Year-end Progress Report
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Optimized wine quality potential through fruit-zone management practices in red varieties

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Objective: Evaluate the effectiveness of canopy management practices such as fruit-zone leaf and lateral removal and early season carbon source limitation as means of optimizing grape composition and wine quality of Bordeaux red varieties.

Introduction/background: Leaf removal from fruit zones is a common viticulture practice, especially in humid grape growing regions, as a reduction in disease incidence and severity is often achieved. Leaf removal effects on fruit composition can be highly variable, with many factors confounding results, such as magnitude and timing of leaf removal, variety, growing region, seasonal weather patterns, and compound of interest in grapes/wines, to name a few. Consequently, leaf removal recommendations are often generalized with no mention of how or if a specific grape compound or compound class will change between varieties. Thus, it is our intention to evaluate if changing the magnitude and timing of leaf removal would change Cabernet Sauvignon, Cabernet franc, and Petit Verdot fruit/wine composition and/or consumer acceptability of wines. The compounds or compound classes of interest in fruit and wines have all been shown to be affected by either light, temperature, or both: carotenoids, norisoprenoids, anthocyanins, and total phenolics. Carotenoids are precursors to norisoprenoids, which are key aroma impact compounds, especially in young Bordeaux wines, due to their low olfactory perception threshold. Anthocyanins and other flavonoids are important for red wine properties such as color and mouthfeel. Taken together, the value of these compounds in determining optimal leaf removal practice is a consequence of their role in aroma, color and mouthfeel of wines and, thus, consumer acceptability.

Design/Methods: The main project was conducted in a commercial vineyard in Shenandoah County, with two smaller experiments conducted with Cabernet Sauvignon grown at the AHS Jr. AREC near Winchester. This project was conducted on Cabernet franc and Petit Verdot and evaluated post-fruit set (MEDIUM, removal of leaves opposite clusters; HIGH, removal of all leaves from above top cluster down to cordon) and pre-bloom (PRE-BLOOM, removal of all leaves from above top cluster down) leaf removal compared to no leaf removal (NONE, removal of no leaves). This project was terminated in after the 2014 field season; data presented herein is an average of the 2013 and 2014 seasons. Two separate experiments in the AHS, Jr. AREC

Cabernet Sauvignon vineyard are being evaluated through the end of the 2015 field season. The pre-bloom leaf removal experiment, initiated in 2013, evaluated a no leaf removal-control (PB-NO) and pre-bloom leaf removal of four (PB-4) and eight (PB-8) basal leaves and laterals from primary shoots. The post-fruit set leaf removal experiment, initiated in 2014, evaluated a no leaf removal-control (PFS-NO) and post-fruit set removal of six basal leaves and laterals (PFS-6). Data presented from the pre-bloom experiment is an average of the 2013 and 2014 seasons and data from the post-fruit set experiment from 2014 only. The following data collection is consistent across all projects. Berry temperature and fruit-zone architecture were collected on several dates throughout the season. One experimental unit of the pre-bloom leaf removal treatment had berry temperature and ambient radiation and light conditions logged on 15-minute and 1-minute intervals. Berry samples were collected, weighed, and frozen for future compositional analyses, namely carotenoids. Yield data were collected by vine and cluster compactness was evaluated on 10 clusters per experimental unit at harvest. Soluble solids, pH, and titratable acidity were determined from 60 berry samples at harvest. Grape anthocyanins and total phenolics were determined from a composite sample of berries from the cluster compactness assessment (Petit Verdot, Cabernet franc, and Cabernet Sauvignon pre-bloom experiment) and from 60 berry samples from both the east and west sides of the canopy (Cabernet Sauvignon post-fruit set experiment). Many of these same responses have been and continue to be collected throughout 2015 in the Cabernet leaf removal experiments. Data that remains to be collected and/or analyzed are the grape carotenoid and wine norisoprenoid contents and consumer preference testing of wines, most of which will be finished by Nov 2015.

Results: The leaf removal treatments were effective in creating a gradient in magnitude of leaf layer (LLN) and fruit cluster exposure (CEFA) (Table 1). As a result, both fruit exposure magnitude (i.e. MEDIUM vs. HIGH, PB-4 vs. PB-8, PFS-6 vs. PFS-NO) and timing (i.e. HIGH vs. PRE-BLOOM) can be explored for their effects on components of yield and fruit composition. Note that conventional leaf removal is at post-fruit set and to a magnitude of about 1.5 leaf layers, here best represented by MEDIUM in Cabernet franc and Petit Verdot.

Table 1. Leaf removal impact on fruit-zone leaf layer (LLN) and radiation (CEFA) in Petit Verdot, Cabernet franc, and Cabernet Sauvignon.

	Petit Verdot		**Cabernet franc**	
	LLN	**CEFA**	**LLN**	**CEFA**
NONE	2.20	0.18	2.30	0.19
MEDIUM	1.20	0.43	1.40	0.45
HIGH	0.10	0.65	0.10	0.71
PRE-BLOOM	0.20	0.66	0.10	0.77

	Cabernet Sauvignon (pre-bloom)	
	LLN	**CEFA**
PB-NO	2.50	0.18
PB-4	0.00	0.65
PB-8	0.00	0.71
	Cabernet Sauvignon (post-fruit set)	
PFS-NO	2.70	0.19
PFS-6	0.00	0.77

Berry temperature is mainly a function of ambient air temperature (Fig. 1). However, sunlight can confound this relationship. This is demonstrated by the straying of the red and blue data points (four and eight leaf removal, respectively) above the air-berry temperature trend line, caused by radiant heating of exposed grapes. The green data points represent the no leaf removal treatments; grapes in this treatment are shaded and, therefore, follow the air-berry temperature trend line much more closely than do the leaf removal treatments. Berry temperatures at or above 35°C (temperature threshold detrimental to anthocyanin accumulation) have been logged for 15.5 hours on the east side and 30.9 hours on the west side of the canopy. The relatively greater amount of time spent above this temperature threshold on the west side of the canopy is attributed to higher ambient air temperatures experienced in the afternoon, when the sun is also cast on the west side of the canopy.

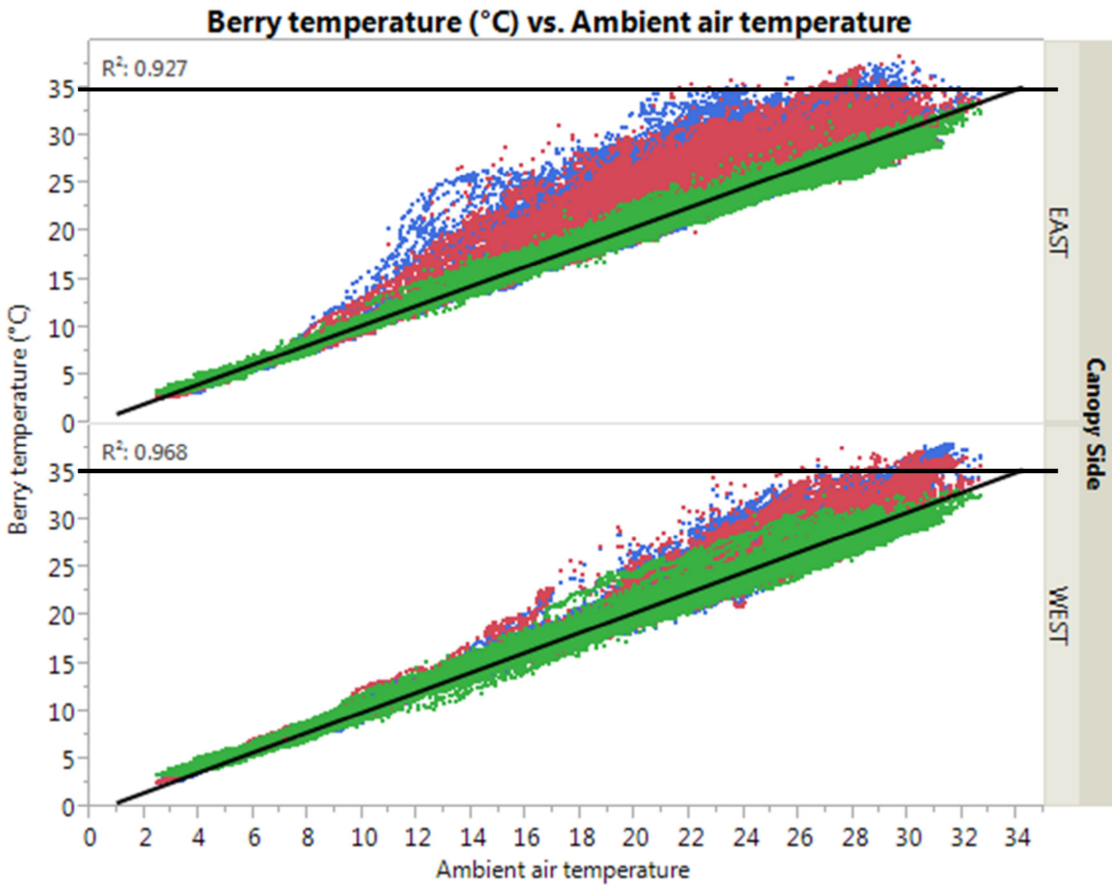

Fig. 1. Grape berry and ambient air temperatures logged at the Alson H. Smith, Jr. AREC in Winchester, VA from July 2013 through 2-Aug 2015; green, red, and blue = no, 4, and 8 leaf removal, respectively.

Pre-bloom leaf removal reduced crop yield by 30% in Cabernet franc, 44% in Petit Verdot, and by 23% and 44% in the four and eight-leaf removal treatments in Cabernet Sauvignon, respectively (Table 3). This reduction in crop yield is explained primarily by a reduction in berry number per cluster (interpreted as reduced fruit set) and subsequent reduction in cluster weight. However, cluster number per vine was greatly reduced in Petit Verdot (data not shown). Post-fruit set leaf removal tended to marginally and inconsistently affect components of crop yield; no post-fruit set leaf removal treatment reduced crop yield, cluster weight, or berry number per cluster, regardless of magnitude or variety (Table 3).

Table 3. Crop yield, cluster weight, and berry number per cluster in Petit Verdot, Cabernet franc, and Cabernet Sauvignon.

	Petit Verdot			**Cabernet franc**		
	Crop yield (tons / acre)	**Cluster weight (g)**	**Berry # / cluster**	**Crop yield (tons / acre)**	**Cluster weight (g)**	**Berry # / cluster**
NONE	3.7 a	62 a	50 a	3.9 a	121 a	86 a
MEDIUM	3.4 a	60 a	49 a	3.6 a	117 a	83 a
HIGH	3.1 a	60 a	49 a	3.5 a	114 a	81 ab
PRE-BLOOM	1.9 b	40 b	41 b	2.6 b	94 b	73 b

	Cabernet Sauvignon (pre-bloom)		
	Crop yield (tons / acre)	**Cluster weight (g)**	**Berry # / cluster**
PB-NO	3.9 a	93 a	104 a
PB-4	3.0 b	57 b	68 b
PB-8	2.2 b	39 c	63 b
	Cabernet Sauvignon (post-fruit set)		
PFS-NO (EAST)	3.2	149	103
PFS-NO (WEST)	3.2	139	95

Primary fruit chemistry was not greatly affected by leaf removal treatment (data not shown). Leaf removal effects on pH were inconsistent, and aggressive leaf removal (regardless of timing) reduced soluble solids in Petit Verdot, and tended to reduce titratable acidity in Cabernet franc and Cabernet Sauvignon. Pre-bloom leaf removal improved total berry phenolics in all varieties and aggressive post-fruit set leaf removal improved total berry phenolics in Cabernet Sauvignon, but not in the other two varieties (Table 3). As berry weight was reduced, total phenolics tended to increase in Cabernet franc and Petit Verdot (Figure 2).

Table 3. Total berry phenolics and anthocyanins in Petit Verdot, Cabernet franc, and Cabernet Sauvignon.

	Petit Verdot		**Cabernet franc**	
	Total anthocyanins (mg / g berry)	**Total phenolics (au / g berry)**	**Total anthocyanins (mg / g berry)**	**Total phenolics (au / g berry)**
NONE	0.99	105.3 b	0.78	86.0 b
MEDIUM	1.07	109.5 ab	0.76	83.4 b
HIGH	1.00	102.9 b	0.80	87.6 b
PRE-BLOOM	1.07	123.0 a	0.83	97.9 a

	Cabernet Sauvignon (pre-bloom)	
	Total anthocyanins (mg / g berry)	**Total phenolics (au / g berry)**
PB-NO	0.89	72.4 b
PB-4	0.98	87.0 a
PB-8	1.00	93.7 a
	Cabernet Sauvignon (post-fruit set)	
PFS-NO (EAST)	0.59	47.7 b
PFS-NO (WEST)	0.63	51.1 b
PFS-6 (EAST)	0.64	55.0 a
PFS-6 (WEST)	0.60	56.5 a

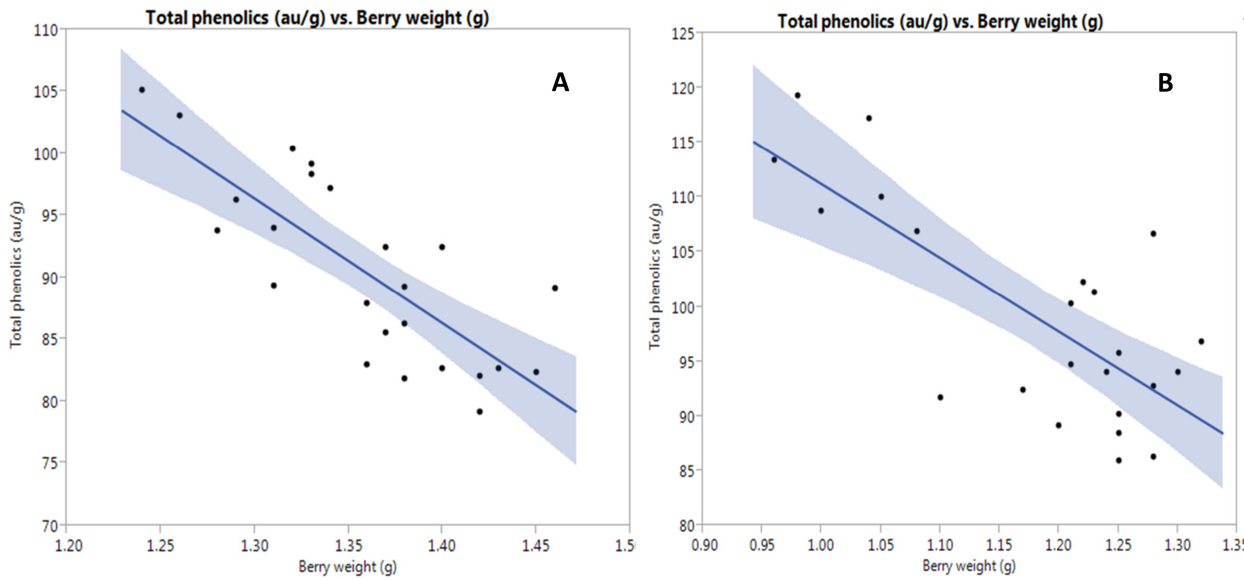

Fig. 2. The relationship of berry weight and total berry phenolics in Cabernet Franc (A) and Petit Verdot (B) in 2013. Phenolics expressed as absorption units per gram berry weight.

Discussion: ***<u>Berry temperature and anthocyanins:</u>*** Current fruit-zone management strategies tend to be conservative, removing less leaves than more, and focusing on the east side of the canopy. This mentality might be traced back to studies conducted in warmer and arid (interpreted as clear blue skies) climates, such as eastern Washington and California, where it was found that aggressive fruit-zone leaf removal resulted in radiant heating of grapes to detrimental temperatures (≥ 35 °C) for extended periods of time, especially on the west canopy side. For example, one study conducted in eastern Washington found that western-exposed grapes spent 89 hours at ≥ 35 °C, which resulted in almost a 50% reduction skin anthocyanins compared to shaded grapes. In our study, however, aggressively removing leaves resulted in no difference in grape anthocyanin content, regardless if leaves were removed pre-bloom or post-fruit set and which side of the canopy fruit was collected from. This appears to be a function of the cloudy, moderate climate of humid eastern growing regions, such as Virginia. Our observations show that to heat berries to ≥ 35 °C, ambient temperatures AND radiation must be relatively high, and it must be at a time of day when the sun is angled to heat the fruit-zone. This meteorological situation, however, rarely happens because (1) it is often cloudy out (see Fig. 3 in appendix) and (2) the greatest radiant heating potential occurs during the hours surrounding solar noon, the time of day when radiation to the fruit-zone is blocked (see Fig. 4 in appendix). As such, out of 585,829 logged berry temperatures over the last three field seasons, only 1,294 (0.2% of all logged temperatures) were ≥ 35 °C. This equated to a sum of 15.5 and 30.9 hours spent ≥ 35 °C on the east and west canopy sides of highly exposed treatments, respectively. Thus, the summation of time berries spent at spent ≥ 35 °C was much lower in Virginia compared to eastern Washington, even when comparing three seasons (in Virginia) to one (in eastern Washington). It is therefore suggested that leaf removal practice need not only be less conservative, but need not be canopy-side specific, particularly if the reluctance to aggressively remove leaves in the fruit-zone is due to fear of reducing grape anthocyanin content. ***<u>Total phenolics:</u>*** Total phenolics were improved with all aggressive pre-bloom leaf removal treatments as well as the aggressive post-fruit set leaf removal treatment in Cabernet Sauvignon. While it cannot be disproven that more phenolics were synthesized in leaf removal treatments, data points to a concentration effect because smaller berries typically have a greater skin: pulp ratio (and phenolics are concentrated in skins). Anthocyanins are found in skins only - why did this “concentration effect” not happen to anthocyanins as well? Anthocyanins are a class of flavonoids, which are a subclass of phenols. Thus, anthocyanins are likely harder to concentrate given their much smaller concentration in skin compared to phenols. ***Crop yield:*** Research from more than 50 years ago found that deprivation of carbon source tissues (leaves) at a time when the inflorescence and setting berry are large carbon sinks (i.e. bloom through early fruit set) results in low pollen viability, low fruit set, and low crop yield potential. This is exactly what is happening when so many leaves are removed during the pre-bloom stage. Couple carbon deprivation at a critical time with the often cool, rainy bloom-time weather and you have a recipe for very low fruit set due to low pollen viability and germination rates. It is important to note that timing of leaf removal can make all the difference in terms of fruit set and crop yield potential.

Putting it all together: Aggressive pre-bloom leaf removal modestly improved fruit quality, but significantly reduced crop yield. Further, it is unknown if pre-bloom leaf removal will have deleterious effects on vine health and productivity over time. Nonetheless, post-fruit set leaf removal improved total berry phenolics in one variety without reducing crop yield. Since disease management is optimized with aggressive fruit-zone leaf removal and there is no apparent risk of heating fruit to temperatures that are detrimental to fruit composition (namely anthocyanins), it is recommended that growers in a humid region either remove fewer leaves at the pre-bloom stage or remove leaves immediately after fruit set. These fruit-zone management methods will ensure good early season disease management and efficacious spray coverage while reducing the incidence of sunburn due to sudden fruit exposure in the pea-berry size stage. Work continues on refining a grape berry temperature model and on extraction and quantification of berry carotenoids, precursors of aroma compounds of interest in the red Bordeaux varieties.

Extension of information:

-Some of this data was presented at the Kentucky Fruit and Vegetable Growers Conference in Lexington, KY in January 2015.

-Some of this data was presented in the Wines and Vines (FST 3114) class at Virginia Tech in Blacksburg, VA in January 2015

-The Cabernet Sauvignon portion of this data was presented at the ASEV National Conference in Portland, OR in June 2015.

-The Cabernet franc portion of this data was presented at the ASEV/Eastern Section Conference in Dunkirk, NY in July 2015

Appendix

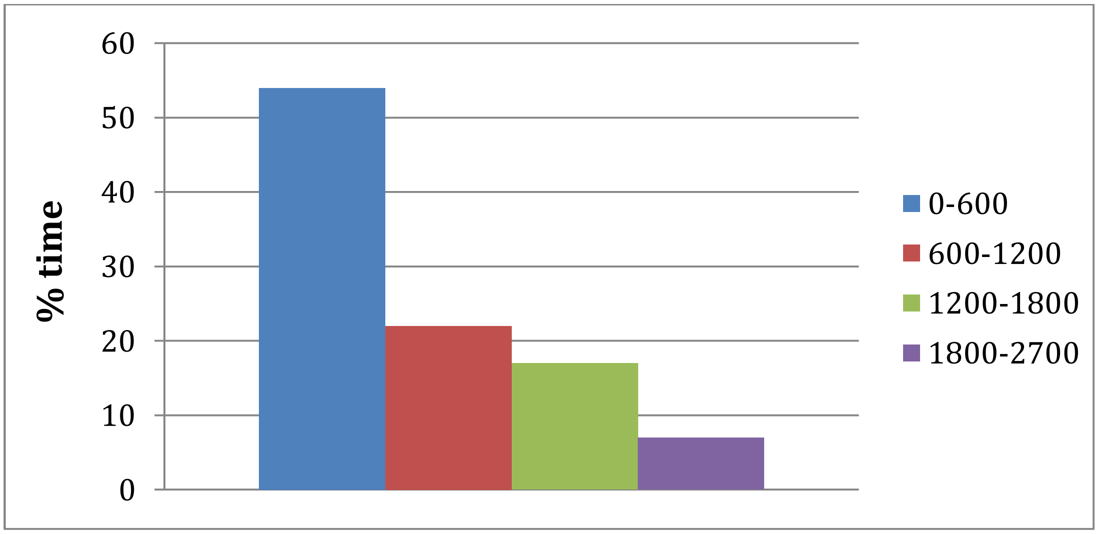

Fig. 3. Percent of time spent at ambient PAR (radiation) ranges from véraison through harvest in 2014 at the Alson H. Smith, Jr. AREC in Winchester, VA. PAR ranges are: 0-600 (cloudy); 600-1200 (hazy); 1200-1800 (full sun outside of solar noon); 1800-2700 (full sun at solar noon).

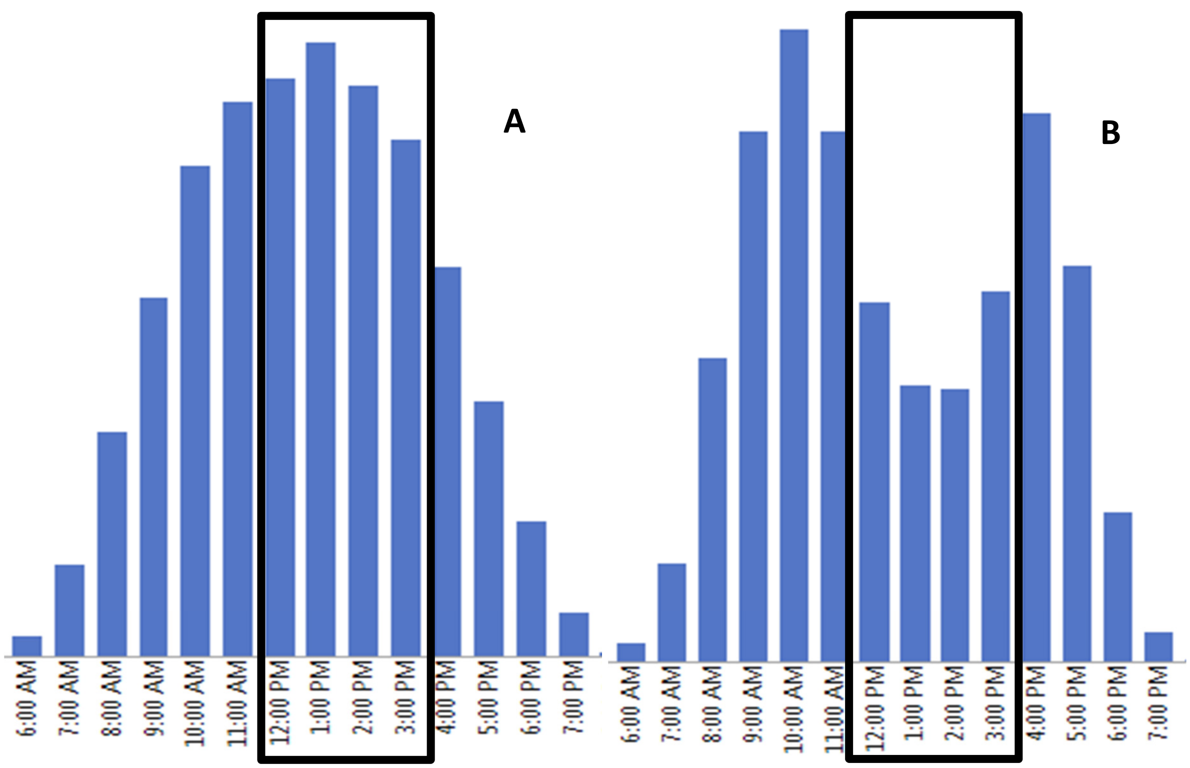

Fig. 4. Daily mean ambient (A) and fruit-zone (B) radiation of all leaf removal treatments throughout the 2014 growing season at the Alson H. Smith, Jr. AREC in Winchester, VA.