SITE-SPECIFIC VARIABILITY OF GRAPE COMPOSITION AND WINE QUALITY

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ABSTRACT

Precision Viticulture (PV) is the application of site-specific tools to delineate management zones in vineyards for either targeting inputs or harvesting blocks according to grape maturity status. The majority of PV studies in winegrapes have focused on the relation of soil and vine-related spatial data with grape composition at harvest. However, the inclusion of site-specific wine quality data are very rare in literature, even though grape quality is ultimately judged upon wine properties. The aim of this study was to investigate the effect of the variability in soil and vine properties on both grape composition and wine quality. The study was conducted in a commercial vineyard in the Nemea area, Southern Greece, during the 2013 vintage. An elevation and an apparent electrical conductivity (ECa) map were created to assess soil variability. The vineyard was sectioned in a regular grid of 18 cells, sized 400-550 m^2. Berries from each cell were sampled three times until harvest and were analyzed for total soluble solids, pH, titratable acidity, anthocyanins and total phenolic compounds. Grape harvesting was performed manually in September 2013 and grapes were destemmed, crushed and vinified separately for each vineyard cell, applying classic red winemaking procedures. The final wines were analyzed for alcohol content, pH, titratable acidity, colour density and hue and phenolic composition. Yield and berry weight showed a two-fold variation within the vineyard. Among berry compounds, anthocyanins and total phenols showed the highest within-filed variability (5-10 fold). Berry weight was the most sensitive among berry attributes to field variability with significant correlations with slope, elevation (negative) and ECa and yield (positive) throughout ripening. Berry weight also presented a consistent spatial pattern throughout ripening, linked to soil variability. On the contrary, berry composition parameters (brix, titratable acidity, anthocyanins and phenols) had no consistent spatial pattern and none of them was related to the variability of topography, soil or yield. Yield variations were not associated with any of grape and wine parameters except for a strong negative correlation with pH. Similarly, wine composition parameters spatial trend did not present any significant correlations with field characteristics. Moreover, no (or limited) connection between grape and wine composition spatial distribution was evident.

Keywords: Precision Viticulture, soil variability, berry ripening, wine composition, phenolic compounds.

INTRODUCTION

Viticulture is one of the most important cultivations worldwide. Vines are cultivated for thousands of years producing various products (wine, table grapes and raisins) that are used daily in human diet. According to the International Organization of Vine and Wine (OIV), vineyards covered 7.694.000 ha of agricultural land worldwide in 2009.

Precision Viticulture (PV) is the implementation of Precision Agriculture (PA) practices in viticulture (Bramley 2003). PV application requires detailed data collection related to vine performance at a high spatial resolution (Bramley and Hamilton 2004). The ultimate goal of PV application is the implementation of targeted agricultural practices in management zones produced from the evaluation of collected field data (Bramley 2001).

It has been well documented that soil spatial variability results in significant differences in vine growth and productivity, in Australian (Bramley and Hamilton 2004) and Chilean vineyards (Ortega, Esser, and Santibanez 2003) among others. Soil attributes commonly measured in the framework of PV are soil structure, texture, water and nutrient content, depth, and electrical conductivity (ECa). The latter is an integrative estimation of soil properties measured with the use of electrical resistivity sensors (Arnó et al. 2009). Previous studies have reported significant correlations between soil ECa and vine properties (Imre et al. 2012, Trought 2005). Moreover, soil depth, as related to topography, was also found to correlate well with vine vigor and yield variability (Bramley 2001, 2003, Bramley and Lanyon 2002), with vineyard blocks on shallow soil presenting the lowest vine size and productivity.

Apart from soil mapping, yield mapping with sensors adapted on grape harvesters gave a major boost in PA application in vineyards (Arno et al. 2005). Previous studies have shown that almost a 10-fold variation in yield can occur in the same vineyard and that yield zones are relatively stable in time (Bramley and Hamilton 2004). However, in many cases, including most Greek vineyards, grapes are manually harvested. In these conditions, yield mapping is executed by measuring and georeferencing the bins of grapes collected (Tagarakis et al. 2006; Tagarakis, 2013a) or by performing a sample yield measurement at specific plots of the vineyard (Hall et al. 2011).

The main difference of grape growing compared to other crops is that vineyard profitability is mostly depended on grape and wine quality, therefore investigation of the spatial variability in grape composition is critical for successful adoption of PV. Of particular interest among berry components are anthocyanins and tannins located in the skins and seeds of grape berries in red cultivars which are responsible for the color and mouthfeel of red wines (Ribéreau-Gayon and Glories 1986). Correlations between grape quality and vine vegetative and reproductive growth have been previously observed (Cortell et al. 2005, Bramley and Hamilton 2007, Reynolds et al. 2007) although a lower spatial variability is commonly observed for grape composition compared to the variability in yield (Bramley and Hamilton 2004; Tagarakis 2013b). In addition, spatial patterns of grape components have a lower consistency over time, because the biological processes controlling berry ripening are complicated (Santesteban et al. 2013; Tagarakis, 2014). Nevertheless, selective harvesting based on zones of similar soil characteristics or vine performance has been proved to be highly profitable for wine industries and grape growers (Bramley et al. 2005).

However, despite the fact that grape quality is ultimately judged upon wine properties, the majority of PV studies have only dealt with the assessment of the spatial variability of grape composition at harvest whereas the inclusion of wine quality spatial data is very rare in literature. Therefore, the aim of this study was to investigate the effect of the variability in soil and vine properties on both grape composition and wine quality under the typical dryland conditions of Mediterranean viticulture.

MATERIALS AND METHODS

Experimental Field

The study was conducted in a non-irrigated vineyard (0.83 ha) at Asprokampos, Peloponnese, Greece (latitude 37.54°, longitude 22.33°), during the 2013 season. The vineyard was situated in the “Nemea” Protected Designation of Origin (PDO) area, which is the biggest in Greece covering about 3000 ha. The vineyard was planted with *Vitis vinifera* L. cv. Agiorgitiko, a Greek red winegrape variety, grafted onto 1103P rootstock. Vines were spaced 1.0 x 2.5 m and trained to a Lyre system. The vineyard was situated on a slope (≈12%) and was sectioned in a regular grid of 18 cells of similar size (400 – 550 m^2) in order to analyze the spatial variability in grape and wine components.

Data Collection and Analysis

Elevation and slope data were acquired from SRTM satellite in Global Mapper 14 (Blue Marble Geographics, Maine, USA). Soil variability was assessed by ECa measurements using an EM-38 probe (EM38 RT, Geonics LTD, Ontario Canada). Ground conductivity was measured within 1.5 m of effective depth range, using vertical dipole mode. The EM-38 probe measurement was taken by walking across the vineyards between the rows, while a DGPS (Differential GPS 106, Trimble LTD., USA) was recording the position of each measurement. Both instruments were connected to a data logger (Allegro CX, Jupiner Systems Inc., Logan Utah, USA) recording a value every second. The mean ECa value of every cell was calculated in ArcMap 10.1 (ArcGIS 10.1, ESRI Inc., California, USA) through the join data menu between cells and measurement points. Maps of the above measurements were produced with the Surfer 11 (Golden Software Inc., Colorado, USA) software.

Harvesting was performed manually and yield was measured by counting and weighing the total number of plastic bins per cell, when completely full. 300-berries samples were taken from each vineyard cell three times during the ripening period, respectively, on 30 August 2013 and 7 September 2013 prior to harvest and at harvest time (17 September 2013). Individual berry fresh weight was determined on a sub-sample of 50 berries per vineyard cell while a second sub-sample of 200 berries per cell was pressed and the must was analyzed for total soluble solids (^{o}Brix) by refractometry, total acidity by titrimetry with 0.1 N NaOH and pH by a laboratory pH-meter.

For the determination of total anthocyanins and total phenolics (Iland et al. 2000, Sarneckis et al. 2006), 50 remaining berries from each cell were transferred into a 125 mL plastic beaker and were homogenized using Polytron at 25.000 rpm for 30 seconds. 1 g of homogenate (in triplicate) was transferred into a pre-tared centrifuge tube (10 to 15 mL). 10 mL of 50% v/v aqueous ethanol at pH 2 were added and mixed for 1 hour. After centrifugation at 3500 rpm for 10 min, the supernatant was used to measure the absorbance as follows: 0.5 mL of the supernatant was transferred into 10 mL of 1M HC1 and mixed thoroughly. After 3 hours, absorbance at 520 nm and 280 nm were recorded in a 10 mm cell. Anthocyanins (expressed as mg per g berry) were calculated from the absorbance measurement at 520 nm. Total phenolics (expressed as absorbance units per g berry weight) were calculated from the measurement of absorbance at 280 nm.

For grape tannins estimation, the MCP (methyl cellulose precipitable) tannin assay method was applied (Sarneckis et al. 2006). 1 g of the same homogenate (in triplicate) was transferred into centrifuge tubes and 10 mL of 50% v/v aqueous ethanol, were added and mixed for 1 hour. After centrifugation at 3500 rpm for 10 min, the supernatant was kept. The method required a control sample (1 mL of supernatant, 2 mL of saturated ammonium sulfate solution at a volume up to 10 mL with water) and a treatment sample (1 mL of supernatant, 3 mL of 0.04% methyl cellulose aqueous solution, 2 mL of saturated ammonium sulphate solution at a volume up to 10 mL with water). After centrifugation at 4000 rpm for 10 min, the absorbance at 280 nm was measured in the supernatant of control and treatment samples. Tannin values were obtained from the standard curve, thus values for tannin are reported in catechin equivalents.

About 20 kg from the total harvested grapes per vineyard cell were transferred to the Oenology Laboratory of the Agricultural University of Athens to be vinified separately. For the winemaking trials, grapes of each cell were crushed and destemmed and 60 mg/L SO_2 (as potassium metabisulfite) were added. Pectolytic enzymes (Safizym Colour, Fermentis, France) at 3 g/hL as well as lyophilized yeasts of the commercial strain SC 22 (Fermentis, France) at 20 g/hL, previously hydrated in water (15 min, 38°C) were also added. Beginning on the second day of fermentation, and for the following days, two punching downs per day were conducted to extract phenolic compounds. After 7 days of maceration, the wines were drained and transferred to other tanks and spontaneous malolactic fermentation was completed after approximately 3 weeks. The wines were racked, supplemented with 50 mg/L SO_2 (as potassium metabisulfite), filtered and bottled until the time of analysis.

In the final wines, alcoholic degree and titratable acidity were determined according to the OIV methods (1990). Color intensity and hue were assessed by measurement of the absorbances at 420, 520 and 620 nm under 1 mm optical way (Glories 1984). Total Anthocyanins were determined using the SO_2 bleaching method at 520 nm optical density in HCl media (Ribereau-Gayon et al. 1999). Tannin concentration was measured by two methods. The first method measures tannin content after heating in acid medium (Ribereau-Gayon et al. 1999) and conversion into cyaniding molecules, whereas the second after precipitation with methyl cellulose (Sarneckis et al. 2006). The results of the second assay are strongly correlated with perceived astringency (Mercurio and Smith 2008) and therefore they can be used as a chemical estimation of wine astringency. Total wine phenolics were determined using the Folin-Ciocalteu reagent (Singleton and Rossi 1965). A 1 mL sample of red wine, diluted 1/10 with distilled water, was mixed with 5 mL of Folin-Ciocalteu reagent (previously diluted 10 times) and 20 mL of sodium carbonate solution (20% w/v). After 120 minutes, the absorbance at 750 nm was measured in a 10 mm optical path. A calibration curve was plotted using solutions of gallic acid (0 - 50 - 100 - 250 - 500 - 1000 mg/L). All analyses were performed in triplicate.

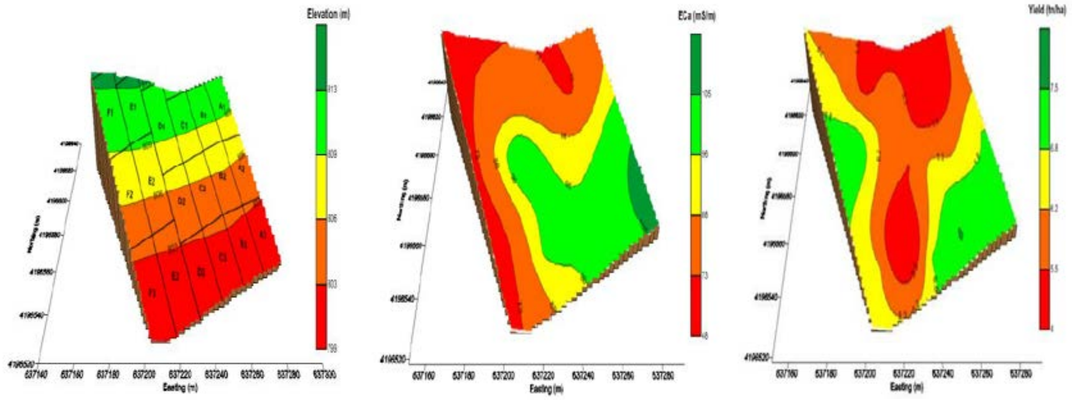
Statistical analysis included correlation matrices and descriptive statistics for all measured parameters by SPSS 20 (IBM Corp., New York, USA).

RESULTS AND DISCUSSION

Initial maps of elevation and ECa provided a visual representation of the variability across the vineyard (Fig. 1). Elevation varied from 785 to 803 m above sea level with a slope of 11.82%. Yield and ECa showed the highest within field variability with higher levels at the lower-east side of the field. ECa ranged from 70.40 to 106.91 while yield presented a two-fold variation (Table 1).

Table 1 Descriptive statistics of field parameters

	N	Min	Max	Mean
Elevation	18	801.25	811.63	805.86
Slope (%)	18	10.93	12.71	11.82
Yield (tn/ha)	18	4.08	7.52	6.12
ECa	18	70.40	106.91	89.62



(a) Elevation (b) ECa (c) Yield

Fig. 1. Elevation (with sampling grid), electrical conductivity (ECa) and yield maps of the experimental vineyard.

ECa presented significant negative correlations with both elevation and slope ($r = -0.638$ and $r = -0.701$ respectively, $p < 0.01$; Table 2). This result shows that the effect of landscape on soil properties was probably due to erosion, soil from the elevated part migrating towards the leveler part of the field. In general, increased slope indicates that soil root zone in the leveler part of the field is deeper thus increasing access to soil water reserves (Tardaguila et al. 2011).

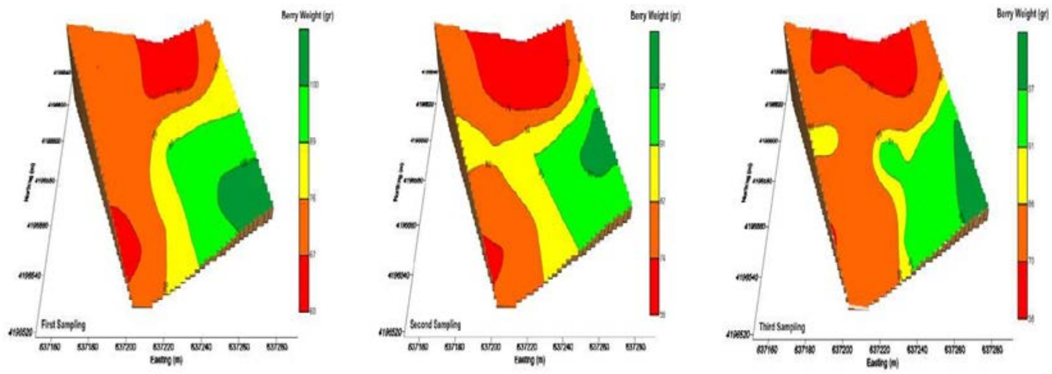
Table 2 Pearson's correlation matrix among field parameters

	Elevation	Slope (%)	Yield (tn/ha)	ECa
Elevation	1			
Slope (%)	***0.977*****	1		
Yield (tn/ha)	-0.432	-0.464	1	
ECa	***-0.638*****	***-0.701*****	0.400	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Berry weight presented a consistent spatial pattern through ripening, linked to soil variability, with consistently higher values at the lowest-east part of the vineyard (Fig. 2). For the harvest sampling, berry weight showed a 2-fold variation within the vineyard (C.V. = 0.14; Table 3). Grape berry size is considered as a particularly important quality index of winegrapes, with small berries generally considered favorable for wine quality since the higher ratio between skin surface area to juice volume in small berries results in a lower dilution of skin-located metabolites in the final wine (Walker et al. 2005).



(a) (b) (c)

Fig. 2. Berry Weight spatial distribution within the vineyard in the 3 samplings: (a) 30 August 2013 (b) 7 September 2013 (c) 17 September 2013

Must components were the least variable within the field in all samplings (Table 3). Similarly, a low variability within the vineyard was observed for wine alcohol, acidity and pH, which are directly related to must chemical composition (Table 4). Grape phenolic compounds (anthocyanins and total phenols) showed the highest (5-10 fold) within-field variability (Table 3). However, this variability in phenolic compounds was reduced in the wines, although remaining the highest among wine components (Table 4).

Table 3 Descriptive statistics of grape composition parameters at harvest

	N	Min	Max	Mean	Std. Deviation	CV (%)
50-berry weight (g)	18	58.20	97.20	82.73	11.85	14
Total Soluble Solids (Brix)	18	20.72	22.72	21.67	0.51	2
Titratable Acidity (g tart./L)	18	5.66	7.58	6.62	0.48	7
pH	18	3.14	3.43	3.27	0.07	2
Anthocyanins (mg/berry)	18	0.49	2.46	1.58	0.59	37
Anthocyanins (mg/g berry)	18	0.39	1.77	0.99	0.35	35
Tannin Content (mg/g)	18	42.55	95.24	72.95	15.99	22
Total Phenolics (au/berry)	18	0.94	3.36	2.19	0.76	34
Total Phenolics (au/g berry)	18	0.74	2.31	1.38	0.43	31

Berry weight was the most sensitive among berry attributes to field variability. Significant negative correlations with elevation ($r = -0.589$, $p<0.01$; Table 5) and slope ($r = -0.656$, $p<0.01$; Table 5) were observed. The negative correlation with elevation shows that the highest part of the field gave smaller berries, possibly due to its more shallow soil. In addition, berry weight showed significant positive correlation with yield ($r = 0.656$; $p<0.01$; Table 5) and ECa ($r = 0.735$; $p<0.01$; Table 5) suggesting that berry weight increased with and soil water content and fertility.

Table 4 Descriptive statistics of wine composition parameters

	N	Min	Max	Mean	Std. Deviation	CV (%)
Alcohol (%)	18	11.02	13.44	12.17	0.65	5
Titratable Acidity (g tart./L)	18	4.60	6.90	5.29	0.50	9
pH	18	3.42	4.08	3.69	0.14	4
Colour Intensity	18	9.96	12.56	11.60	0.78	7
Colour Tint	18	0.62	0.72	0.67	0.03	4
Total Anthocyanins (mg/L)	18	228.36	372.05	298.11	41.93	14
Total Tannins (g/L)	18	2.41	3.58	2.83	0.343	12
Astrigency (g cat./L)	18	0.447	2.81	1.77	.72	40
Total phenolics (g cat./L)	18	1.90	3.19	2.66	.29	11

Yield correlated negatively only with must and wine pH (r = -0.391; p<0.05; Table 5 and r = -0.621; p<0.01; Table 6). Juice components (total soluble solids, titratable acidity and pH) as well as phenolic compounds had no consistent spatial pattern through ripening and none of them was related to the variability of soil, or yield, although anthocyanins had a relatively more stable spatial pattern during ripening (data not shown). Grape anthocyanins, only when expressed per single berry, showed a negative correlation with elevation, an effect that was probably due to the highest berry weight at the lowest parts of the field rather than to differences in anthocyanin content per se.

Table 5 Pearson's correlations among field and grape composition parameters

	Elevation	Slope (%)	Yield (tn/ha)	ECa
50-berry weight (g)	***-0.589****	***-0.656*****	***0.656*****	***0.735*****
Total Soluble Solids (Brix)	-0.344	-0.412	0.416	***0.520****
Titratable Acidity (g tart./L)	0.333	0.291	-0.115	-0.248
pH	0.382	0.256	-0.391	-0.041
Anthocyanins (mg/berry)	-0.415	***-0.514****	0.101	0.433
Anthocyanins (mg/g berry)	-0.219	-0.299	-0.168	0.117
Tannin Content (mg/g)	0.413	0.426	-0.302	-0.205
Total Phenolics (au/berry)	-0.319	-0.457	0.100	0.459
Total Phenolics (au/g berry)	-0.093	-0.213	-0.196	0.121

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Similarly to grape composition, wine composition parameters spatial trend did not present any significant correlations with field characteristics. Moreover, there seemed to be no (or limited) connection between grape and wine phenolic composition (as shown by the absence of significant correlations between the most important grape and wine attributes related to the phenolic potential, Table 7).

Table 6. Pearson's correlations among field and wine composition parameters

	Elevation	Slope (%)	Yield (tn/ha)	ECa
Alcohol (%)	-0.152	-0.170	0.413	0.219
Titratable Acidity (g tart./L)	-0.389	-0.351	0.145	-0.165
pH	0.297	0.313	***-0.621*****	0.041
Colour Intensity	-0.063	0.022	0.037	-0.008
Colour Tint	0.416	0.460	-0.461	-0.166
Total Anthocyanins (mg/L)	0.186	0.199	-0.137	-0.119
Total Tannins (g/L)	0.195	0.306	***-0.535****	-0.318
Astrigency (g cat./L)	0.035	0.072	-0.338	-0.151
Total phenolics (g cat./L)	0.209	0.301	-0.179	-0.252

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

CONCLUSIONS

Most Greek vineyards have small areas but present significant variation in soil properties, mainly due to variations in topography. A key aspect of precision viticulture is the delineation of management zones reflecting differences in fruit quality in a way that all harvested grapes per zone present uniform composition with the desired winery specifications. Among grape composition parameters, sugar (i.e. total soluble solids), titratable acidity and phenolic content of berries are the most commonly used parameters to describe red winegrape quality at harvest. However, grape quality is ultimately judged upon wine properties, therefore, the aim of this study was to investigate the effect of field spatial variability directly on wine composition, by performing separate vinifications on a regular vineyard grid. According the results, grape and wine composition was not strongly spatially structured with the exception of berry weight which was significantly linked to the variation in soil and topography. Moreover, no (or limited) connection between grape and wine composition spatial distribution was observed, suggesting that selective harvesting based on solely grape attributes does not necessarily identify the most suitable areas to be assigned to different wine qualities. This study indicated the necessity to evaluate wine quality spatial data alongside grape yield and composition to increase the profitability of PA implementation in vineyards.

Table 7 Correlations among wine and grape composition parameters

		Grapes						
		50-berry weight (g)	Total Soluble Solids (Brix)	Titratable Acidity (g tart./L)	pH	Anthocyanins (mg/g berry)	Tannin Content (mg/g)	Total Phenolics (au/g berry)
Wines	Alcohol (%)	0.018	-0.166	0.083	-0.264	-0.045	-0.112	-0.083
	Titratable Acidity (g tartaric/L)	0.040	0.105	-0.023	-0.281	-0.103	-0.432	-0.195
	pH	-0.442	-0.172	-0.060	0.423	0.114	0.345	0.166
	Colour Intensity	-0.153	0.095	0.095	-0.456	***-0.589****	0.187	***-0.649*****
	Colour Tint	-0.433	-0.258	-0.245	0.208	0.010	0.394	0.033
	Total Anthocyanins (mg/L)	-0.334	-0.178	0.069	-0.109	-0.096	***0.474****	-0.077
	Total Tannins (g/L)	***-0.518****	-0.157	-0.155	-0.150	-0.160	0.334	-0.171
	Astrigency (g cat. /L)	-0.178	0.015	***-0.510****	0.436	0.107	0.364	0.122
	Total phenolics (g cat. /L)	-0.156	-0.227	-0.037	-0.420	-0.208	0.230	-0.295

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

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