SPATIAL AND TEMPORAL VARIABILITY IN WINE GRAPE NUTRIENTS

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ABSTRACT

Little work has been done to address the extent of spatial and temporal variability in nutrients in wine grape vineyards. In this study, we assessed soil and plant nutrient distribution on a per vine basis, both spatially and temporally across two vineyards, a Ruby Cabernet vineyard in Sunraysia and a Cabernet Sauvignon vineyard in Coonawarra. Petiole tissue was collected at two growth stages: flowering and veraison. Berry tissue was collected at harvest. All samples were analyzed for the plant nutrients N, P, K, Ca, Mg, S, Cu, B, Zn, and Fe, and the non-essential cation Na. The data were interpolated using kriging to examine individual nutrient distribution across each vineyard at each sampling time and to explore differences and similarities between the patterns of nutrient variation. A *k*-means clustering technique was used to determine whether individual nutrients followed similar patterns of spatial variation whether measured in the tissue at flowering or veraison or in soils. Data analysis (*k*-means clusters) for K and Mn showed strong agreement at both sites between all tissue types. Strong spatial and temporal distribution patterns were also found for N, P, S, and Zn. The potential for zonal management of all six of these elements is high. Understanding of both spatial and temporal variability of the nutrients studied was best gained when one or both sites included both optimal and sub-optimal nutrient supply.

INTRODUCTION

One of the challenges of plant nutrient management for grapevines is their perennial nature. Thus, the plant not only accesses nutrients from the soil in a given growing season, but also redistributes them from storage tissues (wood, roots), resulting in a reflection of new and recycled nutrient content (Conradie 1991, Conradie 2005). Little work has been done to fully explore seasonal changes in grape vineyard nutrient status (Davenport et al. 2003).

The objective of this work was to evaluate vineyard nutrient status across the growing season, both from a soil and plant perspective, to increase our understanding of both spatial and temporal patterns of nutrient distribution in wine grape production systems. To this end, two Australian vineyards, with contrasting soils and climate, were intensively sampled for an entire growing season by returning to the same target vines to collect soil, petiole, and berry tissue for nutritional analysis, which was then used to develop an understanding of nutrient distribution patterns.

METHODS

During the 2000/2001 growing season, soil and tissue samples were collected from the same locations in two vineyards, a 7.3 ha (1 ha = 2.5 ha) Cabernet Sauvignon block in Coonawarra (lat 140^{o}50'E and long 37^{o}17'S) and a 4.5 ha Ruby Cabernet block in Sunraysia (lat 142^{o}9'E and

long 34°11'S). Detailed information about both vineyard sites and the sampling strategy used are available in Bramley and Hamilton 2004 and Bramley 2005.

Soil samples were collected at each sample location in each vineyard in June 2000 for the Sunraysia site and October 2000 for the Coonawarra site. Sample cores 50 mm (1 mm = 0.04") in diameter, were collected in triplicate to a 1 m depth and then sectioned on a depth basis into per vine composite samples. The triplicate cores were taken within 50 cm (1 cm = 0.40") of the trunk of the 'target vine' (Bramley 2005) and within 50 cm of each other. At Coonawarra, samples utilized for this data analysis were 30-40 cm depth increments, while at Sunraysia, samples from the 50-55 cm depth were utilized, with the increments chosen representing the predominate root zone at each site. These depths were chosen to reflect the apparent root distributions for the two sites. Samples were oven dried at 40°C (104°F) and sieved to < 2 mm. Samples were extracted with DTPA for Cu, Fe, Mn, and Zn, with ammonium chloride at pH 8.5 for Ca, K, Mg and Na, bicarbonate for P and calcium phosphate for S and analyzed for these elements using ICP spectroscopy following the standard Australian methods described by Rayment and Higginson (1992). Mineral nitrogen was determined as both NO_3-N and NH_4-N using KCl extraction and analyzed colourimetrically, while total N was determined using a LECO-CNS Analyzer (St. Josephs, MI, USA) for dry combustion, again using the standard Australian methods (Rayment and Higginson 1992).

Petiole samples were collected twice during the growing season, at both flowering and veraison, by collecting 8 petioles per target vine; the petiole opposite the basal bunch was sampled from randomly selected canes. After harvest, a 50 berry subsample (Bramley 2005) was freeze-dried for analysis at a later date. Total N was determined by dry combustion on the LECO-CNS Analyzer. All other elements were determined by ICP spectroscopy on concentrated nitric acid tissue digests.

A map for each analyte for each sampling time at both vineyards was developed by interpolating onto a 2 m (1 m = 3.25') grid (pixels of 4 m^2) by global point kriging of the vine data using VESPER (Minasny et al. 2005). A thorough discussion of the method used and the background for this approach is available in Bramley (2005). As with data presented in Bramley (2005), the variograms for each attribute were fitted with an exponential model only, using a common set of input parameters and boundary conditions (maximum distance, number of lags) when running VESPER (Minasny et al. 2005; maximum distance = 150 m; 30 lags; 50% lag tolerance).

Individual vine data were analyzed using standard ANOVA procedures using PC SAS (SAS Institute, Cary, NC, USA). Similarity in patterns of spatial variation was examined using *k*-means cluster analysis of the kriged data using JMP (SAS Institute, Cary, NC, USA). To evaluate correspondence of soil data with tissue derived clusters, the zonal statistics procedure of ArcGIS 8.3 (ESRI, Redlands, Calif., USA) was used. The *k*-means cluster analysis assigns a numeric value of 1, 2, or 3 to each kriged data point in a three cluster solution. The zonal statistics procedure then calculated the number of data points, and the median, maximum and minimum value for a chosen variable (in this case, soil test nutrient concentration) within each cluster zone derived from tissue data. Thus, using the zonal statistics procedure gives an indication of how well or poorly the soil test value of a given nutrient aligns with the cluster zones derived from tissue nutrient concentrations of the same elements.

The data presented here will be limited to the elements that showed conclusive patterns of variability – the macro nutrients N, P, K and S and the micro nutrients Mn and Zn.

RESULTS AND DISCUSSION

Soil test, petiole, and berry nutrient N, P, K, S, Mn and Zn concentrations varied across both vineyards and, in the case of plant tissues, throughout the growing season (Fig. 1). To evaluate both the temporal and spatial relationships for each nutrient, *k*-means clustering analysis of interpolated petiole [both at flowering (FP) and veraison (VP)] and berry (BH) nutrient concentration data was used for each individual element. A three cluster model was used in this analysis. The three cluster model was chosen to be consistent with patterns of a "normal" range as well as above and below normal ranges typically used to describe nutrient distributions (Davenport et al. 1995; Christensen 2000; Weir and Creswell 1993).

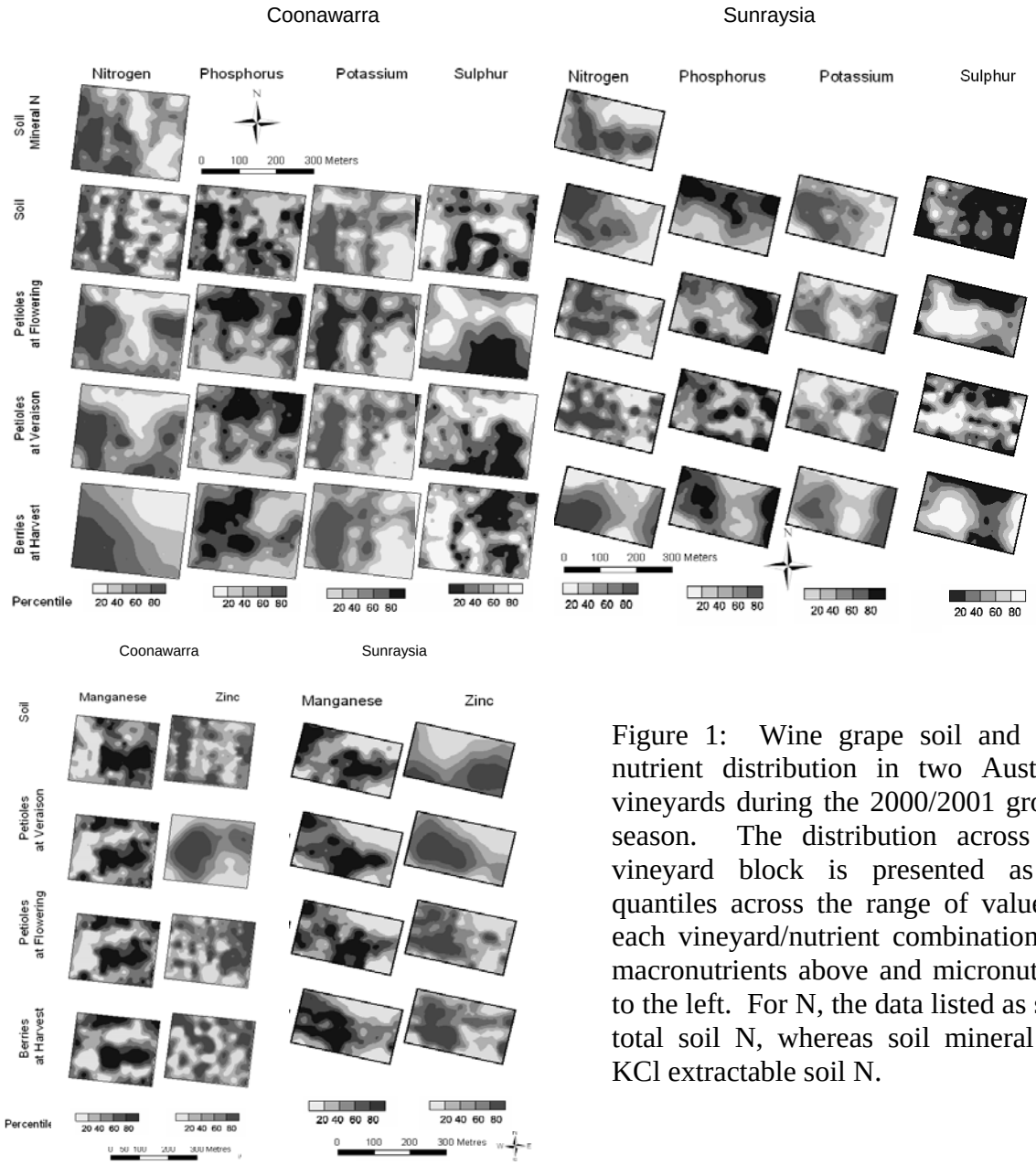

Figure 1: Wine grape soil and tissue nutrient distribution in two Australian vineyards during the 2000/2001 growing season. The distribution across each vineyard block is presented as five quantiles across the range of values for each vineyard/nutrient combination with macronutrients above and micronutrients to the left. For N, the data listed as soil is total soil N, whereas soil mineral N is KCl extractable soil N.

The results from the cluster analysis indicate that there are consistent patterns of spatial variation in nutrient status at both vineyards, irrespective of the time of sampling (Fig. 2). However, temporal relationships, defined by differences in the patterns of FP, VP, and BH median values between clusters show less consistency for some nutrients both within and between vineyards. Temporal patterns could be categorized as having total agreement, good agreement, some agreement or very little agreement (data not presented) as follows: Three nutrient elements, K and Mn, had total agreement between tissue clusterings at both vineyards. With K and Mn, all tissues had the same pattern of low, medium or high medians for FP, VP and BH. In addition, soil test K and Mn values followed median low, medium and high tissue cluster patterns at both sites (Fig. 3).

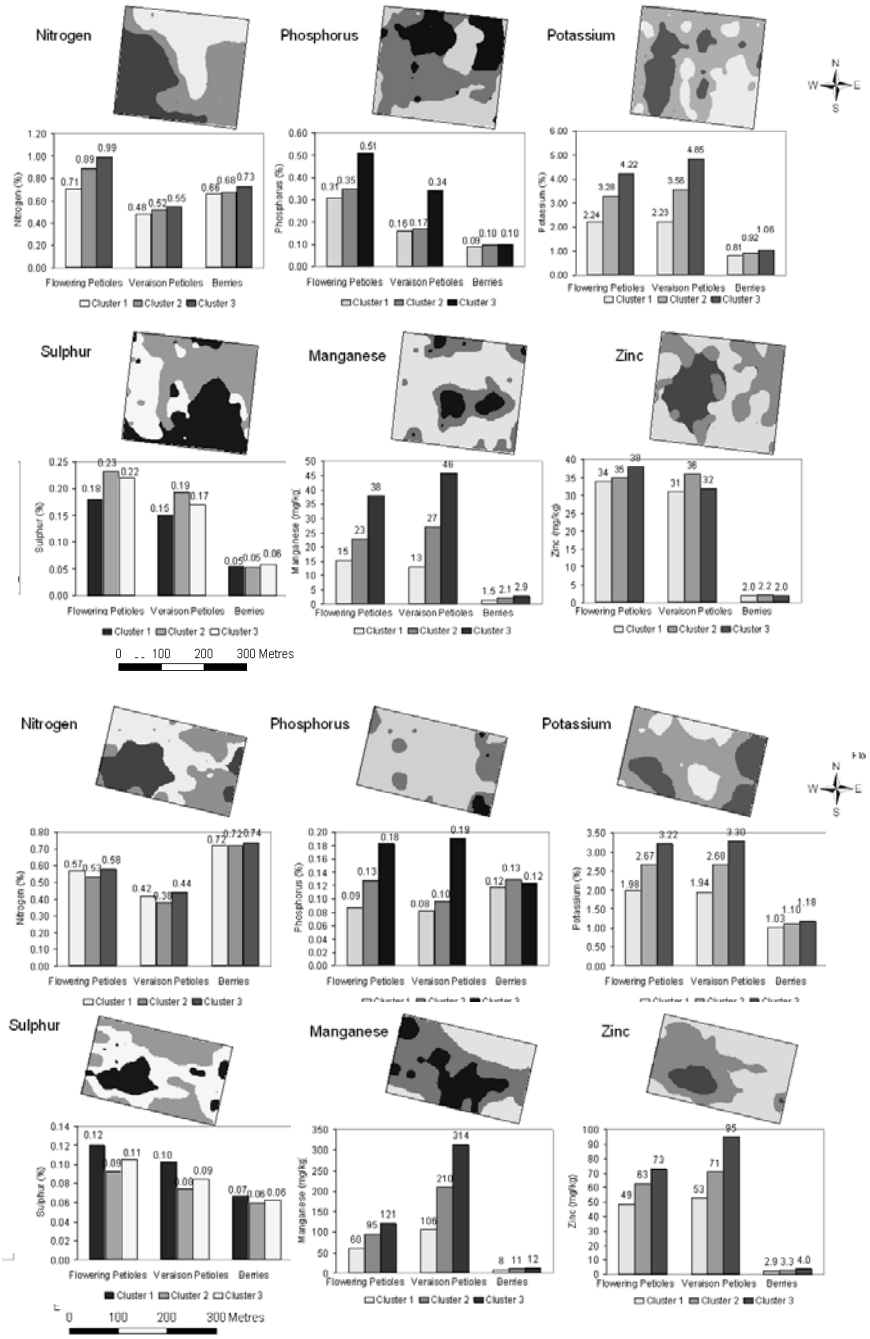

Figure 2: Average petiole (at flowering and veraison) and berry nutrient concentration grouped according by *k*-means clusters across two Australian vineyards (Coonawarra top, Sunraysia bottom). The values in the graphs represent the average FP, VP or BH nutrient concentration in each of the three cluster zones delineated in the vineyard map.

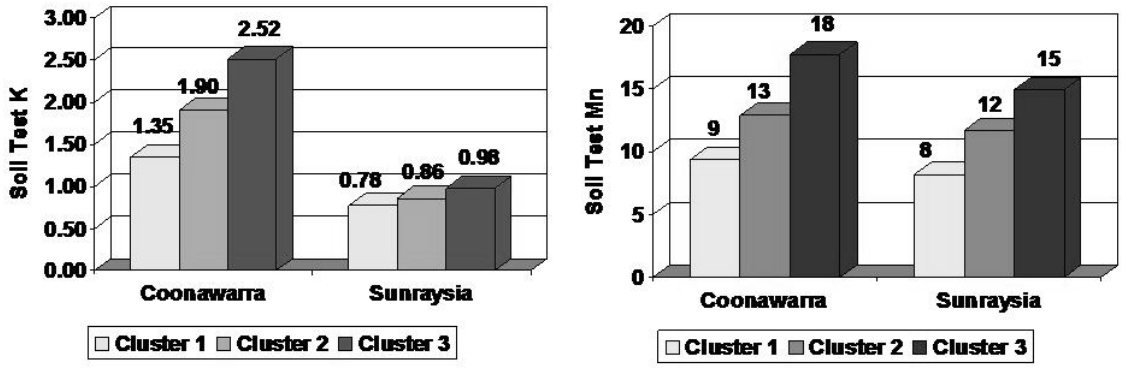

Figure 3: Average soil test K (ppm) and Mn (ppm) grouped into the same classifications of low, medium and high clusters that were developed for plant tissue (Fig. 4). Data analysis conducted using ArcGIS spatial statistics.

For both sites, the areas of adequate and above adequate FP K concentration in petioles at flowering (Fig. 4) encompassed all of the area occupied by the high cluster (Fig. 2). However, the area in which FP K was marginal in petioles at flowering (Fig. 4) was much smaller than the clusters with low median K in both vineyards (Fig. 2). This result may either reflect a possible shortcoming of the cluster analysis in terms of categorizing the clusters as 'low', 'medium' and 'high', or could suggest that modification of the critical values for adequate winegrape petiole K may be needed.

Unlike K, much more of the FP Mn was in the deficient and marginal ranges at Coonawarra (Fig. 4), whereas at Sunraysia most of the FP Mn was in the adequate range (Fig. 4). At the Coonawarra site, there was good agreement between the low Mn cluster and areas identified as having deficient concentrations in petioles at flowering, although marginal FP Mn did not align as closely with the medium Mn cluster. There was better agreement between the distribution of FP Mn in deficient, marginal, and adequate areas and low, medium and high clusters at Coonawarra than at Sunraysia. Overall, the boundaries for deficient, marginal, and adequate FP Mn at Coonawarra were 90% contained in the low, medium and high clusters. However, FP Mn at the Sunraysia site was classified as either adequate or above the adequate range. The area classified as adequate falls within the lowest cluster, whereas the two higher clusters reflect the areas where FP Mn was above the adequate range (Figs. 1 and 4). These findings suggest that the published range for 'deficient' FP Mn is suitable but the lower limit for adequate may need to be decreased. In addition, consideration could be given to listing adequate as a lower limit value only (similar to the range which Robinson et al. (1997) suggest for Fe), with a notation that if FP Mn is higher than 500 ppm there may be an indication of waterlogging. This approach has been taken with other plant tissue nutrient guidelines for fruit crops (Christensen 2000, Davenport et al. 1995).

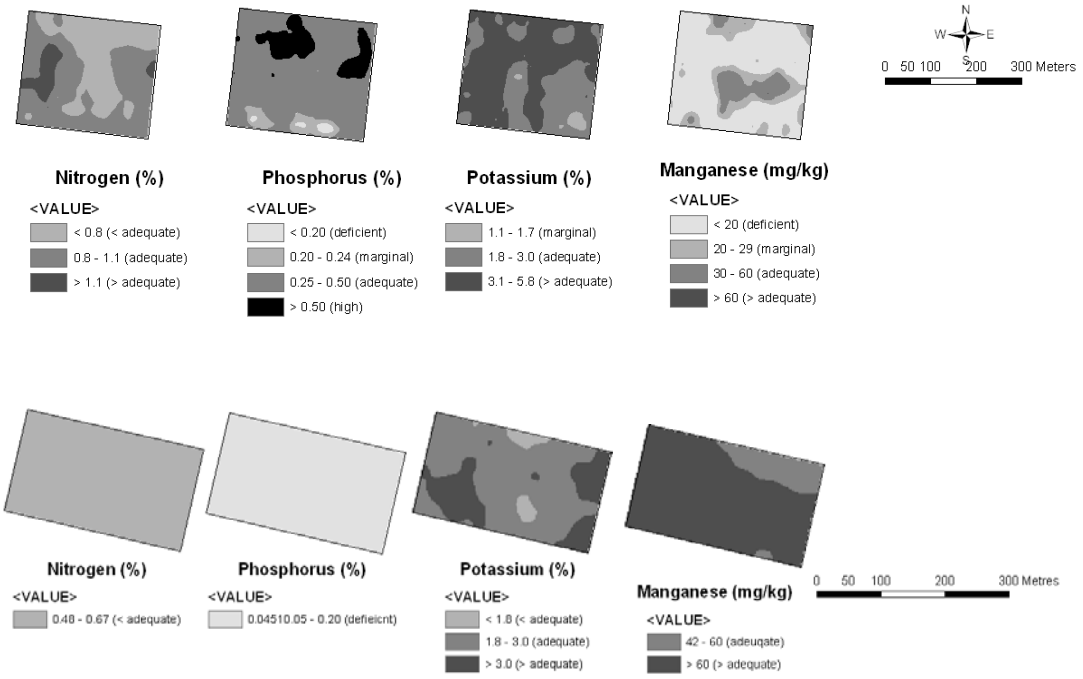

Figure 4: Flowering petiole tissue nutrient concentration at two Australian vineyards (Coonawarra top, Sunraysia bottom) classified across the vineyard block using critical nutrient ranges (Robinson et al., 1997).

Cluster analysis showed good temporal agreement for four additional nutrients: N, P, S and Zn. With N, median FP, VP and BH concentrations followed the same pattern of low, medium and high at Coonawarra whereas at Sunraysia FP and VP, but not BH, were in the same groupings (Fig. 2). Conversely, there was total agreement between low, medium and high medians of FP, VP and BH in S and Zn clusters at Sunraysia, although at Coonawarra, S cluster medians for FP and VP and Zn VP and BH medians agreed. P showed agreement between FP and VP but not BH medians in cluster groupings at both sites (Fig. 2). There was only good agreement between high, medium and low tissue clusters with soil mineral N at the Coonawarra site, where median mineral N values were 7.5, 6.1, 5.8 in these clusters (Fig. 2). At the Sunraysia site, there was a relationship between Zn soil test values (1.79, 1.88, 1.95) and low, medium, and high tissue clusters (Fig. 2).

Of these four elements with good temporal agreement, there are several patterns between vineyards that may help to explain the findings. The only apparent correspondence between areas delineated by critical values for N or P in petioles at flowering with the clusters delineated by *k*-means clustering is that between higher than adequate P and the 'high' P cluster at Coonawarra (Figs. 2 and 4).

The agreement between the clusters and the tissue nutrient distribution data suggests that zonal nutrient management strategies for these elements may be justified. There were no relationships with any of the nutrients and soil pH. However, the soil pH across both fields was high (averages above 8.1) and sites with a wider range of soil pH may show relationships between pH and nutrients.

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