Final report (July 2012)

Virginia Wine Board

Optimized grape potential through root system and soil moisture manipulations

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Objective: Evaluate in a factorial fashion the impact of complete ground cover vs. under-trellis weed control, three rootstocks, and three root manipulation techniques as means of regulating the vegetative/reproductive balance of Cabernet Sauvignon.

Background:
The goal of this research is to explore practical means of favorably regulating vegetative development of vigorous grapevines to create more optimal canopy architecture, fruit ripening conditions, and ultimately improve wine quality potential. The research is based on the premise that highest wine quality potential is achieved when plant available water (PAW) is adequate, but not excessive, vegetative development ceases at or before veraison, berry size is relatively small, and canopy architecture affords adequate, but not excessive, fruit exposure. These conditions, referred to as “balance”, are difficult to achieve in Virginia due to the often surplus soil moisture conditions that are characteristic of Virginia’s humid (as opposed to arid) environment. Our research tests very practical approaches that growers might use to regulate vine growth.

Details: The experimental vineyard was established in 2006. The experimental design is a strip-split-split field plot that consists of 3 treatment levels. The main plot is an under-trellis cover-crop of creeping red fescue (CC) that is compared with conventional herbicide strips under the trellis. Within this main plot is a sub-plot comparing three different rootstocks: 101-14, 420-A, and riparia Gloire. Within each of the rootstock sub-plots are sub-sub plots that compare root-restriction with no root manipulation. Root restriction was achieved at vineyard establishment by planting the vines in durable, water-permeable transplant bags used in the nursery industry. The bags confine the roots to a small volume of soil. The treatments are replicated six times in a randomized, complete block design which allows statistical analysis of data. The 2011 season represented the 6th growing season in which data were collected. We feel that the original objective (stated above) will be satisfactorily met by the end of the 2012 season. A principal reason for continuing this project for one more year (2012) is that harvest was less than optimal during 2011. We also have wines made from this project starting with the 2008 vintage, and sensory analyses of those wines will continue into 2013 and possibly beyond. Aside from the principal investigator (Wolf), the project has been conducted by graduate students Tremain Hatch (now research/extension associate at the Winchester AREC) and Cain Hickey. The accompanying project report illustrates that we have made progress on showing how cover crops, rootstocks and root restriction can be used as tools to modify vine pruning weights, canopy density, and the duration of shoot growth. Certain qualitative aspects of fruit chemistry and wines have also been affected.

Summary of progress to date:

- Root restriction and under-trellis cover crop (UTCC) were independently effective in suppressing vegetative development of vines as measured by rate and seasonal duration of shoot growth, lateral shoot development, trunk circumference, and dormant pruning weights; and, their effects on growth were additive. [*Interpretation: If no other positive benefits accrued from use of these treatments, they would be effective in reducing the amount of labor required to hedge shoots, break out lateral shoots, and shoot-position large shoots* to achieve desirable canopy architecture]
- Riparia Gloire rootstock was the most effective rootstock in limiting vegetative development amongst the three evaluated; vines grafted to riparia Gloire had approximately 25% lower cane pruning weights than did vines grafted to 420-A or 101-14 [*Interpretation: These results are consistent with our knowledge of the relative vigor-conferring abilities of these three rootstocks. Rootstocks were not as effective, however, as UTCC or root-restriction in suppressing vegetative development with these vigorous vines. Furthermore, the rootstock effect was most dramatic in the first several years of the experiment, and less so in the last 2 years of data collection*]
- Canopy architecture was generally improved by both UTCC and by root restriction, but generally unaffected by rootstock [*Interpretation: both UTCC and root restriction provided a sustained improvement in canopy architecture in an environment where annual, remedial hedging and leaf-pulling are often required to achieve the same degree of fruit exposure. We hypothesize that our treatment approach may be more cost-effective if considered over the multi-year life of the vineyard*]
- Root restriction led to a greater discrimination against ^{13}C in both berries and leaf laminae tissue as measured by $\delta^{13}C$, while under-trellis floor management did not affect this parameter [*Interpretation: $\delta^{13}C$ is a measure of the long-term (months) track record of carbon isotope deposition in plant biomass. The discrimination against ^{13}C (as opposed to ^{12}C) is reduced when vines are water stressed. Thus, $\delta^{13}C$ is a convenient and relatively inexpensive way of gauging the long-term, relative water stress caused by our treatments. While other factors might have affected scion performance (e.g., root-to-shoot hormone signaling), the principal effect of root-restriction was a reduction in plant available water. This was the desired effect*].
- The principal direct effect of the UTCC and the root-restriction treatments was a sustained reduction in stem (xylem) water potential (ψ_{stem}). [*Interpretation: 'Stem water potential' is a fancy term for vine water status – how hydrated or dehydrated the vine is. Under-trellis cover crops are intentionally grown under the vines to compete with the vines for plant available water. Thus, they're doing what we want them to do*]
- Stomatal conductance (g_s) and net assimilation rate (A) were depressed by increasing water deficit (-0.8 MPa or lower), particularly for RR vines, while under-trellis floor management and rootstock had less pronounced effects on leaf gas exchange [*Interpretation: We measure leaf gas exchange to determine how efficiently the vine is photosynthesizing – in other words, producing carbohydrates. Water stress reduces photosynthesis by closing leaf stomates and*

reducing gas exchange. When the water status of the vine drops below about -0.8 MPa (-8.0 bars), gas exchange and photosynthesis are substantially reduced. Over time this leads to lower sugar and energy levels. Monitoring these processes then allows us to gauge the impact of treatments on vine physiological function]

- Wines were made from 4 treatment combinations in 2009 and 6 treatment combinations in 2010. The 2009 wines have been evaluated in triangle difference tests and will be subject to follow-up sensory evaluation at Brock University (Ontario) in August 2012. Differences were *detected* among the treatments, but detailed sensory evaluations are necessary to fully describe the wines – which are better, and why? The 2010 wines were subjected to a consumer preference panel (75 panelists) in May 2012 at the University of Arkansas. While specific differences were found between wines in certain attributes, such as color density, the panelists rated the wines from the different treatments equivocally and relatively highly [*Interpretation: our preliminary analyses of young wines from 2009 showed only subtle differences between treatments. An informal, subsequent analysis conducted with Virginia vintners (B. Zoecklein, 2010 pers. Comm.) revealed more perceptible differences; however, this needs to be repeated in a more formal fashion. The equivocal rating of the 2010 wines reminds us that favorable ripening conditions, such as those of the hot, dry 2010 season, can mask the differences in sensory responses to viticultural treatments that might otherwise be apparent in less than optimal seasons*]
- Plant nitrogen levels were depressed by under-trellis cover crops (UTCC) in all years of the study. Fermentable nitrogen levels were also affected by treatment, especially UTCC. An independent study is now underway to determine how most efficiently to apply nitrogen fertilizer in vineyard systems that use the under-trellis cover crops. *[Interpretation: we know this is one of the "down" sides to using under-trellis cover crops – they limit access to soil moisture by the vines, but they also reduce nitrogen availability to the vine. Our associated research is finding ways to deal with this response*]

The following text is a small portion of the data collected by graduate student Cain Hickey during the 2010 and 2011 growing seasons. <u>Admittedly, it does not provide much interpretation of data – we do that at meetings and in publications intended for public consumption</u>. It does, however, show some of the work that is involved with the research. Irrigation was added as an additional variable during the 2010 and 2011 seasons to obtain two levels of water stress (high and low). These two differential levels of water stress were continued in the post-veraison (post-fruit set) period in order to examine how vine size and water stress impacted grape ripening. The reason we examined irrigation is that some growers have a mistaken view that any irrigation water is detrimental to grape and wine quality. Research evidence, however, supports the view that water stress should be minimized post-veraison to obtain optimal fruit and wine quality.

Lateral shoot growth and shoot activity: Relative to vines with an herbicide strip, intra-row cover cropping significantly reduced the number of lateral leaves at veraison in 2010 and 2011 (Table 1). This is also illustrated by the vine canopies depicted in figure 1.

Figure 1. Vines on left are grown with an under-trellis herbicide strip (conventional); those on right utilize under-trellis cover crops. The canopy of vines on the right is more optimal (more in balance) than those on the left, which have abundant, large lateral shoots that add shade to the fruit zone.

Under-trellis cover crop also significantly reduced percent shoot-tip activity at veraison by 50% relative to Herb in 2010 (Table 1). This means that there were more shoots with actively growing shoot tips present on “herb” treatment vines than on “cc” (cover crop) vines at veraison. Both RBG-LOW and RBG-HIGH factor levels significantly reduced the number of unfolded leaves and percent shoot-tip activity at veraison in both years (Table 1). RBG had the greatest effect on vegetative growth regulation, depressing lateral leaf number by an average of 54% and shoot-tip activity by an average of 80%. Desired lateral leaves is 10 or fewer per shoot.

<u>Abbreviations used:</u> UTGC, under-trellis groundcover: either Herb, under-trellis herbicide strip; or CC, under-trellis cover crop. RM, root manipulation: either NRM, no root manipulation; or RBG, root bag; None: no irrigation; LOW: low water stress; HIGH: high water stress; Stock = rootstock (as named).

Table 1. Factor effect on mean sum of unfolded lateral leaves originating from primary shoot nodes 3-7 and mean percent shoot-tip activity, veraison 2010 and 2011.

	Unfolded leaves (n)		**Shoot-tip activity (%)**	
Factor effects[ab]	**2010**	**2011**	**2010**	**2011**
UTGC				
Herb	12.3 a	16.9 a	24 a	35 a
CC	8.8 b	13.1 b	12 b	31 a
RM				
NRM	14.9 a	24.5 a	39 a	69 a
RBG	8.1 b	10.2 b	8 b	14 b
Irrigation				
LOW	9.1 a	10.5 a	14 a	27 a
HIGH	7.3 b	9.8 a	1 b	2 b
Stock				
420-A	9.7 a	13.4 a	22 a	33 a
riparia	10.2 a	15.6 a	16 a	33 a
101-14	11.6 a	16.0 a	17 a	32 a

Dormant pruning weights: Under-trellis cover crop (CC) and RBG reduced pruning weights in both years and the rootbag root manipulation (RM) resulted in a greater separation of this response relative to UTGC (Table 2). Differential irrigation significantly affected pruning weight only in 2011 and no significant differences existed between Stock factor levels in either year (Table 2). Irrigation (Irr) had a less consistent effect on pruning weights than root manipulation (RM). Root bag (RBG) reduced pruning weights by an average of 65%. Importantly, our desired goal is to have vine size (as measured by dormant pruning weights) in the optimal range of 0.30 to 0.60 kg per meter of row. If you multiple the data in Table 2 by 1.5, that will convert the values from kg/vine to kg per m of row. The treatments that tend to put vine size in the optimal range are high water stress, rootbags, and cover crop, with rootbags being most effective.

Table 2. Factor effect on mean cane pruning weight, 2010 and 2011.

	Pruning weight (kg/vine)	
Factor effects[a]	**2010**	**2011**
UTGC		
Herb	0.93 a	0.89 a
CC	0.61 b	0.65 b
RM		
NRM	1.27 a	1.42 a
RBG	0.51 b	0.44 b
Irr (water stress)		
LOW	0.54 a	0.49 a
HIGH	0.48 a	0.39 b
Stock		
420-A	0.89 a	0.72 a
riparia	0.86 a	0.73 a
101-14	0.96 a	0.85 a

[a] Separation of means using Student's T-test for UTGC, RM and Irr and Tukey's HSD for all others ($\alpha = 0.05$). Means within a particular factor effect that are followed by different letters are significantly different.

Components of Yield: Under-trellis cover crop (CC) significantly reduced yield (18%) in 2011, cluster weight in 2010 and 2011 (21% and 17%, respectively), and berry weight in 2010 and 2011 (9% and 4%, respectively) (Table 3). Rootstock (Stock) had inconsistent effects on components of yield. Root bag (RBG) significantly reduced yield and reduced average cluster and berry weight by 32% and 18%, respectively. High water stress (HIGH) significantly reduced cluster and berry weight in 2010 only; likely a function of the deluge muting irrigation treatment effects in 2011. Red wine quality potential is generally enhanced by obtaining smaller berry size. Treatments that consistently caused a smaller berry size included under-trellis cover crops and root restriction with rootbags. Reduced water (HIGH stress irrigation level) generally reduced berry size as well. For the range of treatments imposed, we could alter berry size from 25 to 30%.

The "projected yield" column of Table 3 represents what the actual crop yield of vines might have been had we not lost fruit to fruit rots (yes, we too had a challenge with the near-constant rains of September and October 2011!)

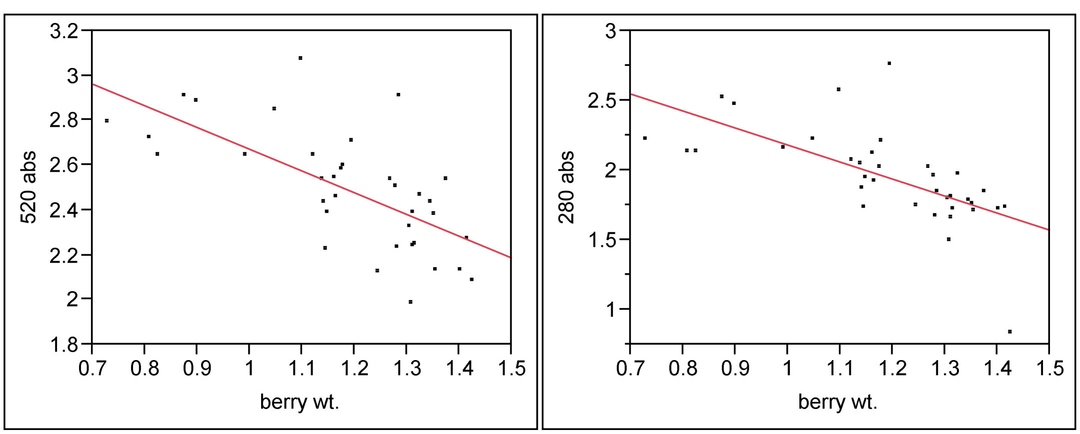
Treatments that decreased berry weight also resulted in increased juice color density and increased estimated total phenolics (figure 1). The increased color and total phenolics were likely an indirect effect of increased cluster exposure to sunlight, particularly with low capacity vines (data not shown).

Table 3. Factor effect on yield per vine and average cluster and berry weight, 2010 and 2011.

	Yield (kg/vine)		Projected yield (kg/vine)	Cluster weight (g)		Berry weight (g)	
Factor effects[a]	**2010**	**2011**	**2011**	**2010**	**2011**	**2010**	**2011**
UTGC							
Herb	3.36 a	3.30 a	3.69 a	139 a	164 a	1.20 a	1.31 a
CC	2.76 b	3.52 a	3.49 a	110 b	136 b	1.09 b	1.26 b
RM							
NRM	3.60 a	5.09 a	5.21 a	141 a	207 a	1.27 a	1.47 a
RBG	2.80 b	2.58 b	2.80 b	116 b	122 b	1.08 b	1.19 b
Irr							
LOW	3.16 a	2.85 a	3.03 a	137 a	126 a	1.17 a	1.21 a
HIGH	2.43 b	2.34 b	2.58 a	96 b	119 a	0.98 b	1.18 a
Stock							
420-A	3.04 a	3.45 a	3.62 a	123 ab	150 a	1.12 b	1.27 a
riparia	3.22 a	3.49 a	3.71 a	133 a	159 a	1.20 a	1.33 a
101-14	2.92 a	3.27 a	3.43 a	118 b	145 a	1.12 b	1.26 a

[a] Separation of means using Student's T-test for UTGC, RM and Irr and Tukey's HSD for all others (α = 0.05).
[b] Significance of factor effects and interactions using standard least squares with REML and an emphasis on effect leverage; one-way ANOVA used for RM and Irr factors (p > F; ns = not significant).
c Mean projected yield was calculated by taking average "sound cluster" (clusters with minimal to no rot) weight and multiplying this number by the total number of clusters on the vine at harvest; only in 2011.
d Mean cluster weight was calculated using only sound clusters.

Figure 1. Relationship between 2011 berry weight and color density as measured at 520 nm (left) and estimated total phenolics, as measured by juice absorption at 280 nm (right).



Fruit Composition: In general, soluble solids (°Brix) was increased in treatment that had low water stress (NRM, LOW) in the dry vintage (2010) but didn't have as consistent effect in the wetter vintage (2011) (Table 4). Total titratable acidity (TA) and pH appeared to be consistently decreased and increased, respectively, by treatment levels that resulted in small vines of higher water stress (i.e. RBG and HIGH).

Table 4. Factor effects on soluble solids (˚Brix), pH, and total acidity (TA), 2010 - 2011.

	Soluble solids (˚Brix)		**pH**		**Total Acidity (g/L)**	
Factor effects[a]	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
UTGC						
Herb	24.6 b	21.0 a	3.41 a	3.38 a	5.54 a	5.3 a
CC	25.0 a	20.9 a	3.43 a	3.41 a	5.25 a	5.4 a
RM						
NRM	25.5 a	21.3 a	3.44 a	3.44 a	5.43 a	5.80 a
RBG	24.5 b	20.8 a	3.41 a	3.37 b	5.36 a	5.13 b
Irr						
LOW	25.2 a	20.2 b	3.38 b	3.32 b	5.61 a	5.77 a
HIGH	23.8 b	21.5 a	3.44 a	3.43 a	5.12 b	4.49 b
Stock						
420-A	24.6 a	21.5 a	3.38 b	3.36 b	5.76 a	5.25 a
riparia	25.1 a	20.7 b	3.44 a	3.39 ab	5.03 b	5.70 a
101-14	24.7 a	20.7 b	3.44 a	3.43 a	5.38 ab	5.11 a

Triangle difference test: Wine lots consisted of fruit from treatment combinations that best displayed a range of both vine size as well as water stress. Wines were made from both the 2010 and 2011 fruit and the 2010 wines have been subjected to a preliminary, triangle difference test. The most consistently and significantly distinguished sensory attribute was color, which was significantly distinguished in seven of the eight sessions, followed by flavor (six of the eight) and then aroma (three of the eight) (Table 6). The 2010 wines, as well as those made in 2011, will need to be subjected to additional sensory evaluations to fully explain the impact of viticultural treatments on wine quality. We wish to use bottle-aged wines for these evaluations, therefore there is a one- to two-year lag-time from harvest to testing.

Wines were made from 4 treatment combinations in 2009 and 6 treatment combinations in 2010. The 2009 wines have been evaluated in triangle difference tests and will be subject to follow-up sensory evaluation at Brock University (Ontario) in August 2012. Differences were *detected* among the treatments, but detailed sensory evaluations are necessary to fully describe the wines – which are better, and why? The 2010 wines were subjected to a consumer preference panel (75 panelists) in May 2012 at the University of Arkansas. While specific differences were found between wines in certain attributes, such as color density, the panelists rated the wines from the different treatments equivocally and relatively highly (data not shown).

Outcomes and Benefits Expected:

The primary purpose of this research is to evaluate means by which wine growers can regulate the vegetative growth of "vigorous", unbalanced grapevines in our humid environment. We have demonstrated several means by which this can be achieved, including the more aggressive use of under-trellis cover crops (Why are you consistently herbiciding under-trellis vegetation?), and rootstock selection. Root-bags are more radical, but may also have practical application. The immediate benefit is reduced labor in canopy management. A more subtle effect of regulated vine size would be improved fruit composition (increased color density) and perhaps improved aroma/flavor profiles. In this latter respect, our results to date do suggest that treatments impact color and phenolic composition. However, the consumer preference assessment of 2010 wines revealed that all wines were rated similarly (average scores of around 7, out of 9 possible). This likely illustrates that good vintages (e.g., 2010) may very well mask treatment effects that might be apparent in less optimal years.

The treatments at the Winchester AREC provided an excellent backdrop to a canopy management workshop which was conducted on 14 June 2012. The workshop was attended by 145 producers and involved both classroom and field exercises. Post meeting evaluations were completed by 68 attendees, representing 466 acres of Virginia vineyards. Ninety percent of attendees “strongly agreed” that the workshop improved their understanding of vine balance and the factors that affect vine balance. Seventy-eight percent of attendees “strongly agreed” that the workshop provided at least one idea to try in their vineyards to reduce the amount of “remedial canopy management” required. The workshop was a direct outgrowth of the research that has been conducted since 2006 with this project.

Objectives of this work also aim to develop a set of recommendations for accurately assessing vine nitrogen status and providing guidance on the optimal means of augmenting the vine’s nitrogen needs in low N environments. While we have historically relied upon bloom-time sampling of leaf petioles to determine N status, there is increased interest in including must analysis of YAN as a diagnostic criterion. Our experiments will allow a direct comparison of must and foliar N levels, addressing both viticultural needs of crop yield and vine size, but also recognizing the importance of N to fermentation and flavor and aroma chemistry.

Table 6. Triangle difference test results for three different sensory characteristics, 2010 vintage.

Treatment Comparison	Date	Panelist #	Sig. Diff.*	Aroma	Color	Flavor
RBG-LOW + CC -- RBG-HIGH + Herb	5-Apr	26	Water stress	ns	ns	ns
RBG-LOW + CC -- RBG-HIGH + CC	6-Apr	32	Both	ns	0.0030*	ns
RBG-LOW + CC -- NRM-None + Herb	8-Apr	28	Capacity	ns	<0.0001*	<0.0001*
RBG-LOW + Herb -- RBG-HIGH + CC	12-Apr	38	Both	0.0021*	<0.0001*	0.0146*
RBG-LOW + Herb -- RBG-HIGH + Herb	13-Apr	39	Water stres	ns	0.0087*	0.0207*
RBG-LOW + Herb -- NRM-None + CC	15-Apr	39	ns	ns	<0.0001*	0.0033*
RBG-HIGH + CC -- NRM-None + Herb	19-Apr	38	Both	0.0007*	<0.0001*	<0.0001*
RBG-HIGH + Herb -- NRM-None + CC	20-Apr	40	Both	0.0018*	<0.0001*	0.0018*

*Significant differences in either vine capacity, water status, or both between treatment level comparisons.