control). Fruit-zone leaf removal is a common canopy management technique, with increasing focus on early (pre-fruit set) timing. Little research exists on the impacts of early fruit-zone leaf removal in semiarid viticultural regions like the inland Pacific Northwest, USA.

Shoot growth after leaf removal in the pre-bloom treatment temporarily decreased relative to the no leaf removal treatment (control). The incidence of summer lateral shoot development within the fruit-zone indicates that only pre-bloom fruit-zone leaf removal recovered to control levels by véraison. Percent fruit set was lowest in the pre-bloom treatment. Sunburn, powdery mildew and Botrytis bunch rot did not develop to any significant level in any treatment. Though not statistically significant, fruit-zone leaf removal increased surface temperatures of clusters and compound buds.

The scope of this report does not provide adequate data for firm conclusions about the effects of early fruit-zone leaf removal on grapevine development and fruit quality. Outside of the summer lateral shoot data, the fruit-zone leaf removal treatments in this experiment were statistically similar to the no leaf removal treatment. However, trends in the data suggest fruit-zone leaf removal may impact vine vigor, fruit set, and fruit-zone microclimate providing ample cause for further research on this canopy management technique.

Resumo

O objetivo deste estudo foi determinar a época óptima de desfolha para a casta tinta 'Merlot', no Vale de Yakima, Washington, usando 4 diferentes épocas de desfolha, (i) pré-floração, (ii) plena floração (iii) 3 semanas após a floração e (iv) sem desfolha (testemunha). A desfolha é uma técnica comum de gestão da folhagem que recentemente tem sido muito estudada na fase precoce antes do vingamento. Existe pouca investigação sobre os impactos da desfolha precoce em regiões vitícolas semi-áridas como é o caso da região interior do Pacífico Noroeste, nos EUA.

Comparativamente à testemunha não desfolhada, no tratamento pré-floração o crescimento dos lançamentos foi temporariamente menor. A análise do desenvolvimento das netas na zona dos cachos indica que apenas no tratamento pré-floração se verificou uma recuperação que atingiu os níveis da testemunha ao pintor. A percentagem de vingamento foi menor no tratamento pré-floração. Em qualquer dos tratamentos não se verificou o desenvolvimento quer do escaldão, quer do oídio ou da podridão cinzenta. Apesar de não ser estatisticamente significativa, verificou-se uma tendência para o aumento da temperatura dos cachos e dos olhos nas modalidades desfolhadas comparativamente à testemunha não desfolhada.

Os resultados obtidos neste trabalho não permitem conclusões robustas sobre os efeitos da desfolha precoce no desenvolvimento da videira e na qualidade da uva. Com excepção do crescimento das netas, os tratamentos de desfolha apresentaram resultados similares à testemunha não desfolhada. No entanto, observaram-se algumas tendências que sugerem que a desfolha pode afetar o vigor, a percentagem de vingamento e o microclima da zona dos cachos, o que indica a necessidade de mais estudos sobre os efeitos desta técnica de gestão da folhagem.

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List of Abbreviations

°C	Degrees Celsius
ANOVA	Analysis of variance
AVA	American Viticultural Area
CDOY	Climate day of year
cm	Centimeters
CO_2	carbon dioxide
EFLR	Early fruit-zone leaf removal
EL	Eichhorn - Lorenz
FLR	Fruit-zone leaf removal
GDD	Growing degree days
m	Meters
m/s	Meters per second
mm	Millimeters
MP	Methoxypyrazine
RDI	Regulated deficit irrigation
TA	Total acidity
TLA	Total leaf area
Tukey's HSD	Tukey's honestly significant difference test
USA	United States of America
VSP	Vertical shoot position
w/m^2	watts per square meter
WA	Washington State
Y1	The current growing season
Y2	The second growing season

Introduction

Introduction to Canopy Management

In viticulture, leaf area, canopy density, and leaf distribution and orientation within the canopy are fundamental characteristics of the canopy light microclimate. These parameters are critical to understanding the varying responses of grapevines to the environment, training systems and canopy management practices (Lopes and Pinto 2005). During recent history, the core principles of modern grapevine canopy management were established with the common goal of optimizing sunlight interception, photosynthetic capacity and fruit-microclimate in an effort to improve yield and wine quality.

Many canopy management studies focus on the following production and fruit quality issues: (i) providing enough total leaf surface area to supply the photosynthate necessary to ripen fruit; (ii) exposing fruit at various stages of development to enhance wine quality; (iii) exposing developing buds to enhance following-year fruitfulness; and (iv) opening up the canopy to reduce disease pressure.

A common canopy management technique employed is fruit-zone leaf removal (FLR). In general, FLR is used to alter either the canopy microclimate, or impact the vine carbohydrate supply. Fruit-zone leaf removal techniques vary considerably. For example, growers may choose to remove some of the leaves in the fruit-zone, or only on one side of the canopy. They may choose to remove summer lateral shoots, or not. They can also vary the timing of the leaf removal and the number of vineyard passes throughout the growing season. These variables can lead to different outcomes which result in confusion regarding the proper treatment application.

Historically, FLR is performed between fruit set and véraison. This is done to alter the microclimate of the fruit-zone through greater cluster exposure and air circulation in an effort to enhance berry ripening (Percival et al. 1994), though this effect can be highly variable (Bavaresco et al. 2008). Leaf removal at véraison of dense canopies can increase assimilates by exposing interior shaded leaves (Percival et al. 1994, Poni et al. 2006) however, this effect is diminished or insignificant in less dense canopies (Reynolds et al. 1996). Véraison FLR was also used to assist with late-season disease control through increased spray penetration (Austin et al. 2011). However, véraison FLR may overexpose fruit during warm, long days resulting in greater risk of sunburn as well as potential anthocyanin degradation (Bergqvist et al. 2001, Bondada 2012, Spayd et al. 2002).

Fruit-zone leaf removal is one of the most commonly applied canopy management techniques, with increasing focus on early fruit-zone leaf removal (EFLR) (Poni et al. 2006) which occurs before fruit set. Removal of the basal leaves and summer lateral shoots within the fruit-zone causes a sudden, severe and prolonged change to the fruit-zone (Smart 1988, Percival et al. 1994, Poni et al. 2009). Reports indicate that EFLR can improve fruit and wine composition by affecting the total leaf area (TLA) to yield ratio, canopy microclimate, and disease pressure (Diago et al. 2010, Tardaguila et al. 2010, Palliotti et al. 2011, Poni et al. 2009, Austin et al. 2011). However, results of EFLR vary considerably due to many factors, including differences in treatment timing and degree of leaf removal, method of leaf removal (manual or mechanical), climate, vine vigor, as well as the impact of other viticultural practices.

Mechanical leaf removal can be a viable alternative to manual leaf removal (Tardaguila et al. 2010, Intrieri et al. 2008, Diago et al. 2011). Results have shown both greater impacts (Diago et al. 2011) and lesser impacts (Intrieri et al. 2008) on grapevine development and fruit quality from mechanical EFLR relative to manual EFLR. In an effort to limit the variables considered, the primary focus of this report is on manual EFLR.

Effects of Early Fruit-zone Leaf Removal on Canopy Development

Canopy development is dependent on several physiological factors, most importantly carbon dioxide (CO_2) fixation, and the coordinated mechanisms of carbon allocation, accumulation, and utilization (Palliotti et al. 2011). New shoots emerge after bud break through water uptake and mobilization of stored carbohydrate reserves in the perennial organs of the vine (woody roots, trunks, cordons and canes) (Bennett et al. 2005). Carbohydrate reserves are critical to pre-bloom vine development until new leaves expand to 50 to 80 percent of their final size (near bloom) and begin to export carbohydrates (Candolfi-Vasconcelos and Koblet 1990, Yang et al. 1980). During the growing season, it is estimated that more than 90 percent of plant dry matter is derived from carbon fixed through photosynthesis (Flore and Lakso, 1989) reinforcing the importance of photosynthate to vine development. As the new shoots extend, a naturally occurring age gradient is formed from shoot base to tip. Studies have demonstrated the effect of leaf age on the rate of CO_2 assimilation, with recently expanded and exposed leaves reaching maximum efficiency between 5 to 8 weeks of age followed by a gradual decline in efficiency (Poni et al. 2006, Vasconcelos et al. 2000, Intrieri et al. 1997, Hofaecker 1978).

Removing the largest and most mature exposed leaves from the canopy can have wide ranging consequences. Studies on leaf age indicate the timing of the leaf removal will vary the effect on net photosynthesis and therefore total carbohydrate supply. However, removing fruit-zone leaves can expose previously shaded interior canopy leaves (Intrieri et al. 1997) which contribute to the rate of net photosynthesis. The contribution of interior leaves to the carbon budget depends on the total interior leaf area, which varies greatly depending on trellis configuration, vine spacing, and vine vigor (Smart 1985, Sommer et al. 2000, Reynolds et al. 1996). Additionally, leaf removal can stimulate a compensating increase in photosynthesis and respiration in the remaining leaves which may help mitigate the impact of leaf removal. However, this response is variable in intensity and is usually observed to be temporary (Candolfi-Vasconcelos and Koblet 1991, Hofaecker 1978, Intrieri et al. 1997, Palliotti et al. 2011, Petrie et al. 2003).

Leaves formed after EFLR have shown improvements in carbon fixation efficiency, contributing to the recovery of whole-vine assimilation rates (Palliotti et al. 2011, Poni and Civardi 2008). One hypothesis for these improvements is that leaf removal provides the developing leaves with an increased supply of water, nutrients and hormones from the roots causing the plant to generate more efficient plant tissue (Palliotti et al. 2011). However, these results are less consistent with leaf removal later in vine development. Petrie et al. (2003) found a significant and persistent decrease of whole-vine and per unit of leaf area photosynthesis rates when fruit-zone leaves were removed during the lag-phase (after the period defined as “early” FLR) of berry growth. Poni and Civardi (2008) believe this result can be explained by the weak canopy re-growth reported after the lag-phase leaf removal which indicated an insufficient carbohydrate demand to stimulate enhanced photosynthesis. These studies underscore the importance of the timing and degree of leaf removal.

Early fruit-zone leaf removal may affect grapevine root development. In young, potted grapevines, root growth was inhibited by leaf removal (Petrie et al. 2000, Kliewer and Fuller 1973, Buttrose 1966). However, with field-grown mature grapevines, partial leaf removal stimulated the growth of fine roots (Hunter et al. 1995, Hunter and Roux 1992) which grow rapidly and increase the utilization of water and nutrients from the soil (Petrie et al. 2000). The difference in response to EFLR between potted grapevines and mature field-grown grapevines may be due to greater carbohydrate reserves in the field-grown vines which help compensate for the stress of leaf removal and allow for an increase in fine root density. An increase of fine roots and root density can provide the plant with greater concentrations of growth regulators (cytokinin, gibberellin, abscisic acid) which regulate shoot and fruit development (Palliotti et al. 2000). Determining the effect of EFLR on root development is challenged by many other influencing factors such as rootstock, scion, soil characteristics, water availability, as well as timing and degree of leaf removal.

A balance between vine vigor and yield is critical to ensuring quality fruit production (Smart 1985). Grapevine pruning weight is one commonly used method to indicate vine balance. However, vine balance indicators that include yield have recently gained wide acceptance. Two examples are, yield to dormant vine pruning weight ratio (Bravdo et al. 1985, Smart 1985), and TLA to yield ratio (Smart 1985, Kliewer and Dokoozlian 2005).

The percentage of TLA resulting from summer lateral shoots can vary considerably (Smart 1985, Palliotti et al. 2000) depending on vine spacing, trellising, shoot spacing, and other vineyard management practices (pruning, shoot thinning, topping, deficit irrigation). Early fruit-zone leaf removal can stimulate the growth and initiation of summer lateral shoots (Kliewer and Fuller 1973, Hunter 2000, Candolfi-Vasconcelos and Koblet 1990, Hunter and Visser 1990, Diago et al. 2012). These newly developed summer lateral shoots may contribute to a recovery of (and occasionally exceed) the total leaf surface area of vines with no leaf removal by véraison (Intrieri et al. 2008, Poni et al. 2009, Palliotti et al. 2011, Diago et al. 2012). Tardaguila et al. (2010) reported significantly lower TLA in both pre-bloom and fruit set leaf removal. However, in relation to the TLA to yield ratio, the pre-bloom leaf removal recovered in both years for both cultivars. This was not the case when leaves were removed at fruit set.

Until the vine recovers from the reduced TLA resulting from EFLR, total carbohydrate supply can be reduced which may help control vine vigor. Excess vigor can create a poor canopy microclimate affecting fruit development and quality (Hunter and Visser 1990). The effects of reduced TLA on vine balance vary considerably due to method, degree and timing of leaf removal. Buttrose (1966) reported that grapevine trunks were affected least by different levels of TLA, followed by shoots, berries and roots; while Kliewer & Fuller (1973) reported the opposite. Petrie et al. (2000) found no significant differences in shoot length or internode length related to TLA, but total dry weight of the vines were lower for vines with severely reduced TLA. Pruning weights (kg/m) can decrease due to reduced TLA (Palliotti et al. 2011) but not in all studies (Vasoncelos and Castagnoli 2000), though this aforementioned study reduced leaf area later in the growing season (4 weeks post-bloom) providing less time for re-growth. Palliotti et al. (2011)

observed lower pruning weight in two subsequent years of reduced TLA but neither year experienced a decline in final TLA primarily due to summer lateral shoot development.

Effects of Early Fruit-zone Leaf Removal on Fruit Development

Berry growth is a combination of two successive sigmoidal curves (Figure 1). The first phase of growth begins 5-10 days pre-bloom and continues until 3 weeks post-bloom (Coombe 1960, Harris et al. 1968). During this phase, berry size increases initially through cell division with subsequent growth due to cell enlargement (Harris et al. 1968) (Figure 1). Coombe (1976) determined the rate of pre-bloom cell division is nearly ten times greater than the rate of cell division post-bloom. Early fruit-zone leaf removal during berry formation can disrupt the rate and duration of cell division and cell enlargement through a reduction in the carbohydrate supply which is critical to early fruit development (Coombe 1959, Caspari et al. 1998). Fruit is a weak sink for carbohydrates at this stage of development and competes with the stronger carbohydrate demands of other plant organs (Hale and Weaver 1962) which can result in fewer carbohydrates available for early fruit development.

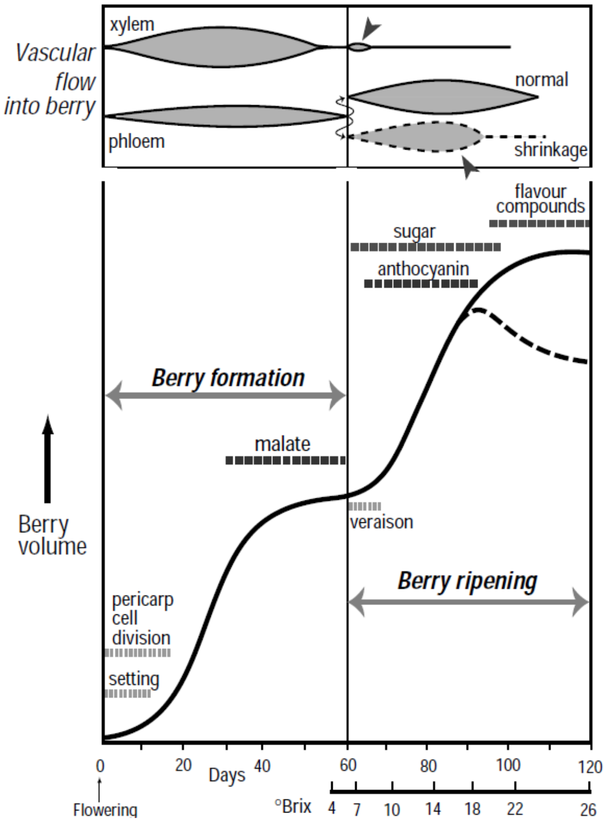


Figure 1. Diagrams of vascular flow into berry, growth curve of berry volume, and solute accumulation for *V. vinifera* 'Muscat' and *V. vinifera* 'Shiraz' (Coombe and McCarthy 2000)

Several studies on EFLR reported reduced fruit set creating looser clusters (Poni et al. 2006, Intrieri et al. 2008, Tardaguila et al. 2010). Caspari et al. (1998) reported reduced fruit set from 17 to 5 percent when the number of mature leaves removed per shoot at bloom increased from 6 to 8. However, timing is critical. Tardaguila et al. (2010) reported a significant reduction in fruit set due to pre-bloom leaf removal but no significant difference for fruit set leaf removal. While Poni et al. (2006) and Intrieri et al. (2008) noted reduced fruit set in both pre-bloom and fruit set leaf removal.

Reduced fruit set resulting from leaf removal at fruit set can be explained by other studies with similar results indicating berry abortion occurred in response to fruit set leaf removal and was the major factor affecting yield (Caspari et al. 1988, Petrie et al. 2003, Poni et al. 2005).

Early fruit-zone leaf removal will also increase the exposure of inflorescences to sunlight, and therefore infrared light, raising plant tissue temperatures (Smart and Sinclair 1976) which can have a positive impact on fruit set (Ebadi et al. 1996). Wet conditions can cause the calyptra to stay attached to the top of the pistil negatively affecting pollination (May 2000). Leaf removal in the fruit-zone has also been shown to increase air-flow which can increase fruit set in a wet year by helping to dry out the canopy through increased evaporation. However, excessive temperatures (Kliewer 1977) and excessive fruit-zone air-flow may negatively impact fruit set (Vasconcelos et al. 2009).

Any change in berry size or weight resulting from leaf removal is likely due to three main elements: anatomy (skin, pulp, seed), cell number and cell volume (Petrie et al. 2000). Grape seeds begin to develop during the first phase of berry growth and continue to mature after skin development slows reaching a maximum size and fresh weight near véraison (Coombe 1960, Friend et al. 2009). A reduction in seed weight has been reported in relation to lower leaf area (Palliotti et al. 2011, Petrie et al. 2000) which could result from lower carbohydrate supply during seed development. For *V. viniferea* ‘Sangiovese’, Poni et al. (2006) reported reduced seed weight for EFLR treatments. However, in 2009, Poni et al. noted pre-bloom leaf removal increased seed weight in *V. vinifera* ‘Barbera’, yet with no significant seed weight increase for *V. vinifera* ‘Lambrusco’ which could indicate cultivar variability. Early fruit-zone leaf removal can increase cluster exposure which can reduce seed weight compared to artificially shaded clusters (Ristic et al. 2007).

Some studies indicate that any correlation between seed and berry development is highly variable (Hardie and Aggenbach 1996). However, other studies show that the number of seeds and the total weight of seeds in a berry are highly correlated to final berry size and weight (Coombe 1960, Ebadi et al. 1996, Petrie et al. 2000, Ristic and Illand 2005, Poni et al. 2006, 2009, Friend et al. 2009). The relationship between seed content and berry development caused Poni et al. (2006) to postulate that the observed increase in skin-to-pulp ratio is due to reduced pulp growth resulting from lower seed weight in EFLR treatments with no significant effects on skin weight. The pulp of the berry can be largely responsible for any changes in final berry weight (Roby and Matthews 2004) through cell expansion.

Most of the berry skin cells are thought to be developed before the onset of bloom (Coombe 1976) which limits the amount of time EFLR can affect skin cell number. Berry skin contains tannins and pigments sought by winemakers for red winemaking. Smaller berries are often viewed as good for winemaking due to the increased surface area-to-volume ratio. However, smaller berries do not always equal more skin. Winemakers should seek higher skin mass to pulp mass ratio (relative skin mass). For example, some EFLR studies report larger berries with greater relative skin mass relative to the smaller berries of the control vines (Poni et al. 2009, Diago et al. 2012). In this case, the larger berries resulting from EFLR had greater concentration of tannins and pigments. Other EFLR studies have also reported increases in relative skin mass due to decreases in berry volume (Poni et al. 2006), as well as decreases in berry volume with increases in both relative skin mass and skin mass per berry (Palliotti 2011). Several studies report EFLR can promote berry skin growth as an adaptation to protect the berry from the persistent increase of cluster sunlight exposure (Poni et al. 2009, Tardaguila et al. 2010, Diago et al. 2012, Palliotti et al. 2011). Overall, many studies support the hypothesis that EFLR will result in an increase in relative skin mass.

The second cycle of berry growth begins at véraison and is marked by the onset of additional cell expansion (Figure 1) which is largely regulated by assimilates (Ollat and Gaudillere 1988, Coombe 1976) supplied by exposed leaves. The amount of assimilates available for berry growth is directly related to the efficiency of the TLA and the TLA to yield ratio. However, the impact of EFLR on berry weight is not clear. Palliotti et al. (2011) reported greater TLA to yield ratios both years of a 2 year study yet observed lower berry weight for pre-bloom FLR in one year, and no effect in another. Diago et al. (2010) reported greater TLA to yield ratios but noted no change in berry weight due to pre-bloom FLR during a 2 year study. Differences in berry weight due to pre-bloom FLR can exist between cultivars within the same study. With no change in TLA to yield ratios due to pre-bloom FLR, Tardaguila et al. (2010) reports lower berry weights for *V. vinifera* 'Graciano' but no difference with *V. vinifera* 'Carignan' while Poni et al. (2009) observed higher berry weights for Barbera but no change for Lambrusco yet both cultivars had larger TLA to yield ratios. However, in all of these studies, pre-bloom FLR yield was lower due to a decline in fruit set.

However, the overall impact of post-bloom FLR on final yield is far less consistent. Post-bloom FLR was observed to be ineffective at significantly lowering total yield or consistently altering berry weight for both Graciano and Carignan when applied at fruit set (Tardaguila et al. 2010). The treatment timing of post-bloom FLR ranging from fruit set to véraison has shown to have no affect on yield (Bledsoe et al. 1988, Bavaresco et al. 2008, Diago et al. 2010). However, other studies report increased yield for leaf removal 3 weeks post-bloom (Zoecklein et al. 1992) and at véraison (Hunter and Visser 1990) while Poni et al. (2006) noted an average decrease in yield over the 3 year study of fruit set FLR. Petrie et al. (2003) theorizes that yield reduction with no effect in berry weight due to post-bloom FLR results from abortion of set berries caused by vine regulation in response to reduced assimilate supply. However FLR may also cause a decline in berry mass due to increased cluster exposure to sunlight and its impact on cell division rates as well as berry transpiration (Bergqvist et al. 2001, Bondada 2012, Spayd et al. 2002, Keller 2010, Dokoozlian and Kliewer 1996).

Effects of Early Fruit-zone Leaf Removal on Fruit Composition

Improving fruit composition without negatively impacting grapevine growth and development can be considered the primary focus of modern viticulture. In general, the goals of producing high-quality grapes are to gain advantage in an increasingly complex and competitive marketplace. Ideally, fruit quality is defined by the intrinsic visual, flavor, or aroma elements which are distinguished as above average compared to similar grapes. Increased fruit quality can be defined through compositional analysis and visual determination of fruit health.

Early fruit-zone leaf removal can have substantial effects on fruit composition. In general, berry skin contains tannins and pigments (anthocyanins), seeds contain tannins, and pulp contains water, sugars and acids (Adams 2006). However, the accumulation rate and final concentration of these chemical compounds is primarily determined during ripening. The impact of EFLR on final composition depends on berry anatomy as well as the available assimilates and canopy microclimate during ripening. To quantify improvements in fruit composition, standard must analysis involves the following parameters: total soluble solids (Brix), pH, total acidity (TA), total anthocyanins and total phenolics (Poni et al. 2009).

Studies on EFLR indicate a more consistent impact on Brix, total phenolics and total anthocyanins than on other parameters when FLR is applied pre-bloom. In a three year study, Palliotti et al. (2011) noted greater Brix, total phenolics and total anthocyanins in EFLR grapes, with similar reports in other studies (Poni et al. 2006, 2009, Intrieri et al. 2008, Tardaguila et al. 2010). In each of these studies the TLA to yield ratio had either recovered or increased in all pre-bloom FLR treatments providing increased assimilates available during ripening. In addition, greater relative skin mass was reported (Palliotti et al. 2011, Poni et al. 2006, 2009) or indicated as contributing to (no data presented) increased total anthocyanin and phenolic concentration

(Tardaguila et al. 2010, Intrieri et al. 2008). The pH and TA results were not consistent in these EFLR studies.

The results for FLR applied at fruit set were less consistent and generally lesser in magnitude than those for pre-bloom leaf removal. In a two cultivar, two year study on FLR at fruit set, Tardaguila et al. (2010) reported no increase in Brix and inconsistent results for total phenolic and anthocyanin concentration. In this study, the effects of FLR at fruit set had no impact in either year on fruit set and inconsistent results were reported for TLA to yield ratio but generally the ratios were lower than with pre-bloom FLR. In a three year study on the effects on fruit composition of FLR at fruit set, Intrieri et al. (2008) noted significant increases in Brix, total anthocyanin and phenolic concentration but all to a lesser magnitude than the pre-bloom treatment which had a higher TLA to yield ratio than the fruit set leaf removal. The differences in fruit composition in these studies between the treatment timings of pre-bloom and fruit set FLR appear to be primarily influenced by the TLA to yield ratios. Leaf removal after bloom did not consistently reduce yield, and exhibited lower TLA to yield ratios and therefore fewer assimilates were available to the fruit during ripening, compared to pre-bloom FLR (Tardaguila et al. 2010, Palliotti et al. 2010, Poni et al. 2009).

Sunlight exposure can increase berry tissue temperature and therefore the metabolic rate of the berry until a threshold temperatures is exceeded and metabolic processes stop or are impaired (Greer 2006, Zufferey et al. 2000, Coombe 1987). Anthocyanin synthesis occurs in the berry (Boss et al. 1996) and follows this same pattern of higher berry temperatures increasing synthesis until reaching a threshold temperature, beyond which synthesis stops or anthocyanin degradation begins (Mori et al. 2007, Spayd et al. 2002, Bergqvist et al. 2001). Yamane et al. (2006) reported anthocyanin accumulation is most sensitive to high temperatures from one to three weeks after the start of véraison. Fruit-zone leaf removal later in the season could expose the fruit to excessive sunlight thereby increasing berry temperature during this sensitive period. Research indicates that excessive temperature can inhibit anthocyanin accumulation through reduction in synthesis or degradation (Spayd et al. 2002, Mori et al. 2007). Lower total anthocyanin levels in ripe grapes can result in lower quality perception due to less dense pigmentation (Somers and Evans 1974).

Flavonol synthesis is stimulated by cluster exposure to help protect the berry against ultraviolet radiation (among other environmental stresses) and is not negatively affected by high temperature (Spayd et al. 2002, Downey et al. 2003, Diago et al. 2012). Copigmentation between anthocyanins and flavonols can increase the concentration of stable color compounds (Downey et al. 2003) which, provided adequate total anthocyanin accumulation, can contribute to increased quality perception (Somers and Evans 1974).

Several studies indicate a positive correlation between berry skin tannin composition and content and increased cluster exposure. Downey et al. (2004) reported significant increases in skin tannin content and molecular length due to greater cluster exposure. Ristic et al. (2007) reported increased tannin content in the skin and wine of exposed clusters and the wines of exposed fruit rated higher for mouthfeel and fruit flavor. In a study on vine vigor, Cortell et al. (2005) attribute the increase of tannin content in low vigor vines to increased fruit exposure to sunlight.

In a review of past research on anthocyanins, flavonols and tannins, Downey et al. (2006) discussed the impact of these compounds on grapes and wine. Anthocyanins contribute to color of red wine, flavonols protect grapes from ultraviolet radiation and contribute to wine color through copigmentation, and tannins contribute to body and mouthfeel of wine and also contribute to color stability through polymerization with anthocyanins. However, the precise impact of these compounds on wine quality is not completely understood and varies greatly between red or white wines, winemaking practices, cultivars and other factors. For instance, Holt et al. (2008) found high concentrations of anthocyanins, flavonols and tannins were not a good indicator of wine quality while Mercurio et al. (2010) reported the opposite.

Another compound influencing fruit quality perception is methoxypyrazine (MP) concentration which is generally associated with “green” herbaceous aromas (Scheiner et al. 2010). The contribution of MP to wine quality is highly dependent on level of concentration. At high concentrations, MP can cause a decrease in perceived wine quality due to “vegetal” and “unripe” aroma characteristics in addition to suppressed fruitiness (Hein et al. 2009). However, at less intense concentrations, MP’s can contribute to wine quality or varietal typicity, like in the example of *V. vinifera* ‘Sauvignon Blanc’ (Allen et al. 1991). According to Scheiner et al. (2010), many studies have observed that attempts to lower MP concentration in the winery is ineffective, or results in other nonselective changes to the wine. Reducing MP in the vineyard may be the most effective way to control MP concentration in wine. There also appears to be a strong correlation between peak MP levels pre-véraison and MP levels in mature berries. Pre-véraison MP levels can be reduced by increasing cluster exposure (Ryona et al. 2008, Koch et al. 2012).

Early fruit-zone leaf removal increases sunlight and air penetration of the fruit-zone which can positively affect berry health by reducing disease incidence and severity through the following mechanisms: increased evaporative potential within the fruit-zone, lowering humidity (Thomas et al. 1988); increased sunlight exposure causing an increase of ultraviolet radiation and berry surface temperature (Austin and Wilcox 2012); and increased coverage of spray treatments (Austin et al. 2011).These mechanisms make the fruit-zone less conducive for the development of fungal diseases. Two of the most pervasive and destructive pathogens in viticulture regions worldwide are powdery mildew caused by *Erysiphe necator,* and Botrytis bunch rot caused by *Botrytis cinerea* (Chellemi and Marois 1992, Gubler et al. 1987, Austin and Wilcox 2011).

The efficacy of EFLR on disease control is driven by leaf removal timing in relation to high-risk periods for infection and/or colonization. For powdery mildew, this period is from approximately pre-bloom until 4 weeks after fruit set when fruit becomes nearly immune to new infection (Ficke et al. 2002). For Botrytis bunch rot, high-risk of colonization and/or infection exists during bloom and ripening (McClellan and Hewitt 1973). The level of disease control achieved by EFLR can be adequate for Botrytis bunch rot (Gubler et al. 1987, 1991) but inadequate for powdery mildew (Chellemi and Marois 1992). Disease control is best achieved by EFLR and fungicide spray treatments which have increased efficacy due to the increased porosity of the canopy (Chellemi and Marois 1992, Austin and Wilcox 2011) and decreased cluster compactness (Hed et al. 2009) resulting from EFLR. The cumulative effects of these treatments allow for reduced fungicide spray application frequency, and number of vineyard passes required for disease control. Both Botrytis bunch rot and powdery mildew can develop resistance to fungicides (Gubler et al. 1996, Jacometti et al. 2009), which reinforces the importance of EFLR to both reduce disease pressure and mitigate the potential for the development of fungicide resistance.

There are risks to berry health associated with increased cluster exposure. Excessive sunlight exposure can lead to sunburn which is an inherent risk associated with FLR. Sunburn risk is particularly high in viticultural regions with sufficient ambient temperature and solar radiation levels to increase berry temperature beyond a threshold temperature that will induce sunburn (Spayd et al 2002, ChuanHua et al. 2009). Most sunburn occurs on the sun-exposed berries on the side of the canopy with greatest exposure to afternoon sun when ambient temperatures are generally highest and therefore actual berry temperatures are highest (Bergqvist et al. 2001, Spayd at al. 2002, Bondada and Keller 2012).

The effects of solar radiation on grapes depend highly on ambient conditions (Bergqvist et al. 2001, Greer et al. 2006). Excessive cluster exposure to solar radiation precedes sunburn which explains why sunburned clusters frequently exhibit many of the same characteristics, such as; berry color decrease (Haselgrove et al. 2000, Bergqvist et al. 2001), water loss (Bondada and Keller 2012), less malic acid and higher pH (Kliewer 1967, Lakso and Kliewer 1978). Sunburn damage in red and white cultivars manifests differently with white grapes showing brown lesions that increase in magnitude with increased exposure (Greer et al. 2006) while the pigments in red cultivars disguise and protect against damage (Price et al. 1995). Sunburn can change the structure of the surface wax of the berry from crystalline to amorphous (Greer et al. 2006, Bondada and Keller 2012), which is a less efficient water barrier (Possingham et al. 1967) and may enhance water loss in sunburned berries (Bondada and Keller 2012). However, Bondada and Keller (2012) noted no berry shrivel in response to this potential water loss indicating a compensating influx of assimilates may have occurred. In cases of severe sunburn, lower yield has been reported (Chorti et al. 2010).

Effects of Early Fruit-zone Leaf Removal on Long-term Vine Fruitfulness

Fully mature compound buds which contain inflorescence primordia are termed fruitful buds (Dry 2000). The number of inflorescence primordia, termed fruitfulness, is a quantitative measure of the fruiting potential of grapevine buds (Sommer et al. 2000). As reviewed by Srinivasan et al. (1981), studies show inflorescence formation follows three steps: (i) formation of uncommitted primordia, (ii) differentiation of the uncommitted primordia to form inflorescence primordia or tendrils, (iii) differentiation of the inflorescence primordia into individual florets. The first two steps occur in the current season (Y1) and the last step occurs in the second growing season (Y2). Inflorescence primordia development during Y1 occurs from approximately 4 to 6 weeks after budbreak and continues to develop until shoot growth ceases and the buds enter dormancy. In Y2, individual flower differentiation occurs around budbreak.

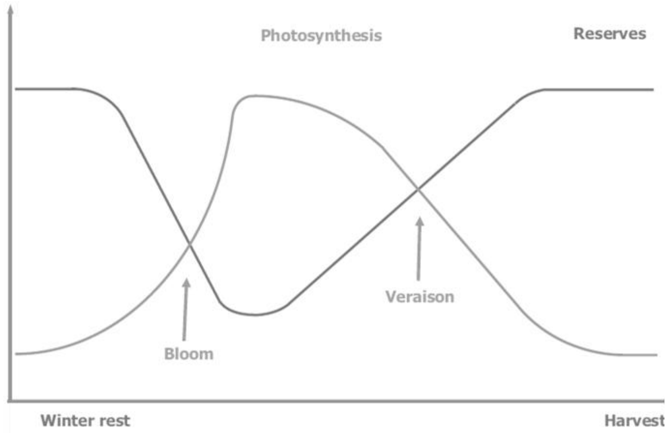


Figure 2. Fluctuation of reserve and photosynthesis supply of carbohydrate throughout the growing season (Lebon et al. 2008)

Carbohydrate supply is critical to fruitfulness. Storage reserves are the primary carbohydrate source during Y1 inflorescence development until canopy photosynthesis becomes the primary contributor to the total carbohydrate pool which occurs around bloom (Yang et al. 1980, Lebon et al. 2008) (Figure 2). At this stage, Y2 primordia initiation and differentiation begins (Swanepoel and Archer 1988), indicating carbohydrate reserves have less influence on primordia formation and development for Y2 compared to inflorescence differentiation in Y1.

Carbohydrate storage reserves are replenished at the end of Y1 (Figure 2). Early fruit-zone leaf removal can provide enough time for recovery of TLA by véraison (Palliotti et al. 2000, 2011, Poni et al. 2009), and the younger re-growth will senesce later in the season, potentially allowing for adequate replenishment of carbohydrate reserves (Candolfi-Vasconcelos and Koblet 1990).

Early fruit-zone leaf removal can impact fruitfulness through reduced photosynthates (Candolfi-Vasconcelos and Koblet 1990). Developing fruitful buds are a weak sink for carbohydrates relative to inflorescence, fruit and shoot development of Y1 (Hale and Weaver 1962). Therefore, reduced photosyntates will most affect overwintering compound buds thereby reducing bud fruitfulness in Y2 (Vasconcelos and Castagnoli 2000).

Research indicates increased temperature and light exposure of developing compound buds is beneficial to fruitfulness. This effect is largely due to the stimulation of inflorescence primordia formation in Y1 thereby increasing the primordia available for differentiation in Y2 (Antcliff and Webster 1955, Buttrose 1969, Smart 1985, Dry 2000, Sánchez and Dokoozlian 2005, Watt et al. 2008). The positive impact of EFLR on fruitfulness through increased light exposure and temperature of developing compound buds can help counterbalance any negative impacts on fruitfulness resulting from altered carbohydrate supply (Sánchez and Dokoozlian 2005).

General Introduction to Washington State Viticulture

Washington State, second in the United States (USA) for wine production, produces just over 3 percent of the wine in the USA. Though a distant second to California in wine production, according to the Wine Spectator (www.winespectator.com), Washington State is building a strong reputation for high quality wines at fair prices. Over the past few decades, wine has become a major contributor to the economic health of the state. After a period of rapid growth, Washington now has over 17,500 hectares of *V. vinifera* planted and produces approximately 150,000 metric tons of wine grapes annually as found on the National Agricultural Statistics Service’s website (www.nass.usda.gov).

Washington's location and climate are unique elements to the production of high quality wine. The climate varies drastically from the Pacific coast on the west side of the Cascade Mountain Range which can receive in excess of 1000 millimeters (mm) of annual rainfall, to the arid east side located in the rain shadow, which can receive less than 100 mm. The temperature of growing regions can range on average from 900-1700 cumulative growing degree days (GDD base 10°Celsius (°C) from 1 April) (Figure 3) according to AgWeatherNet (http://weather.wsu.edu). For much of the agricultural production regions located east of the Cascade Mountains, annual mountain snowpack is the predominant source of irrigation water. Within the eastern part of the state there is large mesoclimate, topographic and soil variation between different viticulture growing regions allowing the successful cultivation of many different cultivars.

The vineyard soils of this region are largely classified as Aridisols which are dry and low in organic content (Norman et al. 2004). As a result, growers have control over, and must provide, water and nutrients.

The northern latitude (47°N) of Washington's vineyards provides long hours of sunlight during peak growing season. From sunrise to sunset, the hours of sunshine range from 12.7 hours (on 1 April) to a maximum of 15.7 hours (on 21 June), decreasing to 9.9 hours by 31 October (astro.unl.edu). On the same days, Napa, California and Lisbon, Portugal have 12.5 hours, 14.7 hours and 10.5 hours of daily sunshine, respectively (astro.unl.edu).

The continental climate provides the necessary heat during the growing season to ripen a wide array of cultivars. During the growing season (1 April – 31 October) the heat during the day can reach 35°C (average of 15 days per year 2007-2010). Mean growing season temperature averages 16°C. The arid desert air and northern latitude allow for a precipitous drop in temperature after sunset creating an average diurnal temperature variation of 16.8°C. The cool night temperatures and cold winters create a frost and freezing risk with an average of 174 frost-free days per year according to AgWeatherNet (Port of Sunnyside weather station; http://weather.wsu.edu).

Phylloxera has yet been unable to create any viable risk and therefore vines are mostly planted on their own roots allowing growers to retrain, from the root system, vines that may have suffered from mid-winter freeze damage allowing the vineyard to return to full production sooner (Folwell et al. 2001).

Project Site Description

The research project described herein was conducted at a commercial vineyard owned by Upland Vineyards located in the Snipes Mountain American Viticultural Area (AVA). This vineyard grows more than 35 different *V. vinifera* cultivars in approximately 275 planted hectares according to Upland Vineyards' website (www.uplandwinery.com). The Snipes Mountain AVA is located (lat.: 46.312168, long.: -120.107601) entirely within the larger Yakima Valley AVA, which itself is encompassed entirely within the even larger Columbia Valley AVA (Figure 4).

The most striking feature is Snipes Mountain itself. The topography of this AVA allows for growing grapes at altitudes of between 225 and 400 meters on slopes facing every direction. The available altitude, slope and aspect choices create a range of macro and mesoclimates with heat accumulation ranging from 1400 to 1700 GDD (base 10°C from 1 April) according to AgWeatherNet (http://weather.wsu.edu) and Upland Vineyards' website (www.uplandwinery.com).

Experimental Hypothesis

When developing a vineyard management strategy, many factors must be considered. In general, vineyard management focuses on the quantity and the quality of fruit production. Choosing one strategy over another depends on the interaction of many elements, including: cultivar, geographic location, climate, existing viticultural practices, operational resources, costs of production, and production targets. These factors can conflict with one another as might the techniques used to achieve the vineyard objectives. Optimizing vineyard management requires balancing these competing elements.

Many variations in response to leaf removal have been observed and attributed to treatment timing, degree of leaf removal, cultivar studied, and regional climate, among other factors. These variations reinforce the need for local research of the impact of EFLR on a red grape cultivar common to the region. The objectives of this study were to determine the optimal timing of FLR for red wine grape cultivars in the Yakima Valley using four different leaf removal timings, (i) pre-bloom, (ii) full-bloom, (iii) post-bloom and (iv) no FLR (control). The treatment effects were monitored throughout the growing season to define the short-term impacts of EFLR on vine health and fruit composition, as well as long-term impacts on bud fruitfulness.

There are few studies of the combined impacts of FLR on fruit composition, vine development, and disease management when practiced in arid growing regions like the inland Pacific Northwest. The climate of eastern Washington provides conditions where berry sunburn is a risk if the fruit-zone is over-exposed at inappropriate times during the growing season. However, EFLR may not increase this risk due to enhanced berry skin and cuticle development, and canopy re-growth. The timing of EFLR is also optimal for disease control and can improve fruit composition and potential quality, as discussed previously. The impact of this one-time treatment on different aspects of vineyard management suggests EFLR has great potential to become a part of routine vineyard practices. This experiment aims to provide a better understanding of the effects of EFLR in this region to help growers achieve their vineyard objectives.

The scope of this report covers the impact of EFLR using data collected during the 2012 growing season up to and including the start of véraison (Table 2).

Figure 3. Map of Washington State AVA's as found on the Washington Wine Commission website (www.washingtonwine.org).

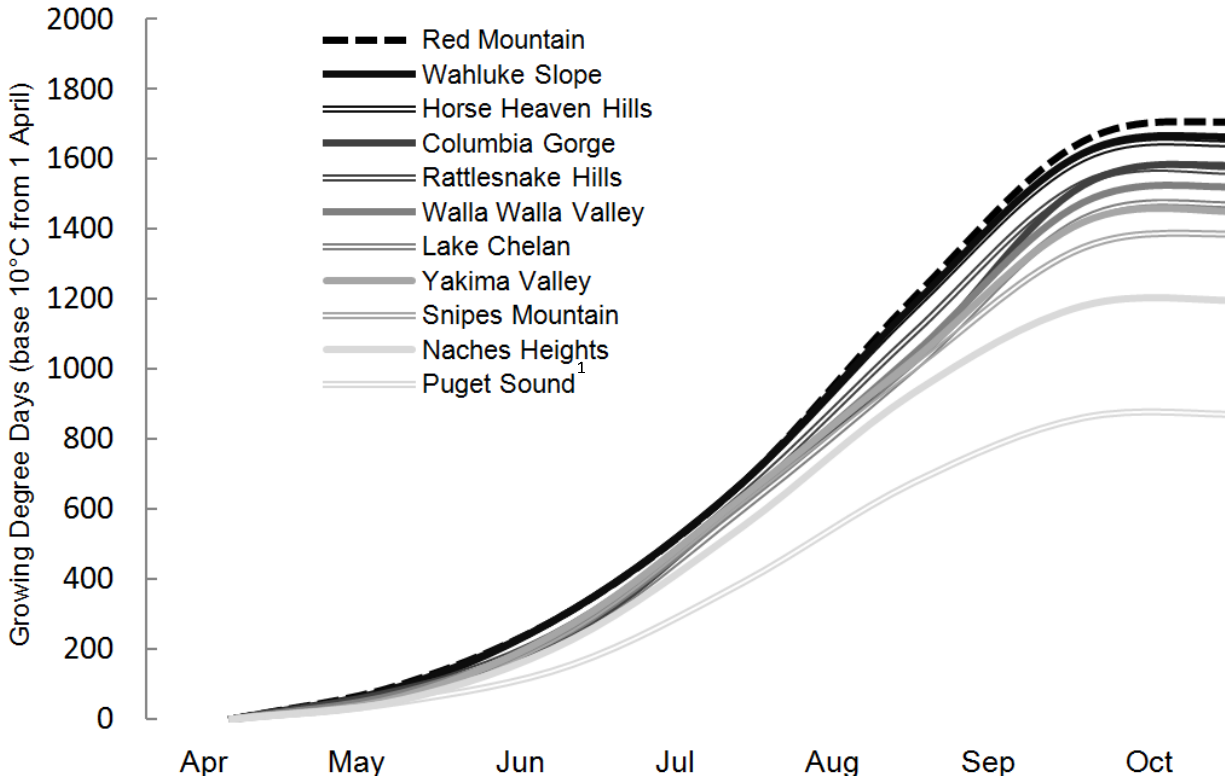


Figure 4. Long term average growing degree days of Washington State American Viticultural Areas as found on the viticulture and enology website of Washington State University (www.wine.wsu.edu).
[1] Puget Sound AVA is located on the western side of the Cascade Range (Figure 4.)

Materials and Methods

Site Description

The experiment was conducted on own-rooted Merlot (clone purchased in 1979 from the foundation block of the Clean Plant Center Northwest, at Washington State University) within a commercial vineyard located in the Snipes Mountain AVA within the State of Washington, USA (lat.: 46.312168, long.: -120.107601). The vineyard was planted in 1979 with north-south row orientation, on a southern facing slope at 8percent grade. The vineyard elevation is at 275 meters (m) above sea-level. Soils are Warden silt-loam.

Site Management

The vines are trained to single trunk, bilateral cordon, spur-pruned with vertical shoot positioned (VSP) canopies positioned with a single set of moveable foliage catchwires. The fruiting wire is at 45 centimeters (cm). The vines spacing is 1.83 m x 2.75 m (vine x row). Vineyard management practices this year included: manual removal of shoots from non-count buds after 8 leaves have separated (Eichhorn and Lorenz stage 15 (EL 15)) (Figure 5), which occurred in late May 2012; mechanized (fan suction) FLR on the east face of the fruit-zone at the start of berry coloration and enlargement (EL 35) on 10 August; cluster removal at véraison (EL 36) on 15 August to reduce the projected yield from 13.5 tons/HA to 8 tons/HA. The pest management program consisted of four disease control spray treatments: sulfur on 20 April and 9 May; Pristine (pyraclostrobin and boscalid) on 10 June, Procure (triflumizole) on 9 July. No fertilizer was applied to this block in 2012. The site is drip irrigated as needed.

Experimental Design

To determine the impact of the timing of FLR on canopy development, fruit composition and long-term fruitfulness; four leaf removal timings were deployed (Table 1): (i) pre-bloom, (ii) full-bloom (defined by 50 percent of clusters at greater than 50 percent bloom), (iii) post-bloom (defined as 4 weeks after the bloom treatment), and (iv) control (no FLR). The experimental design was a randomized complete block design, with individual treatment plots replicated 4 times. Each plot consisted of 6 vines per row, across 3 rows. Data was collected from the center 4 vines per treatment plot; remaining vines served as buffers.

The leaf removal treatments were applied on the following dates in 2012 (Table 1): (i) 29 May, (ii) 6 June, (iii) 2 July, and (iv) no leaf removal, respectively. Leaf removal was completed manually by removing all leaves and summer lateral shoots from the base of the all count shoots up to and including the leaf on the secondary cluster node. Identical leaf removal treatments were applied to all vines within a treatment plot with the exception of the post-bloom treatment, where leaf removal was modified to east-side only in the buffer vines but remained the same as the other treatments for all data vines.

Table 1. Fruit-zone leaf removal timing and key phenological stages.

Action	Date 2012	CDOY[1]	EL Stage[2]	Days Since Budbreak[3]	GDD[4]	Precip.[5]
Budbreak	15-Apr	46	4	0	12	0
Pre-Bloom Leaf Removal	29-May	90	16	44	181	16
Bloom Start	31-May	92	19	46	199	16
Full-Bloom Leaf Removal	6-Jun	98	23	52	237	33
Bloom End	28-Jun	120	27	74	393	42
Post-Bloom Leaf Removal	2-Jul	124	32	78	439	49
Véraison Start	3-Aug	156	35	110	847	51
Véraison	15-Aug	168	36	122	1021	51

[1] CDOY = Climate Day of Year calculated from 1 March

[2] EL = Eichhorn-Lorenz Phenological Stage (Coombe 1995) (Figure 5)

[3] Days since bud break calculated since 15 April

[4] Growing degree days (base 10°C from 1 April)

[5] Precipitation in millimeters as reported by AgWeatherNet, Port of Sunnyside weather station (lat.: 46.28316, long.: -120.00938); http://weather.wsu.edu

Effects of Early Fruit-zone Leaf Removal on Canopy Development

To monitor seasonal canopy development, shoot length, internode length, and incidence of summer lateral shoots were repeatedly recorded for 10 individual shoots. This data was analyzed with analysis of variance (ANOVA), separating treatment means using Tukey's honestly significant difference test (Tukey's HSD).

Shoot length was measured (Table 3) on 10 shoots per replicate, on a repeated, bi-weekly basis from 24 May until the end of shoot growth on 18 July (Table 2). The end of shoot growth was determined through comparison to previous measurements, observation of shortened internode length and absence of tendrils at the apical shoot tip. Average growth rate was determined by plotting shoot length versus measurement date and calculating slope through regression analysis. Treatment slope was analyzed with analysis of covariance to determine statistical significance of any relationships between treatments.

Internode length of each of the basal six nodes of the fruit-zone on 10 shoots was measured from base to tip on 15 August (Table 2). Individual internode length and average fruit-zone shoot length data was used for statistical analysis.

Summer lateral shoot incidence was recorded on 15 August (Table 2), by rating lateral shoots on the basal 5 nodes of the fruit-zone from base to tip on 10 shoots. Summer lateral shoot length was rated per node in the following categories; no lateral shoots, less than 3 cm, 3 cm to 15 cm, and greater than 15 cm. Summer lateral shoot incidence was analyzed between treatments both collectively by category and at individual nodes for each length category.

Table 2. Data collection dates and key phenological stages.

Action	Date 2012	CDOY[1]	EL Stage[2]	Days Since Budbreak[3]	GDD[4]	Precip.[5]
Shoot Measurements	24-May	85	17	39	158	16
Shoot Measurements	5-Jun	97	23	51	234	33
Shoot Measurements	18-Jun	110	27	64	316	34
Shoot Measurements	3-Jul	125	32	79	447	49
Shoot Measurements	18-Jul	140	33	94	658	51
Lateral Ratings	15-Aug	168	35	122	1021	51
Internode Ratings	15-Aug	168	35	122	1021	51
Disease Ratings	25-Jul	147	34	101	740	51
Disease Ratings	15-Aug	168	35	122	1021	51
Cluster Temps	25-Jul	147	34	101	740	51
Cluster Temps	15-Aug	168	35	122	1021	51
Bud Temps	11-Jun	103	26	57	257	34
Bud Temps	3-Jul	125	32	79	447	49
Bud Temps	15-Aug	168	35	122	1021	51
Berry Counts	3-Jul	125	32	79	447	49

[1] CDOY = Climate Day of Year calculated from 1 March.

[2] EL = Eichhorn-Lorenz Phenological Stage (Coombe 1995) (Figure 5).

[3] Days since budbreak. Budbreak: 15 April.

[4] Growing degree days (base 10°C from 1 April)

[5] Precipitation in millimeters from 1 April as reported by AgWeatherNet, Port of Sunnyside weather station (lat.: 46.28316, long.: -120.00938) http://weather.wsu.edu.

Effects of Early Fruit-zone Leaf Removal on Fruit Development

Ten basal clusters were used to record fruit development. This data was analyzed with ANOVA, separating treatment means using Tukey's HSD.

Post-harvest fruit development data of berry weight, berry size, cluster weight, and yield were also measured for this experiment, but not presented within the scope of this report.

The number of berries per cluster was counted non-destructively in the field near bunch closure on 3 July (Table 2).

In-season fruit set was calculated by dividing berry number per cluster by the respective inflorescence calyptra count. Fallen calyptrae were captured by affixing a mesh bag to the main stem of a basal cluster on a numbered shoot. The bags measured 15 cm x 25 cm and composed of nylon mesh with a 1 mm^2 weave, which is small enough to capture all fallen calyptrae. Bags were placed in the vineyard on 24 May and removed on 3 July (Table 2) and stored at 0°C until the calyptrae were counted.

Effects of Early Fruit-zone Leaf Removal on Fruit Composition

Incidence (number of clusters affected) and severity (percent surface area affected) of sunburn, grapevine powdery mildew, and Botrytis bunch rot was estimated; and cluster surface temperature was recorded. This data was analyzed with ANOVA, separating treatment means using Tukey's HSD.

Cluster surface temperature was measured on 10 arbitrarily selected clusters per replicate using an infrared thermometer (Extech Instruments; model: 42510A) on 25 July, and 15 August (Table 2) on the west canopy face between the hours of 1430 and 1600. Treatment data was analyzed along with ambient temperature data using ANOVA, separating means with Tukey's HSD.

Post-harvest data of methoxypyrazine concentration, total phenolics, Brix, TA and pH were also measured, but not presented within the scope of this report.

Incidence and severity of sunburn, powdery mildew and Botrytis bunch rot, were estimated visually. Ten clusters per replicate were arbitrarily selected then rated by recording percent of cluster affected on 25 July and 15 August (Table 2).

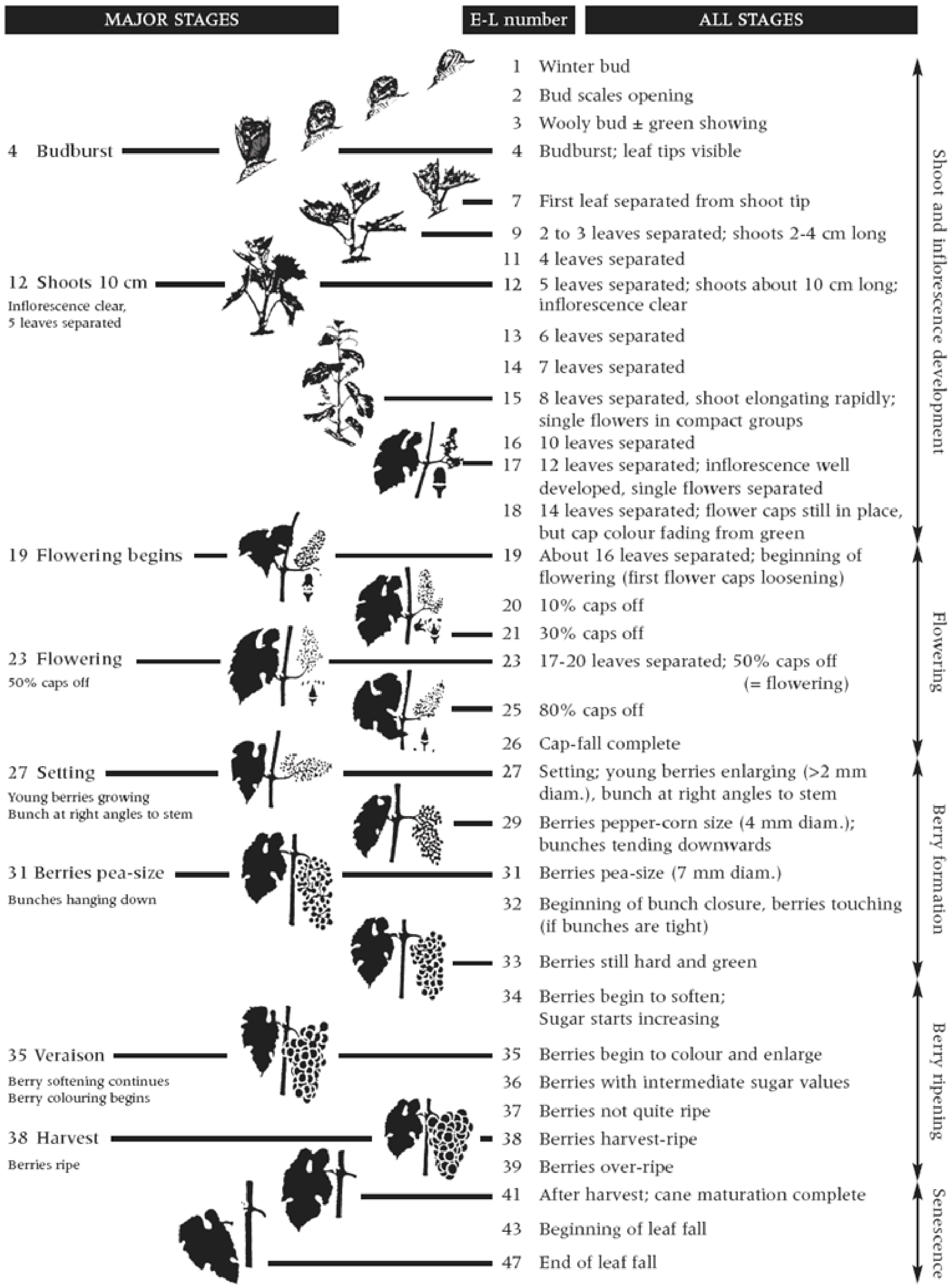
Effects of Early Fruit-zone Leaf Removal on Long-term Vine Fruitfulness

Compound bud temperature was measured (Table 9) using an infrared thermometer on 11 June, 3 July, and véraison on 15 August (Table 2). Surface temperature was recorded for 10 arbitrarily selected fruit-zone compound buds per replicate on the west canopy face between 1500 and 1600 hrs. Treatment data was analyzed along with ambient temperature data using ANOVA, separating means with Tukey's HSD.

Ambient Vineyard Environmental Conditions

Weather data was accessed through AgWeatherNet (Washington Agricultural Weather Network V2.0, Washington State University; http://weather.wsu.edu), an automated weather station network database that provides access to current and historical weather data. Weather data for the experimental plot was recorded from the proximal automated weather station: "Port of Sunnyside" located in Sunnyside, Washington (lat.: 46.28316, long.: -120.00938). This station is located 8 km from the experimental plot at an altitude of 200 m. The data recorded from this weather station was mined to provide growing season data such as: ambient temperature, wind speed (meters per second), precipitation (mm), solar radiation (watts per square meter), and growing degree days (GDD). Growing degree days were calculated by subtracting the base temperature 10°C from the average daily temperature, only recording positive values and summing the totals from 1 April to 31 October.

Statistical analyses were conducted using JMP statistical software (version 10; SAS Institute, Cary, North Carolina).



E-L number	ALL STAGES
1	Winter bud
2	Bud scales opening
3	Wooly bud ± green showing
4	Budburst; leaf tips visible
7	First leaf separated from shoot tip
9	2 to 3 leaves separated; shoots 2-4 cm long
11	4 leaves separated
12	5 leaves separated; shoots about 10 cm long; inflorescence clear
13	6 leaves separated
14	7 leaves separated
15	8 leaves separated, shoot elongating rapidly; single flowers in compact groups
16	10 leaves separated
17	12 leaves separated; inflorescence well developed, single flowers separated
18	14 leaves separated; flower caps still in place, but cap colour fading from green
19	About 16 leaves separated; beginning of flowering (first flower caps loosening)
20	10% caps off
21	30% caps off
23	17-20 leaves separated; 50% caps off (= flowering)
25	80% caps off
26	Cap-fall complete
27	Setting; young berries enlarging (>2 mm diam.), bunch at right angles to stem
29	Berries pepper-corn size (4 mm diam.); bunches tending downwards
31	Berries pea-size (7 mm diam.)
32	Beginning of bunch closure, berries touching (if bunches are tight)
33	Berries still hard and green
34	Berries begin to soften; Sugar starts increasing
35	Berries begin to colour and enlarge
36	Berries with intermediate sugar values
37	Berries not quite ripe
38	Berries harvest-ripe
39	Berries over-ripe
41	After harvest; cane maturation complete
43	Beginning of leaf fall
47	End of leaf fall

Figure 5. Modified Eichhorn-Lorenz system for identifying grapevine growth stages (revised from Coombe 1995)

Results

Effects of Early Fruit-zone Leaf Removal on Canopy Development

Shoot Length

Initial shoot lengths were recorded before any leaf removal treatments were applied and indicated significantly longer shoots in the control and pre-bloom leaf removal treatments relative to the post-bloom treatment (Table 3). The control had significantly longer shoots on CDOY 97 and CDOY 110 relative to the post-bloom treatment. By CDOY 125 there were no significant differences in shoot length among the treatments.

Table 3. Shoot length treatment averages as recorded bi-weekly during shoot development (measured in centimeters).

			Shoot Length[3,4]							
Date 2012	CDOY[1]	EL Stage[2]	Control		Pre-Bloom		Full-Bloom		Post-Bloom	
24-May	85	17	32.5^{a}	(0.9)	32.8^{a}	(1.5)	29.6^{ab}	(2.3)	28.3^{b}	(2.5)
5-Jun	97	23	52.0^{a}	(2.3)	50.3^{ab}	(2.4)	47.6^{ab}	(4.0)	44.4^{b}	(4.0)
18-Jun	110	27	71.3^{a}	(4.5)	66.1^{ab}	(2.3)	66.6^{ab}	(6.4)	61.2^{b}	(5.2)
3-Jul	125	32	88.2^{a}	(4.4)	87.5^{a}	(5.5)	86.4^{a}	(13.5)	77.5^{a}	(10.3)
18-Jul	140	33	95.6^{a}	(5.8)	94.3^{a}	(6.7)	95.8^{a}	(20.3)	82.3^{a}	(11.5)

[1] CDOY = Climate Day of Year calculated from 1 March

[2] EL = Eichhorn-Lorenz Phenological Stage (Coombe 1995) (Figure 5)

[3] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis.

[4] Different letters indicate significant difference determined using Tukey's HSD at alpha = 0.05 for values within a row.

Average growing season shoot growth rate was not significantly different between the treatments (Figure 6).

Internode Length

No significant differences exist between treatments when comparing the total length of the basal 6 internodes on shoots, or when comparing individual internode length (Table 4). The pre-bloom, full-bloom, and post-bloom leaf removal treatments consistently displayed shorter individual internode length, and a shorter total fruit-zone shoot length relative to the control (Table 4), though not statistically significant.

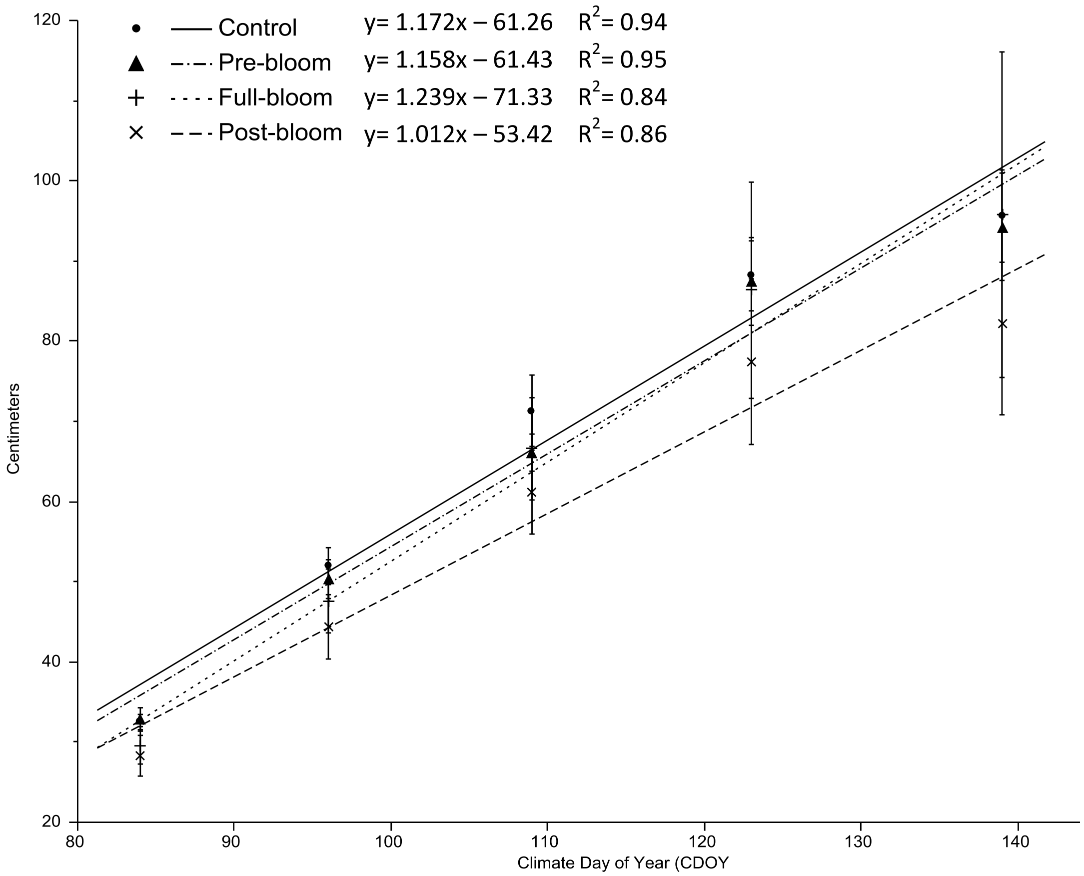


Figure 6. Linear regression of average shoot length[1] versus shoot measurement date (CDOY[2]) to compare shoot growth rate between treatments. Trendlines[3] and error bars[4] displayed.

[1] Calculated from an average of 10 shoots per replicate. Treatments replicated 4 times.
[2] CDOY = Climate Day of Year calculated from 1 March.
[3] Trendlines plotted since budbreak on 15 April.
[4] Each error bar is constructed using 1 standard deviation from the mean.

Table 4. Internode length treatment averages of the basal six nodes of the fruit-zone and average fruit-zone shoot length per treatment (measured in centimeters).

	Length per Internode[2,3]							
Internode[1] #	Control		Pre-Bloom		Full-Bloom		Post-Bloom	
1	3.2^a	(0.3)	2.9^a	(0.3)	3.0^a	(0.1)	3.1^a	(0.4)
2	4.8^a	(1.0)	4.3^a	(0.4)	4.2^a	(0.3)	4.8^a	(0.6)
3	5.7^a	(0.3)	5.1^a	(0.3)	5.1^a	(0.4)	5.1^a	(0.4)
4	5.3^a	(0.5)	5.0^a	(0.3)	4.8^a	(0.4)	4.5^a	(0.4)
5	5.3^a	(0.7)	4.8^a	(0.2)	4.8^a	(0.5)	4.8^a	(0.5)
6	5.2^a	(0.4)	4.9^a	(0.2)	4.8^a	(0.2)	4.9^a	(0.3)
Total fruit-zone shoot length	29.6^a	(2.3)	27.2^a	(1.0)	26.7^a	(1.1)	27.2^a	(1.2)

[1] Basal 6 internodes counted from base (1) upward (6)

[2] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis.

[3] Different letters indicate significant difference determined using Tukey's HSD at alpha = 0.05 for values within a row.

Summer Lateral Shoot Incidence

Comparison of the category ratings of the basal 5 nodes indicated each subsequent treatment exhibited significantly greater levels of “no lateral shoots” (Table 5). The presence of summer lateral shoots in the fruit-zone decreased with each subsequent timing of leaf removal and all treatments with fruit-zone leaves removed had less re-growth of summer laterals (Table 5).

The average of the basal 5 nodes in the pre-bloom and control treatments were similar and had significantly greater in incidence of longer summer laterals than the post-bloom treatment with the least (Table 5). The full-bloom and post-bloom treatments were statistically similar.

All treatments have very low incidence of long summer lateral shoots (Table 5).

At node 1 the control had significantly more summer laterals relative to the full-bloom and post-bloom treatments. At node 3, the control and pre-bloom treatments exhibited significantly more summer laterals relative to the full-bloom and post-bloom treatments (Table 6).

At node 3, the control treatment had significantly greater incidence of longer summer laterals than the full-bloom and post-bloom treatments (Table 6). At node 4, the pre-bloom treatment exhibited significantly greater incidence of longer summer lateral shoots (Table 6).

Table 5. Summer lateral shoot incidence rated by category for the basal five nodes[1] of the fruit-zone

Lateral Shoot Length Category	Lateral Ratings % in Class[2,3]							
	Control		Pre-Bloom		Full-Bloom		Post-Bloom	
No Lateral Shoots	43.9%^{c}	(0.1)	49.4%^{bc}	(0.1)	65.6%^{ab}	(0.1)	71.1%^{a}	(0.1)
Less than 3 cm	37.8%^{a}	(0.1)	32.2%^{a}	(0.1)	22.8%^{a}	(0.1)	23.3%^{a}	(0.1)
3 cm to15 cm	16.7%^{a}	(0.1)	16.1%^{a}	(0.0)	11.1%^{ab}	(0.1)	5.6%^{b}	(0.0)
Greater than 15 cm	1.7%^{a}	(0.0)	1.7%^{a}	(0.0)	0.6%^{a}	(0.0)	0.0%^{a}	(0.0)

[1] Basal 5 internodes rated from base (1) to tip (5)
[2] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis
[3] Different letters indicate significant difference determined using Tukey’s HSD at alpha = 0.05 for values within a row.

Table 6. Summer lateral shoot incidence rated by category for the individual fruit-zone nodes[1]

Node #: Lateral Shoot Length Category	Lateral Rating % in Class[2,3]							
	Control		Pre-Bloom		Full-Bloom		Post-Bloom	
Node 1: No Lateral Shoots	69.4%^{b}	(0.2)	86.1%^{ab}	(0.1)	97.2%^{a}	(0.1)	97.2%^{a}	(0.1)
Node 3: No Lateral Shoots	27.8%^{b}	(0.1)	36.1%^{b}	(0.1)	75.0%^{a}	(0.1)	80.6%^{a}	(0.2)
Node 3: Less than 3 cm	50.0%^{a}	(0.1)	50.0%^{a}	(0.1)	22.2%^{b}	(0.1)	16.7%^{b}	(0.1)
Node 3: 3 cm to 15 cm	22.2%^{a}	(0.1)	11.1%^{ab}	(0.1)	2.8%^{b}	(0.1)	2.8%^{b}	(0.1)
Node 4: 3 cm to 15 cm	27.8%^{ab}	(0.1)	36.1%^{a}	(0.1)	16.7%^{b}	(0.1)	13.9%^{b}	(0.1)

[1] Basal 5 nodes rated for lateral category from base (1) to tip (5)
[2] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis
[3] Different letters indicate significant difference determined using Tukey’s HSD at alpha = 0.05 for values within a row.

Effects of Early Fruit-zone Leaf Removal on Fruit Development

Fruit Set

No statistical significance was observed when comparing fruit set between treatments. However, despite the lack of statistical significance, the fruit set for the pre-bloom treatment showed a tendency to be lower with 18 percent lower fruit set relative to the control (Table 7). An inverse correlation exists between percent fruit set and the number of calyptra collected per cluster (Figure 7).

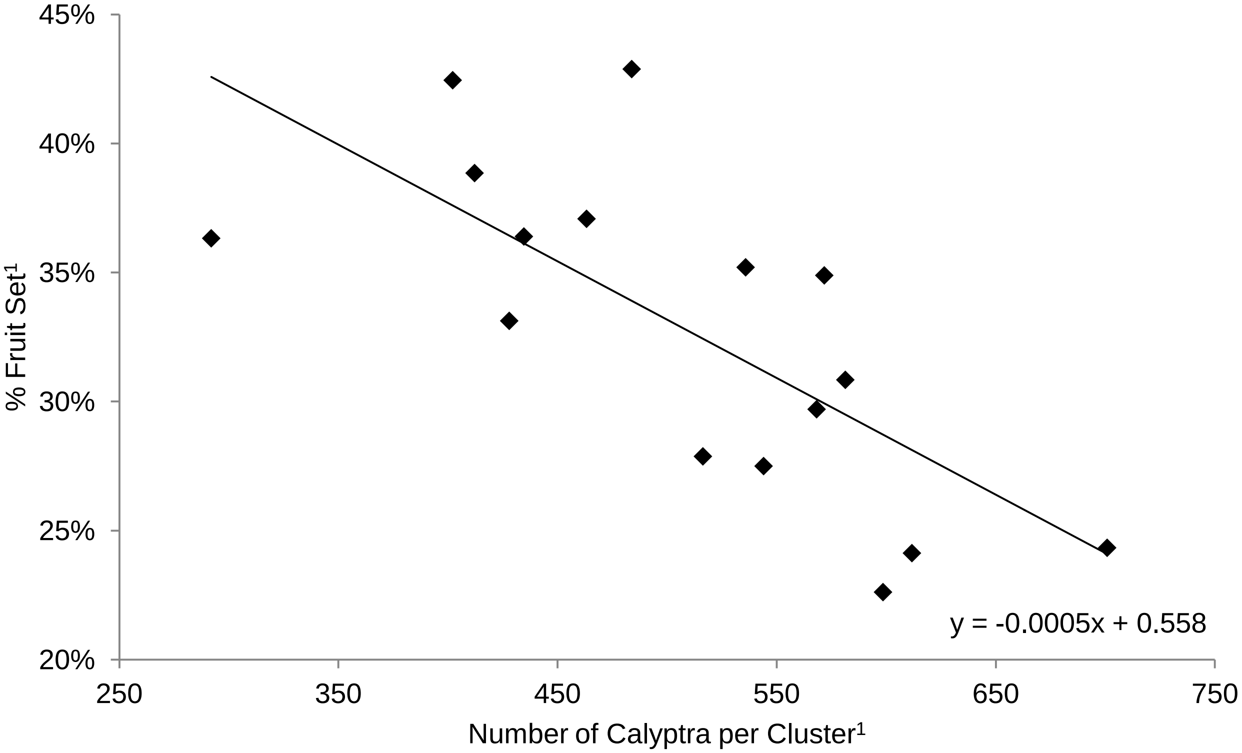


Figure 7. Scatter plot and trend line representing the relationship between percent fruit set and the number of calyptra collected per cluster across all treatments.

[1] Calculated from an average of 10 clusters per replicate. Treatments replicated 4 times. Pooled treatment data.

Number of Berries per Cluster

No significant differences exist between treatments regarding the number of berries per cluster (Table 7).

Table 7. Fruit set percentage and number of berries per cluster.[1,2]

	Control	Pre-Bloom	Full-Bloom	Post-Bloom
% Fruit set	34.0%[a] (0.06)	27.8%[a] (0.05)	35.7%[a] (0.03)	30.6%[a] (0.07)
# of berries per cluster	153.3[a] (18.1)	159.5[a] (28.2)	124.1[a] (20.4)	148.1[a] (34.1)

[1] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis.

[2] Different letters indicate significant difference determined using Tukey's HSD at alpha = 0.05 for values within a row.

Effects of Early Fruit-zone Leaf Removal on Fruit Composition

Sunburn, Powdery Mildew, Botrytis Bunch Rot Incidence

There were no significant levels of powdery mildew or Botrytis bunch rot on the clusters in any of the treatments. Minor sunburn was recorded on the two data collection dates, but no significant differences in incidence or severity existed between treatments (Table 8). Severity was consistently below 0.5 percent for all treatments on both dates.

Cluster Surface Temperature

Cluster temperatures were significantly higher relative to ambient temperature on CDOY 147 in the pre-bloom, full-bloom and post-bloom treatments (Table 9). There were no significant differences on CDOY 168. However, all treatments exhibited temperatures higher than the ambient temperature with the control having the lowest average temperature.

Effects of Early Fruit-zone Leaf Removal on Long-term Vine Fruitfulness

Compound Bud Surface Temperature

No statistical significance was observed in compound bud surface temperature for any treatment relative to ambient temperature on CDOY 103 or 168. On CDOY 125, the ambient temperature was significantly higher than the control treatment (Table 9). The control had the lowest average compound bud surface temperature on all measurement dates. On the first measurement date (CDOY 103), only the pre-bloom and full-bloom treatments had leaves removed (Table 1), and they presented with slightly higher than average temperature compared to the other treatments (Table 9).

Table 8. Incidence and severity of sunburn on clusters.[3,4]

Date 2012	CDOY[1]	EL Stage[2]	Rating	Control	Pre-Bloom	Full-Bloom	Post-Bloom
25-Jul	147	26	incidence	5%^{a} (0.1)	8%^{a} (0.1)	13%^{a} (0.2)	8%^{a} (0.1)
			severity	0.1%^{a} (0)	0.1%^{a} (0)	0.1%^{a} (0)	0.3%^{a} (0)
15-Aug	168	32	incidence	3%^{a} (0.1)	5%^{a} (0.1)	5%^{a} (0.1)	5%^{a} (0.1)
			severity	0.1%^{a} (0)	0.3%^{a} (0)	0.4%^{a} (0)	0.3%^{a} (0)

[1] CDOY = Climate Day of Year calculated from 1 March

[2] EL = Eichhorn-Lorenz Phenological Stage (Coombe 1995) (Figure 5)

[3] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis

[4] Different letters indicate significant difference determined using Tukey's HSD at alpha = 0.05 for values within a row.

Table 9. Surface temperature of compound buds and clusters during the growing season. Measurements recorded on the west side of the canopy in the afternoon.

					Temperature in Celsius[5,6]				
	Date 2012	CDOY[1]	Wind Speed[2,3]	Solar Radiation[2,3]	Ambient	Control	Pre-Bloom	Full-Bloom	Post-Bloom
Compound Bud	11-Jun	103	2.6	700	27.1^{a} (0.1)	25.4^{a} (3.5)	28.4^{a} (2.2)	27.7^{a} (1.4)	26.1^{a} (2.2)
	3-Jul	125	4.8	650	22.8^{a} (0.1)	16.3^{b} (2.4)	17.8^{ab} (2.7)	19.9^{ab} (3.8)	18.7^{ab} (3.1)
	15-Aug	168	3.6	550	34.0^{a} (0.1)	35.2^{a} (1.6)	35.8^{a} (1.3)	37.3^{a} (2.7)	35.3^{a} (1.3)
Cluster	25-Jul	147	1.7	775	32.0^{b} (0.2)	35.7^{ab} (1.8)	38.5^{a} (2.0)	37.7^{a} (1.9)	37.7^{a} (2.1)
	15-Aug	168	3.6	550	34.0^{a} (0.2)	36.5^{a} (2.4)	36.7^{a} (2.9)	38.1^{a} (3.2)	36.9^{a} (2.0)

[1] CDOY = Climate Day of Year calculated from 1 March.

[2] Environmental condition averages during data collection as reported by AgWeatherNet, Port of Sunnyside weather station; (http://weather.wsu.edu).

[3] Metric units. Wind speed expressed as meters/second. Solar radiation expressed as Watts/meter^2.

[4] n = 10 per replicate. Treatments replicated 4 times. Standard deviation in parenthesis.

[5] Different letters indicate significant difference determined using Tukey's HSD at alpha = 0.05 for values within a row.

Discussion

Effects of Early Fruit-zone Leaf Removal on Canopy Development

Pre-bloom FLR occurred 44 days after bud break (Table 1) when shoot apices require abundant carbohydrates to fuel rapid growth (Hale and Weaver 1962). Shoots were at EL 16 with the most mature leaves located in the fruit-zone beginning to perform at peak photosynthesis levels (Poni et al. 2006, Hofaecker 1978). Fruit-zone leaf removal during this period of development can reduce photosynthesis and can explain why the trends in the shoot length data showed reduced post-treatment growth. The decline in shoot length relative to the control stops by the fourth measurement indicating adequate carbohydrates were available for shoot growth (Poni et al 2009, Palliotti et al. 2011, Diago et al. 2012). This response can be due to canopy re-growth and increased canopy efficiency.

The post-bloom treatment exhibits consistently lower shoot length as compared to the other treatments which is likely an artifact of the experimental site or shoot selection.

The impact of EFLR must be considered along with other factors influencing canopy development. At the experimental site, regulated deficit irrigation (RDI) was used to control canopy development (T. Newhouse, personal communication, 2012) and has a powerful impact on shoot growth (Keller 2005). Several in-field studies on leaf removal did not use irrigation during the growing season (Palliotti et al. 2011, Kotseridis et al. 2012, Diago et al. 2012, Sabbatini and Howell 2010). In these regions, control of canopy development is not possible through irrigation. Rainfall and available nutrients can lead to excess vigor in these regions making FLR an important technique. However, in growing regions where regulation of vine nutrition and water supply is possible, growers have greater control over canopy development (Reynolds et al. 2005, Keller 2005) making the impact of EFLR on vine vigor and shoot growth less important than in regions where these other control factors are not available.

Fruit-zone internode length provides insight regarding a window of time critical for the development of clusters and bud fruitfulness of the following year. Pratt and Coombe (1978) noted fruit-zone internodes had finished growing a few weeks before bloom. The fruit-zone internode lengths of Y1 are more dependent upon carbohydrate reserves than photosynthate and therefore leaf removal would not have had a major impact. However, without adequate reserve replenishment due to FLR in Y1, Y2 fruit-zone internode length could be reduced. Fruit-zone internode length can have longer-term impacts on other viticultural practices. For example, when cane pruning, one would have to account for changes in bud count per cane length and consider the impacts on shoot density the following season. For spur pruning, reduced fruit-zone internode length (combined with in-season FLR) could provide more shading from the leaves above the fruit zone and summer lateral shoot re-growth.

In the growing season of this experiment, the pre-bloom, full-bloom and post-bloom treatments all displayed shorter average lengths for both individual internode and combined fruit-zone internode (six basal nodes) relative to the control (Table 4). While not statistically significant, this data will be useful to compare against the fruit-zone internode length in 2013.

Summer lateral shoots were removed during FLR which is the likely reason for a general absence and decreased length of fruit-zone lateral shoots as compared to the control. Each subsequent date of leaf removal exhibited these results with greater magnitude due to less time available for re-growth. All treatments with fruit-zone leaf removal exhibited fewer fruit-zone lateral shoots than the control (Table 5 and 6) illustrating the lasting impact of FLR on canopy microclimate and cluster exposure.

In general, the pre-bloom summer lateral shoot incidence is statistically similar to the control (Table 5 and 6), indicating a recovery of post-treatment summer lateral shoots by véraison potentially contributing to a recovery in TLA to yield ratio. However, neither TLA nor yield was measured within the scope of this report.

The full-bloom and post-bloom treatments both exhibited diminished fruit-zone summer lateral shoot re-growth relative to the pre-bloom treatment (Table 5) suggesting an important relationship between treatment timing and the incidence of fruit-zone summer lateral shoot development. With limited fruit-zone summer lateral shoot development, clusters may be highly exposed during the entire growing season increasing the associated risks of fruit damage. Regarding the impact of fruit-zone summer laterals on TLA, Poni et al. (2009) reported summer lateral shoots will develop from the apical section of the main shoot. Summer lateral shoot incidence outside of the fruit-zone was not measured in this experiment. Other studies on EFLR indicate significant summer lateral shoot re-growth along the entire main shoot is largely responsible for a recovery of leaf area (Diago et al. 2012, Palliotti et al. 2011, Poni et al. 2006, 2009). However, RDI and vine nutrition have a great impact on overall vine vigor and can influence summer lateral shoot development.

In this experiment, the effect of FLR on TLA was not measured. However, numerous studies have reported on the increased efficiency of younger leaves (Poni et al. 1994, Candolfi-Vasconcelos and Koblet 1990) as well as the potential of leaf removal to stimulate the development of new leaf tissue (Palliotti et al. 2011, Poni and Civardi 2008). Early fruit-zone leaf removal lowers the average leaf age of the canopy, and along with canopy re-growth, these factors can contribute to a recovery in whole vine photosynthesis levels by véraison (Palliotti et al. 2011, Poni et al. 2008). When combined with potential reductions in yield which can result from EFLR, TLA to yield ratios can be greater than vines with no leaf removal providing more assimilates to ripening fruit and contributing to improved fruit quality perception (Diago et al. 2012, Palliotti et al. 2011, Poni et al. 2009).

Effects of Early Fruit-zone Leaf Removal on Fruit Development

The fruit set of the pre-bloom treatment exhibited a tendency for lower average percent fruit set relative to other treatments and the full-bloom treatment was the most similar to the control in agreement with other studies on the effect of EFLR on fruit set (Poni et al. 2006, Intrieri et al. 2008, Tardaguila et al. 2010). The lack of statistical significance observed in the pre-bloom FLR may be due to several factors that influence fruit set. Fruit-zone leaf removal at pre-bloom removes the most productive and expanded leaf area of the canopy, reducing the photosynthate contribution to the total carbohydrate supply which is critical for successful fruit set (Coombe 1959, Caspari et al. 1998). This effect may be offset by a buffering capacity of the unaffected carbohydrate reserves through increased mobilization of carbohydrate storage reserves mitigating the negative effect on photosynthate supply (Palliotti et al. 2011).

An inverse correlation between the number of flowers per cluster and percent fruit set has been reported (Vasconcelos and Castagnoli 2000) and was evident in the pooled averages of this experiment (Figure 7). The significantly greater number of calyptra collected for the pre-bloom treatment relative to other treatments may be linked to the lower observed fruit set. Vasconcelos and Castagnoli (2000) concluded fruit set provides another crop regulating mechanism in response to resource availability.

Lastly, increased sunlight and air flow penetration of the fruit-zone as a result of EFLR can positively influence fruit set through increased cluster temperatures and increased evaporation within the fruit-zone (Ebadi et al. 1996). However, these benefits may have been minimized due to the majority of seasonal rainfall occurring during bloom (Table 1).

The fruit set data collected indicated the FLR treatments in this experiment were statistically similar to the no FLR treatment (control). The trends in the data, in agreement with past research, suggest pre-bloom FLR may reduce fruit set, however the data is insufficient to conclude this is a reliable result. The fruit development data collected outside of the scope of this report, in addition to the continuation of this experiment over several years will better allow for well founded conclusions regarding the effect of EFLR on fruit development.

Effects of Early Fruit-zone Leaf Removal on Fruit Composition

At the time of the first cluster temperature reading (CDOY 147) all leaf removal was complete (Table 2). The ambient temperature on CDOY 147 was significantly lower than the cluster temperatures for all non-control treatments indicating a relationship between FLR and increased cluster temperatures (Table 9) during this stage of vine development. In contrast, the cluster temperature data from CDOY 168 did not indicate any significant differences between treatments and ambient temperature (Table 9).

The higher level of solar radiation and lower wind speed during the time of measurement on CDOY 147 relative to 168 allowed for greater solar heating and less evaporative cooling of the clusters creating significant differences between the ambient temperature and the pre-bloom, full-bloom and post-bloom cluster temperatures (Table 9). Cluster temperatures on CDOY 168 may also have been affected by the mechanical east-face FLR on CDOY 162 (10 August). This canopy manipulation by the grower may have further increased the cluster exposure and air flow within the fruit-zone and potentially increased vine respiration in the remaining leaves through photosynthetic compensation. Lower intensity of solar radiation and greater air speed, in combination with increased vine respiration can contribute to the lack of significant differences between treatments on CDOY 168.

Fruit composition can be influenced by cluster exposure in a variety of ways. Solar radiation can increase the surface temperature of plant tissue (Smart and Sinclair 1976) resulting in increased metabolic rate (Greer 2012, Zufferey et al. 2000, Coombe 1987) potentially contributing to greater anthocyanin synthesis and increased accumulation of total soluble solids (Bergqvist et al. 2001) in the berry. Increased exposure to solar radiation can reduce disease pressure (Austin and Wilcox 2012) through increased surface temperature, evaporation, and exposure to ultraviolet radiation. Berry skin mass (Poni et al. 2009, Tardaguila et al. 2010, Diago et al. 2012, Palliotti et al. 2011) and flavonol concentration (Spayd et al. 2002, Downey et al. 2003) have been reported to increase to protect the berry from the increased exposure to the ultraviolet spectrum of solar radiation. However, if solar heating of plant tissues exceeds a threshold temperature, vine metabolism is impaired and can stop (Greer 2012, Zufferey et al. 2000, Coombe 1987), and anthocyanin degradation (Bergqvist et al. 2001, Spayd et al. 2002, Tarara et al. 2008) and cluster sunburn (Bondada and Keller 2012) can occur.

Sunburn incidence and severity levels were low in all treatments and no significant relationship was noted between EFLR and sunburn incidence or severity (Table 8). In this experiment, EFLR did not present an increased risk of sunburn. However, this is contrary to past observations of sunburn in this region (Spayd et al. 2002, Bondada and Keller 2012), and personal observations of sunburn damage on exposed clusters in this region and growing season on Merlot.

Visible incidence and severity of grapevine powdery mildew and Botrytis bunch rot was generally not reported and did not significantly differ between treatments on either data collection date. Fungicide application rate could be reduced in EFLR treatments as a result of the increased spray penetration of the fruit-zone (Austin et al. 2011). However, insufficient levels of disease during this experiment make it impossible to draw conclusions regarding the effect of EFLR on disease incidence or severity.

Ambient weather conditions, additional canopy management treatments and other vineyard management practices have a large influence on fruit composition and can obscure detection of the effects related to EFLR. As mentioned previously, control over irrigation provides control over vine vigor which can impact fruit composition (Smart 1985). In addition, at the experimental site, catch wires were not raised until late June. This “modified sprawl” canopy training contributed to shading of the fruit-zone until the time the catch-wires are raised and the canopy became a more strict representation of the traditional VSP training systems.

The data collected suggests no detriment to fruit composition resulted from EFLR during this experiment. However, due to time constraints, the data collected was limited and insufficient to determine the effects of EFLR on fruit composition.

Effects of Early Fruit-zone Leaf Removal on Long-term Vine Fruitfulness

Exposure to high temperature and high light intensity during compound bud development can improve fruitfulness (Dry 2000, Srinivasan and Mullins 1981). Watt et al. (2008) reported primary and secondary branching of primordia up until véraison.

During the first temperature reading (CDOY 103), only pre-bloom and full-bloom treatments had leaves removed (Table 1), and they had higher average compound bud temperatures relative to the other treatments (Table 9). This result is likely due to the increased exposure of the fruit-zone due to EFLR and the lack of fruit-zone summer lateral shoot development resulting in increased solar heating of plant tissues.

The second temperature reading (CDOY 125) occurred after all leaf removal treatments were completed, and pre-bloom, full-bloom and post-bloom treatments had higher average compound bud temperatures relative to the control (Table 9). The non-control treatments all had lower temperature readings than the ambient temperature which can be a result of the relatively high wind speed at the time of measurement (Table 9).

The third and final temperature reading (CDOY 168) does not exhibit any significant relationship between EFLR and ambient temperature (Table 9). However, all treatments exhibit higher temperatures relative to ambient temperature. This measurement may have been affected by the mechanical leaf removal a few days earlier.

The data collected does not indicate a consistent significant relationship between EFLR and compound bud temperature. This can be due to a variety of factors including the shading effects provided by the “modified sprawl” shoot positioning or increased air flow within the fruit-zone (Table 9). The trend of elevated temperatures in the non-control treatments relative to the control can indicate a minor positive effect of EFLR on increasing compound bud temperature; which has been linked to increased bud fruitfulness (Buttrose 1969a, Smart 1985, Dry 2000). Buttrose (1969b) also reported some evidence suggesting that longer days, such as those in the Yakima Valley, Washington, can improve fruitfulness. The effect of EFLR in this growing season on the long-term fruitfulness of this site will be determined in the successive years of this study.

Conclusion

Results from past research about the effects of EFLR on grapevine development and fruit quality are inconclusive due to the many variables reviewed herein. However adequate research indicates EFLR can improve both grapevine development and fruit quality, providing good reason for extensive local research.

The data collected for this report was limited in scope due to time constraints. This report does not provide adequate data for firm conclusions about the effects of EFLR on grapevine development and fruit quality. Trends in the data suggest FLR may impact vine vigor, fruit set, and fruit-zone microclimate providing ample cause for further research in the Yakima Valley on this potentially valuable canopy management technique.

The additional data collected outside of the scope of this report will be invaluable in formulating well founded conclusions regarding the effect of early fruit-zone leaf removal on grapevine development and fruit quality in *Vitis vinifera* ‘Merlot’.

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