Anthropogenic intervention in shaping Terroir in a California Pinot noir vineyard

Etude des interventions anthropogéniques sur différents terroirs de Pinot noir en Californie

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Abstract

In many vineyards optimal parcel size exceeds the geospatial complexity that exists in soils and topographic features that influence hydrological properties, sunlight interception and soil depth and texture (available water capacity). A premise of precision management is that such variation can be lessened, but the practices that would be used to achieve this have not been subjected to rigorous scientific evaluation. During 2004-2006 we examined spatial heterogeneity of soils and topographical features and related them to yield, industrial quality (soluble solids content, titratable acidity and pH), vine water status (predawn, ψ_{PD}, and midday, ψ_L, leaf water potential) and vigor (pruning weights), in an extremely complex hillside vineyard that had undergone terraforming as a means of increasing planted hectares and diminishing soils variation. Factor analysis was used to identify latent variables used in a multiple linear regression model with least squares estimation to identify correlations among soil and topographic factors, vine physiology and industrial quality parameters. Our results indicated that overall vine water status (ψ_{PD} and ψ_L) had the largest influence on within vineyard variation on an interannual basis, and that extreme spatial heterogeneity was evident in this vineyard in spite of terraforming efforts.

Key Words: Complex slopes, ripening uniformity, precision viticulture, water potential, terraforming

Introduction

Modern concepts of the science of Terroir generally consider geospatial scales corresponding to those of wine regions (Wilson 1999; Tonietto and Carbonneau, 2004). This applies to both climatic variation and variation in geomorphology as it relates to soil origin. Often included in this discourse is the geospatial heterogeneity that occurs at mesoclimatic and mesogeographic scales (Guinard and Cliff, 1987; van Leeuwen et al. 2004). These mesoclimatic and geographic changes occur at distances that can be characterized in terms of kilometers, in contrast to the larger distances over which geologic, cultural, and continental scale climate conditions often change. One assumption implicit in these discussions is that these climatic, geologic and cultural differences outweigh variation that occurs within an individual vineyard or vineyard block as a consequence of heterogeneity that occurs in soils, slope, aspect and other variables like surface depressions and wind turbulence. All of these variables occur at much smaller scales than those of geologic, cultural or continental scale climates.

Spatial variation that exists within vineyards can be the result of multiple soil factors, but few researchers have attempted to examine causality, and at least one report indicates annual climatic variation can override the influence of soil (Reynolds et al. 2007). In the report of Reynolds and co-workers, interannual variation of fruit composition exceeded within vineyard variation. Where available water has been shown as the major soil parameter controlling growth and composition at the regional scale (van Leeuwen et al. 2004), summer rainfall may act to supersede a soils effect related to soil water capacity (van Leeuwen et al. 2004). Recent investigations of within vineyard variation have described a substantial range of heterogeneity in soil properties (Bramley and Lamb, 2003), vine growth (Lamb et al., 2004), yields (Bramley and Hamilton, 2004) and fruit composition (Reynolds et al., 2007). While such variation has been shown to reduce overall yields, decrease fruit quality and therefore profits (Bramley, 2005), from the perspective of precision farming it is based on the premise that such variation can be mitigated in a manner so as to increase yields, quality and profits.

Minimum attention has been devoted in these investigations in attempting to elucidate those soil factors responsible for the observed variation and thus implementing mitigation strategies. Mitigation efforts generally employ site-specific management (SSM), which, as defined by Whelan and McBratney (2000), concerns "matching resource application and agronomic practices with soil and crop requirements as they vary in space and time within a field." The application of SSM must begin with an understanding of the extent of spatial heterogeneity of yield and quality within a vineyard. Then, the mechanisms that drive such variation need to be identified whereby efforts to mitigate can be implemented. Water is most often considered the resource with the largest impact on variability. van Leeuwen and colleagues (van Leeuwen et al. 2004) examined gross soils variation for three red wine cultivars and found that vine water status influenced shoot growth and berry composition more than any other single variable. Reynolds and others (Reynolds et al. 2007) found for a Reisling vineyard in Ontario Canada that the influence of vintage had a greater impact on variation in fruit, must and wine composition than did soil texture or vine size but water relations was not assessed.

This purpose of this study was to examine the degree of spatial variability within a 3.6 ha hillside vineyard in the Carneros region of Napa Valley, California. The vineyard provides a unique and interesting study area due to its complex topography; meaning it has highly variable slopes, slope aspects, and curvature (convexity and concavity, see Figure 1). For most of the above mentioned studies that have started to address the issue of internal spatial variability in vineyards (Bramley and Lamb, 2003; Bramley and Hamilton, 2004; Reynolds et al., 2007) the use of topographical analysis was not used, and complex topographical features that influence a site's hydrology and soil formation were not apparent (but see Failla et al. 2004). A significant relationship between observed variation in yield and crop quality with topographical features and soil properties has been shown for annual crops of corn (Timlin et al., 1998; Mallarino et al., 1999; Cox et al., 2005), soybeans (Kravchenko and Bullock, 2000; Kaspar et al., 2004), and cotton (Terra et al., 2006) but none exist to our knowledge for grape.

The second issue addressed by this investigation is the mitigation potential of terraforming. Terraforming is a means of grading whose intent is to increase planted acreage where steep slopes exist, but also serves as a potential means of precision mitigation of spatial variability. Steep slopes of gullies, where soils are shallow because of pedogenic processes that occur during soils formation (eg. Chamran et al. 2002), and where available water capacity is low, are filled, while areas with deeper subsoils are graded to form a more spatially uniform planting environment. Tin as much as the scale at which heterogeneity in soil properties occurs may annul attempts at site specific management, the use of soil preparation practices like deep ripping and terraforming may serve to mitigate soils heterogeneity.

Material and Methods

The study site was located within a 589 acres ranch in the Carneros region of Napa Valley, California within the coordinates SW (38.247104°N, 122.3663210°W) and NE (38.247982°S, 122.361995°W) (WGS1984). The vineyard is a 3.7 hectares block on an east facing slope ranging in elevation from 20 m to 82 m with slopes ranging from 9-34 degrees (Figure 1). The vineyard contains 9321 vines and was planted in 1991 with Pinot noir (clone UC 2A grafted onto 3309 rootstock). The vines were planted with 5x8 ft spacing, and trained to a vertical shoot positioned (VSP) trellis with unilateral cordons with an average of 8-12 spurs per cordon or approximately 16 to 24 buds per vine. The vineyard was planted over two major soil types: Haire Clay Loam on the lower slopes and Diablo Clay on the upper slopes. Prior to being used as vineyard land, the site was managed and maintained for cattle grazing. Cool wet winters and warm dry summers characterize the local climate, with a substantial marine fog influence during the summer months. The average annual precipitation for 2004-07 was 16 cm per year. The average maximum temp was 21.2˚ C and the average minimum temperature was 6.5˚ C over the same time period (CIMIS, 2006). The vineyard is drip irrigated and managed using a mixture of mechanical and manual practices. Fully mechanized operations in the vineyard included hedging, and some canopy leaf thinning in the fruit zone. The vineyard is an industrial vineyard although because of the steepness of slopes it is hand harvested and hand pruned. It was otherwise managed using standard mechanized commercial vineyard practices.

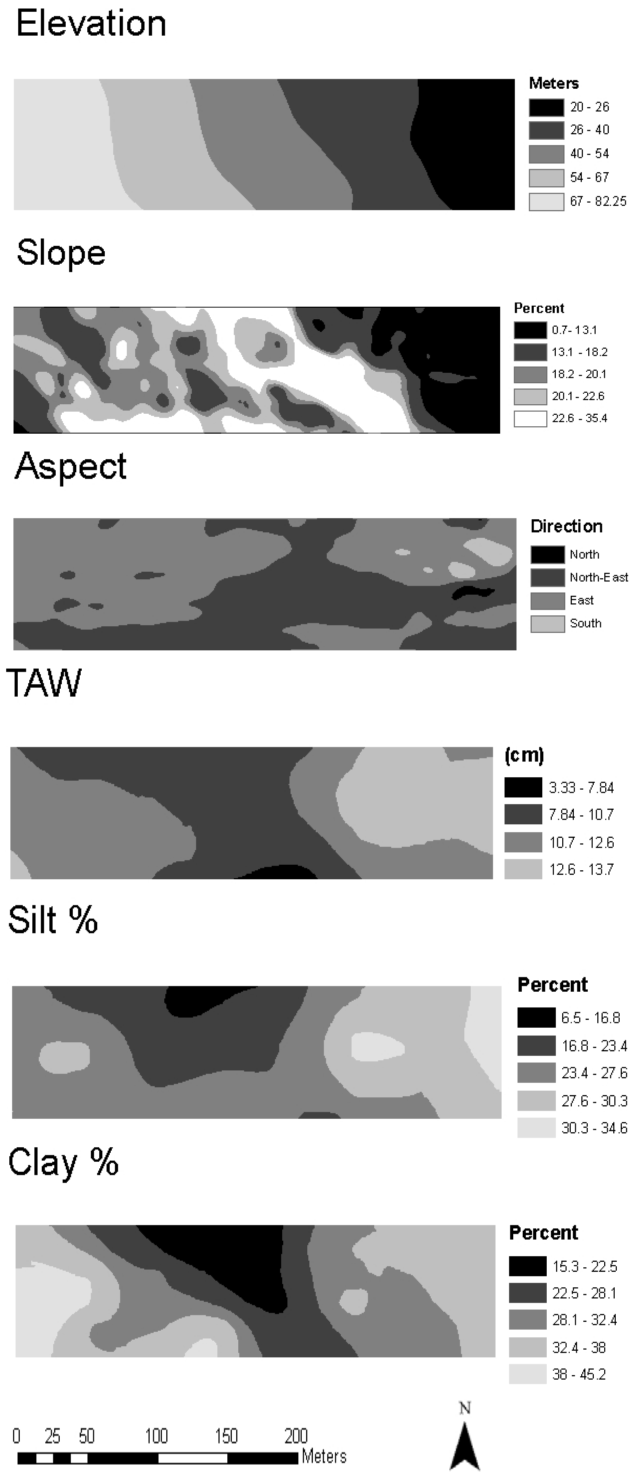

Figure 1 Kriged maps from left to right and top to bottom are elevation, slope, slope aspect, total available water (TAW), soil silt content (%) and soil clay content (%).

An important variable for producing wines of good market quality is using grapes of consistent and uniform industrial ripening. Brix, pH, TA are the most common parameters for monitoring fruit ripening at large scales of production, even though they may be inadequate for premium wines (Jackson and Lombard, 1993). In its most basic conception, quality fruit is harvested when sugar concentration reaches a desirable level for the variety being produced while retaining sufficient acidity for balance and storage life (Jackson and Lombard, 1993). Generally harvesting at 24.0 and slightly higher ºBrix is considered optimal for red varieties. It is well known in the wine industry that grapes produced with lower levels of sugar produce wines with green aromas and undesirably high acidity. Nonetheless, a simple relationship between soluble solids and wine quality has not been fully established in the scientific literature. A major hypothesis in this investigation is that a wide range of variation in ripening within a vineyard diminishes quality since fruit at an optimal ripening level is then mixed with fruit of lesser quality. If soil an other environmental factors that contribute to such variation can be identified, and geographically constrained, then new technologies may make it possible to aggressively mitigate naturally occurring variation by employing management practices that improve quality in these areas.

A digital elevation model (DEM) is one tool used in GIS to calculate the surface topology. DEMs were developed from work done by Miller and Laflamme (1958) on digital terrain models (DTM), which can be defined as "an ordered set of data points that represent the spatial distribution of various types of information on the terrain" (Li et al., 2005). DEMs are a fundamental component of DTMs because they incorporate the elevation component of the model. From the DEM, slope (Figure 1) can be calculated in a 3x3 neighborhood by determining the largest change in elevation value from each cell relative to its neighbors. Aspect (Figure 1) is calculated by finding the steepest down slope neighbor in each 3x3 grid-cell neighborhood. Curvature gives a measure of the concavity and convexity of the surface. Curvature can be directly calculated using ArcGIS software by fitting a fourth order polynomial (i.e. the slope of the slope) on a grid-cell to grid-cell basis. A secondary approach of quantifying hydrological terrain properties and processes is through the wetness index. The wetness index (not shown) is a "hydrological-based compound index and has been used to characterize the spatial distribution of surface saturation and soil water content in landscapes"(Moore et al., 1991). It was calculated by taking the natural log of the flow accumulation. Using the previously described topographic elements, it is possible to link soil properties such as texture, soil depth, nutrients, and soil water retention to landscape position and the approach was used in this report. Maps of the site location and data vines were then created using the ArcInfo geographic information systems (GIS) software version 9.1 (ESRI, Redlands CA USA).

Results and Discussion:

The observed variation in vine to vine yield quality indicated that terraforming did not have a large influence. Our yield results (Table 1) showed slightly less a range to those of Bramley and Hamilton (2004) who found yield to vary by 10 fold (2 to 20 t/ha) but within vineyard variation in other parameters was substantial (Table 1). Yield does not have a consistent effect on berry composition or wine quality with studies showing both an increase in desired sensory characteristics with increased yield (Chapman et al., 2004), no effect on fruit composition (Keller et al., 2005) when clusters are removed to reach a target yield, and an increase in wine quality scores with a decrease in yield (Bravdo et al., 1984). Mean pruning weights ranged from 0.17-3.26 kg in 2004, 0.41-2.9 kg in 2005, and 0.41-2.46 kg in 2006. The variation in pruning weights corresponds to the extreme differences in individual plant size within the vineyard. Variation in vine size and canopy density may have a variety of negative effects on wine quality including decreased proanthocyanadin production and increased green flavors in wines made from more vigorous vines (Cortell et al., 2005). The range in water stress values both predawn and midday is particularly broad with CVs, greater than [50] in some cases. The degree and timing of water stress plays an important role in grape composition (Matthews and Anderson, 1988; Kennedy et al., 2002) and vine growth (Kliewer et al., 1983; Shellie, 2006). Measuring a broad range of values within a topographically complex vineyard tells us that the standard industry practice of taking only one or two measurements per block gives the vineyard manager an unreliable prediction of water stress.

Of 15 original factors the 5 chosen factors explained the majority of variation for each of the variables except for aspect, wetness index, and midday ψ. A similar pattern for communalities was observed for factors in 2005 and 2006. There was no relationship between degrees Brix and pruning weights or yields for any of the three years. The latent variable 'Texture' was the first factor in each of the years, but it was a relatively unimportant driver of variation in the multivariate regression. In 2005 more than 50% of the variation was explained by the 5 factors for all variables except aspect and 3 of 5 water potential measurements. It is possible latent variables did not take into account other factors that influence water status including variability in hydraulic conductivity among vines, inconsistency of irrigation, differing microclimates, or random variability from vine to vine.

Table 1 Berry quality, yield, growth parameters, and water status univariate statistics for 2004-2006

		Mean	Min	Max	Std Dev	Range	CV	Kurtosis	Skewness
2004	°Brix	20.12	16.60	23.50	1.34	6.90	6.66	-0.18	-0.26
	TA g/L	11.23	8.08	15.19	1.39	7.11	12.35	-0.02	0.13
	pH	3.09	2.90	3.24	0.07	0.34	2.19	-0.05	-0.27
	Yield kg	4.19	0.00	7.59	0.96	7.59	22.97	2.83	0.06
	Pruning weight kg	0.98	0.17	3.26	0.44	3.09	45.08	3.84	1.30
	Midday ψ 5/20/04	-5.43	-2.20	-10.20	1.71	8.00	-31.51	-0.04	-0.58
	Midday ψ 6/8/04	-6.12	-1.20	-12.00	1.92	10.80	-31.39	-0.11	-0.39
	Midday ψ 7/15/04	-7.99	-3.80	-13.60	2.06	9.80	-25.76	-0.10	-0.54
	Predawn ψ 7/16/04	-2.13	-0.40	-5.40	1.17	5.00	-55.10	-0.10	-0.86
2005	°Brix	22.90	20.00	25.70	0.99	5.70	4.32	0.08	-0.18
	TA g/L	9.89	7.69	14.94	1.23	7.25	12.45	1.64	0.97
	pH	3.24	2.94	3.52	0.08	0.58	2.39	1.35	-0.15
	Yield kg	2.19	0.00	4.86	0.87	4.86	39.96	0.07	0.25
	Pruning weight kg	1.42	0.41	2.90	0.46	2.49	32.68	0.32	0.49
	Predawn ψ 7/15/05	-2.47	0.00	-5.60	0.94	5.60	-38.27	0.49	-0.66
	Midday ψ 7/15/05	-7.82	-4.18	-13.00	2.06	8.82	-26.34	0.48	0.23
	Predawn ψ 7/29/05	-2.57	-0.40	-6.10	1.31	5.70	-51.21	0.02	-0.77
	Midday ψ 7/29/05	-7.75	-3.28	14.60	2.46	11.32	-31.78	0.61	0.09
	Predawn ψ 9/22/05	-2.67	-0.30	-6.80	1.35	6.50	-50.69	-0.22	-0.73
2006	°Brix	22.16	17.7	26	1.43	8.30	6.46	0.33	-0.44
	TA g/L	8.37	3.47	14.49	1.74	11.02	20.80	2.26	0.92
	pH	3.14	2.26	3.66	0.13	1.40	4.29	12.59	-1.65
	Yield kg	1.53	0.09	4.49	0.87	4.40	56.98	0.63	0.86
	Pruning weight kg	1.44	0.41	2.46	0.48	2.06	33.03	-0.68	0.31
	Predawn ψ 6/21/06	-0.97	-0.1	-3	0.54	2.90	-55.98	0.75	-0.94
	Midday ψ 6/21/06	-9.11	-13.8	0	1.98	13.80	21.71	4.56	-0.95
	Predawn ψ 7/19/06	-2.37	-0.8	-5.2	0.94	4.40	39.74	0.09	0.63
	Midday ψ 7/19/06	-9.99	-4	-14.5	2.12	10.50	21.21	-0.27	-0.32
	Predawn ψ 8/22/06	-1.21	-0.1	-3.4	0.63	3.30	52.14	0.14	0.65
	Midday ψ 8/22/06	-9.72	-2.1	-15.4	1.94	13.30	20.01	1.15	0.01

Table 1 Berry quality, yield, growth parameters, and water status univariate statistics for 2004-2006

The regression coeffiecients between latent factors and vine berry composition and growth patterns varied from year to year, however water status was consistently one of the highest contributors to the regression model for all variables. Pruning weights were particularly affected by water stress especially in the early season and accounted for over 30% of the variation in the data for each of the years. The Pearson correlations also showed very significant correlations between water potential measurements and pruning weights. This result corresponds to other studies in controlled environments that correlated water stress to a decrease in leaf area and dry matter production (Kliewer et al., 1983; Gomez-del-Campo et al., 2002). In 2004, silt and clay had the highest loadings for Factor 1 so the latent variable was termed 'Texture'. TAW had a large factor loading which is expected since the calculations for available water are based on soil texture. Slope and elevation had small negative loadings. Factor 1 had the largest factor loadings, it did not explain much of the variation for the measured plant variables when used in the multiple regression analysis in 2004 (Table 2). Silt and clay percents were positively correlated with pH and clay was also negatively correlated with two of the ψ measurements (Table 2).

TA measurements were also consistently correlated with water status each of the three years along with curvature, and drainage in 2004. TA levels are both related to Brix in that grapes with higher brix generally have lower TA, and independent of Brix because higher TA are seen in vines with larger canopies. TA correlated significantly with pruning weights for each of the three years, and with yield in 2004 and 2005 (Table 2) and this agrees with the observations of Jackson and colleagues (Jackson, 1986; Jackson and Lombard, 1993).

Brix was significantly correlated with slope, and predawn and midday ψ measurements. In 2005 only 7% of the variation in Brix was explained by latent factors, and there was a significant correlation with the profile curvature (Table 2). In 2006 the latent factors were unable to account for any of the variation in Brix (Table 2). Although it is difficult to determine the reason the measured variables failed to account for any of the variation in 2006 and little of the variation in 2005, it is possible that the moisture regime and climate/microclimate trumped the effects of landscape and soil. These results taken together indicate that year to year variation in climatic factors may have a greater influence on the expression of within vineyard variation in soil chemical and physical properties.

Table 2: Multiple regression analyses of latent variables and growth and berry quality parameters from the 2004, 2005 and 2006 vintages.

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	—			
2004	Intercept	Texture	Curvature	Early ψ_L	Late ψ_L	Drainage	Aspect	R^2	Adj R^2	RMSE
Brix (°)	20.09	NS	NS	0.65	-0.93	0.52	NS	0.58	0.55	0.88
TA (g L^{-1})	11.21	NS	0.45	0.80	0.5	-0.54	NS	0.52	0.48	1.08
pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Yield (Kg)	4.13	NS	NS	0.31	NS	-0.3	NS	0.21	0.18	0.76
Canes (Kg)	0.95	NS	NS	0.24	NS	NS	NS	0.33	0.32	0.28
		Factor 1	Factor 4	Factor 3	Factor 2	Factor 5	—			
2005	Intercept	Texture	Curvature	Early ψ_L	Late ψ_L	Drainage	Aspect	R^2	Adj R^2	RMSE
Brix (°)	22.87	NS	-0.31	NS	NS	NS	NS	0.07	0.05	1.01
TA (g L^{-1})	9.75	NS	NS	0.59	NS	NS	NS	0.19	0.17	1.09
PH	3.24	NS	NS	NS	-0.03	-0.02	NS	0.22	0.19	0.06
Yield (Kg)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Canes (Kg)	1.47	NS	NS	0.29	NS	NS	NS	0.32	0.3	0.38
		Factor 1	Factor 4	—	Factor 2	Factor 3	Factor 5			
2006	Intercept	Texture	Curvature	Early ψ_L	Late ψ_L	Drainage	Aspect	R^2	Adj R^2	RMSE
Brix (°)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
TA (g L^{-1})	8.12	0.55	NS	NS	0.99	NS	NS	0.39	0.37	1.2
pH	3.15	-0.03	NS	NS	NS	NS	NS	0.09	0.07	0.08
Yield	1.39	NS	NS	NS	0.33	0.36	NS	0.35	0.32	0.63
Canes (Kg)	1.46	NS	0.34	NS	0.34	NS	NS	0.35	0.31	0.42

Table 2 Multiple regression analyses of latent variables and growth and berry parameters from the 2004, 2005 and 2006 vintages.

Conclusion

Topography plays a major role in soil development and redistribution; and thus, the spatial variation in soil nutrient and water availability results in observed spatial variation crop yields as a consequence. This has been definitively demonstrated for a number of annual crops. Topographical features played a lesser role in industrial quality in the vineyard under considerations in this investigation. Rather, soil properties related to water availability like texture and the water status of vines were the major factors influencing ripening variation. Perennial crops differ from annual crops in as much as permanent roots systems and deeper rooting behavior may moderate heterogeneity in the plow horizon. Terraforming did not seem to diminish spatial variation in vine performance and ripening variation, at least in comparison to other literature reports of complex vineyards. The influence of topography, soil physical and chemical properties and water status on industrial ripening and growth depended on vintage although water status was consistently involved.

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