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

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Objective: Evaluate fruit-zone leaf and lateral removal at earlier times and to greater extents than convention as means of optimizing grape and wine quality of red Bordeaux varieties.

Background: Research dating back to the mid-1980s has shown that exposing the fruit-zone of vine canopies is beneficial, as fungal disease incidence is reduced and fruit and wine quality are often improved. As such, fruit-zone leaf removal became a ubiquitous practice in grape growing regions across the world, with more aggressive leaf removal recommended. However, more recent research showed that too much of a "good thing" can actually be bad, when extreme radiant heating of fruit was shown to decrease grape anthocyanins. Thereafter, fruit-zone leaf removal became more conservative, even in humid growing regions where shaded fruit-zones exacerbate grape fungal disease infections. Though conventionally conducted after fruit set, fruit-zone leaf removal before bloom has many documented benefits, including improved juice soluble solids, grape phenolics and anthocyanins, and reduced cluster compactness and *Botrytis* bunch rot incidence. We questioned whether there might be merit in taking a more aggressive approach to fruit-zone leaf removal – in terms of both timing and extent. Our objective was to evaluate the effects of aggressive pre-bloom and post-fruit set leaf removal on crop yield components and fruit-composition in three regionally important red Bordeaux varieties: Cabernet franc, Petit Verdot, and Cabernet Sauvignon.

Methods: ***Project 1*** was conducted over 2013-2014 in a commercial vineyard in Shenandoah County. Two separate completely randomized designs, consisting of five-vine experimental units, were set up in adjacent Cabernet franc and Petit Verdot vineyards; the effects of post-fruit set removal of fruit-zone leaves to no (NO), medium (MED), high (HIGH) extents, and pre-bloom removal of fruit-zone leaves to the high extent (P-B) were compared in both varieties. ***Project 2*** was conducted over 2013-2015 at the viticulture research vineyard the AHS Jr. AREC near Winchester. Two separate randomized complete block designs were used to evaluate the effects of pre-bloom and post-fruit set leaf removal on several vine responses. The pre-bloom leaf removal experiment, using one-vine experimental units, 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, using two-vine experimental units, evaluated a no leaf removal-control ("PFS-NO") and post-fruit set removal of six basal leaves and laterals ("PFS-6") from primary shoots. New data was collected only from *Project 2* in 2015, and consisted of measurement of: fruit-zone architecture measurement, berry temperature, berry weight over time, and crop yield components and primary juice chemistry at harvest. Further, berry temperature was logged on 1 minute intervals for the third consecutive season. The majority of lab work in 2015 consisted of extracting carotenoids from Petit Verdot and Cabernet franc grapes, and quantifying total grape anthocyanins and phenolics in all three varieties. Quantification of carotenoids with ultra-performance liquid chromatography-mass spectrometry (UPLC-MS) commenced this fall at the University of Missouri's Grape and Wine Institute; three-fourths of the samples are quantified to-date. Grape carotenoid and wine sensory data are the final datasets needed for completion of two chapters of the dissertation in progress. Additionally, a grape temperature prediction model is under development with a colleague from Cornell, using the logged berry temperature data over 2013-2015.

Results: ***Project 1*** (data not shown): Treatments resulted in fruit-zone leaf layer numbers (LLN) that were greater than (1.99-2.71 in NO), equal to (1.17-1.58 in MED), and lower than current recommendation (0-0.4 in HIGH and P-B). ***Project 2*** (data not shown): pre-bloom and post-fruit set leaf removal resulted in more open fruit-zones than currently recommended (0.0 LLN); removing no leaves resulted in more shaded fruit-zones (2.48-2.73 LLN) (data not shown). Removing leaves resulted in greater incident radiation reaching the fruit-zone; thus, grapes were radiantly heated above ambient air temperatures when leaves were removed from fruit-zones (Fig. 1). Radiant heating of grapes occurred from 800-1800 hrs. because of diurnal solar angle patterns and the vine training system employed (low bilateral cordon with VSP). Thus, documented critical temperatures for anthocyanin synthesis/degradation (≥ 30-35 °C) were logged only between 800-1800 hr. periods on relatively sunny days.

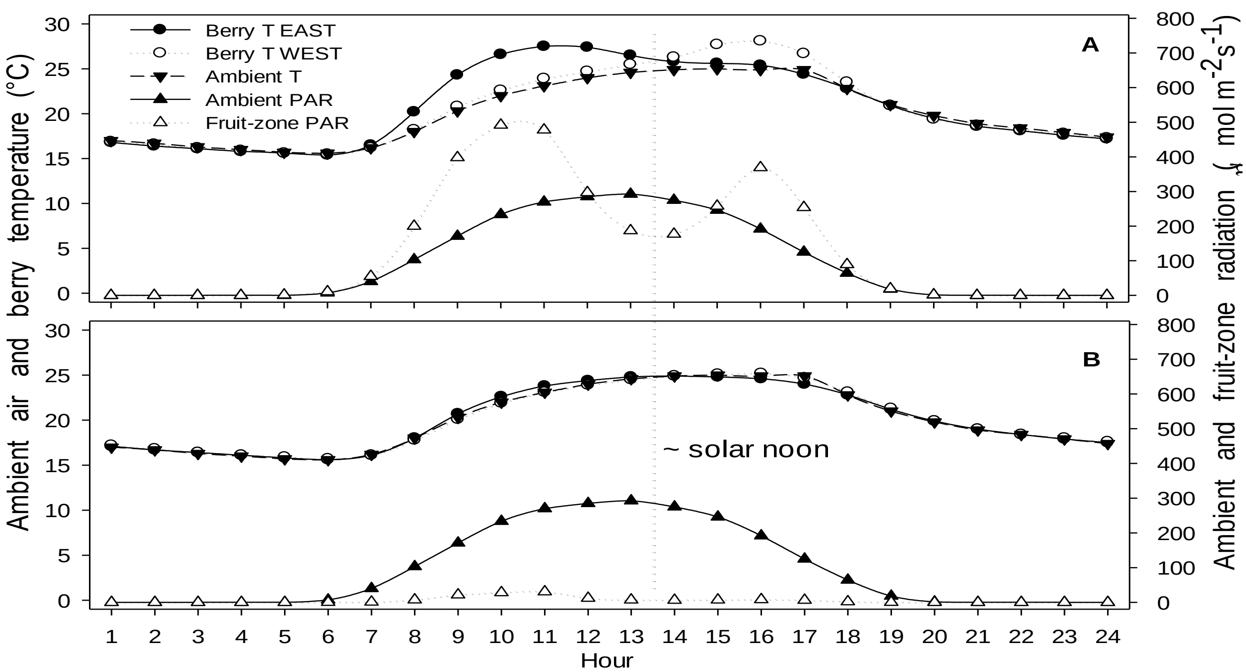

Fig. 1 Daily pattern of ambient air temperature, ambient and fruit-zone radiation, and berry temperature (T) as affected by pre-bloom removal of eight (A) and no (B) fruit-zone leaves in Cabernet Sauvignon. Data logged on 15- and 1-min intervals over 2013-2015 seasons. Ambient PAR (presented as 20% of actual value) was logged on 15- and 1-min intervals over 2014-2015 seasons.

Project 1 (data not shown): P-B reduced cluster number per vine by 10% (significant only in 2014), berry weight by 6%, berry number per cluster by 33%, cluster weight by 39%, and crop yield by 50% when averaged over 2013-2014 in Cabernet franc; P-B reduced cluster number per vine by 29% (significant only in 2014), berry weight by 25%, berry number per cluster by 18% (significant only in 2013), cluster weight by 37%, and crop yield by 53% when averaged over 2013-2014 in Petit Verdot. Crop yield was *further* reduced by 16-25% when P-B was implemented in two consecutive seasons. Post-fruit set leaf removal had less consistent effects on crop yield. P-B tended to reduce cluster compactness to the greatest extent in both varieties, albeit not always significantly. ***Project 2***: PB-4 or PB-8 reduced crop yield by 38% or 66% compared to PB-NO, respectively (Table 1). The decrease in crop yield was due to a reduction in berry number per cluster (42-61%); consequently, cluster weight (44-66%) and cluster compactness were reduced (33-62%). Berry weight was reduced by PB-8 only. As in *Project 1*, crop yield was *further* reduced by 12-20% when PB-4/8 was re-implemented in consecutive seasons, and post-fruit set leaf removal had no consistent effects on crop yield (data not shown). *Botrytis* bunch rot incidence was reduced by PB-4/PB-8 by an average of 94%, and by PFS-6 by 78%, when compared to no leaf removal in 2015 (data not shown).

Table 1. Pre-bloom leaf removal effect on average crop yield components and cluster compactness over 2013-2015, and average count and basal shoot fruitfulness over 2014-2015.

Treatment[a]	Crop yield (t / acre)	Cluster number	Cluster weight (g)	Berry # /cluster	Berry weight (g)	Cluster compactness	Fruitfulness (count/basal)
PB-NO	3.42 a	34	102.3 a	76 a	1.36 a	8.2 a	1.53
PB-4	2.12 b	39	57.0 b	44 b	1.31 a	5.5 b	1.57
PB-8	1.17 c	34	35.1 c	30 c	1.17 b	3.1 c	1.38
Significance[b]	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	ns

[a]PB-NO, 4, and 8 = pre-bloom removal of no, four, and eight leaves, respectively.
[b]Values in same column not sharing a letter are different at 0.05 level using Tukey's HSD.

Project 1 (data not shown): juice soluble solids were unaffected by leaf removal in Cabernet franc, but were reduced by HIGH in two years (4%) and by P-B in one year (7%) in Petit Verdot. Leaf removal treatment inconsistently affected pH, but titratable acidity (TA) was reduced by P-B in two years (14%) in Cabernet franc and by HIGH by in one year (10%) in Petit Verdot. ***Project 2***: PB-8 reduced juice soluble solids compared to PB-4 and PB-NO (Table 2). PB-4 and PB-8 reduced TA by an average of 9% compared to no leaf removal. PFS-6 did not affect soluble solids, but reduced pH by 2% and TA by 17% compared to PFS-NO (Table 2).

Table 2. Pre-bloom and post-fruit set leaf removal effects on average juice soluble solids (SS), pH, and titratable acidity (TA).

Treatment[a]	SS (°Brix)	pH	TA (g/L)
PB-NO	21.8 a	3.36	7.96 a
PB-4	21.8 a	3.37	7.39 b
PB-8	21.1 b	3.36	7.05 b
Significance[b]	0.0010	ns	<0.0001
PFS-NO	21.3	3.50 a	7.41 a
PFS-6	21.2	3.43 b	6.16 b
Significance[b]	ns	0.0003	<0.0001

[a]PB-NO, 4, and 8 = pre-bloom removal of no, four, and eight leaves, respectively – over 2013-2015; PFS-NO and PFS-6 = post-fruit set removal of no and six leaves, respectively – over 2014-2015.
[b]Values in same column not sharing a letter are different at 0.05 level using Tukey's HSD (P-B) or Student's T-test (PFS).

Project 1 (data not shown): Leaf removal treatment had no impact on total grape anthocyanins in either variety. In 2014, total grape phenolics were increased by HIGH by 12% compared to MED, and by P-B by an average of 20% compared to NO and MED in Cabernet franc. In Petit Verdot, P-B increased total grape phenolics by 18-28% compared to all other treatments in 2013 and 2014. ***Project 2***: PB-4 and PB-8 increased total grape phenolics by an average of 14% and total grape anthocyanins by an average of 10% when compared to PB-NO (Table 3). PFS-6 increased total grape phenolics by 14% when compared to PFS-NO.

Table 3. Pre-bloom and post-fruit set leaf removal effects on average total grape phenolics and anthocyanins.

Treatment[a]	Phenolics (mg / g berry)	Anthocyanins (au / g berry)
PB-NO	75.9 b	0.96 b
PB-4	85.4 a	1.07 a
PB-8	88.3 a	1.05 a
Significance[b]	<0.0001	0.0025
PFS-NO	53.5 b	0.66
PFS-6	61.1 a	0.71
Significance[b]	0.0059	ns

[a]PB-NO, 4, and 8 = pre-bloom removal of no, four, and eight leaves, respectively – over 2013-2015; PFS-NO and PFS-6 = post-fruit set removal of no and six leaves, respectively – over 2014-2015.
[b]Values in same column not sharing a letter are different at 0.05 level using Tukey's HSD (P-B) or Student's T-test (PFS).

Discussion: Removing leaves before bloom consistently reduced crop yield whereas removing leaves after fruit set did not. Cluster weight was the primary yield component reduced by pre-bloom leaf removal (likely due to reduced fruit set), and it was differentially reduced by leaf removal extent and between varieties. For example, pre-bloom leaf removal of eight leaves reduced berry number per cluster and cluster weight to a greater extent than pre-bloom removal of four leaves. Berry number per cluster was reduced to a greater extent in Cabernet franc, and berry weight and cluster number per vine were reduced to a greater extent in Petit Verdot. We suggest that these differences were due to the direct relationship between leaf area and fruit set. Aggressive leaf removal tended to reduce soluble solids and TA, but not always. Reduction in leaf area was likely responsible for reduction in soluble solids, and the sparser canopy in Cabernet franc likely resulted in greater incidence of temperature-driven malic acid respiration compared to in Petit Verdot. Aggressive leaf removal before bloom increased total grape phenolics more consistently than anthocyanins across all varieties. This appeared to be partially, but not exclusively, due to the concentrating effect of smaller berries with this treatment. While leaf removal never increased total grape anthocyanins in Petit Verdot or Cabernet franc, anthocyanins were consistently increased in Cabernet Sauvignon, suggestive that temperature/radiation-induced increases in grape anthocyanins is variety-dependent. Bunch rot incidence was reduced to a greater extent in pre-bloom compared to post-fruit set leaf removal plots, perhaps due to looser clusters, better early-season fruit-zone spray coverage, or both. Fungal disease management and total grape phenolics and anthocyanins can be improved with aggressive leaf removal in humid regions. While reduced TA can result in less tart red wine, reduced soluble solids is an unwelcome response in a region that often experiences adverse ripening period weather. The labor and crop yield debts incurred with pre-bloom leaf removal may not be offset or even recovered by an increased bottle price. Furthermore, repeated (over years) pre-bloom leaf removal has the potential to reduce vine capacity, making the recovery from this practice even longer. Thus, the potential benefits need to be weighed against these potential and real negatives.

The project is essentially on track with proposed efforts. Mr. Hickey will complete his dissertation in spring 2016 and has recently accepted a post-doctoral position with Cornell University and the grape research team headed by Dr. Terry Bates.

We will provide a comprehensive project report in July 2016 to include data on the carotenoid quantification as a function of leaf pulling.