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Establishing the correlation between soil and crop production to optimize wine quality

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Abstract: The inherent correlation between soil composition and viticulture productivity is complex and methodologies available are either labour intensive or requires significantly expensive technologies, such as precision viticulture. In this context, the paper elaborates on research that investigated in to establishing the correlation between soil nutrient distribution and soil type using 3-dimentional distribution models. Plant productivity and quality data collected from the vineyard are analysed to obtain weighted correlation of all factors being considered. Field monitoring from spring to autumn (October 2010/May 2011) has been conducted in a commercial vineyard located in Kumeu, New Zealand. Data collected include soil samples at strategic locations and yield production and sugar content of berries at the same specific sites for two grape varieties (Chardonnay and Pinot Noir). Soil properties were collected at three different horizons for a total of 58 sites (137 samples). Chemical experiments were conducted on the soil samples to establish the soil pH, Nitrate, Sodium and Potassium.

Preliminary results show a slight difference between the availability of nutrients at different layers of soil in the vineyard. The spatial analysis at two different depths showed the top layers with lower pH values than bottom layers. In addition a significant correlation was found on Sodium, Nitrate and yield in relation to the elevation, slope and depth. Environmental conditions were an important factor on yield productivity at plant level, revealed by the Pearson's and Spearman's correlation (r= 0.408; rho=0.388), but a minor factor at field level (T-pair Sig (2.tailed) value of 0.397) when considering orientation of the plant. Figure 1 shows the locations where the yield was collected and the total yield produced per site (in Kg). From the map, it is evident that there is an 18° shift of the field from the true south-north direction, favouring the eastern branches of the vine which produced 10% more than the western side.

Finally, geostatistical analysis to obtain accurate nutrient distribution maps using interpolation techniques to relate the nutrients with plant performance and berry quality are presented.

Keywords: *Soil nutrient, grapevine, geostatistical analysis*

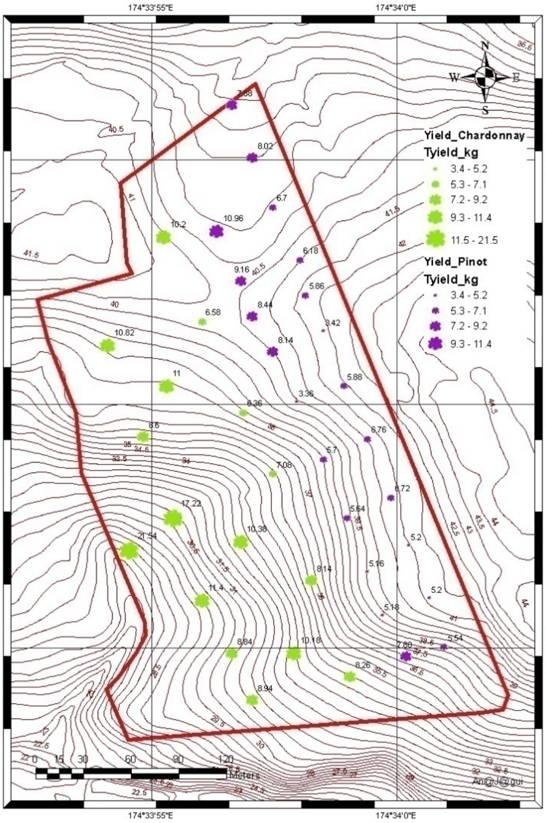

Figure 1. Sampling sites and yield production per site (considering 4 plants at each site)

1. INTRODUCTION

Understanding the factors relating to the successful production of high quality wine grapes has been the main target for winemakers. Climate is commonly recognized as the main driving force for the success of the wine industry, hence determining the ideal conditions under which wine regions and their varieties prosper is considered as vital for producing premium quality wine. Nevertheless there are additional factors that come into play at micro-scale (often expressed in meters rather than kilometres as it happened at macro-scale level). These factors are related to soil properties of the area including soil texture, composition, hydrological factors and water availability. The significance of soil fertility and it impacts on vine has been widely studied (CRS 95/1, 2002), including the influence of the vineyard design and environment (Gee, 2011; Jackson and Lombard, 1993). However, a comprehensive spatial distribution study including all the parameters influencing grapevine growth has not been performed at this stage in New Zealand and the paper presents such a study in view of the importance of geospatial aspects in grapevine yield and wine production.

2. METHODOLOGY

Site and Samples:

Data used in this study was collected in two series of experiments: (i) Soil nutrient data at 3 different horizons (depths) from equally distributed sampling sites across a field of 5.2ha at Kumeu River Winery, New Zealand (36°46′30″S 174°34′0″E), collected in October 2010; (ii) plant yield at particular locations, collected during March, 2011 (same sites where soil samples were taken) from a 10-year-old Pinot Noir and 7 to 9-year-old Chardonnay varieties.

Total number of soil samples studied on the experiment (i) was 137 samples from 58 sites. From depths labelled as horizon A (5~15cm depth) and horizon B (15~25cm depth) samples were collected at each site; at horizon C (25~35cm depth) samples were collected at specific sites only (every other site). Chemical experiments (Table 1) were performed for each soil sample to obtain pH, Sodium (Na), Potassium (K) and Nitrate (NO_3). Soil samples were collected using a 5-cm diameter cast iron auger, immediately after extraction the soil pH was measured with a Field Scout pH 110 Meter Data Logger, then sealed in clean plastic bags and taken to the lab for further analysis. Once in the laboratory the samples were air dried to minimize biological transformation and other chemical reactions, plant and root material were removed, they were ground and passed through a 1mm sieve, finally they were bagged, labelled and stored in a dry and cool place until chemical experiments were performed.

Vine yield data for the experiment (ii) was collected from the four vines closest to selected soil sampling sites. A total of 152 vines, out of 12793 (~1.2% of the vine population on a vineyard with a density of 2460vines/ha) were used in this study. The selected vines are termed as the North-East (NE), North-West (NW), South-East (SE) and South-West (SW)

Table 1. Equipment and protocol followed during experiments.

Element	Equipment	Protocol followed from:
Soil pH	Field Scout pH 110 Meter pH meter	Spectrum (a) Hill and Sparling, 2009
Sodium	Cardy Sodium Na+ Meter	Spectrum (b)
Potassium	Cardy Potassium K+ Meter	Spectrum (c)
Nitrate	Cardy Twin Nitrate Meter	Spectrum (d)

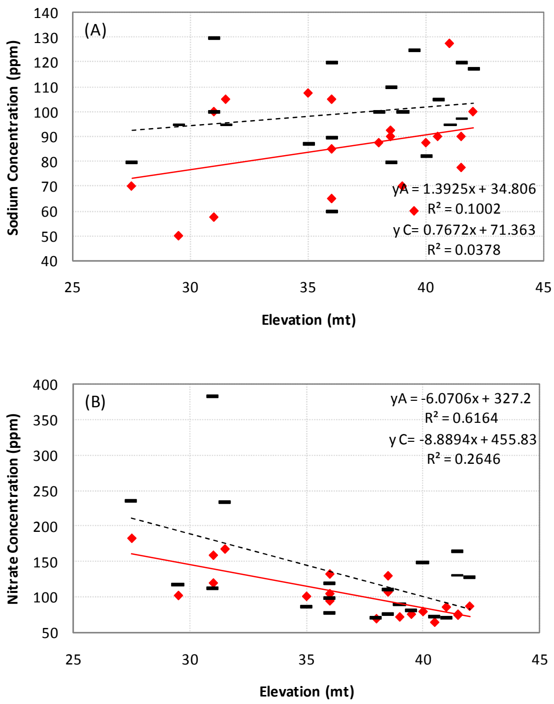

Figure 2. (A) Na concentration and (B) NO_3 concentration vs. site elevation at Kumeu River Winery studied field; depths between 5~15cm (♦: Horizon A) and 25~35cm (▬: Horizon C).

based on directions with respect to the soil sampling sites. Each vine has two *cordons* (branches), one facing East (E) and the other facing West (W) from a U or Lyre trellis system array (Smart and Robinson, 2006). Collected data consist on the amount of berries (in Kg) that each vine produced per *cordon.* Other physical characteristics of the vine and its production were collected such as number of bunches per cordon, number of berries per bunches; also sugar content, pH and weight of representative sampled berries. In addition, it was calculated the % of sand, silt, and clay of the soil, the temperature and moisture of undisturbed soil measured at each site. Only part of these datasets will be used for this paper.

Numerical Analysis:

The statistical analysis of the database aims at identifying the correlations existing between the measured parameters (pH, NO_3, K, Na and yield) and inherent location related parameters (elevation, sunshine, weather, etc). Descriptive statistics is carried out to characterize the dataset, including minimum, maximum and mean values are calculated in addition to their dispersion and distribution using the following general equations:

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}, \qquad g_1 = \frac{m_3}{m_2^{3/2}}, \qquad g_2 = \frac{m_4}{m_2^2 - 3}, \qquad m_r = \frac{1}{n}\sum(x_i - \bar{x})^r$$

Where σ is the standard deviation used to calculate the dispersion and its square value is the variance of that dataset; x and $\bar{x}$ are the value and its mean, *n* is the total number of samples. Regardless of the smaller standard deviation, its distribution should be carefully considered as tailed values could introduce interesting correlations. Moreover, a measurement describing the shape of the distribution is given by g_1 and g_2, skewness and kurtosis respectively (Joanes and Gill, 1998); a measure of asymmetry or skewness close to zero is stated to be indicating a normal distribution; in contrast to a positive or negative value which could normally reveal a right or left tail (values more than twice its standard error represent departure from symmetry). On the other hand, a measure of peakness or kurtosis is used to evaluate the extent of the values clustered around a central point; positive values represent a sharper peak and longer tails, with the opposite for negative values.

Correlation models were utilized to obtain the statistical dependence of parameters studied in this research (linear and non-linear). To evaluate the strength of the relationship between variables, Pearson's product-moment correlation coefficient and Spearmans's rank correlation (Spearmans's rho) were used for its linear and non-parametric measure of dependency, respectively (Rodgers and Nicewander, 1988; Potvin and Roff, 1993).

The data analysis is performed in three stages: First stage by performing statistical analysis of all nutrient data obtained in the experiment (i) and finding the relationships within the data set. Second stage is performed by exploring the vine yield data collected during experiment (ii), considering the orientation and topography of the vineyard. Final stage consists of comparisons between the interpolated results from the soil data and total yield per site.

Table 2. Descriptive Statistics of relevant parameters extracted from Kumeu River Winery field. Each parameter was measure at two different depths, between 5~15cm (horizon A) and 25~35cm (horizon C). Plant density of 2460 vines/ha.

	ID	N	Min	Max	Sum	Mean		Std.	Variance	Skewness		Kurtosis	
						Statistic	Std. Er	Deviation		Statistic	Std. Er	Statistic	Std. Er
Elevation		20	28	42	734	36.68	0.99	4.43	19.59	-0.71	0.51	-0.67	0.99
Yield (Kg)	NE plant	20	0.64	6.98	48.30	2.42	0.33	1.49	2.22	1.59	0.51	3.71	0.99
	NW plant	20	0.80	3.58	40.56	2.03	0.16	0.73	0.53	0.36	0.51	-0.30	0.99
	SE Plant	20	0.12	6.40	44.92	2.25	0.31	1.39	1.93	1.86	0.51	4.42	0.99
	SW plant	20	1.14	4.58	44.02	2.20	0.20	0.91	0.83	1.70	0.51	2.89	0.99
pH (ppm)	A Horz	20	5.34	5.92	112.90	5.65	0.04	0.18	0.03	-0.07	0.51	-1.23	0.99
	C Horz	20	5.22	6.43	117.42	5.8710	0.07	0.30	0.09	0.07	0.51	0.05	0.99
Na (ppm)	A Horz	20	50.0	127.5	1717.5	85.88	4.35	19.47	379.13	-0.01	0.51	-0.20	0.99
	C Horz	20	60	130	1990	99.50	3.91	17.46	305.00	-0.16	0.51	0.03	0.99
K (ppm)	A Horz	20	10	150	933	46.63	9.31	41.63	1733.08	1.16	0.51	0.28	0.99
	C Horz	20	0	140	560	28.00	8.26	36.96	1366.18	2.22	0.51	4.47	0.99
NO_3 (ppm)	A Horz	20	65	183	2091	104.56	7.65	34.22	1170.93	1.01	0.51	0.14	0.99
	C Horz	20	70	383	2596	129.81	17.10	76.48	5849.55	2.25	0.51	5.70	0.99

3. RESULTS

Statistical Analysis:

The summaries of statistical parameters considered in the research are shown on Table 2. Data at similar depth and locations were grouped to analyse the correlations at these depths being studied. From their descriptive statistics it is not possible to draw any conclusions or obtain any evidence on any parametric dependency with each other or with the soil depth.

Table 3. Statistical analysis of relevant parameters considering Pearson's Correlation and Speaman's rho coefficient. Each parameter was measure at two different depths, between 5~15cm (horizon A) and 25~35cm (horizon C).

		Elev		pH		Na		K		NO_3		Yield	
		Horz A	Horz C	Horz A	Horz C	Horz A	Horz C	Horz A	Horz C	Horz A	Horz C	Horz A	Horz C
Elev	Pearson Correlation	1	1	0.001	-0.136	0.194	0.316	-0.093	-0.071	-0.514*	-0.785**	-0.750**	-0.750**
	Sig. (2-tailed)			0.996	0.568	0.411	0.174	0.696	0.765	0.020	0.000	0.000	0.000
	Spearman's rho Correlation	1.000	1.000	0.009	-0.030	0.278	0.219	-0.002	0.117	-0.235	-0.710**	-0.768**	-0.768**
	Sig. (2-tailed)	#NULL!	#NULL!	0.970	0.900	0.236	0.354	0.995	0.623	0.318	0.000	0.000	0.000
pH	Pearson Correlation	0.001	-0.136	1	1	0.502*	-0.064	0.074	0.045	0.044	0.056	-0.090	-0.034
	Sig. (2-tailed)	0.996	0.568			0.024	0.789	0.758	0.849	0.855	0.815	0.704	0.886
	Spearman's rho Correlation	0.009	-0.030	1.000	1.000	0.489*	0.001	-0.049	0.022	0.020	-0.005	0.047	-0.036
	Sig. (2-tailed)	0.970	0.900	#NULL!	#NULL!	0.029	0.997	0.837	0.926	0.932	0.985	0.845	0.880
Na	Pearson Correlation	0.194	0.316	0.502*	-0.064	1	1	0.303	0.060	0.232	-0.004	-0.316	-0.359
	Sig. (2-tailed)	0.411	0.174	0.024	0.789			0.194	0.802	0.324	0.986	0.174	0.120
	Spearman's rho Correlation	0.278	0.219	0.489*	0.001	1.000	1.000	0.133	0.026	.042	0.072	-0.371	-0.142
	Sig. (2-tailed)	0.236	0.354	0.029	0.997	#NULL!	#NULL!	0.576	0.915	.862	0.764	0.108	0.551
K	Pearson Correlation	-0.093	-0.071	0.074	0.045	0.303	0.060	1	1	0.394	0.137	0.061	0.330
	Sig. (2-tailed)	0.696	0.765	0.758	0.849	0.194	0.802			0.086	0.565	0.799	0.156
	Spearman's rho Correlation	-0.002	0.117	-0.049	0.022	0.133	0.026	1.000	1.000	-0.210	-0.006	0.175	0.085
	Sig. (2-tailed)	0.995	0.623	0.837	0.926	0.576	0.915	#NULL!	#NULL!	0.375	0.980	0.461	0.722
NO_3	Pearson Correlation	-0.514*	-0.785**	0.044	0.056	0.232	-0.004	0.394	0.137	1	1	0.244	0.609**
	Sig. (2-tailed)	0.020	0.000	0.855	0.815	0.324	0.986	0.086	0.565			0.300	0.004
	Spearman's rho Correlation	-0.235	-0.710	0.020	-0.005	0.042	0.072	-0.210	-0.006	1.000	1.000	0.018	0.566**
	Sig. (2-tailed)	0.318	0.000	0.932	0.985	0.862	0.764	0.375	0.980	#NULL!	#NULL!	0.940	0.009
Yield	Pearson Correlation	-0.750**	-0.750**	-0.090	-0.034	-0.316	-0.359	0.061	0.330	0.244	0.609**	1	1
	Sig. (2-tailed)	0.000	0.000	0.704	0.886	0.174	0.120	0.799	0.156	0.300	0.004		
	Spearman's rho Correlation	-0.768**	-0.768**	0.047	-0.036	-0.371	-0.142	0.175	0.085	0.018	0.566**	1.000	1.000
	Sig. (2-tailed)	0.000	0.000	0.845	0.880	0.108	0.551	0.461	0.722	0.940	0.009	#NULL!	#NULL!

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

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

Information obtained from this table shows that pH values are within normal range for grape production (Dami et al., 2005), however potassium (K) and Sodium (Na) are significantly lower than the average values reported on general soil samples for Northern areas of NZ (Kim and Taylor, 2009). Nevertheless, related literature reveals that higher concentration of potassium on the soil could affect directly on the quality of the grapes in terms of colour and pH (Deb, 2011; Rouhana, 2010) and the recommended soil K levels for vineyards is between 75 to 100ppm (Bates and Gee, 2011).

Although, the descriptive statistics did not reveal any correlation between parameters, it should be noted that those parameters and their distributions (skewness and kurtosis) are not normal. From Table 2, it is evident that Yield, K and NO_3 show a right tail and rounder distribution.

Further statistical analysis conducted using the same parameters are shown on Table 3, based on Pearson's correlation (r) and Spearman's rho (rho) of this table it is evident that there is a relationship in the variability of certain parameters across the vineyard. The relationships found between Sodium concentrations against elevation and those of Nitrate against elevation, are consistent to some previously reported behaviour (White, 1987; Selim et al., 1983; Ioka et al., 2001). Positive correlations found on the Sodium-Elevation relation (Figure 2A), is explained when salt ions (Ca^{2+}, Mg^{2+}, Na^{+}, etc) rise to upper layers due to evaporation, either from groundwater sources or irrigation practices.

It then appears that the results on this study are in line with the literature. The upper layer (Horizon A) Na concentration change faster with elevation, meaning that at higher areas evaporation occurs faster. Nevertheless, based on the comparisons of the Na concentrations at different depths, it is evident that this trend is not consistent with the evaporation theory, which could be due to different soil type and its corresponding percolation coefficient, which will have to be further studied.

On the other hand, Nitrate concentrations are associated with polluted rivers and groundwater from runoff and leaching leading to higher concentrations of pollutants in the area (Elrashidil et al., 2005; Ocampoa et al.,

Table 4. Simple rule to identify orientation preferences of the plants: If $Y_E>Y_W$ then c=1 otherwise c=0. Plant yield is in Kg per branch.

ID/	Plant yield		C	Plant yield		C	Plant yield		C	Plant yield		C
	NWW	NWE		NEW	NEE		SWW	SWE		SEW	SEE	
1	1.12	1.12	0	0.64	0.30	0	1.32	1.44	1	1.02	0.92	0
2	0.96	0.42	0	1.14	1.00	0	1.64	0.70	0	1.00	1.16	1
3	1.34	0.86	0	0.48	0.54	1	0.78	0.98	1	0.70	1.02	1
4	0.58	0.98	1	0.30	0.66	1	1.38	0.74	0	0.78	0.76	0
5	0.92	0.74	0	0.44	0.66	1	0.54	0.62	1	0.74	1.20	1
6	0.28	0.34	1	0.28	0.44	1	0.50	0.52	1	0.46	0.60	1
7	0.58	0.92	1	0.70	0.66	0	0.72	1.14	1	0.42	0.74	1
8	0.34	0.46	1	0.48	1.62	1	1.00	0.84	0	0.98	1.04	1
9	1.10	0.34	0	0.70	1.18	1	0.84	0.90	1	0.78	0.88	1
10	0.28	0.78	1	0.42	0.78	1	0.48	0.66	1	0.82	0.98	1
11	0.54	1.00	1	1.22	0.16	0	0.38	0.80	1	0.60	0.50	0
12	0.40	0.94	1	0.88	1.10	1	0.72	0.72	0	0.66	0.12	0
13	0.64	1.22	1	1.18	0.84	0	1.28	0.74	0	0.84	1.14	1
14	0.48	0.26	0	0.00	1.14	1	0.58	1.30	1	0.58	0.84	1
15	0.56	0.20	0	0.58	0.84	1	0.60	0.82	1	1.06	0.50	0
16	0.06	0.18	1	0.70	1.00	1	0.92	1.16	1	0.72	0.90	1
17	0.70	0.80	1	0.00	0.54	1	1.02	0.54	0	1.02	1.08	1
18	0.30	0.54	1	0.36	0.68	1	0.20	0.28	1	0.44	0.56	1
19	0.64	1.50	1	0.74	2.20	1	1.14	0.60	0	0.90	0.42	0
20	1.84	0.32	0	0.60	1.08	1	1.20	1.46	1	0.94	1.00	1
21	1.82	0.86	0	1.94	1.22	0	1.06	0.52	0	0.48	1.26	1
22	1.30	2.50	1	0.48	1.02	1	1.10	1.16	1	2.14	1.26	0
25	1.60	1.12	0	1.78	1.22	0	0.66	1.78	1	1.22	0.82	0
27	0.9	1.14	1	1.48	0.9	0	0.98	1.06	1	0	0.12	1
29	0.56	0.92	1	0.22	0.78	1	1.16	0.72	0	0.90	1.10	1
30	1.38	1.22	0	0	0.64	1	0.8	0.76	0	1.04	1.24	1
32	0.54	0.74	1	1.28	1.60	1	0.74	1.34	1	0.98	0.92	0
34	1.16	0.72	0	1.6	1.4	0	1.04	0.9	0	0.64	0.8	1
36	1.12	1.38	1	1.10	1.74	1	1.30	1.06	0	1.28	1.20	0
38	1.20	1.30	1	1.30	1.34	1	1.58	1.40	0	1.40	0.86	0
41	1.16	1.24	1	1.10	1.56	1	2.28	1.36	0	1.22	1.08	0
43	1.20	1.26	1	1.74	1.20	0	1.12	1.40	1	1.30	1.60	1
45	1.42	0.92	0	1.30	1.12	0	0.42	1.46	1	1.10	0.86	0
47	1.10	1.58	1	2.66	2.14	0	1.08	3.38	1	4.32	0.96	0
49	2.04	1.20	0	0.98	1.84	1	1.84	0.96	0	1.00	1.54	1
50	1.26	0.16	0	1.10	1.56	1	1.20	0.96	0	1.20	1.40	1
51	1.52	0.52	0	1.30	1.78	1	0.78	0.94	1	1.40	0.70	0
54	0.28	3.30	1	3.70	3.28	0	1.78	2.80	1	3.48	2.92	0
		ΣC=	22		ΣC=	25		ΣC=	22		ΣC=	22

2006). Depending on the type of soil and slope of the area, the influence of leaching or runoff could vary, nevertheless NO_3 concentration is expected to be higher for lower elevations and deeper layers, and this is reflected in the results for our study (r_A= -0.514 and rho_A=-0.238; r_C= -0.785 and rho_C=-0.710) as shown in Figure 2B. Other variables such as amount of dissolve oxygen present or permeability units on the soil (Cey et al., 1999, Selim et al., 1983; Ioka et al., 2001) affect the Nitrate concentrations in the area, but that analysis will be performed in another study.

Yield Productivity:

The strongest correlation was found between total yield and elevation with r= -0.750 and rho=-0.768 (Table 3), with a non-linear relationship reflected on a slightly higher rho value. Although there is a grape variety factor to be included in the analysis, the predominant behaviour is that at lower elevations the yield is slightly higher. In addition to elevation, there are some other factors that influence the vine productivity, such as NO_3 concentrations, specifically at deeper layers (r_C= 0.609; rho_C=0.566).

Evidence of the sunshine influence on yield production is shown on Table 4, which presents the yield per cordon per plant location with respect to the soil sampling site; The ID represents the site location and NWW=North-West plant-West branch, NWE=North-West plant-east branch, and so on. Table 4 was constructed using a simple rule to determine which cordon of the plant produced more yield: If $\text{Yield}_E>\text{Yield}_W$ then c=1 otherwise c=0, where Yield_i is the plant yield (in Kg) per cordon at East or West direction and $\sum c$ represents the yield dependency with respect to the orientation. If $\sum c>X$, then the yield has strong correlation to the Eastern direction, for this case X=19 which is the critical value of total number of sampled sites divided by 2. This rule simply reflects if more than half of the sampled plants had higher yield on the Eastern cordon, and if so then the sunlight could be a deterministic factor as far as vine yield was concerned.

Table 4 shows that there is a strong correlation between yield production and orientation, for all the NW, NE, SW and SE plants $\sum c>19$, which means 10.5% of the sampled plants had more yield on the Eastern cordon than the Western side. This number was obtained from a simple calculation that out of 152 studied plants 91 produced more yield on the Eastern cordon. Table 5 presents the descriptive analysis and the correlation calculated for each side.

Table 5. Descriptive analysis of the plant's production per cordon orientation (East and West cordons)

	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance	Pearson's		Spearman's	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	r	Sig.(2t)	rho	Sig.(2t)
East	152	3.26	0.12	3.38	157.68	1.0374	0.04627	0.57045	0.325	0.408**	0.000	0.388**	0.000
West	152	4.32	0.00	4.32	150.84	0.9924	0.05086	0.62708	0.393	0.408**	0.000	0.388**	0.000

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

Although, results from the yield/orientation are relevant at plant level, no correlation was found at the field level, once the mean value of orientation was introduced (see Table 6), the paired analysis did not reveal any statistical significance on the means of the sample groups (as Sig. 2-tailed is >> than 0.05).

Table 6. Paired Sample Test

	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
East -West	0.0450	0.65299	0.05296	-0.0597	0.1497	0.85	151	0.397

95% Confidence Interval of the Difference

From mappings of the area, it is evident that there is an 18° shift of the field from the true south-north direction, favouring more sunlight to the eastern branches of the vine. Calculating from the apparent motion of the Earth, which takes 24 hours to revolve 360 degrees (360 degrees/24 hours x 1 hour = 15 degrees), we could infer that the eastern branches will receive about 2 more hours of sunshine than the western side (if the east side get one more hour and the west side one hour less, the difference between them is 2 hours). Further analyses are required to characterize and weight the relevant of parameters involve on the development and quality of wine grapes.

Finally, Figure 3 shows the soil nutrient distribution of interpolated values (Using Ordinary Kriging) for upper (Horizon A) and deeper layers (Horizon C). From these maps is clear to observe the Na concentration on the soil (Figure 3a and 3b) and how at lower elevations its concentration increases (on both layers). On the other hand, NO_3 concentration shows its increment at lower elevation (Figure 3c and 3d). These figures are only an example of geostatistical tools and its application on precision agriculture. Further studies will be required to obtain improved mappings.

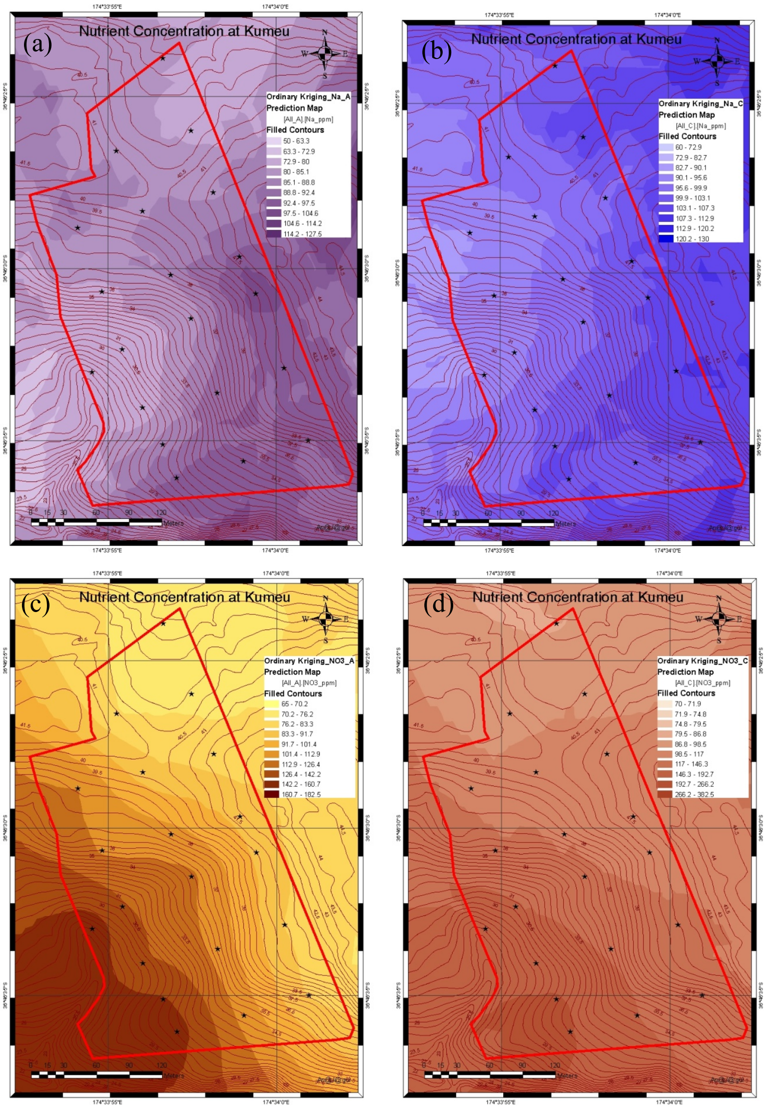

Figure 3. Soil Nutrient distribution obtained from Ordinary Kriging interpolation: Na concentration for (a) Horizon A, (b) Horizon C. NO_3 concentration for (c) Horizon A, (d) Horizon C

4. CONCLUSIONS

Although this study represents a preliminary analysis of the data obtained during the harvest season (March 2011) at Kumeu River Winery, including pre- and post- harvest soil data, it is evident that the strong correlation found between the soil nutrient availability and the yield production, is caused by the topography of the vineyard. It should be noted that the availability of these nutrients depends on their cycle and interactions that in turn depend on the environment. However, another factor noteworthy of mention is that the study has revealed the inherent correlation between the sunlight hours and the yield production; of course another vital factor in this study is the quality of the grapes which is yet to be analysed. Calculations revealed that two more hours of sunshine could have contributed to the increase in the yield by 10% in the east branch hence more pruning is recommended to lessen sun-graced sides of the plant.

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