Scaling of *terroir* and geospatial mapping of vineyard soils via electromagnetic induction

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Abstract

Vineyard site assessment is the critical phase for high quality winegrape production. Site suitability is an important criterion; but it is also advantageous to understand the strengths and weaknesses of the landform at the outset of vineyard development, especially in regard to soil variability and pathogenicity. We conducted vineyard site analysis via geographic information systems (GIS) to determine suitability for growing *Vitis vinifera*. Geospatial mapping of subsurface soil horizons was conducted by measuring the apparent electrical conductivity (EC_a) via electromagnetic induction (EMI), to geolocate soil profiles via global positioning systems (GPS) for pedon description. By correlating EC_a values of the outlier soils with associative EC_a values, we were able to geolocate outliers. Soil chemistry, biology, pedology, surface morphometry, and micro-meteorology were evaluated and quantitatively scaled via an analytical hierarchy in order to determine site vigor. After the landform was deemed suitable for winegrape production, principal emphasis was directed to recommendations on vertical tillage methods and depths, rootstock and scion selection, liming rates, row orientation, vine density, irrigation needs, erosion control, cover cropping, canopy management, tiling, row spacing, soil amendments, and nematode control. By evaluating the analytical hierarchy, agronomic choices can be made concordant with their economic impact on quality.

Key Words

Pedology, winegrape-production-systems, mapping, viticulture, terroir, vineyard-development.

Introduction

Due to the unique morphology of the grapevine root, deep soils are of notable significance for successful viticulture. In an udic regime, the high disease susceptibility of *Vitis vinifera* requires well-drained soils for high quality winegrape production; and a well-balanced fertility program is essential due to the effects of soil nutrients upon vine vigor and berry maturation. Initiation of vineyard development requires intensive soil mapping (White *et al*. 2007) in order to detect the presence or absence of restrictive horizons (notably fragipan, claypan, duripan), variance in permeability, redoximorphic features, depth to bedrock or paralithic bedrock, perched horizon interfaces, penetration resistance, effective rooting depth (ERD), and pedotransfer functions such as texture, structure, and rock content by depth, which can be used to calculate available water capacity. By marrying the technologies of GPS, GIS, and pedology, soil mapping and scaling can be useful to strategize pre-planting soil preparations such as vertical tillage, as well as to serve as a template for variance in fruit quality, berry maturation rates, and yield.

EMI transmits a primary magnetic field at preselected frequencies to induce an electric current into a given solum, and a secondary magnetic field is created, depending upon the mineralogy of the soil solid, ionic strength of the soil solution, salinity, and the content of soil water, clay, rock, and nutrients. The values (dS/m) were heuristically stored in a compatible field computer. A geospatial map of the field site was analyzed by correlating disparities in soil EC_a within a test area (Doolittle *et al*. 1995). An analytical hierarchy was generated (Figure 1), in order to provide a comprehensive rating system which is essential in a complex system such as viticultural site assessment. In addition to providing guidelines for suitable varieties, the analytical hierarchy assists the grower in choosing cultural practices to modify an existing site. The analytical hierarchy uses a percentage system, which can be directly applied to other analytical systems, such as budget, integrated pest management (IPM), best management practices (BMP), or cropping decisions. A budget designed for site development optimally maximizes soil potential index (SPI), by allocating funds according to greatest economic benefit (Soil Survey Division Staff 1993): SPI = P-CM-CL, in which P is optimal performance of soils, CM is an index of successful corrective measures, and CL is an index of corrective measures which were not fully successful. Our aim of this process was to perform a site analysis by maximizing accuracy as well as economy of time and money.

Methods

Geospatial maps serve as reconnaissance tools for positioning soil profiles to analyze the site's pedology. By correlating the overt trends of the field's EC_a values with the results of pedology analysis, a model of variance can be inferred in a time-efficient and cost-effective manner. Results obtained from soil profile analysis, surface morphometry descriptions, soil sampling, and micrometeorological data were geolocated by GIS database. Resultant site scores determined viticultural methods. EC_a is affected by soil depth, soil and rock mineralogy, clay and crystal morphology, clay content (Doolittle *et al.* 1994), soil water, salinity, and rock content (Sudduth *et al.* 2001). The development of an analytical hierarchy assists in site selection (Itami *et al.* 2000).

Reconnaissance studies were conducted with an EM-400 Profiler (GSSI, New Hampshire) in concert with a Trimble field computer, by walking a grid with the device held at a constant pre-ordained height from the soil surface. The field site was 2 hectares (5 acres), in southeastern Pennsylvania, USA. Grid rows were staked every 3.04 meters (10 ft), oriented on the Y-axis, and extended 152 meters (500 ft). GPS was tracked and synchronized with EC_a values. After completing data acquisition, the data was transferred from the field computer to a laptop computer and manipulated with MagMapper software to create a dat.file, which was exported as a grd.file into Surfer 8.0 software to create a map (see Figure 2). A northwest-to-southeast transect was established to represent disparity in EC_a. Soil profiles were dug in pedons according to associative EC_a values. Soil water greatly influences soil EC (volumetric water content was measured at 18.1%, via time-domain reflectometry {TDR}). Pedology analysis was conducted in the field following the conventions of the US Soil Survey Staff (1993). Site description of terrain was conducted using the conventions of the National Cooperative Soil Survey (Schoeneberger *et al*. 2002). Particle size distribution and inductively coupled plasma emission spectrometry (ICP) were conducted by Logan Labs LLC, Lakeview, OH. Liming rates were calculated by assessing exchangeable bases, exchangeable Al, amphoteric Al, and sodium adsorption ratios (SAR) via the Gapon equation: $K_G = [Na^+] / (\{[Ca^{++}+[Mg^{++}]\}/2)^{-1/2}$.

Results and discussion

Field site characteristics and pedology

The Dystrudept soils represent the summit, shoulder, and backslope of the hill, in an udic water regime, at an elevation of 213 m (700 ft) MSL, at 40º North latitude, on a southern aspect at 154º, with a 4.1º slope. Mean annual precipitation is 1000 mm; mean annual air temperature is 12º C (54º F). Parent material was shale and siltstone, with an ochric epipedon. Surface morphometry ranges from convex-linear, to convex-convex at Profiles # 1 & 2, linear-convex at Profiles 3 & 4, linear-linear at the northeastern corner, and a slight (concave-concave) depression at the southeastern corner. The deep, friable, very well-drained, slightly acid, moderately permeable soils which reside on the shoulder and convex backslope of the hill varied drastically from the soils of Profile 3, which were very shallow with paralithic and lithic bedrock at 53 cm (21 in). Surface soils were dark brown (7.5YR 3/4) to brown (10YR 4/3), granular crumb to weak coarse subangular blocky, very friable with 15% channery/ 5% gravelly silt loams, underlain by strong brown (7.5YR 5/8) to yellowish brown (10YR 5/6), strong medium subangular blocky, friable, very sticky, very plastic, 20% channery/ 10% stony silty clay loams. Subsoils were reddish yellow (5YR 6/6) to pale brown (10YR 6/3), massive, firm to hard, 85% channery silty clay loams to a depth of 145 cm (57 in). Loamy-skeletal grains represent the colloid. ERD averaged field-wide at 61 cm (24 in); whereas the outlier at Profile 3 had an ERD of 45 cm (18 in).

Pedology analysis showed many fine rooting and high vesicular, tubular porosity in surface soils atop common fine rooting in the upper B horizons underlain by few and fine rooting to none below 69 cm (27 in). The slopes ranging from 4.1º - 8.4º exhibit a medium- to very high- hazard of surface runoff. Generally an accumulation of clay existed in the Bt horizon. Profile 3 lacked substantial clay cutans. The pedology of Profile 3 represented the outlier pedon, possessing a shallow bedrock at 53 cm, a feature which could adversely affect vine growth uniformity within the block. Although very little can be done to mollify a shallow soil such as this, viticultural techniques can be applied to moderate the detrimental effects of shallow soils. These techniques include – but are not limited to – vine density and usage of alternative rootstocks. Therefore the locations of such aberrations are of utmost importance. EMI can only be conducted before a trellis is installed due to the interference of metal. The pedon of profile #3 represented an EC_a reading of -25 dS/m. EC_a values were inversely proportional with rock content, and positively correlated with clay content. Total available water (TAW) capacity was 97.16 mm to a depth of 1.5 meters. ERD was 55 cm. Recommended rootstocks for this site's TAW were 101-14, or *V. riparia* Gloire (Cass, 2009), with irrigation.

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Parameter	Weighting	Data	Rating	Analytical score
Soils				
pH	0.0658	5.9	0.7	0.04606
drainage	0.3465	very well-drained	0.9	0.31185
texture	0.0308	SiL	0.75	0.0231
biology	0.0641	0 per 100 cc	1	0.0641
base saturation	0.0641	low Ca, K	0.7	0.04487
ERD	0.1288	22 inches	0.7	0.09016
Terrain				
slope	0.0143	4.1	0.9	0.01287
aspect	0.0453	SSE @ 154	1	0.0453
convexity	0.0213	CVX/LIN	0.8	0.01704
air drainage	0.0191	excellent	0.9	0.01719
Micro-Climate				
spring frost	0.0146	low	0.9	0.01314
GDD^C	0.0922	1159	0.75	0.06915
flowering season	0.0282	good	0.9	0.02538
ripening season	0.0564	good	0.9	0.05076
pathogenicity	0.0086	low	0.85	0.00731
		TOTAL SCORE		83.83%
Notes: 101-14, 420-A, Riparia 'Gloire' / vertical tillage with winged tine to 50 cm / row orientation NE-SW / aromatic whites / Pinot noir / 6000 kg ha^{-1} calcitic lime tilled in to 28 cm depth in soil.				

Figure 1. An analytical hierarchy, adapted from Itami *et al.* 2000, for an udic regime, in which a scoring key designates 100% as optimal, 70-100% as suitable for *Vitis vinifera* winegrape varietals, 50-70% as suitable for hybrid and native North American varieties; whereas sites ranking less than 50% are allocated for alternative crops. This site is suitable for *vinifera*.

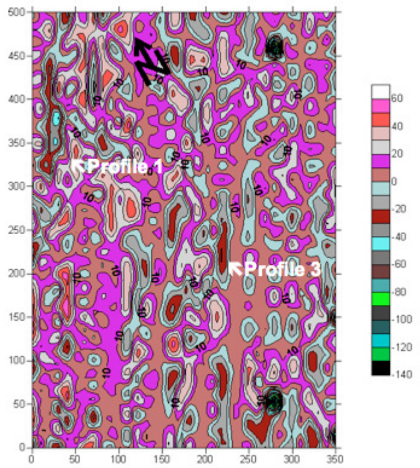

Figure 2. Geospatial map conducted at 1000 Hz, representing outlier pedon at -25 dS/m.

Variety selection: Vitis vinifera

The effect of Growing Degree Days (GDD) on berry maturation is prominent. Growing Cabernet sauvignon in a climate < 1390 GDD^C will result in off-flavors and -aromas, due to excessive production of isobutyl methoxypyrazines (Winkler, 1974). Methoxypyrazines are naturally abundant in reds particularly Cabernet sauvignon (as well as Sauvignon blanc). These methoxypyrazines begin translocation from leaves to fruit around veraison, resulting in vegetal off-flavors & -aromas if harvested before they can be dissipated sufficiently. These compounds are noticeably detrimental to wine quality at concentrations as low as 10 parts per trillion. In sites of marginal GDD, canopy management can focus on basal leaf removal pre-veraison.

Pinot noir which is rated at 1150 GDD^C (Gladstone 1992) is an exception due to its anomalous lack of production of anthocyanidids, a phenolic phytochrome which lends color attributes to red wine. 1159 GDD^C was recorded at a site proximal to this field site in 2008. Aromatic white varieties suitable for production on this site included Chardonnay, Sauvignon blanc, Albariño, Grüner veltliner, Arneis. A suitable red variety included Pinot noir.

Row orientation and vine density
Many factors determine row orientation, including but not limited to slope gradient, aspect, prevailing winds, and pathogenicity. On this site the excellent air drainage and ideal aspect can be exploited by aligning vine rows in a northeast-to-southwest orientation at 20°. This will maximize early sun exposure to reduce leaf wetness, and offset afternoon heat since *Vitis vinifera* will most efficiently photosynthesize between 20-25° C (70-80° F) (Slavcheva 1983); whereas photorespiration predominates at temperatures greater than 30° C (90° F). Recommended vine spacing for *V. vinifera* was on 1-meter centers; however 2-meter spacing is recommended on outlier soils in order to promote greater vine root density at shallower depths.

Conclusions
In concert with pedology analysis, geospatial mapping via EMI provided a general survey of the field, which served as a template to place soil profiles. Time and money was saved by using this technology; additionally, the disparity of the solum was accurately mapped to reveal and geolocate outliers. Finally, the use of an analytical hierarchy provided a score of the site strength. These techniques combine well to assess site strength and vigor in order to determine rootstock and scion selection, vine density, and ripping depth. Further work is currently underway to calibrate the skin depth of each frequency in order to better utilize EMI.

References:

Anderson-Cook CM, Alley MM, Roygard JKF, Khosla R, Noble RB, Doolittle JA (2002) Differentiating soil types using electromagnetic conductivity and crop yield maps. *Soil Sci. Soc. Am. J.* **66**, 1562-1570.

Cass A, Bazzano M (2009) *Influence of soil on wine quality*, 11th International Symposium on Soil and Plant Analysis, Santa Rosa, California, USA. July 21.

Doolittle JA, Kitchen NR, Indorante SJ (1994) Estimating depths to claypans using electromagnetic induction methods. *J. Soil Water Conserv.* **49**, 572-575.

Doolittle JA, Ealy E, Secrist G, Rector D, Crouch M (1995) Reconnaissance soil mapping of a small watershed using electromagnetic induction and global positioning system techniques. *Soil Surv. Horiz.* **36**, 86-94.

Gladstone J (1992) *Viticulture and Environment*, Winetitles, Adelaide

Itami RM, Whiting J, Hirst K, Maclaren G (2000) Use of analytical hierarchy process in cool climate GIS site selection for wine grapes. In ‘Proceedings 5th International Symposium on Cool Climate Viticulture and Oenology, Section 1B Climate and Crop Estimation’. pp. 1-8. (Adelaide: Australian Society of Viticulture and Oenology).

Soil Survey Division Staff (1993) ‘Soil survey manual’. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

Schoeneberger PJ, Wysocki DA, Benham EC, Broderson WD (2002) Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Slavcheva T (1983) Effect of temperature on photosynthesis in grapevine. *Gradinarska i Lozarska Nauka* **20**, 73-81.

Winkler AJ, Cook JA, Kliwer WM, Lider LA (1974) *General viticulture*. University of California Press, Berkeley, USA.

White R, Balachandra L, Chen D (2007) The soil component of terroir. *International Journal of Vine and Wine Sciences* **41**, 9-18.