The effects of soil on the taste of wine

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ABSTRACT

The conventional wisdom of vintners is that alkalinity, and thus less sour and more rounded taste, are enhanced in wine and grapes challenged by low-nutrient soils. A common thread here is pH, an objectively measurable variable that is both a part of wine taste and a proxy for soil fertility. The role of low-pH soils is supported by metadata on Oregon wines from different soils in the Willamette Valley of Oregon, USA, which show significant inverse correlations between minimum pH of the soil and pH of finished Pinot Noir wine. There is also a direct correlation between depth of clayey horizons and pH of the finished wine. The minimum pH of these soils is near the base of the clayey (Bw or Bt) horizon and is inversely correlated with depth of the clayey horizon. Low soil pH is found in thick middle Pleistocene soils of bedrock (Jory, Willakenzie, Laurelwood, and Bellpine soil series) and high soil pH in thin soils on late Pleistocene and Holocene Missoula Flood deposits and loess (Hazelair, Woodburn, and Chehulpum soil series). Similar relationships are found between soil pH or depth and the pH of grapes at harvest, which is lower and more varied than pH in finished wine. These relationships are especially notable in years of good harvest, but obscured by winemaking techniques in years of poor harvest. Good harvest years are not necessarily vintages esteemed by wine connoisseurs, which are more strongly correlated with low October precipitation.

INTRODUCTION

The effects of soil on wine are a key component of the French concept of *goût de terroir* (taste of soil), first codified in 1905 legislation of *Appellation d'origine contrôlée* (Trubek, 2008). The French concept of soil at the time was less scientific than romantic and political, as revealed by Emile Zola's (1888) famous novel *La Terre* (*The Soil*). An expanded concept of wine terroir, including local climate and winemaking traditions, can be traced back to fifteenth-century Burgundian monks, but the naming of local wines after localities and comparisons of their relative quality were recorded in ancient Rome, Greece, and Egypt, back about 4,980 years ago (McGovern, 2003). Nevertheless, it has been difficult to find a scientific justification for judgements like the following quotation: "The sandy soil will, in general, produce a delicate wine, the calcareous soil a spirituous wine and the decomposed granite a brisk wine" (Busby, 1825, p. 11). In contrast is the opinion of Maltman (2008, p. 1), "The notion of being able to taste the vineyard geology in the wine—*a goût de terroir*—is a romantic notion that makes good journalistic copy and is manifestly a powerful marketing tactic, but it is wholly anecdotal and in any literal way is scientifically impossible." Maltman particularly decries descriptions of wines as tasting "slaty" or "earthy." Between these extremes of literally tasting soils in wine and the implausibility of transferring tastes from soil to wine are numerous studies documenting soils' effects on wine quality (Imre et al., 2012; Costantini et al., 2012; Burns, 2012), including this study. Here we address the conventional wisdom of vintners that low-fertility soils produce more profitable wines (Goode, 2014) in a case study of pH as a proxy for soil fertility compared with the pH of Pinot Noir wines produced from that soil in the Willamette Valley of Oregon, USA.

Wine within the usual pH range of 3.4–3.8 tastes pleasantly fresh, brisk or tart, but with too much acid it can be as sour as vinegar, and too little acid leaves it flat and prone to spoilage (Goode, 2014). Wines are 80%–90% water and 0.1%–20% sugar, with pH determined by a balance between 0.3%–1% acids (tartaric, malic, citric, lactic) and mildly alkaline alcohol (8%–20% ethanol, glycerol), organic compounds (0.3%–1% flavor compounds, such as anthocyanins, tannins, and flavonoids), and mineral cations (0.1%–0.3% potassium, sodium, calcium, and magnesium; Jackson, 1994). Pinot Noir wine has more than 800 distinct organic compounds, which determine aroma, color, and flavor (Fang and Qian, 2005).

Soil pH is a convenient proxy for fertility. Moderately acidic soils (pH 4.5–5.8) are low in plant nutrients (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) because the exchange complex has high amounts of non-nutrient cations (H^{+}, $AlOH^{2+}$, $Al(OH)_2^{+}$). Moderately alkaline soils (pH 8–10) have growth-limiting salts and moisture deficits. The most fertile soils for plant growth are between these extremes (Retallack, 2001).

GEOLOGICAL AND PEDOLOGICAL BACKGROUND

Oregon's Willamette Valley is a tectonic forearc basin on the convergent margin of the northwestern United States, dividing an uplifted subduction complex of the Coast Range from active andesitic volcanoes of the Cascade Range. Much of the valley is underlain by volcaniclastic marine sandstones and siltstones ranging in age from Eocene to Oligocene, but parts of the region were overrun by middle Miocene Grande Ronde and Wanupum Basalts of the Columbia River Basalt Group (Yeats et al., 1996). Large areas of the valley floor are covered by Willamette silts from the 15–18 ka Missoula Floods (O'Connor et al., 2001; Allen et al., 2009). These three geological elements determine three main kinds of soils planted in vineyards (Moore, 2002; Burns, 2012): (1) middle to late Pleistocene soils on Miocene basalt, (2) on Eocene-Oligocene sedimentary rock, and (3) late Pleistocene soils on loess or alluvium (Fig. 1).

The thick Jory silt loam was named the state soil of Oregon for its importance to the wine industry (Oregon State Legislature, 2011). It includes two distinct varieties developed on bauxitic laterite and basalt. At the type locality of Jory Hill south of Salem,

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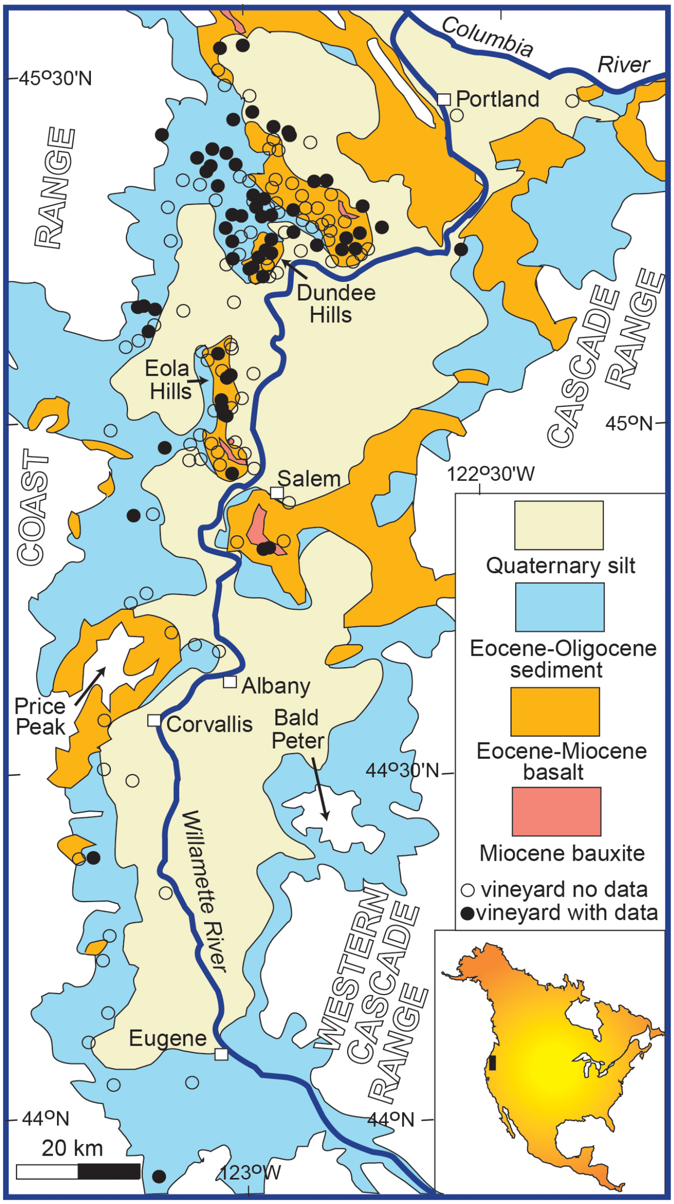

Figure 1. Simplified geological map of the Willamette Valley, Oregon, USA, with distribution of vineyards (modified from Moore, 2002; with bauxite occurrences from Libbey et al., 1945).

these Ultisols are developed on Oxisol paleosol remnants between flows of the Columbia Basalt Group (Libbey et al., 1945; Liu et al., 2013) dated at 15.7 Ma (Martin et al., 2013). Elsewhere the Oxisol bauxites below the Jory clay loam are 18 m thick (Fig. 2). Such Oxisol paleosols required mean annual temperatures of at least 17 °C and mean annual precipitation of at least 1100 mm during the middle Miocene (Retallack, 2008, 2010). In contrast, from 1971–2000, Salem had a mean annual temperature of 11.4 °C and a mean annual precipitation of 1016 mm (National Oceanographic and Atmospheric Administration, 2015), so that Ultisols are the most deeply weathered soils forming in Oregon today (Lindeburg et al., 2013). Elsewhere in the red hills of Dundee Jory, Ultisols are developed on middle Miocene Grande Ronde basalt without the bauxitic paleosol (Otte et al., 1974).

Other wine-producing soils of middle Pleistocene terraces that cut into marine sediments are Bellpine Ultisols and Willakenzie Alfisols, developed on volcaniclastic siltstone and sandstone, such as the Spencer Formation (Otte et al., 1974; Patching et al., 1987; Fillmore et al., 2009). These Alfisols are more nutrient-rich and less acidic than Ultisols, but both have the lowest pH near the base of thick clayey (Bt) horizons. In contrast, soils formed from Missoula Flood deposits and loess are less acidic and more fertile Mollisols of the Woodburn, Hazelair, and Chehulpum Series (Otte et al., 1974; Gerig et al., 1985). The 16 distinct soil series and variants of this study are detailed in the GSA Supplemental Data Repository[1] and provide an array of substrates for wines.

The Willamette Valley is a cool and humid climate viticultural district well suited for Pinot Noir grapes (Jones et al., 2012). Irrigation is not necessary in such climates, and vine vigor is limited by low soil nutrients (Burns, 2012).

METHODS

Our choice of Pinot Noir wines from the Willamette Valley for this study was due to long experience with local vintners and soils, and particularly, the "great debate" about differences in the taste of wines from Jory versus Willakenzie soils (Burns, 2012). To supplement such small-scale studies, we compiled all available metadata from the Web pages of all 177 wineries of the Willamette Valley Wineries Association, whose technical sheets give wine and grape pH and total acidity, grape sugar content, wine alcohol content, harvest dates, recommended price, and vineyard location. Sugar content in weight percent is given by the wine industry term "Brix," and all these commercial data were obtained using twenty-first-century equipment and industrial standards. By experimental design, as many factors as possible were kept constant: data were limited to a single grape variety (Pinot Noir), a single vinicultural area (Willamette Valley), and grouped by vintage (to equalize climate effects). Blended wines were excluded, and single-vineyard single-clone wines were located using Google Earth and then checked in county soil surveys (Williams et al., 1972; Otte et al., 1974; Knezevich et al., 1975, 1982; Green et al., 1982; Gerig et al., 1985; Patching et al., 1987; Fillmore et al., 2009). These same soil surveys were the source of soil data, which included both maximum and minimum soil pH (determined by pH meter on 1:1 soil:water), cation exchange capacity (by ammonium acetate displacement of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), depth to base of clay-enriched (Bt) horizon, and clay and organic matter content (both weight percent) in representative profiles for each county survey. Geological data are from Walker and McLeod (1991). Some wines were excluded because there were multiple soil series in a single vineyard area when checked with county soil surveys. Vintners vary in the extent of data recorded, and few vintners posted archival data back to 1999. In the final database of 267 wines, only the 2008, 2009, 2010, and 2011 vintages had 20 or more wines (see the GSA Data Repository Supplemental [footnote 1]). Uncontrolled in these data were details of viticulture other

[1] GSA Supplemental Data Item 2016052, compiled data on wines and soils with graphs of additional vintages, is online at www.geosociety.org/pubs/ft2016.htm. You can also request a copy from *GSA Today*, P.O. Box 9140, Boulder, CO 80301-9140, USA; gsatoday@geosociety.org.

Figure 2. Red Jory Ultisol of Willamette Estate Vineyards in the south Salem Hills, Oregon, USA, where it is developed atop a thick middle-Miocene Oxisol (lateritic bauxite), red in the vineyards (A), and thick in a nearby quarry (B). The Jory soil series is intensely planted in vines, but comes in two distinct varieties parented by bauxite or by basalt. Photo A courtesy of Matt Boyington; photo B courtesy of Marli Miller.

than harvest date (vine age, plant spacing, trellising, rootstocks, fertilization, canopy management) and of viniculture other than blending (crush methods, destemming, sulphite and acid addition).

Other data compilations used in this study were precipitation records from 1999 to 2012 for Rex Station near Newberg (National Oceanographic and Atmospheric Administration, 2015), Oregon vineyard harvest reports (National Agricultural Statistics Service, 2015), and Chehalem Vineyard harvest reports (Chehalem Wines, 2015).

SOIL DETERMINANTS OF WINE ACIDITY

The main result of this study is discovery of an inverse relationship between the pH of wine and the minimum pH of the soil in which it is grown (Fig. 3A). A comparable but direct (not inverse) relationship was found between wine pH and the depth to the base of the clayey (Bw or Bt) horizon in the soil (Fig. 3B). These relationships have a common cause with soil age, because in Oregon, as elsewhere, pH declines and soil depth increases as soils develop through time (Lindeburg et al., 2013). Among the soils studied, there is a significant negative correlation between minimum soil pH and depth to the base of the clayey horizon (Fig. 3C). All these relationships are significant at greater than 99% confidence determined by an ANOVA *F* test, because more than 20 wines are included within each series.

Within the data assembled, wine pH showed no relation with maximum soil pH, perhaps confounded by different practices of mulching, cover crop, or fallow at the surface. Wine pH correlated with neither minimum nor maximum soil clay content, nor minimum nor maximum cation exchange capacity, again perhaps confounded by local vineyard practices. Wine pH also did not show any relation to grape Brix or wine total acidity, alcohol content, price per bottle, or harvest date.

VINTAGE VARIATION

Vintages of wines were kept separate as a part of the experimental design to keep seasonal differences in weather constant for individual series of wines compared, but there is a strong vintage effect in the coefficient of correlation (r^2) of the relationship between wine pH and soil pH or depth. In 2009, soil pH and depth determined 57%–59% of the variance in wine pH, but in other years, it determined only 11%–30% of the variance. A very strong correlation in 2009 and 2011 was also found between grape and wine pH, with lesser correlations for 2008 and not enough data for 2010 (Fig. 4A). Thus, vintage differences reflect growing conditions and not differences in winemaking techniques.

There is a very strong relationship between the size of the grape harvest and the strength of the correlation between soil and wine pH (Fig. - 4B). The size of the harvest was measured two different ways with similar results: (1) total Pinot Noir harvest from a single

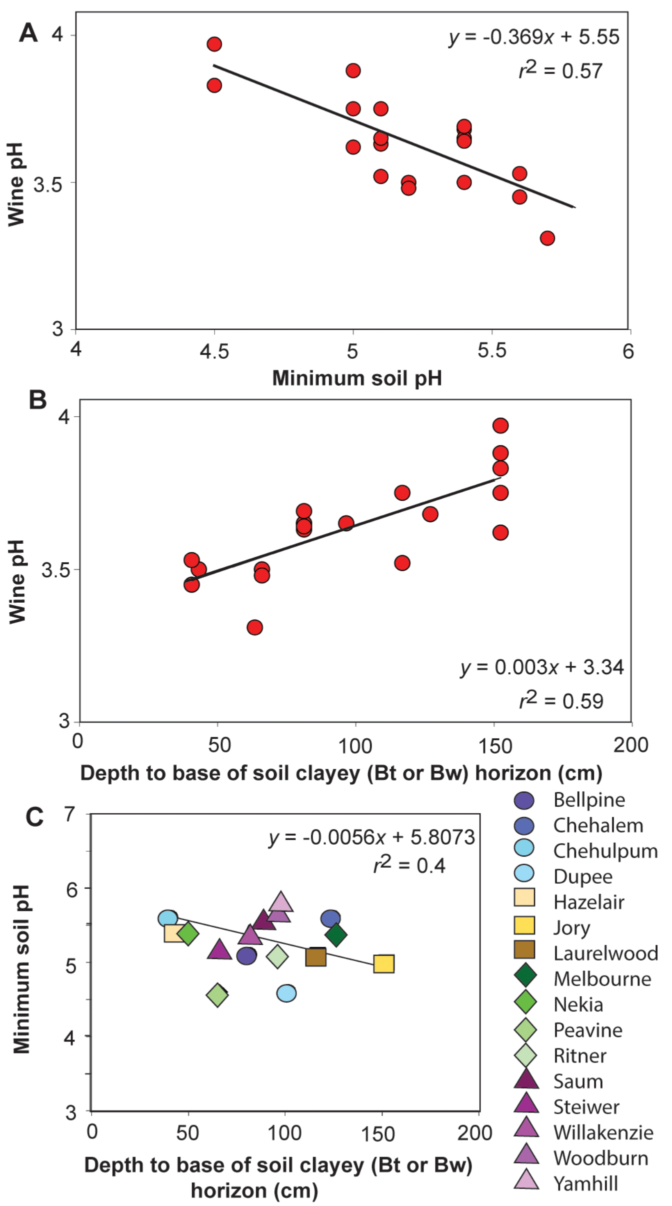

Figure 3. Relationships between wine pH and minimum soil pH (A) and depth to base of clayey (Bt or Bw) horizon (B) in the 2009 vintage Pinot Noir wine from the Willamette Valley, Oregon, USA. These correlations are all highly significant using an ANOVA *F* test. One relationship is inverse and the other direct, because minimum soil pH and depth of clayey horizon are inversely correlated (C). Comparable correlations for three other vintages are in the GSA Supplemental Data Repository [see footnote 1].

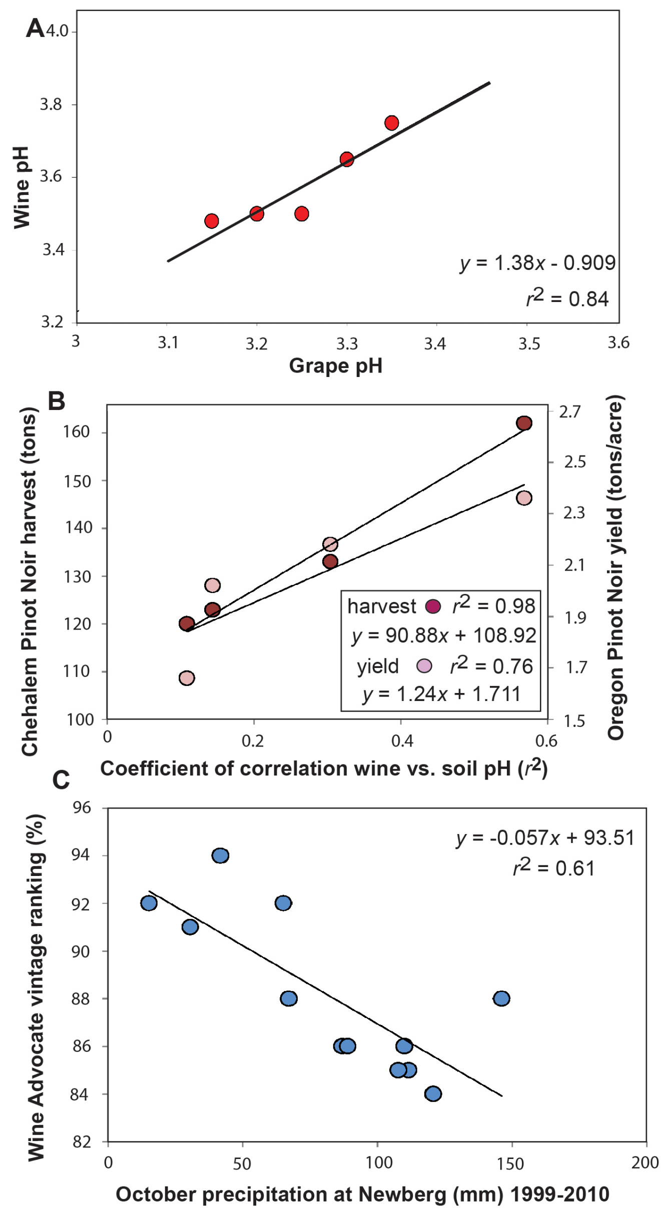

Figure 4. Correlation between pH of grapes at harvest and pH of wine in the 2009 vintage Pinot Noir from the Willamette Valley, Oregon (A), between variance of coefficient of correlation between wine-soil pH and grape harvest size for vintages 2008–2011 (B), and between Wine Advocate vintage ranking and local October precipitation for that vintage (C).

group of vineyards (Chehalem Wines, 2015) and (2) yield of Oregon Pinot Noir from the National Agricultural Statistics Service (2015). Terroir pH thus is most strongly expressed in vintages when there are a lot of grapes, perhaps because winemakers impose fewer interventions.

OTHER DETERMINANTS OF WINE QUALITY

The 2009 vintage was excellent (86 points), like that of 2010 (88 points), but not exceptional like 2008 (94 points), as ranked by wine industry appointed connoisseurs (Parker, 2015, who did not rank 2011). Thus, the years of good soil pH expression in wines were not necessarily years of acclaimed and highly profitable wines. The acclaimed vintages show a very clear relationship with lack of precipitation in October (Fig. 4C), one of the reasons why wine production is so successful in regions with dry summer (Mediterranean) climates (Goode, 2014). No correlation was found between mean annual precipitation and either the size of the harvest or quality of the wine vintage.

CONCLUSIONS

This study supports with data two traditional tenets of vineyard management: (1) "treat vines mean to keep them keen," and (2) "deep-rooted vines better express terroir" (Goode, 2014). By these epigrams, vintners mean keen in the sense of more flavorful, and terroir in the sense of soil-related differences. One hardship for vines is lack of moisture before harvest, which is related closely to the quality of vintages (Fig. 4C). Another handicap to vine vigor is low soil pH, and thus fewer mineral nutrients, which has the effect of raising wine pH (Fig. 3A). It is the pH minima of the deep levels of soils in Oregon that appear to most affect both grape and wine pH (Fig. 3B). These stresses may induce vines to invest in future propagation rather than vegetative growth, by producing more fruit than leaves, and within the grapes, less organic acid, and more cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) and flavor, color, or aroma compounds to attract dispersers (Goode, 2014). These organic compounds are complex and beyond the scope of this study (Fang and Qian, 2005), so our study does not address the fruit versus spice flavors of Willamette Valley wine (Burns, 2012), nor perceived "slaty" or "earthy" flavors in wine (Maltman, 2008). Nevertheless, pH is also an important element of the taste of wine. High pH (3.7–4.0) Pinot Noir wines with rounded and complex flavor are produced on low-pH, deep, middle Pleistocene soils, such as the Jory Series. Low pH (3.3–3.7) Pinot Noir wines with brisk and less complex flavor are produced on high-pH, shallow, late Pleistocene to Holocene soils, such as the Hazelair Series. Soil age and nutrient status has also been noted as a factor in wine quality in other regions (Costantini et al., 2012). Soils have a significant effect on the pH and taste of both grapes and wine, but these effects are increasingly obscured by blending and other winemaking techniques (Goode, 2014).

We conclude that one can taste some aspects of soil in wine, especially acidity. For Pinot Noir wines of our region, astringent taste tending toward vinegar comes from vines overfed by fertile Holocene soils, but rounded and buttery taste comes from vines that struggled in infertile mid-Pleistocene soils. However, acidic wines from young soils are less prone to spoilage than less acidic wines from old soils. Wine, like soil, is a living medium with a geological heritage.

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