FINAL REPORT TO:

Pennsylvania Wine Marketing and Research Board

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Title: Evaluating the impact of under-trellis groundcover practices on winegrape production profitability and sustainability

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Overall Goal and Objectives

The primary goal of this multi-year project is to implement weed control practices in vineyards that reduce herbicide use while increasing the profitability of growing premium quality grapes in Pennsylvania (PA). With that goal in mind, the **objectives** of this proposed study are to:

1. Assess the effects of annual and perennial cover crops planted directly under the trellis (under vine cover crop) on vine vegetative growth, productivity, fruit quality, disease incidence, winter hardiness, and weed suppression.

2. Learn from grape growers in the Commonwealth what challenges they face in managing weeds and excessive vine vigor and what barriers prevent them for adopting alternative under-trellis management practices. This information can then direct researchers with developing future research and extension efforts.

3. Determine consumer awareness and interest in buying and consuming wines produced with both herbicides and under-trellis cover crops. Identify consumer segments that are willing to pay a price premium for PA wines produced from grapes grown using under-trellis cover crops.

4. Advise industry members on marketing strategies they can use to inform consumers about the potential benefits of planting under-trellis cover crops and why these wines command a higher retail price, based on consumer survey outcomes.

Data collected and major results:

Three well-replicated field trials were conducted in 2018 thanks to funds provided by the WMRB:

a) Marquette: For this trial we used Marquette own-rooted vines planted in 2015 at the Penn State Agricultural Research Center (Rock Springs, PA). Marquette vines tend to be highly vigorous; we evaluated the use of three cover crop species for vigor reduction and additional benefits. The three cover crops were compared to an under-trellis 85-cm-wide strip treated with repeated glyphosate herbicide applications. Two perennial cover crop mixes were planted under the vines in Spring 2017: 1) perennial cover crop mix "Clean and Green" (80% tall fescue; 20% annual ryegrass; seeding rate 70 lb/acre); 2) perennial cover crop mix "Companion" (80% perennial ryegrass; 20% creeping red fescue; seeding rate 50 lb/acre). The third cover crop was a summer annual cover crop: 3) brown top millet, planted annually (seeding date and rate: 6/25/2018 at 30 lb/acre). Criteria for cover crop selection included: low maintenance, rapid establishment, slow growth, and shade and drought tolerance.

b) Noiret: For this trial we used Noiret vines growing with either under-trellis creeping red fescue (*Festuca rubra*) or bare soil and two rootstocks with different vigor potential (Riparia versus 101-14Mgt). Noiret vines were planted in at the Penn State Agricultural Research Center in 2015 (Rock Springs, PA) and the red fescue was seeded under the vine in fall 2017. The use of two different rootstocks allowed us to assess how vigorous vines respond to competition with a perennial cover crop (*Festuca rubra*) when grafted to a low vigor (Riparia Gloire) or medium vigor (101-14Mgt) rootstock (**Figure 1**).

c) Merlot: A new trial was established in 2018 at a grower cooperator site (*Waltz Vineyards Estate Winery*) in two distinct vineyard blocks. Both blocks are planted with Merlot, but vines are grafted on two different rootstocks, 3309C and Mgt 101-14. PI Centinari met with the grower cooperator in spring 2018 to identify cover crop species to plant based on the grower's goals and needs (e.g., reducing vine vigor, suppressing weeds). Three cover crop species (chicory, cowboy annual ryegrass, and brown top millet) were planted at both vineyard blocks on June 7, 2018 and compared to the grower's standard under-trellis management practice (e.g., vegetation free strip maintained by soil cultivation; Figure 2). It was not possible to continue the study in 2019 because the vines sustained extensive winter damage, but we have discussed with the grower cooperator possibility to expand the trial and plant perennial cover crops in 2020.

The following data were collected at each site:

Cover crop performance: To assess under-trellis cover crop performance, stand density – the percentage of grass-covered soil – was visually assessed on aimlessly distributed 0.33 m2 quadrats two times during the season. At the Marquette site both perennial mixes planted in 2017 covered almost 100% of the ground by the end of July 2018 (**Table 1**); however, the annual summer cover crop did not perform as well and only covered about 39% of the ground, while 8% was covered by weeds and the other 43% was 'bare ground'. At Noiret site (site b) the red fescue covered 100% of the soil (**Figure1B**). At the third site (site c) the only cover crop that

established well was chicory (**Figure 2; Table 2**). The ryegrass and millet plots were primarily covered by weeds (crabgrass). Most of the ryegrass was choked out by the crabgrass and died (**Figure 3**). The millet survived but most of the ground was covered by weeds (see Table 2). Persistent wet weather and lateness in seeding were contributing factors to the poor cover crop establishment (note: The lateness in seeding was due a delay in funding and weather conditions).

Vine vegetative growth, production, and fruit chemistry: At sites a and c, neither perennial mixes nor annual cover crop affected vine size, yield, or fruit chemistry. Marquette vines tend to be very vigorous and our goal was to reduce vine growth by planting perennial grasses directly under the trellis when the vines were young (third year of vineyard establishment). However, vines growing with the two perennial mixes had similar pruning weight of the control vines (**Table 3**). On a positive note, cover crop did not reduce yield and cluster weight or had negative effects on fruit chemistry (**Table 3 and 4**). We conducted plant tissue nutrient analysis at veraison to assess if cover crop competition would affect vine nutrient status. There was no indication of nutrient competition induced by cover crops, which was not surprising since the vines did not have lower pruning weight as compared to the control (nitrogen concentration is reported at Table 3).

At site c, cover crops planted under mature Merlot vines grafted either on 3309 or 101-14 did not affect pruning weight, yield parameters (**Table 5**; note: yield is overall low because of winter and herbicide drift injuries) or fruit chemistry (**Table 6).** However, it might take a few years for cover crops to reduce vegetative growth when planted under mature vines with an already established root system. Cover crops did not reduce nutrient concentrations in the leaf petioles except for the Merlot vines grafted on 3309 growing with the chicory (**Table 7**). Vines growing with chicory had lower nitrogen concentration in the leaf petiole compered to control vines. At the Noiret site, control vines grafted on 101-14 rootstock (medium vigor) had the highest shoot growth rate and pruning weight (**Figure 4 and Table 8**).

Bud freeze tolerance analysis: This analysis was done to determine if groundcover treatments indirectly impact - through modification of vine vigor - vine ability to survive cold winters. Differential thermal analysis (DTA) was used to estimate bud freeze tolerance at each site at least once during the dormant season following treatments application. DTA detects the low-temperature exotherm (LT) released when the intracellular water freezes inside the bud causing its death. The relationship between LT and bud injury in grapevines has been confirmed by several studies. At each site, four canes were collected from every experimental unit, for a total of 24 canes/treatment. Four buds per cane were excised from nodes two through five with ~2 mm of intact surrounding tissue and placed on a thermoelectric module (Melcor Corporation). Six trays, each containing nine cell modules, were placed in a programmable temperature-controlled freezer (Tenney, Thermal Products Solutions). The temperature was lowered from 4°C (39.2 °F) to -40°C (°-39.2 °F) at a rate of 4°C/ hr, held at -40°C for 1 hr, and then increased to 4°C at the rate of 4°C/hr. Lethal bud temperature was calculated and expressed as median low temperature exotherm (LT_{50}), or the temperature at which 50% of primary buds died.

There were no differences in mid-winter bud freeze tolerance between control vines (vines growing on bare soil) and vine growing with under-trellis cover crop at site a, where we used a cold-hardy variety (Marquette) or a site c were we used a cold-tender variety (Merlot; **Table 9).** At site c we collected data only for Merlot vines grafted on 101-14, because those grafted on Riparia were already pruned when we arrived at the site. At site b (Noiret) the vines growing

with under- trellis cover crop were more freeze tolerant than those growing without under- trellis cover crop (**Table 10**). Although statistically significant, these differences were small and likely not biologically relevant. Interestingly vines grown on Riparia had higher bud freeze tolerance than those grown on 101-14. Again, these differences were small and likely not biologically relevant.

Short summary:
Site a –Overall the perennial mixes were effective in suppressing weeds (no herbicide was applied since grasses were planted in 2017) without negative effects on Marquette yield or fruit chemistry. However, none of the three cover crops species used was able to regulate vine grow during an extremely wet year (2018)
Site b – At the Noiret site, red fescue competition reduced shoot growth rate and pruning weight, but effects were more significant when vines were grafted on 101-14 as compared to Riparia. Reduction in vegetative growth was caused by nutrient competition, mainly nitrogen. However, nitrogen competition did not affect YAN concentration in the juice at harvest (**Table 8**).
Site c –Chicory was the only cover crop that established well at the Merlot site. The grower noticed that vines growing with chicory had less lateral shoot growth and fewer suckers developed from the trunk, but there was no difference in pruning weight between vines goring with or without under-trellis cover crops.


Figure 1. Left: Noiret vines growing with either under-trellis red fescue or bare soil. Picture taken on July 8, 2019. Right: Closer view of the red fescue.

Figure 2. Chicory planted under Merlot vines. Picture was taken at harvest.

Figure 3. This photo shows poor annual ryegrass performance. The ryegrass died (see red circle), chocked out by the crabgrass

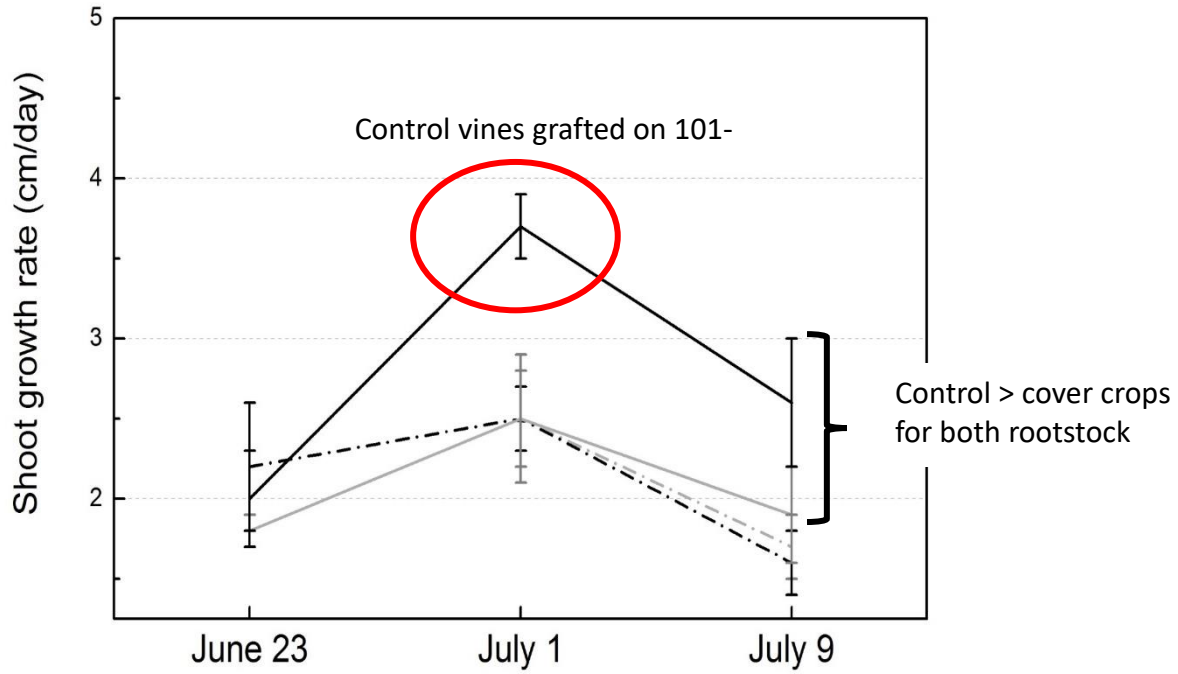

Figure 4. Shoot growth rate (cm/day) of Noiret vines grafted on 1010-14 (clack line) and Riparia (gray line) with under-trellis fescue (dashed line) or bare soil (solid line).

Table 1. Percentage of ground covered by cover crop, weed, and bare ground on August 1, 2018. Same measurements were conducted on July 20 (data not shown)

Treatment	% cover crop	% weed cover	% bare ground
Control	0.0 c	11.3 ab	88.7 a
Clean and Green	98.7 a	1.3 b	0.0 c
Companion	94.7 a	5.3 b	0.0 c
Brown Top Millet	39.3 b	18.0 a	42.7 b
P-value	< 0.001	< 0.001	< 0.001

Table 2. Percentage of ground covered by cover crop, weed, and bare ground on September 7, 2018. Same measurements were conducted on August 8 (data not shown).

Treatment	% cover crop	% weed cover	% bare ground
Merlot/3309			
Control	0.0 b	66.0 ab	37.3 a
Chicory	56.0 a	42.0 b	2.0 b
Brown Top Millet	18.0 a	73.3 a	7.0 b
Annual ryegrass	10.3 a	83.0 a	6.7 b
P-value	< 0.001	< 0.001	< 0.001
	Merlot/101-14		
Control	0.0 c	71.0 b	29.0 a
Chicory	80.0 a	19.7 c	0.3 b
Brown Top Millet	42.0 b	56.3 b	1.7 b
Annual ryegrass	3.3 c	91.7 a	5.0 b
P-value	< 0.001	< 0.001	< 0.001

Table 3. Production parameters for Marquette vines growing with under-trellis cover crops or on bare soil (control). Vines were harvested on September 13, 2018.

Treatment	Yield (tons/acre)	Cluster wt (gram)	Clusters /vine	Pruning weight (kg/vine)	N (%)
Control	5.53	101.8	82	1.40	1.04 ab
Clean and Green	5.89	115.5	76	1.43	1.08 a
Companion	6.04	100.9	89	1.35	0.96 b
Brown Top Millet	5.90	101.8	87	1.93	1.08 a
P-Value	0.958	0.577	0.434	0.326	0.017

Table 4. Fruit chemical composition and average berry weight for the Marquette vines growing with under-trellis cover crops or on bare soil (control). Vines were harvested on September 13, 2018.

Treatment	TSS (ºBrix)	pH	TA (g/L)	Average berry weight (g)
Control	22.4 ab	3.50	9.03	1.22
Clean and Green	21.7 b	3.51	9.44	1.23
Companion	22.2 ab	3.48	9.20	1.25
Brown Top Millet	22.9 a	3.58	9.22	1.14
P-Value	0.038	0.011	0.929	0.166

Table 5. Fruit chemical composition and average berry weight for Merlot vines grown with under-trellis cover crops and on bare soil (control). Vines were harvested on October 1, 2018.

Treatment	Yield (tons/acre)	Cluster wt (grams)	Clusters /vine	Pruning weight (kg/vine)	Crop load (kg fruit/kg prun wt.)
		Merlot/3309			
Control	1.47	81.5	15	0.76	1.67
Chicory	1.31	73.5	15	0.70	1.60
Brown Top Millet	1.67	86.0	16	0.72	1.93
Annual ryegrass	1.54	75.0	16	0.75	1.70
P-value	0.407	0.284	0.483	0.735	0.558
		Merlot/101-14			
Control	0.41 b	39.0 b	8.7	0.94	0.37
Chicory	0.64 ab	50.3 ab	10.0	0.79	0.72
Brown Top Millet	0.68 ab	54.5 ab	10.4	0.98	0.55
Annual ryegrass	0.81 a	59.0 a	11.1	0.83	0.88
P-value	0.060	0.007	0.378	0.077	0.110

Table 6. Production parameters for Merlot vines grown with under-trellis cover crops and on bare soil (control). Vines were harvested on October 1, 2018.

Treatment	TSS (ºBrix)	pH	TA (g/L)	Average berry weight (g)
		Merlot/3309		
Control	17.1	3.58	6.27	1.48
Chicory	17.5	3.58	6.38	1.47
Brown Top Millet	16.8	3.61	6.00	1.48
Annual ryegrass	17.1	3.52	6.62	1.52
P-value	0.705	0.050	0.146	0.868
		Merlot/101-14		
Control	16.7	3.49	6.32	1.41
Chicory	16.5	3.46	6.71	1.42
Brown Top Millet	16.4	3.48	6.40	1.44
Annual ryegrass	16.9	3.47	6.55	1.47
P-value	0.266	0.643	0.435	0.492

Table 7. Leaf petiole macronutrient concentration at veraison for the Merlot vines grown with under-trellis bare soil and cover crops.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
		Merlot/3309			
Control	0.78	0.34	2.47	1.41	0.61
Chicory	0.69	0.31	2.20	1.40	0.65
Brown Top Millet	0.70	0.29	2.23	1.38	0.59
Annual ryegrass	0.75	0.37	2.60	1.38	0.55
P-value	0.036	0.051	0.084	0.839	0.418
		Merlot/101-14			
Control	0.80	0.41	2.53	1.27	0.55
Chicory	0.75	0.40	2.56	1.27	0.62
Brown Top Millet	0.74	0.42	2.86	1.21	0.55
Annual ryegrass	0.75	0.43	2.54	1.32	0.62
P-value	0.736	0.510	0.541	0.395	0.418

Table 8. Production parameters, pruning weight, leaf petiole nitrogen (N) concentration and yeast assimilable nitrogen (YAN) for Noiret vines grafted on 101-14 and Riparia and grown with under-trellis cover crops and on bare soil (control).

Treatment	Yield (kg/vine)	Cluster wt (grams)	Pruning wt (kg/vine)	Cane wt (grams)	N (%)	YAN (mg/l)
Control/101-14	6.45	153	2.61	103.3	0.98	169.1
Red fescue/101-14	6.22	153	1.76	70.6	0.89	164.6
Control /Riparia	8.38	158	1.87	67.0	0.98	177.7
Red fescue/ Riparia	7.47	165	1.34	52.9	0.88	169.2
P-value (	0.092	0.910	0.003	0.006	0.010	0.103

Table 9. Effect of under-trellis cover crops on bud freeze tolerance of Merlot vines grafted on 101-14 in January 2019. Bud freeze tolerance is expressed as low-temperature exotherm (LT50) required to kill 50% of the buds.

Treatment	(LT_{50}, °F)
Control	-6.20
Chicory	-6.20
Brown Top Millet	-6.90
Annual ryegrass	-6.72
P-value	0.878

Table 10. Effect of under-trellis cover crops on bud freeze tolerance of Noiret vines grafted on 101-14 and Riparia and grown with under-trellis cover crops and on bare soil (control) in February 2019. Bud freeze tolerance is expressed as low-temperature exotherm (LT50) required to kill 50% of the buds.

Treatment	(LT_{50}, °F)
Control	-7.71
Red fescue	-8.27
P-value	0.077
Noiret/101-14	-7.51
Noiret/Riparia	-8.46
P-value	0.008

Objective 2 – Grower survey

A 15-minute survey targeting PA wine grape growers was developed and administrated online (April 8-30, 2019) to quantify who in the Commonwealth currently uses a cover crop, what under-trellis groundcover practices are currently used in the Commonwealth, and learn who might be interested in planting under-trellis cover crops. In total, 49 PA grape growers participated in the cover crop survey. Key outcomes from the study include:

Items that were of concern to participants regarding their vineyard management practices:

- Reaching consistent grape quality at harvest (n= 41).
- Managing weeds underneath vines (n= 38).
- Vine vigor/excessive vegetative growth (n = 34).
- Soil health, erosion and/or water runoff (n = 31).
- Herbicides are applied properly (n = 27).
- Finding enough employees for pruning, harvest, canopy management, pesticide application, etc. (n = 27).
- Obtaining the price that will cover the expenses related to production practices used (n = 26).
- Finding skilled labor to properly prune vines, etc. (n = 23).
- Consumers concerned about pesticide use at my vineyard (n = 19).
- Consumers concerned about how I control disease and pests at my vineyard (n = 17).

Only two of the participants responded that they used under-trellis cover crops. Both participants allow weeds/natural vegetation to grow. While one uses grasses as a cover crop, the other also uses herbicides to control weeds, tills/cultivates the ground, and uses grasses, legumes, and nonlegumes for cover crops. Of the 47 other participants that do not use cover crops, weed control methods ranged from using herbicides (n=27), a combination of letting weeds/natural vegetation grow and herbicides, many other techniques such as applying fabric weed barrier and flame weeding.

A few of the participants provided comments:

- "I have used natural vegetation, but will be using herbicide this season."
- "We have tried letting natural vegetation grow under vines in the past and have found it to be way too much work to control."
- "Wet years we allow for a cover to grow on normal to dry years or periods during a growing year that are dry we maintain bare ground under vine."

These 47 survey participants were then asked to indicate their involvement or interest in using cover crops.

- Four were actively making plans to plant cover crops.
- Twenty-eight would be interested in doing so in the future.
- Eleven had no interest.
- Three indicated that would be interested in learning more about cover crops.
- One commented that he/she was working with USDA & NRCS but provided no further details.

These participants also selected factors that would motivate them to change their current practices and plant cover crops. Participants were allowed to select all factors that applied:

- Reduced amount of labor needed to control weeds (n= 34)
- Reduced costs required to managing weeds (n = 32)
- Improved soil quality (n = 31)
- Reduced number of weeds that grow underneath vines (n= 30)
- Improved grape quality (n = 29)
- Reduced vine vigor/excessive vegetative growth (n = 23)
- Reduced soil erosion and/or water runoff (n = 21)
- Improved consumer perception of my vineyard/business (n = 14)
- Increased soil nitrogen if legume cover crops are used (n = 14)
- Additional consumers will become interested in wines made from grapes grown using cover crops (n = 8)
- Increased price for a bottle of wine made from grapes grown using cover crops (n = 6)

Two participants selected "none of the above" and provided written responses instead:

- "Attractive economic incentive paid directly to me."
- "If there [was] positive evidence that cover crops provide better quality grapes for making wine."

Of the potential issues that concerned the 47 participants about using cover crops, of which participants could select all that apply, the top four were:

- The cover crop will not successfully suppress weeds underneath vines (n= 30)
- A greater number of labor hours will be needed to manage weeds after cover crops are established, compared to my current weed control practices (n=25).
- I will not have enough time to establish a cover crop before weeds become an issue (n= 19)
- I will need to purchase additional equipment to plant cover crops and manage weeds after the cover crop is established (n= 17)

Survey outcomes will be used to understand the potential to expand production acreage with cover crops, but also identify perceived and actual barriers that impact growers' willingness to adopt under-trellis groundcover management options alternative to the use of herbicides.

Objective 3 - Consumer focus group:

The goal of the consumer focus group was to evaluate mid-Atlantic wine consumer awareness and interest in wine produced from grapes harvest from vines grown with under-trellis cover crops. Two separate focus group sessions were conducted on March 28 and April 24, 2019, each with six participants who were regular wine drinkers, age 21 and older, participants who had an interest in locally-grown foods, and met other key criteria. The one-hour sessions provided a great deal of insight that helped the researchers develop the draft for the consumer Internet survey.

Key outcomes include:

• Participants were willing to pay a price premium for wine grown using cover crops to help offset the additional labor and mechanical costs that growers might incur.

• Participants, overall, had an awareness of what sustainability was; however, there were concerns that if a cover crop was planted below grape vines that pollen from the cover crop would somehow affect the taste/flavor of the grape (cross-pollination issues with honey were mentioned).

• A majority of participants in each session indicated that they do ask at the winery tasting rooms how the grapes are grown and how the wine is made. A few mentioned that they "can tell" that a wine is produced sustainably by talking with the grower/winery tasting room staff member.

• Several participants responded that they buy as much of the food that they and their families consume from the growers who produced them and/or are labeled locally grown. This did not necessarily translate into wine purchases. Promotion/marketing efforts that inform wine consumers about sustainable wine and the advantages of cover crops in the vineyard would be very helpful.

• A label of some sort of sticker/point-of-sale sign would be greatly appreciated. Also, as a majority of participants purchased wine from PA Wine and Spirit stores (one or two participants purchased wine online), being labeled as a "Chairman's Select" wine would be appealing.

Based on focus group discussions, the PIs developed an online consumer survey, which was implanted in fall 2019. Data will be included in the progress report of the year 2 of the project.

Outreach:

Centinari M. How to utilize under vine cover crops to reach your vineyard production goal. *Ohio Grape and Wine Conference*. Dublin, Ohio, February 18, 2019

Centinari M., Fleishman S., Kelley K. Under-trellis cover crops: Can they mitigate vine vigor and control weeds while maintaining vine productivity? *WMRB Research Symposium* – March 5, 2019

Centinari M., Eissenstat D., Fleishman S., Klodd A., Bauerle T. Untangling belowground response of grapevines to cover crop competition. *21st International GiESCO Meeting Thessaloniki, June 27, 2019*