KECK GEOLOGY CONSORTIUM

21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

April 2008

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Greg Wiles (The College of Wooster)
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Funding provided by:
Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium: Projects 2007-2008
Short Contributions – Walla Walla

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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ELECTRICAL CONDUCTIVITY AS A PREDICTOR OF SOIL CHARACTERISTICS IN THE WALLA WALLA VALLEY, OREGON

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INTRODUCTION

Spatial variations in soil properties control fertility, drainage, erodability, and other aspects of soil quality of interest in agriculture. In viticulture and other high-value agriculture, understanding spatial variation is especially important due to the precise nature of field planning, management, and water use. Measuring the electrical conductivity (EC) of soil across a field has become a widely used technique for indirectly assessing soil quality. Conductivity measures how well soil conducts an electric current, which is quantitatively related to properties of interest in some areas (e.g. Corwin and Lesch, 2003; Mueller et al., 2003; Jung et al., 2005; Table 1). Under favorable conditions, a single EC survey can provide low-cost information related to a range of important soil characteristics.

Characteristic	Possible Relation to EC
Water Content	Water readily conducts electricity; increasing soil water content increases soil EC
Texture	Soils with a higher clay content have smaller, more continuous pores than sandy soils; fine soils have a higher EC than coarse soils
Chemistry	Conductivity in a solution depends on the concentration of dissolved ions in the solution; increasing the concentration of salts in soil pore water increases soil EC
Cation Exchange Capacity (CEC)	High CEC indicates particles' ability to retain cations; increasing CEC will increase soil EC
Compaction/ Bulk Density	Bulk density, a measure of compaction, may be related to size and continuity of pore space; increasing bulk density will decrease soil EC
Organic Matter	Presence of organic matter increases available water content; increasing organic content will increase soil EC
Temperature	Conductivity of a solution increases with increasing temperature; increasing temperature will increase soil EC

Table 1. Soil characteristics and possible relation to soil EC. Adapted from Soil Survey Staff (1993).

This study investigates the relationships between soil EC and a suite of chemical and physical soil properties at a field site in the Walla Walla Valley, northwest Oregon. There have been no formal studies of these relationships in the Valley, though it is generally assumed that high soil EC reflects an area particularly suitable for viticulture, and fields are managed accordingly (Pogue, 2007). Here, this assumption is tested to determine which soil characteristics are statistically related to EC at the field site and the resulting implications for viticulture in the Walla Walla Valley.

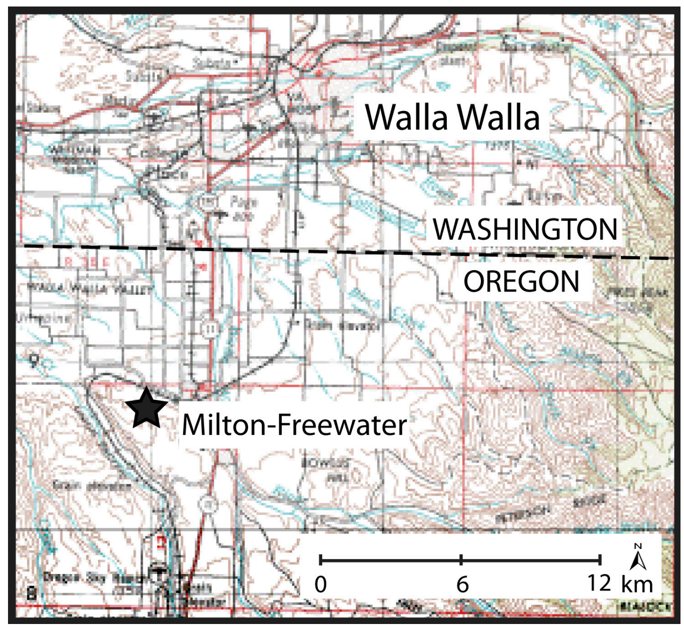

Figure 1. Location of the field site in the Walla Walla Valley, WA and OR. Star indicates location of field site; dashed line indicates Washington-Oregon border.

LOCATION AND DESCRIPTION OF FIELD SITE

The field area lies near the town of Milton-Freewater, in Umatilla County, Oregon, in the southern part of the Walla Walla Valley (Fig. 1). The town of Walla Walla is approximately 13 km to the north, over the Washington-Oregon border. The property historically had been farmed for wheat and then lay fallow for one or two growing seasons before the summer of 2007. The owner planned to convert the site to a vineyard for the growing season of 2008. The field covers ~220 acres (0.9 km^2) and the aspect is northeast to north. Slope averages ~5% across the field.

The site's Walla Walla silt loam and Lickskillet very stony loam are classified as Mollisols, grassland soils that typically form in areas with a moderate to pronounced seasonal moisture deficit (Soil Survey Staff, 1999). More specifically, the soils in the field area are haploxerolls, with *hapl-* signifying minimal horizon development, *xer-* signifying a xeric or limited moisture regime, and *-oll* signifying the Mollisol classification. Both the Walla Walla and Lickskillet soils are well drained haploxerolls formed primarily in loess. Unlike the meters-thick Walla Walla soils, the Lickskillet soils tend to form a profile <1 m deep. As a result, this unit's texture and composition is more influenced locally by the region's basalt bedrock (Johnson and Makinson, 1988).

FIELD METHODS

Site Preparations and Observations

In the early summer of 2007, ten soil pits, each ~2 m deep, were dug on the property (Fig. 2): three at the base of the slope (B2, B10, B22), four in the middle portion of the slope (M1, M8, M15, M26) and three at the top of the slope (T10, T16, T23). All field data were gathered in or around these pits. At each of the pits, the depth of the pit was measured and the soil profile and notable features of the pit's surface and subsurface were described, including type and extent of surface vegetation, soil horizons, depth to bedrock, presence of large grains, and depth of roots. Latitude and longitude of each pit were determined using a GPS device.

Soil Chemistry

In the field, we used the Innov-X Handheld XRF Analyzer Alpha Series to gather site-specific measurements of soil chemistry. The handheld X-ray fluorescence device (XRF) operates in the same manner as a lab-based XRF, bombarding the sample with X-rays and measuring the wavelengths of the energy emitted by the sample. This particular device uses an X-ray tube with a tungsten anode and produces an excitation of 10-40 kV at 10–50 μA. At each pit, loose material was scraped from a strip of the pit wall ~0.5 m wide and we marked the strip at 20 cm intervals from the surface to 1 m depth. We ran the XRF for two 30 sec intervals at 20 cm below the pit surface, repeating this every 20 cm to a depth of 1 m. Additional spot analyses were run on any bedrock or carbonate deposits exposed in the pit, as well as on the organic-rich horizon where it did not extend 20 cm below the surface. At pits with exposed bedrock (M26, T10, T16, T23), we collected samples of the bedrock, sawed them roughly in half, and collected XRF data from the slabbed surfaces.

Soil Hydrology

We measured the field-saturated hydraulic conductivity (Kfs), which gives a measure of soil permeability, using a SoilMoisture Corp. Guelph Permeameter Model 2800K1. The Guelph Permeameter is a constant-head method of measuring Kfs: water is applied to a soil at constant head and the rate of infiltration is measured. Within about 2 m of each soil pit, we chose a relatively level, apparently non-compacted location and drilled a 6 cm hole 15 to 20 cm below the soil surface. We inserted the well of the Guelph Permeameter into the hole and applied a head of 5 cm. After allowing the soil to become saturated, we recorded water column height every two minutes until an approximately constant rate (steady-state condition) was achieved. This process was then repeated with a 10 cm head.

LABORATORY METHODS

Electrical Conductivity

In June 2007, soil samples were collected by coring from the top 1 m of 3010 sites (every few meters) on the property. To determine soil EC, AV Labs (Othello, WA) made each sample into a saturated soil paste using a 1:1 soil:water ratio and tested the extract with an Omega CDH-46 conductimeter. AV Labs divided these EC values into magnitude-based zones for each pit group (B, M, T) and calculated an average EC value for each zone. These average values were the numbers used in the following EC calculations and will be referred to as the zone-average EC.

Soil Chemistry

Soil samples collected from the top 0.3 m and 1 m of each pit were analyzed by AV Labs for texture, organic matter (OM), available nutrients (Na, K, Ca, Fe), pH, and cation exchange capacity (CEC) using standard techniques. Additional analysis for CEC was performed on each sample by Utah State University Analytical Laboratories.

Statistical Analysis

The relationships between soil EC and other measured soil properties were analyzed using the JMP 6.0 software package. A series of simple and multiple linear regressions were run to quantify these relationships, and their strengths were compared based on the regressions' R^2 and adjusted R^2 values. The R^2 value is a standard test of correlation strength, representing the fraction of variance in the dependent variable that is accounted for by the variation of the independent variable(s):

$$R^2 = \frac{SS_{reg}}{SS_{tot}} \qquad (1)$$

where SS_{reg} is the variance of the model's predictions and SS_{tot} is the total variance of the data. However, because the R^2 value increases slightly with the number of variables in a model, an adjustment is necessary when comparing models with different numbers of regressors:

$$R^2(\text{adjusted}) = 1 - (1 - R^2)\frac{n-1}{n-p-1} \qquad (2)$$

where p is the total number of regressors in the model and n is the sample size. The adjusted R^2 value was used as the main indicator of relative correlation strength when comparing models with different numbers of variables.

RESULTS

Spatial Characteristics of the Field

The average soil texture at the site plots in the silt loam field of the textural triangle, with approximately 26% sand, 70% silt and 7% clay. Texture did not vary significantly across the field. Organic matter was very low throughout the soils at the site, averaging <1%. Available Ca was ~6% of total Ca, available K was ~3% of total K, and available Fe was <1% of total Fe. Ksf ranged from 1.7 cm/h at pit M26 to 5. 45 cm/h at pit M16, and average Ksf for the field was approximately 3 cm/h.

The distribution of EC values across the field (Fig. 2) shows that a swath of high EC roughly follows the crest of the hill, and another area of high EC is located in the northeast section of the field near the base of the hill. Most low EC values are concentrated in the northwest corner of the field.

For total Ca, K, and Fe, XRF data were used to portray the relationship between chemistry and depth (Fig 3). Total Ca tends to increase with depth, whereas total K decreases with depth, though the concentration-depth relationship is weaker for total K. Total Fe does not appear to vary significantly with depth.

Linear Regressions

Sixteen simple linear regressions (Table 2A) show the correlation of each of the chemical or physical properties measured at the pits (as well as the sum of the four available cations measured) with the zone-average EC. Of the five simple regressions that gave adjusted R^2 values >0.01, available K (which varied negatively with respect to EC) was the strongest. The pH, available Ca, sum of the four available cations, and available Na had moderately strong positive relationships with zone-average EC. The hydraulic variable Ksf, total Ca, total K and soil texture did not show significant linear relationships

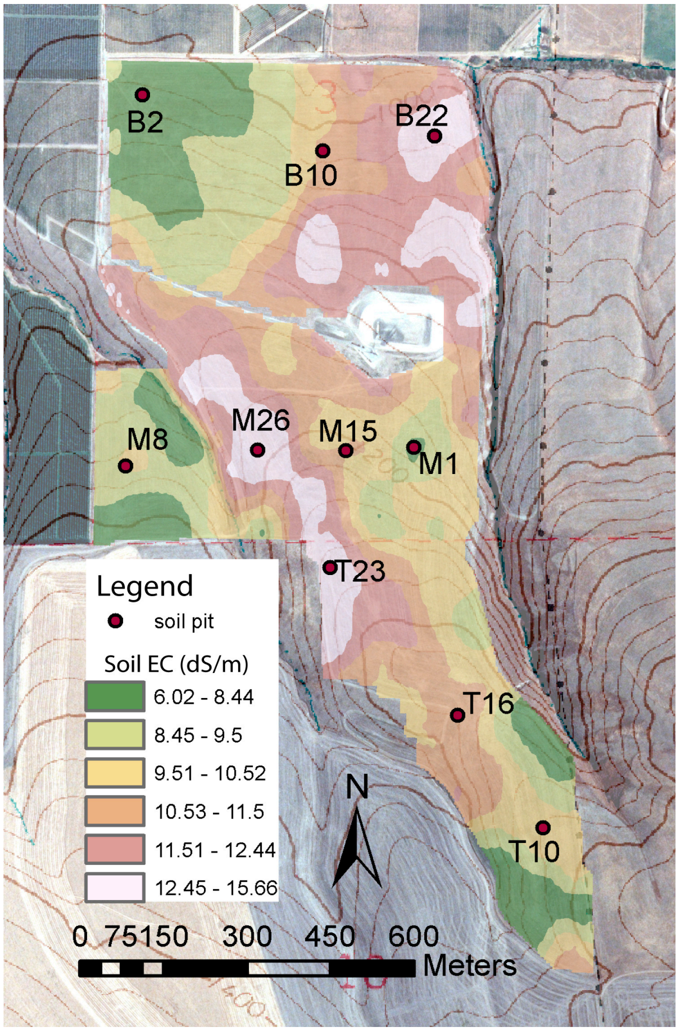

Figure 2. Map of soil EC distribution at the field site (IDW model), color-coded by EC zone. The base of the hill is located at the north end of the field.

with EC.

Table 2B summarizes the results of thirty-two multivariate models run against zone-average EC. Only those models that resulted in an adjusted R^2 of >0.50 are shown. The models with the highest adjusted R^2 (0.79 and 0.75) involve available Na, K and Ca, pH, CEC, ± percent clay. The strongest two-variable model (adjusted R^2 = 0.58) used pH and negative available K.

DISCUSSION AND CONCLUSIONS

At the field site, soil EC is likely controlled by eolian deposition and bedrock weathering, complex processes that link EC to a variety of soil properties. Multiple linear regression using available Na, K and Ca, pH and CEC can account for three-quarters of the variation in zone-average EC at the field site. It is unlikely, however, that this five-variable model would prove useful due to the large number of regressors. A more practical relationship may be that of zone-average EC with available K, an essential plant nutrient. Since available K has a strong negative relationship with EC, soil areas at the site with a high EC are likely to have a low level of available K. As zone-average EC also has a moderately strong positive relationship with available Ca and pH, soil EC is a potentially effective method for predicting trends of available K, available Ca, and pH across the field.

A. Simple Linear Regressions

Variable vs. Zone-Average EC	Sign	R^2	Adj. R^2
K_{sf}	+	<0.01	<0.01
% sand	+	<0.01	<0.01
% silt	-	<0.01	<0.01
total Ca	+	<0.01	<0.01
total K	+	<0.01	<0.01
CEC	-	0.02	<0.01
OM	+	0.02	<0.01
*a*Fe *	+	0.08	<0.01
total Fe	+	0.08	<0.01
depth **	-	0.09	<0.01
% clay	+	0.14	<0.01
*a*Na	+	0.26	0.17
*a*Na +*a*K+*a*Ca+*a*Fe	+	0.31	0.22
*a*Ca	+	0.31	0.23
pH	+	0.38	0.30
*a*K	-	0.62	0.57

B. Multiple Linear Regressions

#	Variables vs. Zone-Average EC	R^2	Adj. R^2
2	*a*Na, *a*K	0.62	0.51
2	*a*Ca, *a*K	0.62	0.51
2	*a*K, pH	0.67	0.58
3	*a*K, *a*Ca, pH	0.67	0.51
3	*a*Na, *a*K, pH	0.67	0.51
5	*a*Na, *a*K, *a*Ca, pH, depth	0.85	0.65
5	*a*Na, *a*K, *a*Ca, pH, CEC	0.89	0.75
6	*a*Na, *a*K, *a*Ca, pH, depth, % clay	0.86	0.57
6	*a*Na, *a*K, *a*Ca, pH, OM, depth	0.86	0.60
6	*a*Na, *a*K, *a*Ca, pH, *a*Fe, depth	0.88	0.65
6	*a*Na, *a*K, *a*Ca, pH, CEC, OM	0.90	0.70
6	*a*Na, *a*K, *a*Ca, pH, CEC, *a*Fe	0.91	0.72
6	*a*Na, *a*K, *a*Ca, pH, CEC, depth	0.91	0.74
6	*a*Na, *a*K, *a*Ca, pH, CEC, % clay	0.93	0.79

*Table 2. Results of statistical analyses. A. Results of simple linear regressions of all variables run against zone-average soil EC. "Sign" column indicates the sign of the linear relationship. B. Results of multiple linear regressions that yielded adjusted R^2 >0.50. The # column indicates the number of variables used in the model. Notes: * an a preceding an element name signifies available (rather than total); ** approximate depth to bedrock.*

The total K, Ca and Fe values yielded by the portable XRF device do not correlate significantly with zone-average EC. Therefore, these values cannot be statistically predicted by an EC survey. However, the chemistry-vs.-depth patterns derived from the XRF data help to explain the relationships between Ca, K, and EC in the field. The main sources of Ca

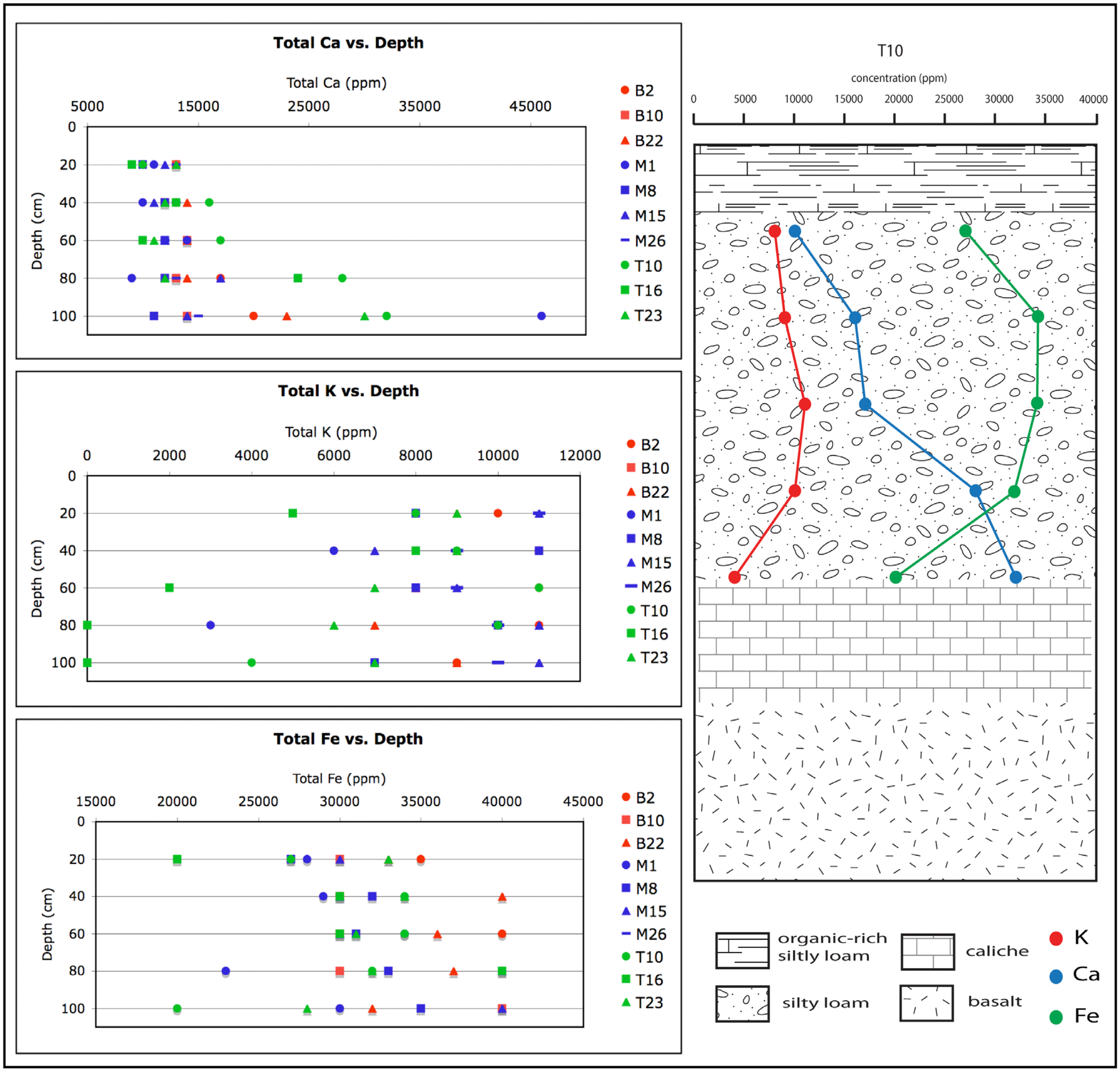

Figure 3. Chemistry vs. depth comparisons. Left: total Ca, K, and Fe vs. depth for all pits, 20-100 cm below the surface. Right: sample soil profile (for pit T10) with total Ca, K, and Fe trends for that pit. The base of pit T10 is 1.7 m below the surface.

to the soil are likely to be the nodules and layers of caliche present locally in the soil and the weathering of basalt bedrock. Since these Ca-rich zones tend to occur at ≥ 1m depth, total Ca in most pits increases with depth to 1 m (Fig 2A). Conversely, the main source of soil K is the eolian sediment found in the upper portion of the soil profile, and total K does not tend to increase with depth. At the field site, a high EC generally indicates a high level of available Ca and a low level of available K. This suggests, broadly, that EC is related to the presence of soil carbonate, the formation of which may be encouraged by near-surface bedrock. Indeed, depth to bedrock has a weak negative relationship with zone-average EC (Table 2A).

Soil EC at the site mainly reflects levels of available K and Ca, as well as soil pH. While soil EC is driven by a complex network of soil characteristics, soil

EC values can predict trends of these properties across the field. Additional studies are necessary to determine whether these relationships hold for the region's other eolian silt- and bedrock-influenced dry soils.

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