ELECTROMAGNETIC CONDUCTIVITY MAPPING AND HARVEST ZONING: DECIPHERING RELATIONSHIPS BETWEEN SOIL AND WINE QUALITY

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Abstract
Using electromagnetic conductivity mapping and GIS technology, we identified two unique soil zones within a 0.8-hectare Cabernet Franc block in central Virginia, USA. For three vintages we implemented a differential harvest and experimental winemaking based on soil zoning and noted that each zone produces unique wines despite the fact that both consist of the same rootstock, clone, row orientation, trellis system, vine age and undergo the same farming practices. Significant differences observed between the two lots, particularly potassium (K^+) levels and pH of the fruit and wine, have been consistent from vintage to vintage. Our findings suggest a relationship between soil physical characteristics, site hydrology, soil chemistry, nutrient levels in the vine and fruit, and wine chemistry (specifically K^+ and pH).

Keywords: geophysics, viticulture, terroir, soil, management zoning, potassium, wine, precision viticulture

INTRODUCTION

Previous research suggests that geophysical surveys have the potential to increase vineyard profitability and improve wine quality by shaping vineyard management practices to make the most of small-scale soil variations, unique to the growing site (Priori 2012, Tisseyre 2005). It has also been suggested that geophysics could serve as a useful tool for prospecting and site selection (Andre et al. 2012, Hubbard et al. 2004). Many commercial growers have experienced loss of fruit and/or fruit quality due to previously undetected soil variability and have voiced the broad need for new site-scale soils and geologic mapping techniques that provide complete coverage (Beasley 2014).

Soil properties have long been known to affect wine quality and numerous published works have attempted to shed light on this complex dynamic (i.e. White 2003, Wilson 1998). A recent study in Virginia suggested correlations between soil K^+ and fruit pH (an important wine quality parameter affected by fruit K^+) on single sites with other confounding viticultural and environmental variables controlled (Beasley, Morton, and Ambers 2015).

Potassium in fruit plays a critical role in the pH of must and wine (Keller 2010). pH is known to be a major influence on a number of wine quality factors including color, acid balance and microbiological stability (Zoecklein et al. 1990). Potassium availability in the soil can vary greatly and deficiencies can occur; however, in Virginia excess K^+ absorption by wine grapes is much more common than K^+ deficiency (Wolf 2007). Growers are commonly led to believe by laboratory analysis that potassium levels in their soils are low, when petiole analysis from the same location often shows elevated K^+ levels in the plant tissue. This has historically led to unnecessary K^+ additions to many Mid-Atlantic vineyards and has recently brought potassium nutrition into the spotlight in the commercial wine industry of the Mid-Atlantic US.

This work integrates EM mapping and GIS technology, field geology and experimental winemaking to examine the soil-vine relationship within a single vineyard block.

MATERIALS AND METHODS

Research Site

The study block (Figure 1) is located at Pollak Vineyards on the footslope of an early Pleistocene to Late Pliocene age debris fan deposit (Morgan et al. 2003) in western Albemarle County, Monticello American Viticultural Area (AVA), Virginia, USA. The Natural Resources Conservation Service (NRCS) mapped soil series is Dyke silt loam, an ultisol formed from predominantly greenstone colluvium. The Dyke soil taxonomic class is fine, mixed, semiactive, mesic Typic Rhodudults (NRCS 2006).

A two-acre Cabernet Franc planting (within a larger 4.05-hectare block) was selected for this work as it consists entirely of FPS 04 clone on 101-14 rootstock planted in 2003. Consistent vineyard management practices are employed across the entire block (bilateral cordon-training and a 3.05 x 2.13 m vine spacing, which equates to 1,537 vines/hectare). This study documents measurable differences in fruit and wine quality parameters due to soil variability within an otherwise homogeneously managed vineyard block.

Electromagnetic Conductivity Mapping

The geophysical data in this work were collected with the Geonics EM38-MK2 ground conductivity meter (EM38), which uses electromagnetic induction (EM or EMI) to measure both the electrical conductivity (EC) and the magnetic susceptibility of subsurface materials. EMI allows the user to survey large areas quickly, without any requirement for ground-to-instrument contact. The EM38 consists of boom-mounted coplanar electromagnetic transmitter and receiver coils that are set at a fixed distance. A current applied to the transmitter coil produces a time-varying magnetic field, which induces small secondary currents within the earth. These currents generate a secondary magnetic field, which is detected along with the primary field by the receiver coil, providing indications of subsurface electrical properties. The EM38 and similar meters are designed for relatively shallow applications, specifically within the agricultural root zone; the instrument is reported by the manufacturer to have a depth-of-penetration of 1.5 meters when run in the vertical dipole mode with the one-meter coil spacing. (McNeil 1980)

For this work, survey data were collected as individual transect lines and stored in a digital data recorder attached to the instrument. GPS coordinates were constantly streamed from a Differential GPS antenna, worn on the field worker's back, throughout the surveys. The instrument was held at a consistent height of approximately 8 cm above ground surface and was carried at a steady pace along each survey line. EM data were gridded via Kriging and were filtered, contoured and processed into maps using Surfer 12 by Golden Software and Global Mapper by Blue Marble Geographics.

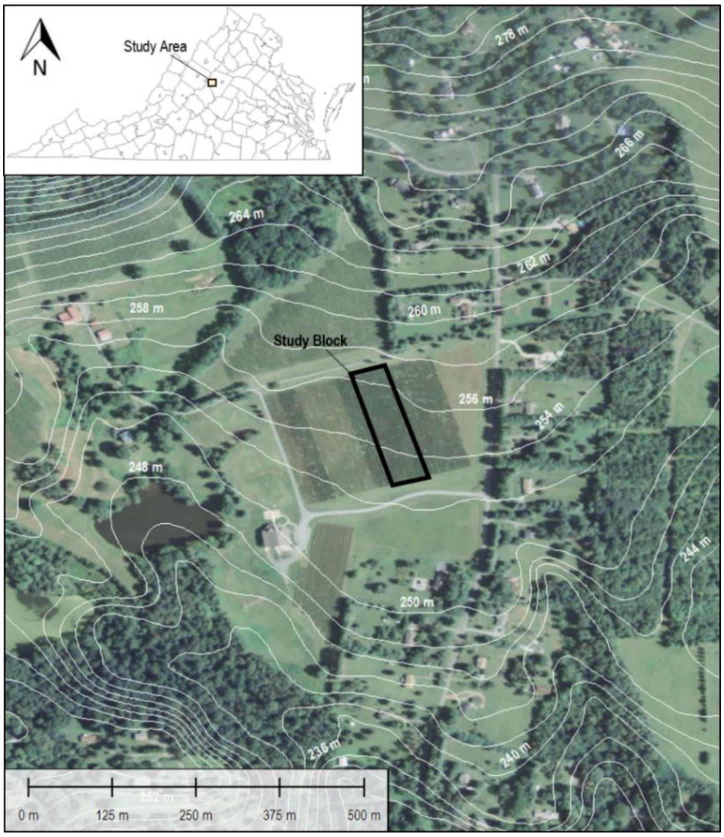

Figure 1: Study block consists of an approximately 0.81-hectare Cabernet Franc block with consistent clone, rootstock, vine age and viticultural practices.

Soil Profile Evaluation and Saturated Hydraulic Conductivity Testing

Backhoe pits facilitated field evaluation of soil profiles. United States Department of Agriculture-Natural Resource Conservation Service (USDA-NRCS) field methods were employed (Schoenberger et al. 2002) and detailed notes and photographs were taken. Samples were collected from discrete depths (selected in the field based upon soil horizon configuration and location of root zone) for chemical analysis by a commercial laboratory.

We performed saturated hydraulic conductivity tests (Ksats) at discrete depths at mapped locations within each zone to assess for correlations between drainage and the geophysical data. Ksats were executed using the Johnson Permeameter, a constant-head soil permeameter for determining hydraulic conductivity of earthen materials.

Viticultural Parameters

Pruning weights, average berry weights, and total yield measurements were conducted onsite with scales owned by Pollak Vineyards. We conducted composite petiole and berry sampling for laboratory chemical analysis to characterize the nutrient status of the vines and chemistry of the fruit. Petioles were collected at veraison in attempt to characterize the potassium status of the vines. All petioles and fruit samples in this work were analyzed by the same certified commercial laboratory for consistency.

Wine Chemistry, Harvest pH/Brix

Wine chemistry was analyzed by a certified commercial laboratory specializing in oenology. All wine samples analyzed in this work were submitted to the same laboratory year after year for consistency. Fruit maturity parameters (sugar and pH) were measured onsite with a refractometer and pH meter owned by Pollak Vineyards.

Differential Harvest and Experimental Winemaking

A differential harvest was carried out in the 2013, 2014, and 2015 vintages wherein fruit from two distinct 0.3-hectare soil zones within the study block was harvested separately. Each year, fruit from the two contributing zones was vinified separately in T-bins (insulated containers designed for fermentation with a capacity of 0.82 metric tons each). After destemming and a three-day cold maceration, the T-bins were inoculated with yeast. Any oenological additions or treatments required during vinification (ex: sulfur addition, tartaric acid, cap management, timing of press) were identical for each lot and detailed records were kept throughout the process. Each year, the experimental wines were aged in identical French oak barrels from the same cooperage for five months before bottling.

RESULTS AND DISCUSSION

Dozens of EM surveys over the course of three years and during a wide range of seasonal field conditions exhibited reproducible soil conductivity datasets at the study site. It must be noted that while trellis systems have been reported as sources of electromagnetic noise, amplifying EM conductivity readings to the point that the technique no longer can effectively map soil variability (Beasley 2014, Lamb 2009), the presence of metal trellis wire in its current configuration does not appear to affect the integrity of EM data at our site. The trellis system in our study block consists of wooden posts with a 10-foot (3.05 m) row spacing and a cordon wire set at 48 inches (121.9 cm) above ground surface.

Two distinct soil zones, referred to herein as “High Conductivity” (HC) and “Low Conductivity” (LC), were identified via EM mapping and an October 2015 backhoe pit investigation confirmed significant differences in soil profile characteristics.

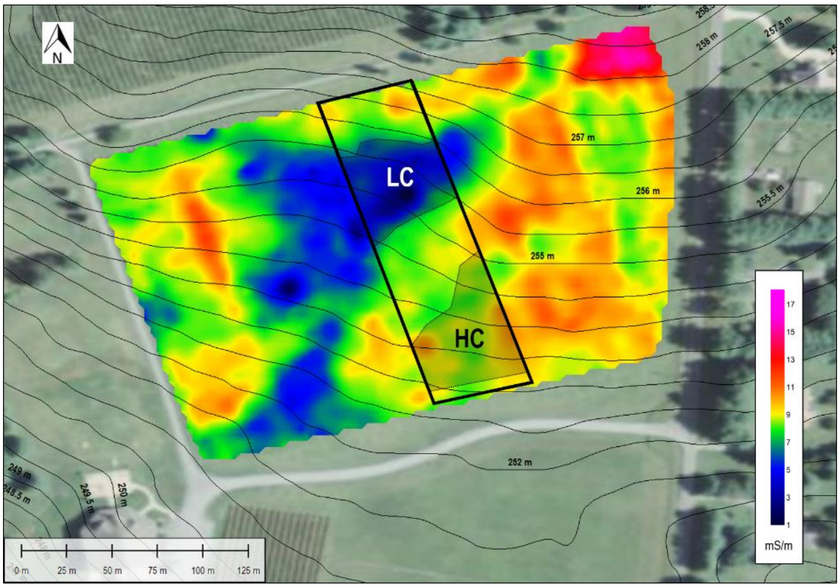

Figure 2: Electromagnetic conductivity map showing soil variability in study area. The two harvest zones (labeled LC and HC) are distinguished in the field by differences in soil properties which correlate to soil EC.

HC Zone Soil Physical Properties

The HC soil consists of silty clay topsoil (15 cm depth) over a clay subsoil and lies on a convex landform. Minor signs of compaction (platy structure) were observed in the upper 15 cm of the profile. The root zone extends down to approximately 45.7 cm below ground surface (bgs), where the top of a hardpan was observed. A corresponding abrupt shift in soil pH was noted at the upper hardpan boundary, suggesting a lack of downward mobility of historically applied liming materials as a result of the hardpan.

LC Zone Soil Physical Properties

The LC soil consists of silt loam topsoil (29 cm depth) over a silty clay loam subsoil and lies on a slightly concave landform. Abundant subangular greenstone gravels were observed throughout the profile. The root zone extends down to approximately 106.7 cm bgs, where a hardpan was observed. Redoximorphic features (iron accumulations and depletions) were noted from 106.7 cm down to the bottom of the pit (137 cm) and 5 cm of standing water was observed in the bottom of the backhoe pit.

Ksats

Saturated hydraulic conductivity testing at discrete depths in both soil zones suggested faster soil infiltration rates in the LC zone. Topsoil Ksats were 50.8 and 12.2 mm/hr and subsoil Ksats were 40.8 and 0.5 mm/hr, for the LC and HC zones respectively.

Table 1: Soil Properties

	LC Zone	HC Zone
Soil EC	0-3 mS/m	6-8 mS/m
Topsoil Texture	Silt Loam	Silty Clay
Subsoil Texture	Silty Clay Loam w/ gravels	Clay
Root Zone Depth	106.7 cm	45.7 cm
Landform	Concave	Convex
Ksat @ 35 cm depth	50.8 mm/hr	12.2 mm/hr
Ksat @ 82 cm depth	40.6 mm/hr	0.5 mm/hr

Soil Chemical Data

Soil chemical data are included on Tables 2a and b. In summary, the LC sample did have higher soil organic matter (OM); however, Tables 2a and b indicate that the HC sample was generally more nutrient-rich within the root zone. Of particular interest are the elevated potassium levels in the HC subsoil (approximately 2x those in the LC subsoil), which correlate to higher fruit and wine potassium and thus higher wine pH. This is a complex dynamic affected by soil pH and competing cations (among other factors) and isolating and fully exploring it in detail is beyond the scope of this phase of our study.

Table 2a: Soil Chemical Data

	LC Zone			**HC Zone**		
	Topsoil (0-29 cm)	Subsoil (46-61cm)	Deeper Subsoil (107 cm)	Topsoil (0-15 cm)	Subsoil (46 cm)	Deeper Subsoil (122 cm)
OM (%)	5.6	3.5	3.8	3.1	2.4	2.8
P (ppm)	18	3	1	21	5	1
K (ppm)	151	33	29	160	75	70
Mg (ppm)	243	140	138	292	251	187
Ca (ppm)	1494	1024	1151	1538	1429	1114
Na (ppm)	65	67	79	71	81	73
pH	6.4	5.3	5.2	7	7.1	4.9
CEC (meq/100g)	11.2	9.7	11.1	10.8	9.8	13.6
S (ppm)	17	224	184	42	26	300
Zn (ppm)	8.9	2.7	2.8	6.2	3.4	2.4
Mn (ppm)	94	9	8	117	78	34
Fe (ppm)	111	55	59	67	68	47
Cu (ppm)	6.8	0.8	0.4	2.7	0.9	0.5
B (ppm)	0.6	0.3	0.3	0.6	0.5	0.4

Table 2b: Base Saturation

	LC Zone			**HC Zone**		
	Topsoil (0-29 cm)	Subsoil (46-61cm)	Deeper Subsoil (107 cm)	Topsoil (0-15 cm)	Subsoil (46 cm)	Deeper Subsoil (122 cm)
K (%)	3.5	0.9	0.7	3.8	2.0	1.3
Mg (%)	18.1	12.0	10.4	22.5	21.3	11.5
Ca (%)	66.7	52.8	51.8	71.2	72.9	41.0
Na (%)	2.5	3.0	3.1	2.9	3.6	2.3
H (%)	8.9	30.9	34.2	0.0	0.0	43.9

Petiole, Fruit, and Wine Data

The minimal difference in sugar levels between the two blocks each vintage suggests even ripening across the study block at harvest (Table 3). Compared to the LC zone, the HC zone generally produced higher yields, more vigor, and fruit with higher pH. Of particular interest is the fact that higher soil K^+ in the HC root zone correlates to higher petiole K^+, fruit K^+, and ultimately wine K^+ and pH (Tables 3-5, Figure 3). It is very important to note that even in the LC zone (the zone with the lower K^+), potassium levels in the petiole are still significantly higher than the standard international viticultural recommendation of < 1.50% (Morton 2016).

Table 3: Harvest Data

	2013		2014		2015	
	LC Zone	HC Zone	LC Zone	HC Zone	LC Zone	HC Zone
Fruit pH	3.61	3.72	3.6	3.7	3.7	3.8
Sugar (°Bx)	23.7	23.7	24	24	22.7	22.9
Titratable Acidity (g/L tartaric)	6	6.5	5.1	5	ND	ND
Berry Weight (g/100 berries)	ND	ND	178	180	188	201
Pruning Weight (kg/panel)	4.26	5.17	3.36	3.90	4.60	5.10
Yield (tons/acre)	ND	ND	3.2	3.35	3.28	3.87

Table 4: Veraison Petiole Data

	2014		2015	
	LC Zone	HC Zone	LC Zone	HC Zone
N (%)	ND	ND	0.65	0.89
S (%)	0.22	0.23	0.37	0.37
P (%)	0.27	0.40	0.52	0.54
K (%)	3.23	3.79	3.01	4.03
Mg (%)	1.03	1.31	1.14	0.79
Ca (%)	1.90	1.87	2.21	1.75
Na (%)	0.07	0.07	0.09	0.12
B (ppm)	33	31	41	37
Zn (ppm)	104	114	118	107
Mn (ppm)	453	615	497	357
Fe (ppm)	58	69	79	152
Cu (ppm)	94	97	197	165
Al (ppm)	18	30	66	101

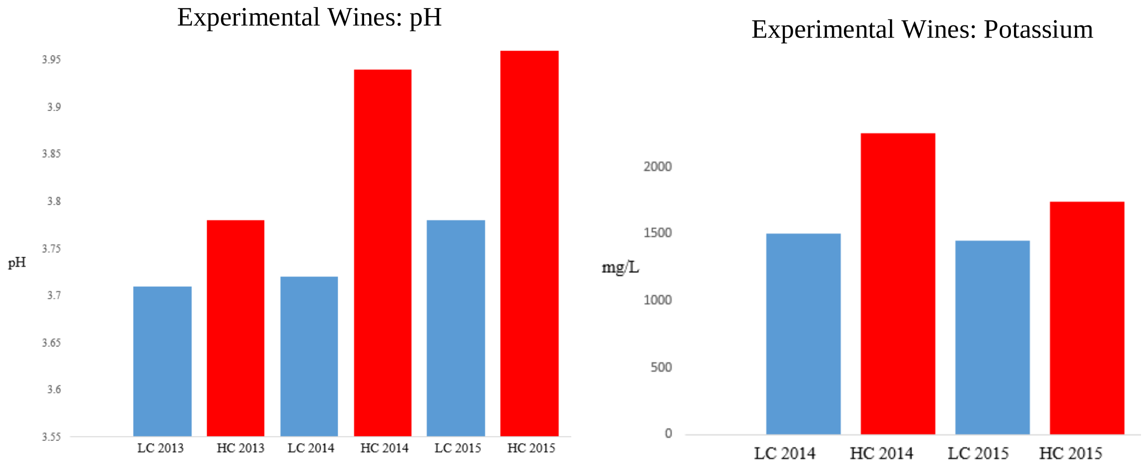

Figure 3: Bar graphs showing the pH and potassium concentrations of the final experimental wines. The LC wine consistently shows lower K^+ concentration and lower pH than the HC wine. Note that only pH values for the 2013 wines are provided as K^+ analysis was not initiated for this study until the 2014 vintage.

Table 5: Experimental Wine Chemical Data

	2013		2014		2015	
	LC Zone	HC Zone	LC Zone	HC Zone	LC Zone	HC Zone
Residual Sugar (%)	<1g/L	<1g/L	<1g/L	<1g/L	<1g/L	<1g/L
Alcohol (%)	13.62	13.81	13.61	13.46	13.25	13.28
pH	3.71	3.78	3.72	3.94	3.78	3.96
Volatile Acidity (g acetic acid/L)	0.61	0.59	0.67	0.6	0.5	0.49
Total Polyphenols (mg GA/L)	43	41	45	44	37	37
Calcium (mg/L)	ND	ND	72.38	67.83	61	53
Potassium (mg/L)	ND	ND	1505	2250	1454	1740
Magnesium (mg/L)	ND	ND	98.2	113.9	ND	ND
Manganese (mg/L)	ND	ND	1.12	2	ND	ND

CONCLUSION

EM mapping provided reproducible datasets and facilitated the identification of two distinct soil zones in our study block at Pollak Vineyards in Greenwood, Virginia. For the 2013, 2014, and 2015 vintages, each of the two zones were harvested and vinified separately. The High Conductivity zone, with higher clay content, a shallower root zone, higher subsoil potassium levels, and slower soil infiltration rates, produced wines of lighter color and higher pH than the Low Conductivity zone, with lower clay fraction, more gravels, a deeper root zone, less subsoil potassium, and faster soil infiltration rates. Of particular importance is the fact that the LC zone (the area with the lowest soil K^+ in this study) still showed elevated plant tissue potassium based on petiole analysis.

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