UNTANGLING BELOWGROUND RESPONSE OF GRAPEVINES TO COVER CROP COMPETITION

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Abstract:

Context and purpose of the study - Cover crops are planted in vineyards for multiple benefits including soil conservation, weed management, regulation of grapevine vegetative growth, and improved fruit quality. In humid climates where inter-row cover crops are standard management, we evaluated under-vine cover crops for beneficial reductions in vegetative growth. Several factors affect the impact of under-vine cover crops on vine growth and productivity, including seasonal resource availability, vine age, and rootstock. To better understand these factors, we examined belowground processes that might clarify mechanisms of resource competition between grapevines and cover crops.

Material and methods - Field examinations of mature *vinifera* and young inter-specific hybrid grapevines grafted on two rootstocks varying in vigor, Riparia (*Vitis riparia*) and 101-14 Mgt (*Vitis riparia* x *Vitis rupestris*), were conducted at three humid, eastern US vineyards. Both destructive (soil coring) and non-destructive (minirhizotron technique) methods were used for root observations and analysis.

Results - Roots of young and mature vines coped with under-vine cover crop competition by avoiding shallow soil regions mainly colonized by cover crops roots, suggesting complementary use of water and nutrients. In mature vines, cover crop competition also induced shorter lifespan of grapevine roots, but did not affect root morphological traits, such as specific root length, diameter, mycorrhizal fungal colonization, and root branching. In contrast, young grapevine root systems responded to competition by increasing specific root length and decreasing absorptive root diameter, regardless of the rootstock. Although rootstocks displayed a similar belowground response, young vines grafted on the low-vigor rootstock exhibited less growth reduction during the first year suggesting that tolerance of cover crop competition may be rootstock dependent. Overall, young grapevines growing with cover crops tended to have greater reductions in growth compared to mature vines, suggesting that vines acclimate to competition over multiple years.

Keywords - Cover crops, plasticity, root distribution, *Vitis*

1. Introduction

In recent years, interest in US wine grape production has expanded from traditional production areas to regions characterized by higher water availability and more fertile soils, such as the eastern USA (Wolf, 2008). The high soil resource availability typical of this region can lead to excessive vegetative growth, which reduces fruit exposure to sunlight. Shaded clusters are more susceptible to fungal diseases (Valdes-Gomez et al., 2008; Valdes-Gomez et al., 2011) and might have altered juice composition leading to decreased wine quality (Marais et al., 1992; Naor et al., 2002). Planting cover crops, as an alternative to the standard under-vine management practice of herbicide-treated soil, may reduce excessive vegetative growth (Giese et al. 2014; Karl et al. 2016a; Hickey et al. 2016) and offer ecological benefits, including reduced soil erosion and nutrient runoff, herbicide elimination, and enhanced species diversity (Karl et al., 2016b).

Studies often report that under-vine cover crops reduce vegetative growth (e.g., pruning weight, shoot growth rate) and yield. However, there is a high variability in grapevine response to under-vine cover crops. For example, growth reduction can vary from no effect (Jordan et al., 2016) to reductions of nearly 60% of pruning weight and 50% of yield (Karl et al., 2016a). Seasonal resource availability, soil properties, cover crop species, vine age, and rootstock genotype are amongst the main factors influencing vine response to cover crop competition for resources. To increase predictability of grapevine response to under-vine cover crops, a more mechanistic understanding of belowground resource competition is necessary. Here, we review belowground investigations that we conducted to better understand how under-vine cover crops compete with vines.

2. Material and methods

Plant materials - Targeted examinations of below- and aboveground grapevine responses to under-vine cover crops were conducted at three vineyards in the eastern US (New York State, Pennsylvania, Virginia) between 2011 and 2018. Results of these studies have been summarized in three peer-reviewed publications (Centinari et al., 2016; Klodd et al., 2016; Fleishman et al., accepted). The first study was established on mature Cabernet Franc (*Vitisvinifera*) vines grafted on 3309C (Centinari et al., 2016); a second study was conducted on mature Cabernet Sauvignon (*Vitisvinifera*) vines grafted on 101-14 Mgt (Klodd et al., 2016); and a third on young Noiret (*Vitis* hybrid) vines grafted on 101-14 Mgt and Riparia (Fleishman et al., in press). At site 1, three cover crops were planted on an annual basis in the 1-m strip under the vines: annual ryegrass (*Lolium multiflorum*), buckwheat (*Fagopyrum esculentum*), and rosette forming turnips (*Brassica rapa* var. *rapa*). A perennial cover crop, creeping red fescue (*Festuca rubra*), was planted under the vines in the fall of the second year of vineyard establishment at sites 2 and 3. Belowground investigations were conducted one year (sites 1 and 3) or seven years (site 2) after cover crop establishment. Cover crops were compared to a control, which was under-vine cultivation (site 1) and an 85-cm herbicide-treated strip at sites 2 and 3. The alleys between the rows (inter-row) were maintained with a permanent, mixed sward.

Plant measurements – At site 1, the seasonal pattern of root production of grapevines growing with and without under-vine cover crops was examined using minirhizotrons, clear plastic tubes (1.2 m long and 0.06 m outer diameter) installed in the area beneath the vines (Comas et al., 2000). Root images were recorded with a specially-designed digital-imaging camera down the length of each tube every two weeks during the growing season and once per month during the winter. Root images were analyzed for root number, location, depth, diameter, and date of first appearance and disappearance. At the other two sites, soil coring to one-meter depth were used for analysis of grapevine root distribution and morphological traits. Roots were sorted by branching order (Pregitzer et al., 2002; McCormack et al., 2015) and classified as primarily absorptive (first and second order) or transportive (third order and higher; Valenzuela-Estrada et al., 2008; McCormack et al., 2015). Root measurements included root diameter (mm), arbuscular mycorrhizal colonization, root length density (RLD; $cm\ cm^{-3}$), and specific root length (SRL; $cm\ g^{-1}$); RLD and SRL were calculated as root length divided by soil volume or mass, respectively.Grapevine aboveground measurements included pruning weight, yield components, basic juice chemistry, plant nutrient status, and soil resource availability. Rainfall and air temperature data were recorded by on-site weather stations.

Statistical analysis -Statistical analysis was performed with SAS software package (SAS Institute, Cary, NC, USA). Above and belowground data were subjected to ANOVA to calculate significant differences among treatments due to cover crop or depth increment effects. To evaluate the effect of treatments and soil depth on the lifespan of individual grapevine fine roots, Cox proportional hazards regression model was run using PROC PHREG in SAS (Wells and Eissenstat, 2001).

3. Results and discussion

3.1. *Competition between grapevine and cover crop roots decreased roots in shallow soil layers*

At all sites, the presence of under-vine cover crops decreased the number of grapevine absorptive roots (site 1) and their RLD (site 2 and 3). Cover crops, and grasses in particular, typically have shallow and dense root systems and can be considered aggressive competitors in the surface soil layers (Fleishman et al., in press). At site 1, grapevines competing with annual ryegrass ($P = 0.003$; Figure 1) and buckwheat ($P = 0.01$) had fewer roots in the top 20 cm soil compared with the control by the third year of the study. Similarly, roots of young and mature vines growing with under-vine red fescue for one year (site 3) or seven years (site 2) avoided shallow soil regions mainly colonized by cover crop roots and distributed roots deeper when compared to the control (Figure 2). Overall, the two rootstocks used at site 3 (Riparia and 101-14 Mgt) had a similar re-distribution response to cover crop competition. Collectively, these results suggest that grapevines tend to shift root production deeper with cover crops to avoid competition and allow for complementary resource use by increasing uptake in deep soil layers.

3.2.*Competition between grapevine and cover crop roots modified root traits*

Vines displayed other belowground plastic responses to competition with under-vine cover crops. At site 1, absorptive roots in the control treatment had a shorter median lifespan than those growing with annual ryegrass or buckwheat ($P< 0.05$). Differences in root lifespan amongst treatments might be explained by shifts in root distribution induced by cover crops, as roots produced at deeper soil layers tend to live longer (Anderson et al., 2003; Centinari et al., 2016). However, within the individual root system of vines growing with annual ryegrass or buckwheat, roots growing near cover crops roots (i.e., with neighboring roots) had more than a 50% reduction in lifespan (106 and 72 days in neighborhoods of annual ryegrass or buckwheat, respectively) compared to those growing without neighboring cover crop roots (366 and 302 days, respectively). This suggests that vines growing with cover crops may shed roots in soil patches with higher competitive pressure, while maintaining roots longer in patches with lower pressure to optimize resource uptake strategy.

At sites 2 and 3 morphological traits were affected differently, perhaps due to vine age, which influences the acclimation time to under-vine cover crops. At site 2, where vines had several years to acclimate to cover crop competition, the presence of a perennial grass under the vines did not affect root morphological traits, such as SRL, diameter, and root branching. In contrast, young grapevine root systems exposed to cover crops for the first year exhibited an increased SRL and smaller absorptive root diameter, regardless of the rootstock ($P< 0.05$). Greater SRL and smaller root diameter, together with increased abundance of beneficial root-associated microbes (e.g., mycorrhizal fungi), are plastic responses to heterogeneous soil resource supplies (Hodge 2004). The presence of under-vine cover crops, however, did not affect mycorrhizal fungal colonization.

3.3.*Aboveground response to competition*

Even though vines growing with under-vine cover crops for several years had smaller root system size, they were able to acquire enough water and nutrient to sustain vegetative growth during a wet year (site 2). In contrast, cover crop competition for nutrients, mainly nitrogen, induced growth reduction in young vines (site 3). Interestingly, young vines grafted on Riparia (low-vigor rootstock) exhibited less aboveground growth reduction than those grafted on 101-14 Mgt (medium-vigor rootstock) during the first year, which was a wetter than average growing season. This suggests a conservative use of resources of the low-vigor rootstock which was more tolerant of nutrient competition.

4. Conclusions

Regardless of age and acclimation time to under-vine cover crop competition, grapevines exhibited primarily an avoidance response to competition by shifting roots deeper, away from shallow soil where cover crop roots are dense. Lower root production in shallow soil might reduce grapevines access to soil nutrients, especially nitrogen which tend to be less available at deeper depths. Young grapevines responded to cover crop competition by modifying root morphological traits, such as diameter and SRL; but still had substantial reductions in vegetative growth. However, grapevines growing with under-vine cover crops for seven years showed a greater acclimation response to cover crop competition, leading to less effects on growth above- and belowground.

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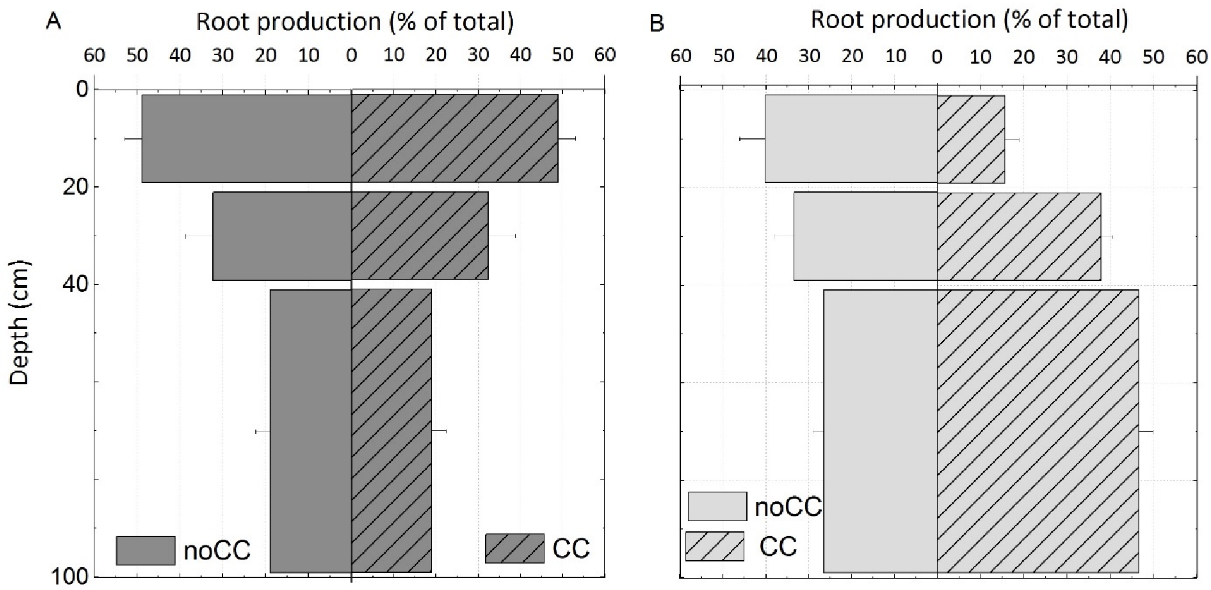

Figure 1. Fine root production expressed as a proportion of total production by soil depth intervals two years **(A)** and three years **(B)** after annual ryegrass establishment. Error bars represent ±1 SE.

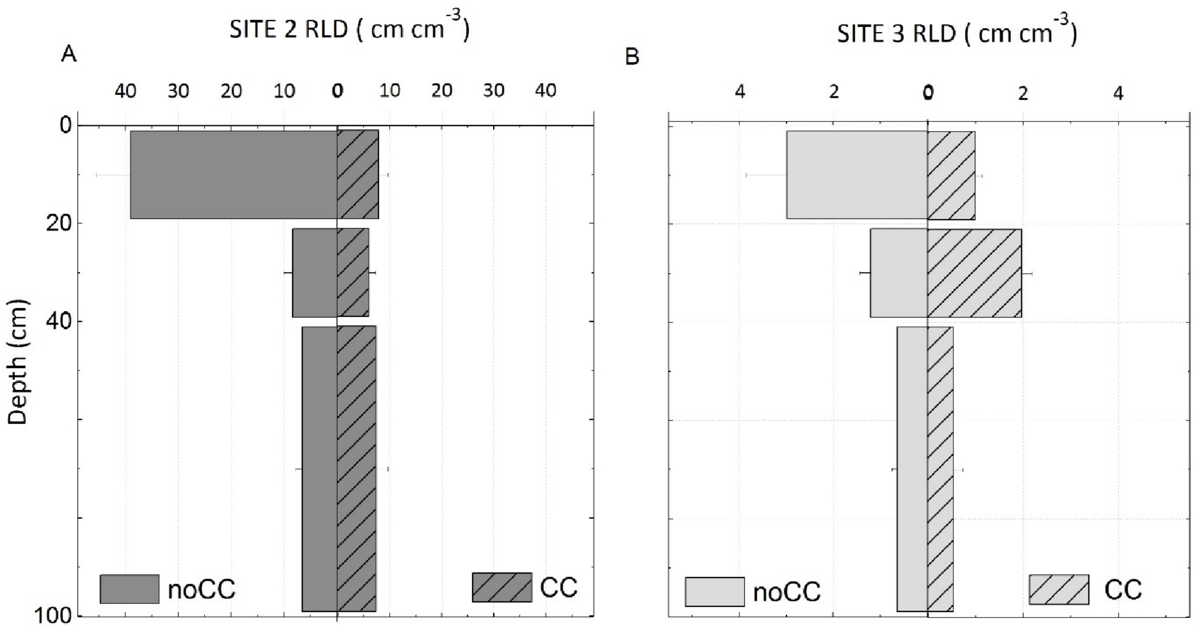

Figure 2. Fine root length density (RLD) (cm cm-3) by soil depth of grapevines growing with acover crop (CC) or without a cover crop (No CC) at site 2 (P_{cc}<0.001; P_{depth}<0.001) **(A)** and site 3 (P_{cc}<0.05; P_{depth}<0.05) **(B).** Error bars represent ±1 SE. At site 3, RLD data for Riparia and 101-14 Mgt rootstock were combined because the rootstock factor was not significant at P = 0.05.