SOIL PROXIMAL SENSING PROVIDES DIRECTION IN DELINEATING PLANT WATER STATUS OF 'CRIMSON SEEDLESS' (*VITIS VINIFERA* L.) VINEYARDS

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Abstract:

Context and Purpose of the Study – 'Crimson Seedless' (*Vitis vinifera* L.) is a late-ripening, red seedless table grape cultivar with inadequate anthocyanin accumulation and less than ideal berry size issues. It was necessary to understand the natural variations in the vineyard as well as the application of proximal sensing to monitor, and estimate these variations to get desirable attributes in this cultivar. The objective of this study was to use of proximal and remote sensing tools, specifically soil electrical conductivity (EC), canopy normalized difference vegetation index (NDVI), and carbon isotope discrimination in a precision agriculture context, to assess the water status variability, and determine the effect of inferred variability on skin anthocyanin and flavonol concentration at harvest.

Material and Methods – A 'Crimson Seedless' (*V. vinifera* L.) grafted on to 'Freedom' (27% *vinifera* hybrid) rootstock vineyard was studied for two years with contrasting precipitation amounts. Soil electrical conductivity (EC) was proximally sensed with electromagnetic induction and canopy reflectance was sensed remotely to calculate normalized difference vegetation index (NDVI). Random and equi-distant (30 m × 30 m) sampling grids were utilized in 2016 and 2017 to ground truth proximally sensed data. Grape primary metabolites, including total soluble solids, total acidity, isotopic discrimination of berry sugars ($\delta^{13}C$) and pH were measured, and secondary metabolites were characterized with a C18 reversed-phase HPLC.

Results – Soil EC was related to the variation of season-long plant water status in 2016 (Deep EC: r = -0.71; Surface EC: r = -0.53). There was not a significant relationship between NDVI and plant water status in either year. The vineyard was separated and delineated into two water status zones based on stem water potential (Ψ_{stem}) in each year, and the water status between two zones were significantly and consistently different. The juice pH showed significant differences between two zones. The $\delta^{13}C$ was directly and significantly related to Ψ_{stem} integrals and the differences between the two water status zones were confirmed by either method in 2016. There were no differences in total anthocyanins in 2016. However, anthocyanin derivatives were greater in the low water status zone in the following year. Flavonol amounts were not consistently different between the two zones in either year. Our results indicated deep soil EC, season-long water status or $\delta^{13}C$ can be used interchangeably to spatialize and cluster management zones in commercial table grape vineyards.

Key Words: Crimson Seedless, table grapes, anthocyanins, flavonoids, water status, electrical conductivity, normalized difference vegetation index (NDVI), spatial variability, viticulture.

1. Introduction.

Proximal Soil Sensing for Vineyard Management in 'Crimson Seedless' Table Grape

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Abstract

A 'Crimson Seedless' vineyard was modeled to examine the ecophysical variation and plant water status influence on productivity and berry chemistry for two years. Electrical conductivity (EC) of the soil was proximally sensed with electromagnetic induction. A stratified random sampling method and an equidistant 30 m × 50 m grid sampling were utilized in 2016 and 2017 to ground truth proximally sensed data. Soil EC was related to variation of plant water status in 2016 (Deep EC: r = - 0.8; Surface EC: r = - 0.68). The vineyard was separated into two zones based on grape vine water status, and the two zones were significantly separated in water status. Grape primary metabolism was measured for total soluble solids, total acidity, pH and berry weight. Only pH showed significant differences based on different degrees of water stress in both seasons. Secondary metabolites were characterized with a C18 reversed-phase HPLC. The results indicated that peonidin was the most dominant anthocyanin form in 'Crimson Seedless' table grape. There was no difference in anthocyanins in 2016. However, delphinidin-, petunidin-, malvidin-3-glucoside; peonidin-, malvidin-3-acetyl-glucoside; and all the coumaryl- acylated except cyanidin- derivatives were higher in the relatively higher water stressed zone. Flavonols were not different between the two zones. This study provides evidence for optimizing the application of proximal sensing to monitor, estimate, and manage the on-site measurements of plant water status, productivity and berry chemistry in a large-scale vineyard.

Introduction

- Crimson Seedless is a late-ripening, red seedless table grape cultivar released by the U.S. Dept. of Agriculture Horticultural Crops Research laboratory (Ramming, Tarailo et al. 1995). This cultivar was described having firm, crunch berries and excellent flavor extending the availability of fresh fruit into late fall due to its late ripening. However, inadequate anthocyanin biosynthesis and less than ideal berry size may reduce the amount of fruit packed at the farm gate by 30% of the total yield. Almost all table grape production in California is in the southern San Joaquin Valley. The regions is classified as Region V with high evapotranspiration demand (Amerine and Winkler 1944) and all table grape producers use supplemental irrigation.
- Vineyards tend to have natural variations in soil electrical conductivity and topography even within the same growing site (Bramley, Ouzman et al. 2011). These growing site variabilities determined soil water availability to the grapevines (Bernstein 1975, Bramley, Ouzman et al. 2011).
- Previous studies have been investigating precision agriculture as a tool to manage and minimize the spatial variation (Hall, Lamb et al. 2002, Bramley, Proffitt et al. 2005). This approach allowed more focused and targeted handlings because the advancing modern technologies, including global positioning system (GPS), remote sensing, and geographical information systems (GIS), empowered the ability in precisely measuring site attributes based on the whole vineyard system. By these technologies, traditional on-site measurements can be linked to specific locations in the vineyard, and the data can be processed with a computer-based GIS to make appropriate management decisions by layering and integrating multiple maps (Hall, Lamb et al. 2002). Previous research has been conducted on the relationship between vine vigor (Lamb, Weedon et al. 2004, Cortell, Halbleib et al. 2005), vine water status (Brillante, Martínez-Lüscher et al. 2017), yield, and topography (Bramley, Ouzman et al. 2011) with flavonoid contents by precision viticulture approach.
- The purpose of this study was to investigate the application of precision viticulture tools to assess the variability in a red table grape variety 'Crimson Seedless' vineyard on monitoring soil EC, and how it can be linked to plant water status. Furthermore, to study on how plant water status manipulates grape berry primary and secondary metabolites in a large commercial vineyard scale.

Materials and Methods

- **Vineyard Site and Plant Materials:** This study was conducted in a commercial *Vitis vinifera* L. 'Crimson Seedless' vineyard grafted onto Freedom (Fresno 1613-59 × Dog Ridge 5, 27% *V. vinifera* hybrid; high vigor, nematode resistant) rootstock located in Earlimart, Tulare County, CA. USA. Vines were planted at 2.13 m × 3.25 m (vine × row). The grapevines were trained to a quadrilateral system with fruiting zone spaced 60 cm apart and located 1.2 m above ground. The vines were cane pruned, leaving 8 canes per vine, and 8, two-node renewal spurs on each cane.
- **Soil Measurements:** The instrument used for surface mapping of the electric conductivity was the EM38-DD (Geonics Ltd., Ontario, Canada) used in both vertical dipole mode (VDM) and horizontal dipole mode (HDM). The instrument was placed on a PVC sled and pulled by a tractor along the inter-rows, at a distance of about 5 m to avoid interference phenomena.
- **Vine Measurements and Berry Chemistry Analysis:** Plant water status was measured at solar noon as stem water potential (Ψs). Final Ψs measurements (September 7, 2016; August 29, 2017) were utilized to exhibit plant water status. Berry primary metabolites were measured, including total soluble solids (Brix °), total acidity (TA), pH and berry weight. Skin flavonoids were analyzed by RP-HPLC (Ritchey & Waterhouse, 1999). Carbon isotope discrimination δ13C analysis was assessed from grape juice (Gaudillère et al. 2002).

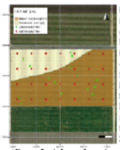

Figure 1. Soil map of the experimental site, obtained from USDA Natural Resources Conservation Service – Web Soil Survey. Soil unit types include: **Hanford Sandy Loam:** Coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents; and **Yettem Sandy Loam:** Coarse-loamy, mixed, superactive, thermic Entic Haploxerolls.

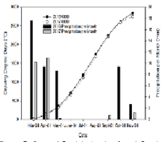

Figure 2. Seasonal Precipitation (mm), and Growing Degree Day (°C) in a commercial red table grape 'Crimson Seedless' vineyard in Earlimart, California, USA

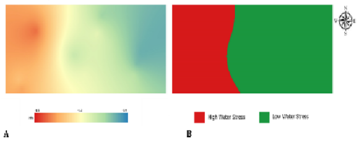

Figure 3. Interpolation map of vine stem water potentials (Ψs) and k-means clustering in 2016. (A) Kriged map on vine water potentials (Ψs); (B) k-means clustering of vine stem water potential from kriged maps into two zones.

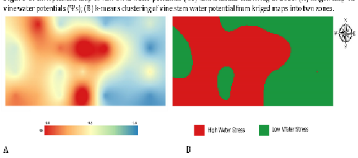

Figure 4. Interpolation map of vine stem water potentials (Ψs) and k-means clustering in 2017. (A) Kriged map on vine water potentials (Ψs); (B) k-means clustering of vine stem water potential from kriged maps into two zones.

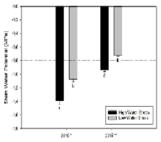

Figure 5. Vine stem water potentials (Ψs) comparison between the two zones in 2016 and 2017 in a commercial red table grape 'Crimson Seedless' vineyard in Earlimart, California, USA. Dot line (-0.8 MPa) represents the industry applied water stress standard.

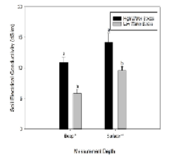

Figure 6. Deep EC and Surface EC comparison between the two zones in 2016 in a commercial red table grape 'Crimson Seedless' vineyard in Earlimart, California, USA

Table 1. Berry Composition between Two Clusters Based on Stem Water Potential in Red Table Grape 'Crimson Seedless' in 2016 and 2017 [1]

		2016			2017		
		High Water Stress ± SE	Low Water Stress ± SE	*p* value	High Water Stress ± SE	Low Water Stress ± SE	*p* value
TSS (Brix °)		20.50 ± 0.29	20.54 ± 0.21	0.924	19.50 ± 0.53	19.06 ± 0.27	0.465
TA (g / 100 mL)		0.38 ± 0.01	0.39 ± 0.01	0.381	0.44 ± 0.01	0.45 ± 0.01	0.601
pH		4.03 ± 0.01 a	3.98 ± 0.01 b	0.020	3.77 ± 0.01 a	3.70 ± 0.02 b	0.018
Berry Weight (g)		5.45 ± 0.15	5.75 ± 0.10	0.118	5.00 ± 0.11	4.85 ± 0.09	0.080
TSA (mg / kg SDW)		1669.41 ± 65.65	1805.10 ± 203.39	0.749	1753.02 ± 277.50	1382.42 ± 138.39	0.148
TSF (mg / kg SDW)		198.946 ± 9.966	227.589 ± 22.916	0.479	279.106 ± 31.430	232.108 ± 23.156	0.217
3'4'5'OH/3'4'OH Ratio [2]	Anthocyanins	17.56 ± 1.05	14.38 ± 1.29	0.274	11.72 ± 0.88 a	9.19 ± 0.62 b	0.002
	Flavonols	8.35 ± 0.67	7.20 ± 0.77	0.161	8.00 ± 0.58	8.48 ± 0.59	0.785

[1] ANOVA to compare data (*p* value indicated); Letters within columns indicate significant mean separation according to Tukey's HSD test.
[2] Ratio is expressed in percentage (%)

Abbreviations: TSA, total skin anthocyanins; TSF, total skin flavonols; OH, hydroxylation.

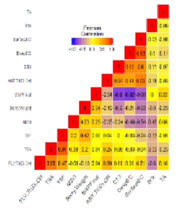

Figure 8. Correlation matrix, values were expressed in Pearson Correlation 'R' in 2016 in a commercial red table grape 'Crimson Seedless' vineyard in Earlimart, California, USA

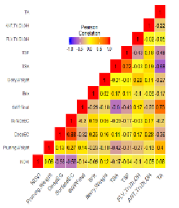

Figure 9. Correlation matrix, values were expressed in Pearson Correlation 'R' in 2017 in a commercial red table grape 'Crimson Seedless' vineyard in Earlimart, California, USA

Conclusion

Overall, the proximal soil sensing for soil EC and its final effects in plant water status could give us an approach towards understanding the variations in the vineyard. Because the water status played an undeniably critical role in grapevine biological development, it was forward-thinking to combine soil EC (Brevik, Fenton et al. 2006) and δ13C (Farquhar, O'Leary et al. 1982) analysis to simplify the assessment of grapevine water status across the whole vineyard. Also, NDVI needed modification for fitting in specific vineyards with various trellis systems to access grapevine vigor. Based on these precision viticulture tools, many strategies can be applied to overcome the variability in space, such as differential harvest (Bramley, Ouzman et al. 2011), and irrigating the vineyard differentially (Gardner, Blad et al. 1981). This study provides evidence for optimizing the application of proximal sensing, specific towards soil EC, to monitor, and to estimate grapevine water status, berry chemistry in a large-scale table grape 'Crimson Seedless' vineyard.

References