Under-vine management effects on grapevine production, soil properties, and plant communities in South Australia

Merek M. Kesser, Timothy R. Cavagnaro, Roberta De Bei, and Cassandra Collins*

The University of Adelaide, School of Agriculture, Food & Wine, Waite Research Institute, PMB 1 Glen Osmond, 5064 South Australia, Australia

***Corresponding author:** cassandra.collins@adelaide.edu.au

Keywords: Under-vine management, spontaneous vegetation, soil physiochemical properties, grapevine performance, juice composition

Abstract

With impending limits on the use of chemical herbicides in many countries worldwide, it is relevant to explore how alternative under-vine management practices may affect the vineyard agroecosystem. Long-term under-vine management practices carried out at commercial vineyard sites in Eden Valley (herbicide and spontaneous vegetation) and McLaren Vale (cultivation and spontaneous vegetation) were assessed by measuring their impacts on under-vine plant communities, soil properties, and grapevine performance. The impacts of the spontaneous vegetation treatments differed greatly between sites, which can largely be attributed to the soil types of loamy sand at Eden Valley compared to silty loam at McLaren Vale. Higher soil nitrate, electrical conductivity, and cation exchange capacity were measured on the herbicide soils in Eden Valley. Therefore, the lower plant cover, biomass and species richness measured in this treatment compared to the spontaneous vegetation suggests the under-vine plants were directly competing with grapevines for these available nutrients as is reflected in yield and juice measurements. Faster water infiltration and higher phosphorus levels in the spontaneous vegetation soils at McLaren Vale led to higher yield measurements compared to the cultivation treatment, whereas juice composition was not affected due to the higher cation exchange capacity of the silty loam soils at this site.

Introduction

Vineyard under-vine management practices have traditionally consisted of 3-4 applications of herbicides during a growing season to eliminate weeds which may compete with grapevines and pose an interference to routine viticultural management. With the current shift towards less frequent herbicide use due to potential bans of glyphosate use in Europe (European Union, 2017) and in Australia (Walsh and Kingwell, 2021), coupled with the heightening interest in regenerative agricultural practices (Gordon *et al.*, 2021), it is relevant to explore the effects of alternative management strategies for the under-vine areas of vineyards. Numerous studies have explored the multitude of ecosystem services that permanent or annual cover crops and spontaneous vegetation in vineyard mid-rows can contribute to the agroecosystem, including improving soil organic carbon and facilitating the establishment of connected, continuous soil pores which reduce compaction and improve water infiltration (García-Díaz *et al.*, 2018). Evidence that benefits of the long-term incorporation of cover crops as opposed to herbicide treatments can be extended to the under-vine areas of vineyards as part of an agroecological management approach include improved soil organic carbon stocks in trials at Langhorne Creek and the Barossa Valley of South Australia (Marks *et al.*, 2022).

Grapevine responses to spontaneous or seeded under-vine plant coverage can include reduction in vigour due to competition for soil resources, even in high-precipitation climates (Vanden Heuvel and Centinari, 2021). Because wine is a substantial contributor to the Australian landscape and economy, it is essential that the drivers and effects of different under-vine management practices be carefully assessed in order to optimise the trade-offs between ecosystem functionality, biodiversity, soil health, and grape production as the wine and viticulture industry continues to develop (Nordblom *et al.*, 2019). The aims of this study were to holistically investigate how the long-term maintenance of spontaneous vegetation in the under-vine rows of commercial South Australian vineyards with different soil types affect the dynamics of plant communities, physiochemical soil properties, and grapevine performance.

Materials and methods

This study was carried out at two commercial Shiraz vineyard sites in South Australia, one in Eden Valley and the other in McLaren Vale. At both sites, two adjacent treatment blocks were compared where the only management difference was in under-vine management practices. Both sites had a spontaneous vegetation treatment without any management practices applied for the last five consecutive growing seasons. Typical best-practice management strategies are used at both vineyards including banding compost under-vine every 3-4 years and applying foliar sprays to combat fungal diseases. An average rate of 1.1 ML/ha of water per growing season were applied to all treatment blocks via drip irrigation. In Eden Valley, this spontaneous vegetation treatment was compared to a traditional herbicide treatment, where herbicides had been applied to the under-vine rows four times per growing season, since 1998. One row of 170 metres in length for each treatment were used for the study, where sampling replicates consisting of nine vines were established at evenly spaced intervals. The mid-rows are characterised by a permanent, spontaneous sward that are grazed by sheep in the winter months and slashed 2-3 times during spring and summer. The soils at Eden Valley are classified as loamy sand.

Since 2014 at the site in McLaren Vale, an under-vine knife was used to cultivate the under-vine rows in early spring in a treatment block of 13 rows (0.70 ha). This was compared to an adjacent treatment block of 14 rows (0.71 ha) with spontaneous vegetation under-vine. Sampling replicates of nine vines in length were established at equally spaced intervals along a diagonal transect of each block. Both blocks are otherwise farmed identically with organic management practices consisting of a cereal-legume cover crop cultivated in alternate rows every year. The soils at McLaren Vale are classified as silty loam.

The under-vine rows at both sites were surveyed each season in winter, spring, summer, and autumn from 2020-2021 to characterise the effects of the different under-vine treatments on the plant communities. Wooden frames measuring $1 m^2$ in area were placed in the middle of the under-vine row at each replicate to carry out the surveys. All plants rooted within the frames were identified and their percent cover was estimated, in addition to percent cover attributed to bare ground (Guzmán *et al.*, 2019). The surveys were repeated three times per replicate for a total of nine surveys per treatment block during each season. During each seasonal sampling campaign, one frame measuring $0.25 m^2$ was placed randomly in the under-vine row at each replicate where all plant biomass was cut with an electric hedger and was dried in an oven at 60˚C for 7 days before being weighed.

Soil physiochemical measurements were conducted at each treatment block in March of 2021. To collect soil for the chemical properties, a soil auger was used to extract soil samples from the top 2-12 cm of the profile at each replicate until a composite sample of approximately 500 grams was gathered. The soil was dried at 40˚C for 5 days before being sieved with a 2mm sieve and prepared for analyses at the Australian Precision Agriculture Laboratory (APAL, Adelaide, Australia). pH and electrical conductivity were measured with a 1:5 soil:water dilution, and additional measurements included soil cation exchange capacity and Colwell phosphorus (Rayment and Lyons, 2011). Total carbon and total nitrogen were measured by combustion using the Dumas method. After conducting a fizz test to detect for the presence of inorganic carbon fractions in the form of calcium carbonate ($CaCO_3$), total organic carbon was measured. Nitrate was measured in the soil after preparing extractions using a 2M KCl solution (Rayment and Lyons, 2011). Mid-infared (MIR) spectroscopy was used to classify the soils based on the Australian Soil Classification (Isbell *et al.*, 2021). To measure bulk density, three undisturbed soil cores ($300 cm^3$ in volume) were extracted from the 2-12 cm profile at each replicate, followed by an in-situ water infiltration measurement using a method conducted with the rings of the same volume (Porzig *et al.*, 2018).

Shoots and bunches per metre were counted on all nine vines of each replicate prior to harvest in 2021. Once per week for the 5-6 weeks prior to being harvested, 100 berries were collected and crushed by hand from each replicate to assess maturity development by measuring pH, titratable acidity, and total soluble solids. pH was measured with a pH probe on an automatic titrator, which was used to titrate the samples to an end-point of 8.2 pH with 0.33M sodium hydroxide to measure titratable acidity. Total soluble solids were measured with a digital refractometer. When the treatment blocks were harvested, 27 bunches from each replicate were picked and brought back to the laboratory to be weighed and hand-crushed. Data was analysed using R (version 4.1.2, R Core Team, 2021) and figures were made using the “ggplot2” package in R Studio (Wickham, 2016). A Shapiro-Wilks test for normality ($p < 0.05$) and a F-test for variance ($p < 0.05$) were used to determine if data for each measurement met the criteria for independent t-tests, and if not, then a non-parametric Wilcoxon test was conducted to compare means from the two treatments at each vineyard site.

Results and discussion

The herbicide treatment in Eden Valley greatly impacted the make-up of the plant communities in the under-vine area, with significantly lower plant % ground-cover, biomass, and species identified per season than at the adjacent spontaneous vegetation treatment (Table 1). Cultivation did not impact the under-vine plant community for the same parameters measured at the McLaren Vale site, where the treatment resulted in similar plant dynamics as in the spontaneous vegetation treatment (Table 1).

Table 1. Under-vine plant measurements of plant ground-cover, plant biomass, and plant species identified for the herbicide and spontaneous vegetation treatments in Eden Valley and the cultivation and spontaneous vegetation treatments in McLaren Vale during the 2020-2021 growing season.

	Eden Valley				McLaren Vale			
Under-vine plant measurements	Herbicide	Spontaneous vegetation	*P* -value	Sig.	Cultivation	Spontaneous vegetation	*P* -value	Sig.
Plant ground-cover (%)[a]	6.58	99.44	< 0.001	***	70.47	67.89	0.639	n.s.
Plant biomass (tonnes/ha)[b]	0.06	3.76	< 0.001	***	2.13	2.51	0.441	n.s.
Plant species identified per season[c]	3.50	8.50	0.046	*	8.50	6.25	0.161	n.s.

Levels of significant differences between treatments are shown by: $p > 0.05$ (n.s.), $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

[a] Plant ground cover was averaged for the entire growing season (n = 36). A Wilcoxon non-parametric test was used to compare treatment means at both sites.

[b] Plant biomass was averaged for the entire growing season (n = 12). A Wilcoxon non-parametric test in Eden Valley and an independent t-test in McLaren Vale were used to compare treatment means.

[c] Plant species identified were totalled per season (winter, spring, summer, and autumn) and averaged (n = 4). Independent t-tests were conducted to compare means at both sites.

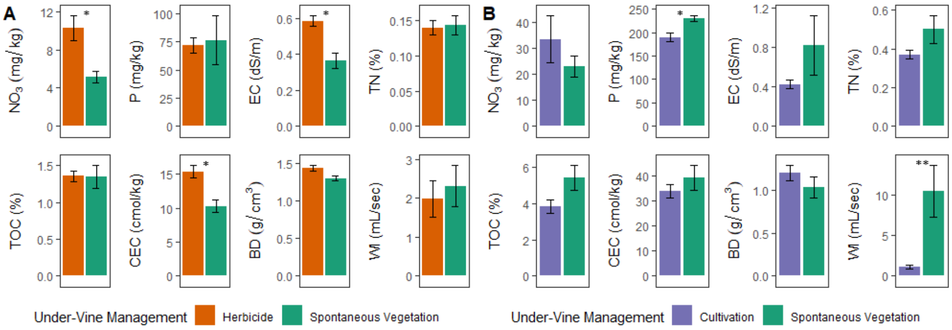

Figure 1. Bar charts showing the average and standard errors for under-vine soil measurements collected during the 2020-2021 growing season at (Union) Eden Valley for herbicide and spontaneous vegetation treatments; and at (B) McLaren Vale for cultivation and spontaneous vegetation treatments.

Nitrate (NO_3^-), Colwell phosphorus (P), electrical conductivity (EC), total nitrogen (TN), total organic carbon (TOC), cation exchange capacity (CEC), and bulk density (BD) were compared between treatments using an independent t-test (n = 3) while a Wilcoxon non-parametric test was used for water infiltration (WI, n = 9). Significance levels are indicated where $p < 0.05$ (*) and $p < 0.01$ (**).

The herbicide treatment in Eden Valley affected some of the measured soil physiochemical properties, resulting in higher nitrate, electrical conductivity, and cation exchange capacity (Figure 1). Given that the plant dynamics were very different between the treatments at the site, it is suggested that the greater plant coverage in the spontaneous vegetation treatment likely consumed more nitrate from the sampled soil horizon (Celette *et al.*, 2009). Bulk density was marginally lower for the spontaneous vegetation treatment (*p*-value = 0.081), which suggests that soil macro-porosity was increased by the below-ground root system (Figure 1, Ruiz-Colmenero *et al.*, 2012). Less shoots per metre were observed in the spontaneous vegetation treatment (Figure 2), likely driven by the competition with plant species for available cations and nitrate, which aligns with the soil results (Figure

1, Tesic *et al.*, 2007). The maturity curves indicate that although the two treatments followed a parallel ripening pattern up until harvest, the spontaneous vegetation treatment separated at harvest and the resulting fruit was higher in total soluble solids, while otherwise having lower pH and titratable acidity (Figure 3).

In McLaren Vale, because the under-vine plant dynamics ensuing from the two different under-vine management techniques were comparable, it appears that the mechanical and disruptive nature of under-vine cultivation itself was the primary driver in the differences observed between the under-vine soil and grapevine measures of these two treatments (Armengot *et al.*, 2016). Phosphorus was lower in the cultivation treatment with 230 mg/kg compared to 190 mg/kg in the spontaneous vegetation (Figure 1). This difference can be attributed to a couple of parameters, namely that the mechanical nature of cultivation was potentially eroding soil as one avenue of phosphorus loss (Alewell *et al.*, 2020), and furthermore was possibly disrupting the symbiotic relationship between plant roots and soil microorganisms such as arbuscular mycorrhiza fungi, which can enhance phosphorus mobility in the soil (Hallama *et al*., 2019). In addition to the effect on soil phosphorus, the cultivation treatment also resulted in significantly slower rates of water infiltration (Figure 1) likely because of less connected, discontinuous soil pores (García-Díaz *et al.*, 2018), and thus had resultingly lower yields than the spontaneous vegetation treatment (Figure 2).

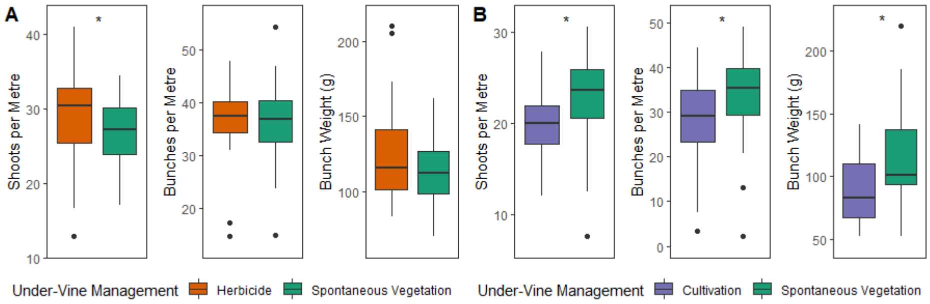

Figure 2. Boxplots showing yield measurements collected for the under-vine treatments during the 2020-2021 growing season at (Union) Eden Valley for herbicide and spontaneous vegetation treatments; and at (B) McLaren Vale for cultivation and spontaneous vegetation treatments.
Yield measurements of shoots per metre, bunches per metre, and bunch weight were compared using Wilcoxon non-parametric tests (n = 27) between treatments where significance levels are indicated by $p < 0.05$ (*).

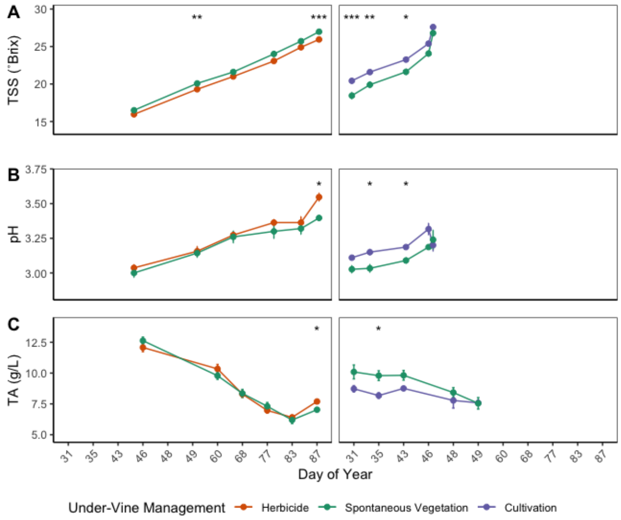

Figure 3. Maturity curves showing total soluble solids (TSS), pH, and titratable acidity (TA) at different sampling times prior to harvest at (A) Eden Valley for herbicide and spontaneous vegetation treatments; and at (B) McLaren Vale for cultivation and spontaneous vegetation treatments.
Wilcoxon non-parametric tests (n = 3) were used for all measurements where significance levels are indicated by $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

The silty loam soil texture of the McLaren Vale soils facilitated the ability of plant roots to establish connective, continuous soil pores that greatly impacted water movement, whereas the spontaneous vegetation treatment on the hydrophobic, sandy loam soils of Eden Valley did not enable the same trend. The final juice composition measured in McLaren Vale indicated that there were no differences in total soluble solids, pH, or titratable acidity once the fruit was harvested, which can likely be attributed to the relatively high cation exchange capacity at this site in both treatments, and as such grapevines were not limited when taking up nutrients (Leibar *et al.*, 2017, Figure 3).

Conclusion

This study investigated the effects of long-term under-vine management practices carried out at commercial vineyard sites in Eden Valley and McLaren Vale on plant communities, soil properties, and grapevine responses. At both sites, a treatment area with an unmanaged spontaneous vegetation under-vine row was compared to either an herbicide (Eden Valley) or an under-vine cultivation (McLaren Vale) treatment. The effects of the herbicide and cultivation treatments at the two sites were very different. The herbicide treatment very significantly lowered plant cover, biomass, and species richness, whereas the cultivation treatment did not impact these same plant dynamics. The two different soil types were the primary drivers of how the soils responded directly to the different management variables and indirectly to the different resulting plant communities. The hydrophobic, sandy loam soils at Eden Valley showed differences in nitrate in particular, with the higher concentration in the herbicide treatment indicating the under-vine plant species likely directly competed for this plant-available form of nitrogen. This difference in soil nitrate between the treatments therefore led to more shoots per metre in the herbicide treatment. At both sites, there was an indication that the plant roots in the spontaneous vegetation treatment contributed to lessening soil compaction in Eden Valley and increased water infiltration in McLaren Vale, enabled by the network of continuous, connected pores. Harvest juice chemistry was more impacted by the herbicide treatment at Eden Valley than the cultivation treatment at McLaren Vale, which can be attributed to the different cation exchange capacities of the soils at these sites. At McLaren Vale, the fruit composition was similar between treatments, yet yields were higher at the spontaneous vegetation treatment due to ultimately higher water availability as a result of greater water infiltration. Ultimately, this study reveals the significant interaction between under-vine management and soil type, and how production goals can be aligned to create economically and environmentally favourable under-vine management strategies.

References

Alewell, C., Ringeval, B., Ballabio, C., Robinson, D.A., Panagos, P., Borrelli, P. (2020). Global phosphorus shortage will be aggravated by soil erosion. *Nature Communications*, 11, 1-12. https://doi.org/10.1038/s41467-020-18326-7

Armengot, L., Blanco-Moreno, J.M., Barberi, P., Bocci, G., Carlesi, S., Aendekerk, R., Berner, A., Celette, F., Grosse, M., Huiting, H., Kranzler, A., Luik, A., Mader, P., Peigne, J., Stoll, E., Delfosse, P., Sukkel, W., Surbock, A., Westaway, S., Sans, F.X. (2016). Tillage as a driver of change in weed communities: a functional perspective. *Agriculture, Ecosystems and Environment*, 222, 276-285. https://doi.org/10.1016/j.agee.2016.02.021

Celette, F., Findeling, A., Gary, C. (2009). Competition for nitrogen in an unfertilized intercropping system: The case of an association of grapevine and grass cover in a Mediterranean climate. *European Journal of Agronomy*, 30(1), 41–51. https://doi.org10.1016/j.eja.2008.07.003

European Union, (2017). Commission Implementing Regulation (EU) 2017/2324 of 12 December 2017 renewing the approval of the active substance glyphosate in accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market, and amending the Annex to Commission Implementing Regulation (EU) No 540/2011. *Official Journal of the European Union,* L 333, 10-16.

García-Díaz, A., José Marqués, M., Sastre, B., Bienes, R. (2018). Labile and stable soil organic carbon and physical improvements using groundcovers in vineyards from central Spain. *Science of the Total Environment*, 621, 387-397. https://doi.org/10.1016/j.scitotenv.2017.11.240

Gordon, E., Davila, F., Riedy, C. (2021). Transforming landscapes and mindscapes through regenerative agriculture. *Agriculture and Human Values*, 1-18. https://doi.org/10.1007/s10460-021-10276-0

Guzmán, G., Cabezas, J.M., Sánchez-Cuesta, R., Lora, Á., Bauer, T., Strauss, P., Winter, S., Zaller, J.G., Gómez, J.A. (2019). A field evaluation of the impact of temporary cover crops on soil properties and vegetation communities in southern Spain vineyards. *Agriculture, Ecosystems, and Environment*, 272, 135–145. https://doi.org/10.1016/j.agee.2018.11.010

Hallama, M., Pekrun, C., Lambers, H., Kandeler, E. (2018). Hidden miners—the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. *Plants and Soil*, 434, 7-45. https://doi.org/10.1007/s11104-018-3810-7

Isbell, R.F., National Committee on Soil Terrain (2021). *The Australian Soil Classification*. 3rd edn. CSIRO Publishing, Melbourne, Victoria.

Leibar, U., Pascual, I., Aizpurua, A., Morales, F., Unamunzaga, O. (2017). Grapevine nutritional status and K concentration of must under future expected climatic conditions texturally different soils. *Journal of Soil Science and Plant Nutrition*, 17(2), 385-397.

Marks, J.N.J., Lines, T.E.P., Penfold, C., Cavagnaro, T.R. (2022). Cover crops and carbon stocks: How under- vine management influences SOC inputs and turnover in two vineyards. *Science of the Total Environment*, 831, 1-11. http://dx.doi.org/10.1016/j.scitotenv.2022.154800

Nordblom, T., Penfold, C., Weckert, M., Norton, M., Howie, J., Hutchings, T. (2018). Economic and financial risks in under-vine management alternatives to herbicide in four South Australian wine-grape districts, 2016 & 2017. Conference proceedings for the 62nd AARES Annual Conference, Adelaide, 6-9 February, 2018, 1-28.

Porzig, E.L., Seavy, N.E., Owens, B.E., Gardali, T. (2018). Field evaluation of a simple infiltration test and its relationship with bulk density and soil organic carbon in California rangelands. *Journal of Soil and Water Conservation*, 73(2), 200-206. http://doi:10.2489/jswc.73.2.200

Rayment, G.E., Lyons, D.J. (2011). *Soil Chemical Methods - Australasia, Soil Use and Management*. CSIRO Publishing, Collinswood, Victoria.

Reeve, A.L., Skinkis, P.A., Vance, A.J., Lee, J., Tarara, J.M. (2016). Vineyard floor management influence 'Pinot noir' vine growth and productivity more than cluster thinning. *Journal of the American Society for Horticultural Science*, 51(10), 1-12. https://doi.org/10.21273/HORTSCI10998-16

Tesic, D., Keller, M., Hutton, R.J. (2007). Influence of vineyard floor management practices on grapevine vegetative growth, yield, and fruit composition. *American Journal of Enology and Viticulture*, 58(1), 1- 11.

Ruiz-Colmenero, M., Bienes, R., Eldridge, D.J., Marques, M.J. (2012). Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. *Catena*, 104, 153-160. https://doi.org/10.1016/j.catena.2012.11.007

Vanden Heuvel, J., Centinari, M. (2021). Under-vine vegetation mitigates the impacts of excessive precipitation in vineyards. *Frontiers in Plant Science*, 12, 1-14. https://doi.org/10.3389/fpls.2021.713135

Walsh, A., Kingwell, R. (2021). Economic implications of the loss of glyphosate and paraquot on Australian mixed enterprise farms. *Agricultural Systems*, 193, 1-9. https://doi.org/10.1016/j.agsy.2021.103207