Report Type: Final

Title: A field evaluation of mycorrhizal inoculants on grapevine growth and nutrient uptake

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Abstract: Because plant-mycorrhizal fungal interactions are known to be context dependent, a better understanding of the conditions in which mycorrhizal fungal inoculations may be beneficial to grapevine growth will help to inform vineyard management strategies aimed at incorporating biological inputs and improving agricultural sustainability. In a field experiment at WSU Tri-Cities (WSUTC), we tested the growth response of Merlot (clone 4) with both self-rooted and grafted rootstock (1103P) to inoculation with arbuscular mycorrhizal fungi (AMF) under different phosphorous (P) fertilizer conditions. Field plots were arranged in a randomized complete block design with the following treatments: AMF inoculation, P fertilizer addition, both AMF inocula and P fertilizer addition, and Control (no P fertilizer or live AMF inocula added). Plants were grown in field plots from August 2020 to September 2021. At the end of the experiment, plants were destructively harvested. The following data were collected on plant growth: plant height and dry biomass, leaf chlorophyll and foliar nutrient content, percentage mycorrhizal colonization of roots, as well as soil nutrients. These measurements were taken to determine the conditions in which mycorrhizal inoculations may benefit wine grape growth or nutrient uptake. We hypothesized that inoculation with mycorrhizal fungi would improve plant growth and leaf nutrient content in both self-rooted and grafted vines. However, due to COVID-related delays in planting in spring/summer 2020, in combination with a harsh winter, the plants experienced high mortality. We only had enough surviving plants of the grafted variety to include in the statistical analysis. Our analysis of the grafted plants showed that the addition of P fertilizer increased the amount of P in both soil and leaves, and that the grafted grapevines grown in plots with both mycorrhizal inocula and P fertilizer had the highest amount of foliar P in leaves at the end of the experiment. We also found that the grafted plants grown in plots inoculated with mycorrhizal fungi had the highest leaf chlorophyll content. Root biomass (g, dry weight) of the grafted plants was highest in the Control plots and lowest in the AMF+P plots. Mycorrhizal colonization of roots of the grafted plants was lower in the P fertilizer plots compared to the unamended Control plots that contained the resident mycorrhizal fungal communities and compared to the AMF+P plots that were amended with mycorrhizal inocula and P fertilizer. However, we detected no treatment effect on final plant height (cm), aboveground biomass (g, dry weight), plant survival, or other leaf nutrients (e.g., N, K, Fe, Zn) in this short-term field study. Taken together, this study shows that young grapevine growth response to P fertilizer and mycorrhizal inoculation can be variable and suggests that growers may benefit from testing the effects of amendments in small areas of the vineyard or in a greenhouse before applying to the whole system. This study provided research and training opportunities for two Master's students and five undergraduate researchers in the School of Biological Sciences and the Viticulture and Enology program at WSUTC.

Project Description: This study addresses BIOAg priorities aimed at developing biologically-intensive management strategies that are renewable, non-polluting, and mutually beneficial to

farmers and society by evaluating the conditions in which mycorrhizal fungal inoculations may be favorable to grapevine growth in Washington. Washington is the second largest producer of wine grapes in the United States, providing a total economic impact of $7 billion. Wine grapes are the 4th largest fruit crop grown in Washington and there are over 59,000 acres of vineyards across the state. Increasingly, Washington grape growers are interested in incorporating biological amendments, such as compost, compost tea, and inoculations with beneficial soil organisms, such as mycorrhizal fungi, into their nutrient management regimes. However, data on the potential benefits of mycorrhizal inoculations to wine grape growth under field conditions in Washington State, with and without P fertilizer additions, are lacking.

Arbuscular mycorrhizal fungi (AMF) form symbiotic relationships with plant roots and benefit plant growth by improving nutrient and water uptake. In a bi-directional exchange, plants provide carbon (C) to mycorrhizal fungi and mycorrhizal fungal hyphae extend the surface area of the root system, increasing plant access to nitrogen, phosphorus (P), and water outside of the root zone. Grapevine growth often benefits from interactions with mycorrhizal fungi and inoculations with AMF have been shown to increase shoot length and P uptake in Pinot noir (*Vitis vinifera*) and other grape varieties. Arbuscular mycorrhizal fungi are also important to soil structure and function, and are known to increase soil aggregation, contribute to nutrient cycling, and enhance soil C storage. However, management practices such as tillage, pesticides, and chemical fertilizer applications can negatively impact resident mycorrhizal fungal communities in soil. Therefore, it may be beneficial to add mycorrhizal fungi back into soil periodically through targeted inoculations in order to achieve maximal benefits of this symbiosis.

While interest in using mycorrhizal inoculants in vineyards is increasing, the benefits of AMF are known to vary among plant genotypes and are also influenced by environmental factors, such as soil nutrients, soil type, and agricultural management practices. To determine the impact of mycorrhizal inoculations on wine grape growth, we grew self-rooted and grafted Merlot vines inoculated with mycorrhizal fungi under different phosphorus fertilizer conditions in a field experiment at WSU Tri-Cities (Richland, WA). This research builds upon a greenhouse study examining the impact of AMF inoculations and P fertilizer additions and was the next logical step in understanding the conditions in which mycorrhizal inoculations may impact grapevine growth in Washington State. A better understanding of the field conditions in which mycorrhizal fungal inoculations may be beneficial to grapevine growth will help to optimize vineyard management plans in Washington aimed at incorporating biological inputs and improving agricultural sustainability.

Outputs

Overview of Work Completed and in Progress: We set up a field experiment on the WSU Tri-Cities campus in summer 2020 to test for effects of mycorrhizal fungal inoculations on grapevine growth and nutrient uptake under different P fertilizer conditions. Because grafting on rootstock is expected to become more common in Washington due to problems associated with phylloxera (a root-borne quarantine pest), we focused on evaluating self-rooted and rootstock-grafted (1103P) *Vitis vinifera* 'Merlot' (clone 4) vines. Plants were grown in field plots (1 x 4 m) with the following treatments: AMF inocula (AMF), P fertilizer (P), AMF inocula and P fertilizer (AMF+P), and Control (no P fertilizer or live AMF inocula added). All field plots contained resident soil microbial communities, including mycorrhizal fungi. Plots were arranged in a

randomized complete block design to account for spatial heterogeneity in the field, with five replicates of each treatment, and 3 m aisles between plots and edges to maintain treatment effects (total of 40 plots). Each plot contained seven grape plants, with 0.5 m spacing between each plant and plot edges, for a total of 280 plants in the experiment. Two weeks before transplanting into the field, vines were rooted in pots with live field soil amended with 30 cc of MycoBloom mycorrhizal fungal inocula added to the root zone for the plants going into the AMF and AMF+P field plots or in pots containing live field soil and amended with 30 cc of autoclaved (killed) MycoBloom inocula added to the root zone of plants going into the Control and P fertilizer field plots. After vines were transplanted into the field, phosphorous fertilizer was added to the P plots in the field at a typical rate used by grape growers in the region (advised by Dr. Moyer, IAREC) through fertigation and an equivalent amount of water was added to the control treatments. Soil samples were collected from each plot before and after treatments were added and analyzed for nutrient content over the course of two growing seasons. Plants were harvested in Fall 2021 and data were collected on plant growth (height and biomass), leaf chlorophyll content, foliar nutrient content, and soil nutrients. Root samples were collected to determine percent colonization of mycorrhizal fungi in plants grown in each plot.

COVID-related impacts: The field experiment was established later than we originally planned due to COVID-related delays in spring 2020 associated with accessing campus facilities and equipment, staggered work-schedules, and social distancing. This limited the number of people who could work in a given area at the same time. The delivering nursery suffered similar delays in planting stock preparations. Because the field experiment was planted in late summer 2020, rather than in spring 2020 as originally planned, we opted not to collect root and leaf samples at the end of the first growing season or at the beginning of the second growing season, as we did not want to stress the young plants immediately before or after the winter. However, even with our precautions, there was significant vine mortality, potentially due to the combination of harsh winter conditions and the late planting date. By the end of the experiment in Fall 2021, most of the self-rooted plants and approximately half of the grafted plants had died. Data collected on the surviving plants, including plant height and biomass, leaf chlorophyll content, foliar nutrient content, and soil nutrient data, were used to evaluate the effects of the different treatments (AMF, P, AMF+P, or unamended Control) on grafted wine grape growth and leaf nutrient uptake in the field.

Methods, Results, and Discussion:

Methods: The field plots at WSUTC were prepared in June 2020 (e.g., tillage, staking out the plots, setting up irrigation, initial soil sampling). The field site was located near the WSUTC Research and Teaching Vineyard, but had not been cultivated previously. Prior to tilling and preparing plots for our experiment, the only management of this field site had been mowing (no history of fertilizer or pesticide applications). The field site was not fumigated and fungicide was not added to the control plots at any point before, during, or after the experiment. Thus, all plots in the experiment contained resident mycorrhizal fungal communities and other soil microbiota. The 'AMF' and 'AMF+P' treatments in the experiment were inoculated with MycoBloom mycorrhizal inocula. Dormant non-rooted cuttings of *Vitis vinifera* 'Merlot' (clone 4), both ungrafted and grafted to the rootstock '1103P', were obtained from Inland Desert Nursery (Benton City, WA) in July 2020. Plants were rooted in pots containing live field soil with their

respective mycorrhizal inoculation treatments (MycoBloom inocula or heat-killed MycoBloom inocula) for two weeks prior to being transplanted into the field. The mycorrhizal inoculant product, MycoBloom, was used as the AMF inocula for this experiment because it has been shown to improve the growth of perennial plants in >15 peer-reviewed scientific papers and is publicly available for purchase by growers (e.g., via Amazon.com). Data on initial vine size were recorded before transplanting into the field and used as a co-variate in the statistical analysis. Phosphorous fertilizer treatments were applied to the +P plots (an equivalent amount of water was applied to the -P plots) after the plants had established. Because we did not want to stress the plants by sampling roots or leaves of the recently planted vines before winter, qualitative viability data were collected (scale 0-4) on height, health, and appearance of each plant in October 2020. Despite using vine covers and not collecting samples from the plants at the end of the first growing season, many of the plants died over the winter. In spring and summer 2021, data were collected on plant survival and growth (e.g., height, leaf chlorophyll content), and soil nutrients (KUO labs, Pasco, WA). In spring 2021, P fertilizer treatments were again applied to the +P and AMF+P plots at the same rate as before and soil nutrient data were collected from each plot before and after P fertilizer application. A dilute, phosphorous-free fertilizer was added to all plots to avoid nutrient stress over the course of the experiment. At harvest in September 2021, the surviving plants were measured (height, cm), leaf chlorophyll content was recorded using a SPAD meter (three measurements averaged for the newest, fully emerged leaf on each plant), and foliar nutrient content was collected from leaf samples (20 leaves per plant). Plants were destructively harvested and roots and shoots were separated and dried for biomass. Fresh weights were recorded before drying and subsamples of roots were collected from each plant to quantify the mycorrhizal colonization levels of roots in each treatment. The dry weight equivalent of the subsample was added back into the root biomass before analysis. Data on plant biomass, leaf nutrient content, leaf chlorophyll content, percentage mycorrhizal colonization of roots, and soil nutrients were analyzed. Because of the high mortality of grapevines over the course of the experiment, only grafted plants were included in the statistical analysis presented here as most of the self-rooted plants died over the winter. Data from the grafted plants were analyzed in R using linear mixed effects models with treatment as a fixed effect, initial size as a covariate, and block as a random effect. Response variables in the models were final plant height (cm), aboveground biomass (g, dry weight), root biomass (g, dry weight), leaf chlorophyll content, foliar nutrient content (KUO labs, Pasco, WA), percentage mycorrhizal colonization of roots, and soil nutrients (KUO labs, Pasco, WA). Analysis of variance (ANOVA) was used to determine main effects of the model. Contrast analyses, using the "emmeans" package, were used to determine the mean pairwise differences in plant response between treatments. We performed a survival analysis using the proportion of plants that survived in each treatment to determine whether there was a treatment effect on grafted plant survival.

Results: Soil nutrient results showed that P content in soil of the P fertilized field plots (AMF+P and P treatments) was approximately double the background soil P levels in the field plots (Table 1). Grafted plants grown with P fertilizer in the +P and the AMF+P treatments had higher P content (%) in leaves than plants grown without P fertilizer ($p < 0.001$; Fig. 1), as well as higher phosphate (PO_4, %; $p < 0.001$). We found that mean root biomass (g, dry weight) varied by treatment ($p = 0.03$) and was highest in the control plants grown in plots with no P fertilizer or AMF inocula added (57.1 ± 4.9), followed by plants grown in the AMF treatment (54.2 ± 5.2), the P fertilizer treatment (47.5 ± 5.1), and the AMF+P treatment (41.0 ± 4.5); Fig. 2. There was a

significant effect of treatment on leaf chlorophyll content ($p = 0.03$; Fig. 3), in which mean leaf chlorophyll content was highest in the AMF treatment (13.11 ± 1.08) and lowest in the P treatment (9.77 ± 1.04). We detected no difference in final height, aboveground biomass, or other foliar nutrients (e.g., N, K, Mn, Zn, Fe) among treatments (all $p > 0.05$). There were also no differences in the survival among grafted plants grown in plots with AMF inocula, P fertilizer, AMF+P, or in control plots with no P fertilizer or AMF inocula added ($p = 0.68$).

Soil treatment had a strong effect on percentage mycorrhizal colonization of roots ($p = 0.0005$; Table 2; Fig. 4). The addition of P fertilizer resulted in lower mycorrhizal colonization levels of roots in vines grown in the P fertilizer treatment compared to vines grown in the unamended control plots ($p = 0.0003$) and to vines grown in the AMF+P plots ($p = 0.0190$). However, there was no difference in percentage AMF colonization in roots of vines grown in the unamended control plots that contained resident mycorrhizal fungal communities compared to vines grown in the AMF plots amended with mycorrhizal inocula ($p = 0.6883$). We also detected no correlation between percentage mycorrhizal colonization of roots and any growth parameter measured in the young vines (e.g., final biomass, height, leaf chlorophyll content, foliar P; all $p > 0.05$).

Discussion: In a field experiment, we tested the effects of four different soil treatments (P fertilizer addition, mycorrhizal fungal inocula, addition of both P fertilizer and mycorrhizal inocula, and Control with no addition of P fertilizer or live mycorrhizal inocula) on the growth and foliar nutrient uptake of *Vitis vinifera* 'Merlot' (clone 4) that were self-rooted or rootstock-grafted (1103P). However, because most of the self-rooted vines died over the winter and could not be included in the statistical analysis, we focus the discussion here on the results of *Vitis vinifera* 'Merlot' (clone 4) grafted onto the rootstock 1103P. After one year, we found that P fertilizer addition increased the amount of P in soil and in the leaves of the rootstock-grafted vines, demonstrating that these grapevines could benefit from the addition of P fertilizer compared to the baseline soil P concentrations in the Washington field soil. The rootstock-grafted vines grown in plots containing both mycorrhizal inocula and P fertilizer had the highest amount of foliar P, suggesting that mycorrhizal inoculations used in combination with P fertilizer could benefit foliar P uptake. The rootstock-grafted vines grown in plots inoculated with mycorrhizal fungi also had the highest leaf chlorophyll content (a proxy for nitrogen) compared to the other treatments, suggesting that mycorrhizal fungi may facilitate nitrogen uptake in the new leaves of young grapevines. We also found that root biomass was highest in the unamended Control plots and lowest in the AMF+P plots. This suggests that young grapevines grown without the addition of P fertilizer or mycorrhizal inocula may need to increase their root biomass to obtain a similar amount of nutrients as plants grown in the other treatments. We detected no effect of treatment on final plant height, aboveground biomass, plant survival, or other leaf nutrients (e.g., N, K, Fe, Zn), however, it is possible this may be due in part to the short-term nature of the field study.

Plots that only received the P fertilizer treatment had the lowest amount of mycorrhizal colonization in roots, suggesting that when P is readily available in soil, plants may invest less in supporting mycorrhizal fungi in their root systems. These findings support those of our previous greenhouse experiment and mirrors the results of other studies that typically show a negative correlation between nutrient addition and mycorrhizal colonization of roots. Interestingly, the

addition of P fertilizer only appeared to have a negative effect on mycorrhizal colonization of roots by the resident mycorrhizal fungal communities in the background field soil as mycorrhizal colonization levels were lower in plants grown in the P fertilized plots (estimated marginal mean % colonization = 23.7% ± 4.7%; Table 2) compared to plants grown in the unamended Control plots (estimated marginal mean % colonization 40.7% ± 4.6%; Table 2). However, when plants were inoculated with the MycoBloom mycorrhizal inocula two weeks prior to transplanting into the field, mycorrhizal colonization levels of roots in the AMF+P plots were similar to the Control and AMF plots at the time of harvest (Table 2; Fig. 4). This suggests that pre-inoculating vines with a mycorrhizal inoculant product before transplanting into the field may help to reduce potential negative impacts of P fertilizer addition on mycorrhizal colonization levels in the roots of young vines. It is also possible that the composition of mycorrhizal fungal species in the MycoBloom inocula is different than the resident mycorrhizal fungal species present in the field soil, and perhaps more tolerant to P fertilizer addition than the resident mycorrhizal fungal communities. Taken together, our study provides evidence that the growth response of the rootstock-grafted vines to mycorrhizal fungal inoculations and addition of P fertilizer can be variable and suggests that growers may benefit from testing amendments on smaller areas of their vineyards or in short-term greenhouse studies before investing time and effort on larger scale applications. Our study also provides evidence that inoculating vines with a mycorrhizal inoculant product prior to planting into the field may help to mitigate potential negative effects of P fertilizer additions on mycorrhizal colonization levels of roots.

Tables and Figures

Table 1. Estimated marginal (EM) means of phosphorus (P) levels (%) in soil samples collected from field plots (Washington State University, Richland, WA) before and after P fertilizer application in each growing season. Table 1 shows the estimated marginal mean, standard error (SE), and lower and upper confidence intervals (CL) of P (%) for each treatment (phosphorous fertilizer (P), arbuscular mycorrhizal fungal inocula and P fertilizer (AMF+P), arbuscular mycorrhizal fungal inocula (AMF), and unamended Control (no live AMF inocula or P fertilizer added).

Treatment	EM Mean	SE	df	lower.CL	upper.CL
Pre-Treatment Season1					
P	10.7	0.5	13.3	9.6	11.8
AMF+P	10.3	0.5	13.3	9.2	11.4
AMF	9.4	0.5	13.3	8.3	10.5
Control	9.3	0.5	13.3	8.2	10.4
Post-Treatment Season 1					
P	22.4	1.4	30.1	19.7	25.1
AMF+P	20.0	1.4	30.1	17.3	22.7
AMF	10.6	1.4	30.1	7.9	13.3
Control	9.9	1.4	30.1	7.2	12.6
Pre-Treatment Season2					
P	15.0	1.1	13.1	12.7	17.3
AMF+P	14.9	1.1	13.1	12.6	17.2
AMF	13.0	1.1	13.1	10.7	15.3
Control	12.9	1.1	13.1	10.6	15.2
Post-Treatment Season 2					
P	21.5	1.3	10.6	18.6	24.5
AMF+P	20.9	1.3	10.6	18.0	23.9
AMF	9.6	1.3	10.6	6.7	12.6
Control	9.8	1.3	10.6	6.9	12.8

Table 2. Estimated marginal (EM) means, standard error (SE), and lower and upper confidence intervals (CL) of percentage mycorrhizal colonization of roots at the time of harvest in *Vitis vinifera* 'Merlot' (clone 4) grafted onto 1103P rootstock grown in field plots (Washington State University, Richland, WA) amended with P fertilizer (P), arbuscular mycorrhizal fungal inocula and P fertilizer (AMF+P), arbuscular mycorrhizal fungal inocula (AMF), or unamended Control plots that contained resident mycorrhizal fungi and other soil biota, but did not have live mycorrhizal inocula or P fertilizer added.

Treatment	EM Mean	SE	df	lower.CL	upper.CL
P	23.7	4.7	17.9	13.8	33.6
AMF+P	47.2	4.2	11.7	38.0	56.5
AMF	34.3	4.9	17.4	24.1	44.5
Control	40.7	4.6	15.2	31.0	50.4

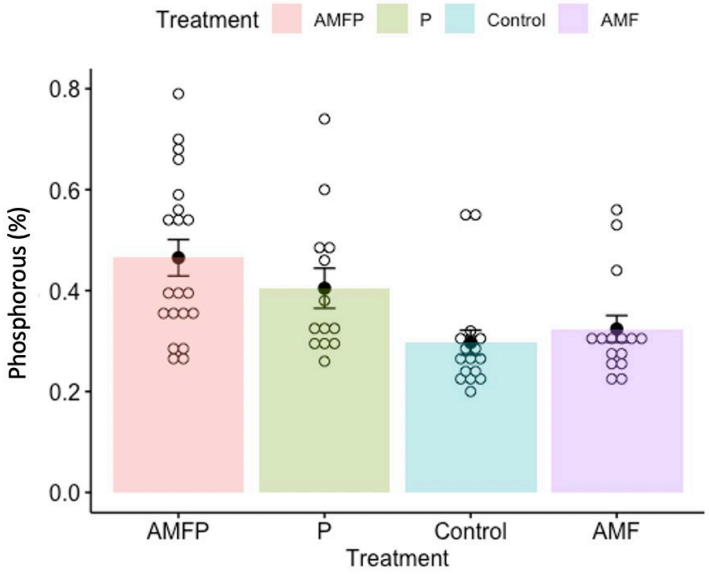

Figure 1. Foliar phosphorous (P, %) in leaves of *Vitis vinifera* 'Merlot' (clone 4) grafted onto 1103P rootstock grown in field plots inoculated with arbuscular mycorrhizal fungi (AMF) and P fertilizer (AMFP; red), P fertilizer (P; green), control (blue), and AMF (purple). Open circles represent the foliar P (%) of each plant in the respective treatments. Treatment had a significant effect on foliar phosphorus ($p < 0.001$).

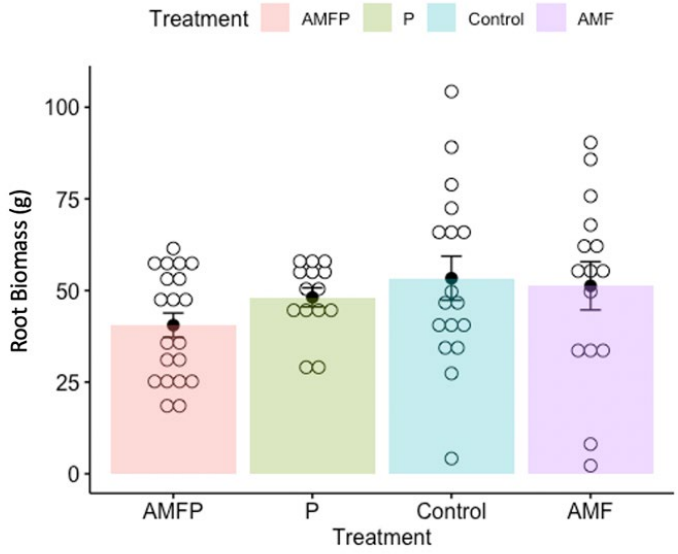

Figure 2. Root biomass (g, dry weight) in *Vitis vinifera* 'Merlot' (clone 4) grafted onto 1103P rootstock grown in field plots inoculated with arbuscular mycorrhizal fungi (AMF) and P fertilizer (AMFP; red), P fertilizer (P; green), control (blue), and AMF (purple). Open circles represent the root biomass of each plant in the respective treatments. Treatment had a significant effect on root biomass ($p = 0.03$).

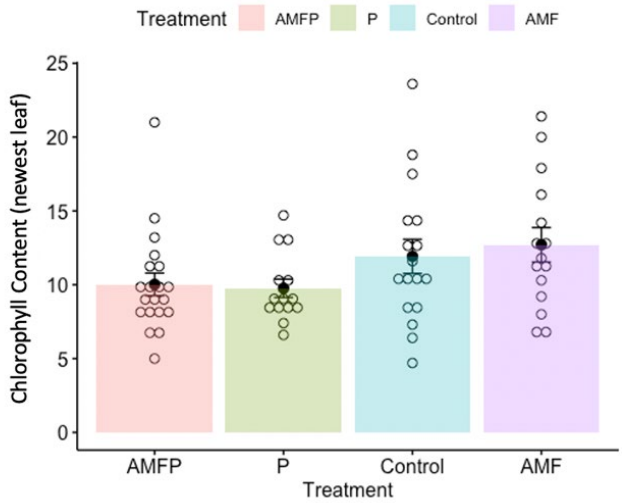

Figure 3. Leaf chlorophyll content (SPAD meter) of the newest, fully open leaf at the time of harvest in *Vitis vinifera* 'Merlot' (clone 4) grafted onto 1103P rootstock grown in field plots inoculated with arbuscular mycorrhizal fungi (AMF) and P fertilizer (AMFP; red), P fertilizer (P; green), control (blue), and AMF (purple). Open circles represent the leaf chlorophyll content of each plant in the respective treatments. Treatment had a significant effect on leaf chlorophyll content ($p = 0.03$).

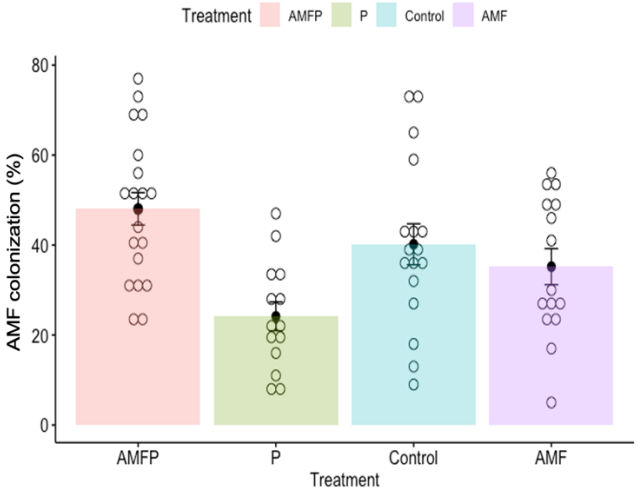

Figure 4. Percentage arbuscular mycorrhizal fungi (AMF) colonization of roots at the time of harvest in *Vitis vinifera* 'Merlot' (clone 4) grafted onto 1103P rootstock grown in field plots treated with AMF inocula and P fertilizer (AMFP; red), P fertilizer (P; green), control (blue), and AMF inocula (purple). Open circles represent the percentage AMF colonization of roots of each plant grown in the respective treatments. Treatment had a significant effect on percentage AMF colonization of roots ($p = 0.0005$).

Publications, Handouts, Other Text & Web Products: Data analysis and writing are currently underway, so we do not have any publications, handouts, or web products to report at this time. However, our wine grape research did get coverage in the media over the past couple of years:

- **The Good Fruit Grower**: *Good to Know: Harnessing fungi power, How soil fungi could reduce fertilizer needs and improve grapevine growth* https://www.goodfruit.com/good-to-know-harnessing-fungi-power/
- **The Daily Evergreen:** *WSU Tri-Cities researchers use fungi to replace chemical fertilizers* https://dailyevergreen.com/95641/news/wsu-tri-cities-researchers-use-fungi-to-replace-chemical-fertilizers/
- **WSU Insider:** *Wine and fungi: The perfect pairing, news article on my wine grape research* https://news.wsu.edu/2020/11/30/wine-fungi-perfect-pairing/
- **Pacific Northwest Ag Network, Wave Minute:** *Relationship Between Wine Health And Soil Health, Radio story highlighting my wine grape research* https://www.washingtonagnetwork.com/2020/08/07/wave-minute-relationship-between-wine-health-and-soil-health/

Outreach & Education Activities: This project provided a Research Assistant position for two WSU Master's students and provided valuable research and training opportunities for > five undergraduate students and technicians from the Biology and the Viticulture and Enology programs at WSU. The Master's student on the project presented a poster and gave a talk at the 2021 WineVit conference, as well as presented their research in several different symposia at WSU, including the School of Biological Sciences Graduate Symposium and the WSUTC Three-Minute Thesis competition.

Impacts

- **Short-Term:** This project provided valuable research training for two graduate students and five undergraduate students/technicians at WSUTC. Because our experiment was located in a prominent position on the WSUTC campus (along the main road into campus), it garnered substantial attention from faculty, students, and members of the greater Tri-Cities community and increased the public engagement of this work (see media coverage above). The Master's student on the project presented a poster of their research at the 2021 WineVit conference, as well as in several different graduate student symposia at WSU.
- **Intermediate-Term:** The preliminary data obtained from this field experiment will be used to inform future studies aimed at determining the impact of mycorrhizal inoculations on grapevine growth, wine and fruit quality, and soil health. We can also use our preliminary data to estimate effect sizes, variance, and spread of the data within and between groups in a power analysis to increase the power of the study for the next experiment, in the event of high mortality of vines in the field in the future.
- **Long-Term:** The graduate student funded on this project successfully defended their Master's thesis and secured a job at the United States Department of Agriculture (USDA) shortly after graduating. Results from this study should be helpful for growers as we found that the grafted plants were more resilient to late planting and harsh winter conditions than the self-vines. We also showed that plants in our study at WSUTC

(Richland, WA) used up the added P fertilizer over the course of each growing season, as soil P levels were close to baseline again the following season.

Additional funding applied for/secured: I received funding from the Washington State Grape and Wine Research Program to test a cross-section of commercially-available mycorrhizal inoculant products on wine grape growth and nutrient uptake in a greenhouse study to determine whether different types or formulations of mycorrhizal product(s) could be beneficial for Washington State wine grape growers.

Graduate students funded: Two Master's students at WSUTC were funded by this research. One MS student successfully defended and was hired by the USDA shortly after graduating.

Recommendations for future research: In the future, I think it would be interesting to test a cross-section of commercial mycorrhizal inoculants on different wine grape rootstocks (e.g. with phylloxera and/or nematode resistance), and under different nutrient regimes, under greenhouse and field conditions.

Photos of our field experiment can be viewed here:
https://www.flickr.com/photos/wsutricities/albums/72157716632542281
All photos were taken by Maegan Murray, Assistant Director of Marketing and Communication, Washington State University Tri-Cities