RELATIONSHIPS BETWEEN VINEYARD SOIL PHYSIOCHEMICAL PROPERTIES AND UNDER-VINE SOIL COVER AS POTENTIAL DRIVERS OF TERROIR IN THE BAROSSA

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Abstract

Aims: Soils are an intrinsic feature of the landscape and have influenced culturally and economically important terroir delineation in many wine-producing regions of the world. Soil physiochemical properties govern a wide array of ecosystem services, and can therefore affect grapevine health and fruit development. These physiochemical properties can reflect a combination of factors, including geology and environmental conditions, as well as soil management. In order to evaluate to what extent each of these factors contribute to the soil-driven aspect of terroir, this study examines soil properties and under-vine soil cover of twenty-four vineyard sites located in six sub-regions within the Barossa Geographical Indication (GI) Zone in South Australia. The aims of this study are to investigate relationships between soil properties and soil management as potential features that shape sub-regional variation in terroir characteristics that may eventuate in the development of smaller, distinctive sub-regional GI's within the Barossa GI Zone.

Methods and Results: Soil samples were collected from the under-vine rows of twenty-four vineyard sites, with four sites located in each of the six Barossa sub-regions of Central Grounds, Southern Grounds, Northern Grounds, Western Ridge, Eastern Ridge and Eden Valley. Soil physiochemical properties such as texture (% sand, % silt, and % clay), total carbon (TC), total nitrogen (TN), plant-available (Colwell) phosphorus (P), pH, electrical conductivity (EC), and gravimetric water content (GWC) were measured at each site. Under-vine soil cover at each vineyard site was then assessed by using 1m^2 quadrat surveys to categorise the under-vine zone based on the dominant plant species (perennial grasses or broadleaf weeds) or soil cover (bare soil or mulch). Results indicated that the Eden Valley had lower P than the Eastern Ridge and lower % clay than the Eastern Ridge and Central Grounds. The other measured soil properties were not different between the sub-regions. Under-vine floor cover did not play a significant role in shaping the measured soil properties in this study, instead it appears that soil texture was the main driver that explains these relationships.

Conclusions: Sub-regional variation in soil properties in the Barossa GI Zone was most strongly influenced by soil texture, which was variable at the sub-regional level in most of the sub-regions, however differences were found between the Eden Valley, Central Grounds and Eastern Ridge with the latter two sub-regions being characterised by soils with higher clay contents. Plant-available P was lowest in the Eden Valley, which could be explained by the higher sand content and therefore higher P leachability of soils in this sub-region. Under-vine soil cover did not have any effects on soil physiochemical properties between the vineyard sites, also likely because of the variability of soil texture between sites. The next steps in this study are to characterise the structure of soil microbial communities (i.e. microbiomes) in these six sub-regions to gain insight on how soil biogeography changes over an Australian wine-producing landscape.

Significance and Impact of the Study: This study provides insights as to the main drivers of soil sub-regional variation in the Barossa GI Zone and indicates that soils are highly variable even at the sub-regional level.

Keywords: Terroir, sub-regions, soil physiochemistry, under-vine soil cover

Introduction

The concept of terroir has significant cultural and economic importance in wine-producing regions of the world. Terroir refers to a combination of factors including geography, climate, soil, and cultural practices that contribute to unique wine sensory profiles imparted by their place of origin (van Leeuwen *et al.,* 2018). Wine-producing regions characterised by environmental similarities have historically been regulated and delineated in many countries around the world. In Australia, Geographical Indications (GI's) have been established in order to identify wines originating from particular localities, particularly to enhance international perceptions and gains from trade (van Caenegem *et al.,* 2014). Due to the large scale and therefore relatively high variability in wines resonating from these Australian GI's, it has been suggested that these larger regions could be delineated further into smaller more homogeneous sub-regions that may better represent collective wine sensory characteristics with the aim of improving marketability and economics for sub-regional producers (Skinner, 2020).

It has been demonstrated that soil physiochemical properties across a landscape are dependent on spatial and environmental factors (eg. Xue *et al.,* 2018), and can be related to unique soil microbial community structure on a spatial scale of a wine-producing region (Burns *et al.,* 2015). However, the relationship between regional soil properties, soil microbial communities, and wine sensory characteristics is relatively unknown, yet there is evidence that shows grape must bacterial communities display regional patterns that likely contribute to the concept of terroir (Bokulich *et al.,* 2013). Soil management may also play a significant role in defining terroir-related soil properties across a wine-producing region (Burns *et al.,* 2016), such as by increasing soil carbon and macroaggregate stability when cover crops or spontaneous vegetation were maintained instead of bare soil mid-rows in Spanish vineyards (Guzman *et al.,* 2019). Different soil management properties such as the use of cover crops, herbicides, tillage and spontaneous vegetation have direct implications for grapevine development and their suitability can vary significantly depending on site environmental characteristics and production goals (Garcia *et al.,* 2018).

This study takes a closer look at the sub-regional soil variation of the Barossa GI Zone of South Australia, which in 2019 reported 14,180 hectares under vine (Wine Australia, 2020). In order to investigate the potential provenance of smaller subregions with the larger zone, the Barossa GI Zone has been divided into six smaller sub-regions: Northern Grounds, Central Grounds, Southern Grounds, Eastern Ridge, Western Ridge and the Eden Valley. The under-vine row areas where the soil samples were collected were also categorised based on their predominant soil cover type in order to assess relationships between soil physiochemical properties and soil management as potential features influencing collective sub-regional terroir-related soil characteristics.

Materials and Methods

Soil samples were collected from the under-vine zones of twenty-four vineyard sites in the Barossa GI Zone. The samples were collected from 0-10 cm depth at three sampling zones in each site to form a composite soil sample of approximately 500 grams. Samples were stored on ice until returning to the laboratory, after which they were frozen at -20 ˚C for six months. The composite samples from each site were then divided into homogenous sub-samples. One subsample was used to measure gravimetric water content (GWC) by weighing the sample before and after drying in a 105 ˚C oven for 48 hours. Another subsample was air-dried at 40˚C for five days and sieved using a 2mm sieve. Physiochemical analyses were performed on the air-dried, sieved fraction by the Australian Precision Agriculture Laboratory. These included a particle size assessment measured by mid-infrared spectroscopy (Merry and Janik, 2001), total carbon (TC) and total nitrogen (TN) measured by dry combustion, and plant-available (Colwell) phosphorus (P). Soil pH and electrical conductivity (EC) were measured after preparing a 1:5 soil:water dilution and shaking end-over-end for one hour. Relationships between sub-regions and soil physiochemical properties was then assessed using a non-parametric Kruskall-Wallis test (R Core Team, 2013).

Under-vine soil cover at each site was measured using 1 m^2 quadrats that were sectioned into 10 x 10 cm subplots. Three quadrats were randomly placed in the under-vine rows of the three sampling zones at each site, for a total of nine quadrat surveys per site. Plant species in the quadrats were identified and the percent cover of each species were estimated in the quadrat by counting the 100 cm^2 squares (Guzman *et al.,* 2019). If no plants were present in the square, then it was assigned as either "bare soil" or "mulch" based on the cover observed. The under-vine soil cover of each of the vineyard sites was then categorised into the following groups: perennial grasses, broadleaf weeds, bare soil or mulch based on the cover type that was the majority after conducting all nine surveys. Relationships between soil cover and soil physiochemical properties were examined using a principal component analysis (PCA) using the XLSTAT software (Addinsoft, 2020).

Results and Discussion

The sub-regional delineations within the Barossa Zone GI were assessed by evaluating soil properties and under-vine soil cover from four vineyards within each sub-region. The Eden Valley sub-region differed significantly in plant-available P from the Eastern Ridge sub-region, with 20.25 mg kg^{-1} P and 94.00 mg kg^{-1} P, respectively, while P was not different between the other sub-regions (Figure 1a). This lower P in Eden Valley is likely due to the higher sand content of vineyards in the sub-region, which had the highest % sand, 86.5%, out of the six sub-regions (Figure 1b). In sandy soils, such as those in the Eden Valley, it can be expected that plant-available P would be lower than in soils with smaller particle sizes such as those with higher % clay such as the Eastern Ridge, due to a lower capacity to hold soil nutrients and water because of less interaction between infiltrating water and the soil matrix (Andersson *et al.,* 2013). Particle size distribution was also different between the Eden Valley, Central Grounds, and Eastern Ridge sub-regions. Percent clay was higher in the Central Grounds and Eastern Ridge sub-regions with means of 21.48% and 14.75% clay, respectively, than in the Eden Valley, with 7.03% clay (Figure 1c). The Central Grounds was further characterised by having greater % silt than the Eden Valley (Figure 1d). These distinctive differences in soil texture between the Central Grounds and Eastern Ridge compared to the Eden Valley likely play a role in determining grapevine water and nitrogen status, which have direct implications for berry properties such as sugar, anthocyanin, and nitrogen contents (van Leeuwen *et al.,* 2004).

There were no significant differences between the Barossa sub-regions in regards to the measurements for the other soil properties of GWC, pH, EC, TC, TN, and C:N ratio, indicating that the Barossa soils are fairly variable and therefore difficult to categorise into sub-regions based on these soil measurements alone.

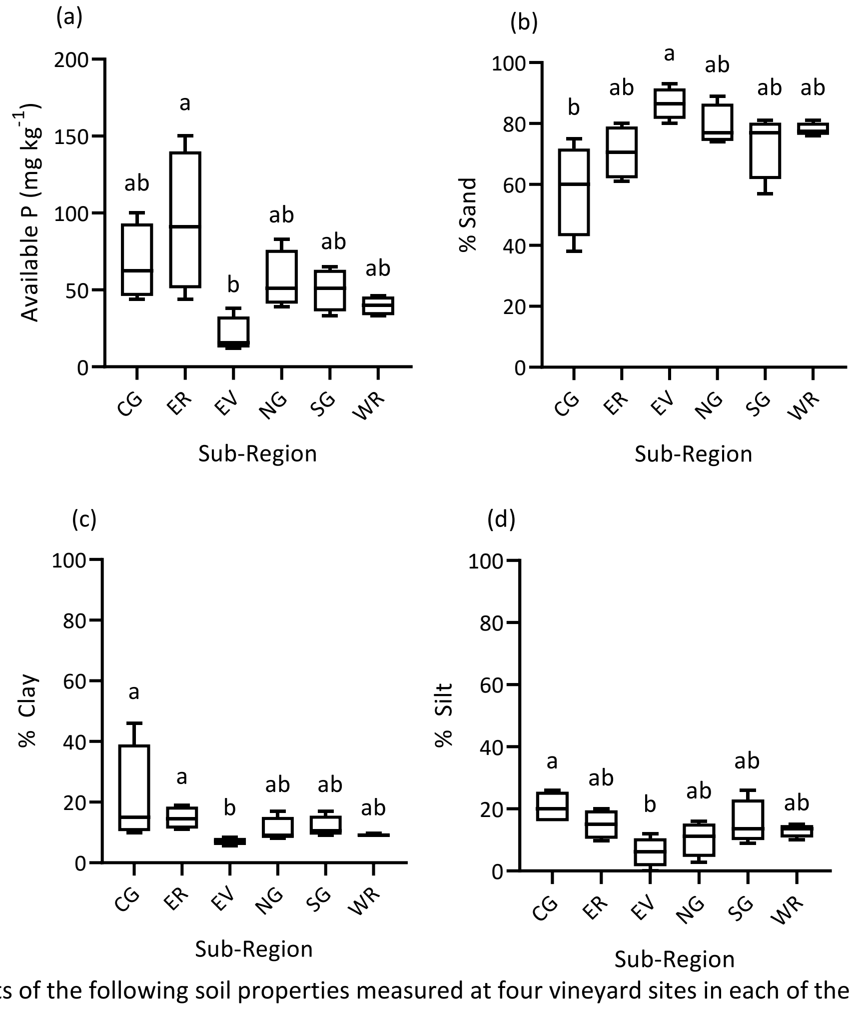

Figure 1: Boxplots of the following soil properties measured at four vineyard sites in each of the six Barossa sub-regions (CG=Central Grounds, ER=Eastern Ridge, EV=Eden Valley, NG=Northern Grounds, SG=Southern Grounds,

WR=Western Ridge): (a) Available (Colwell) P, (b) % sand, (c) % clay, and (d) % silt. Significant differences between sub-regions was determined by a Kruskal-Wallis test (df = 5) at $p < 0.05^*$, indicated by different lowercase letters.

Under-vine floor plant cover did not play a substantial role in shaping the measured soil properties in this study; instead, it appears that soil texture was the more significant driver that explains these relationships (Figure 2). There were no apparent correlations between sites including perennial grasses, broadleaf weeds, bare soil or mulch in the under-vine row. This finding is different from a block-designed study in a Spanish vineyard where maintaining permanent under-vine vegetation for six years compared to under-vine tillage significantly increased TC by four times (Lopez-Pineiro *et al.,* 2013). It is likely, therefore, that the variability of soil textures between sites in the same sub-region make it difficult to observe significant effects of different under-vine cover across a landscape. It is therefore necessary to further categorise groups of sites based on soil textural class (Salome et al., 2016), and microbial community (Burns *et al.,* 2015) which will be explored in future work.

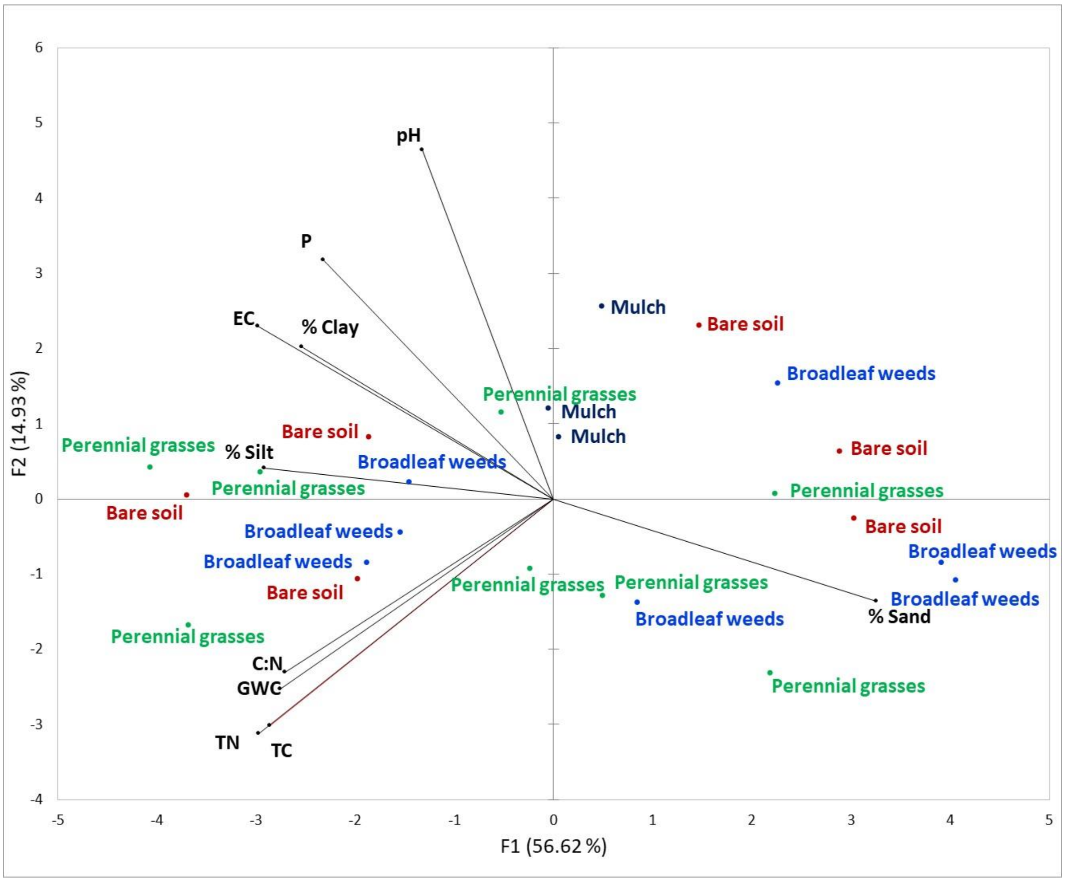

Figure 2: A principal component analysis (PCA) plot of the measured soil properties: % total carbon (TC), % total nitrogen (TN), gravimetric water content (g^{-1} g^{-1}) (GWC), electrical conductivity (dS m^{-1}) (EC), pH, available (Colwell) P (mg kg^{-1}) (P), % clay, % silt, and % sand; and the 24 vineyard sites delineated by their floor plant cover categories (bare soil, mulch, broadleaf weeds and perennial grasses).

Conclusions

In this study soil texture was a principle factor that influenced the sub-regional soil variation between twenty-four vineyard sites located in six-sub-regions of the Barossa GI Zone. There were significant differences between the soil texture of sites studied in the Eden Valley compared to the Central Grounds and Eastern Ridge sub-regions, with the latter being characterised by having higher % clay, which likely influences grapevine development due to different water and nutrient holding capacities. Under-vine soil cover did not have a significant effect on soil physiochemical properties as was expected, likely because of the observed variability in soil texture within sub-regions. The extent to which these factors contribute to defining the structure of the soil microbial communities (i.e. microbiomes) of these Barossa sub-regions is yet to be determined and is the next step of this study.

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References

Andersson, H., Bergstrom, L., Djodjic, F., Ulen, B., Kirchmann, H., 2013. Topsoil and subsoil properties influence phosphorus leaching from four agricultural soils. Journal of Environmental Quality, 42:2, 455-463.

Burns, KN., Bokulich, NA., Cantu, D., Greenhut, RF., Kluepfel, DA., O'Geen, AT., Strauss, SL., Steenwerth, KL., 2016. Vineyard soil bacterial diversity and composition revealed by 16S rRNA genes: Differentiation by vineyard management. Soil Biology and Biochemistry, 103: 337-348.

Burns, KN., Kluepfel, DA., Strauss, SL., Bokulich, NA., Cantu, D., Steenwerth, KL., 2015. Vineyard soil bacterial diversity and composition revealed by 16S rRNA genes: Differentiation by geographic features. Soil Biology and Biochemistry, 91: 232–247.

Bokulich, NA., Thorngate, JH., Richardson, PM., Mills, DA., 2013. Microbial biogeography of wine grapes is conditioned by cultivar, vintage, and climate. Proceedings of the National Academy of Sciences, 111: E139-E148.

Garcia, L., Celette, F., Gary, C., Ripoche, A., Valdés-Gómez, H., Metay, A., 2018. Management of service crops for the provision of ecosystem services in vineyards: A review. Agriculture, Ecosystems, and Environment, 251: 158-170.

Guzman, G., Cabezas, JM., Sanchez-Cuesta, R., Lora, A., Bauer, T., Strauss, P., Winter, S., Zaller, JG., Gomez, J.A., 2019. A field evaluation of the impact of temporary cover crops on soil properties and vegetation communitites in southern Spain vineyards. Agriculture, Ecosystems, and Environment, 272: 135-145.

Lopez-Pineiro, A., Munoz, A., Zamora, E., Ramierz, M., 2013. Influence of the management regime and phenological state of the vines on the physiochemical properties and the seasonal fluctuations of the microorganisms in a vineyard soil under semi-arid conditions**.** Soil & Tillage Research, 126: 119-126.

Merry, RH., Janik, LJ., 2001. Mid infared spectroscopy for rapid and cheap analysis of soils. In: *Proceedings of the 10th Agronomy Conference:* Hobart, Tasmania, Australia, pp. 1-5.

R Core Team, 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from: http://www.R-project.org/

Salome, C., Coll, P., Lardo, E., Metay, A., Villenave, C., Marsden, C., Blanchart, E., Hinsinger, P., Le Cadre, E., 2016. The soil quality concept as a framework to assess management practices in vulnerable agroecosystems: A case study in Mediterranean vineyards. Ecological Indicators, 61: 456–465.

Skinner, W., 2020. Wine, geology mapping and the value of place in McLaren Vale. The Australian Journal of Anthropology, 31: 85-100.

van Caenegem, W., Cleary, JA., Drahos, P., 2014. Pride and profit: Geographical Indications as regional development tools in Australia. Journal of Economic and Social Policy, 16(1): 1-23.

van Leeuwen, C., Friant, P., Chone, X., Tregoat, O., Koundouras, S., Dubourdieu, D., 2004. Influence of climate, soil, and cultivar on terroir. American Journal of Enology and Viticulture, 55(3): 207-217.

van Leeuwen, C., Roby, J-P., de Rességuier, L., 2018. Soil-related terroir factors: A review. OENO One, 52: 173–188. doi: 10.20870/oeno-one.2018.52.2.2208.

Wine Australia, 2020. SA winegrape crush survey 2020. Retrieved from: https://vinehealth.com.au/wp-content/uploads/2020/03/SA-state-summary-2020.pdf

Xue, PP., Carrillo, Y., Pino, V., Minasny, B., McBratney, AB., 2018. Soil properties drive microbial community structure in a large scale transect in South Eastern Australia. Scientific Reports, 8: 1–11.