Zonal vineyard management through airborne remote sensing

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Following the introduction of Precision Viticulture (PV) tools such as global positioning systems (GPS), grape yield monitors, airborne remote sensing, and soil sensing instrumentation to the grape and wine industry in the late 1990s, and the associated research during the intervening years, grapegrowers and winemakers are now recognising the magnitude of within-vineyard variation and the causes of that variation. Subsequently, the industry is becoming more aware of the inefficiencies in the way that inputs are applied to vineyards (eg. water, fertiliser, labour and machinery), and why there are uncertainties in both the forecasting of the potential crop yield and the delivery of fruit parcels of uniform quality to the winery.

One approach for managing variable yield and quality is to use PV tools to identify different zones of characteristic vine performance within individual vineyard blocks and to manage them accordingly. This system of differential management has been referred to as zonal vineyard management (Bramley 2005). Several examples of the commercial implementation of this approach to improve the uniformity of fruit parcels delivered to the winery have already been demonstrated (eg. Bramley *et al*. 2005; Proffitt and Pearse 2004). Through the selective harvesting of certain zones within vineyard blocks and the separate vinification of the fruit, increased profitability has been achieved.

This article describes some recent experiences in the implementation of zonal vineyard management to improve (a) the application of inputs; in this case irrigation water during the season and labour at pruning, and (b) the forecasting of crop yield.

Airborne remote sensing

Obtaining information on vine performance across whole vineyard blocks can be both difficult and expensive. However, vines, like any plants, are likely to integrate the effects of their local environment (eg. climate, soil properties, and disease, nutrient and water pressures) and express them through their canopy characteristics (Wiegand and Richardson 1984). Airborne remote sensing provides a means by which information on vine canopy status can be easily collected (Hall *et al*. 2002; Dobrowski *et al*. 2003; Lamb *et al*. 2004). Similarly, vine yield information can be easily acquired through the use of yield monitors on-board mechanical harvesters (Bramley and Hamilton 2004a).

Airborne remote sensing refers to the acquisition of digital imagery from light aircraft flying at altitudes ranging from 150m to 3km. This is not to be confused with satellite remote sensing whereby digital imagery is acquired from satellites operating at hundreds of kilometres above the earth. Experience has shown that veraison (± 2 weeks, and before the application of bird netting) is an appropriate time for image acquisition using light aircraft. SpecTerra Services (Perth, WA) is a commercial provider of airborne Digital Multi-Spectral Imagery (DMSI) that has demonstrated that by using 0.5 m resolution, vine dominated pixels can be delineated from pixels dominated by non-vine features such as soil, shadow and inter-row vegetation. The DMSI sensor collects data in four wavebands corresponding to the infra-red, red, green and blue wavelengths from which 'images' of the ratio of infra-red to red reflectance are then produced. There are two ratio-based vegetation indices which are commonly used to produce the images from which zones of different vine productivity in the vineyard are identified. One is referred to as the Plant Cell Density index (PCD), whilst the other is referred to as the Normalised Difference Vegetation Index (NDVI). SpecTerra Services prefer to use the PCD index.

Implementing zonal vineyard management – case studies

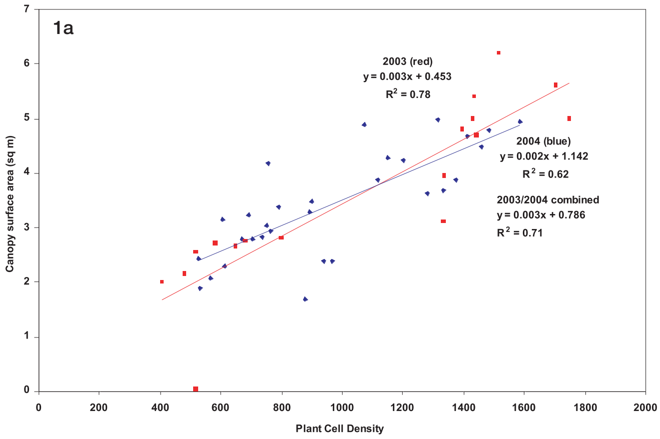
Applying inputs differentially

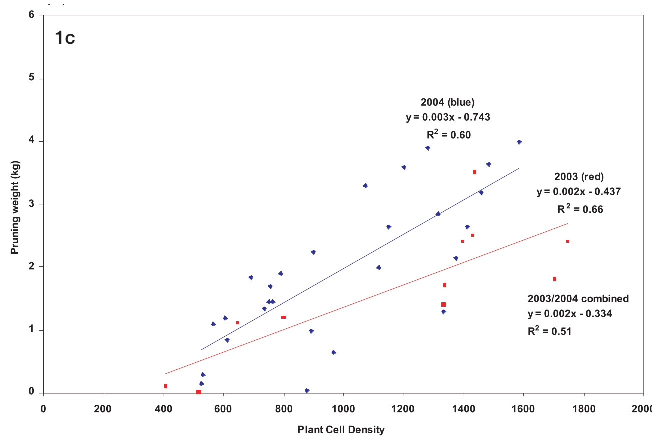
The inefficient use of inputs in a vineyard may compromise the productivity and subsequent profitability of that vineyard, as well as increase the risk of causing undesirable environmental impacts both on and off site.

Irrigation water during the season

This case study has been briefly described in an earlier article (Proffitt and Pearse 2004) and is repeated here in more detail. In 2003 and 2004, DMSI data was acquired for a 38ha vineyard property in the Margaret River region. In 2003, 30 vines within an 8.8ha block of Cabernet Sauvignon were spatially located using a differential GPS. The selected vines represented a range of visually different canopies and vine vigour, and for both years, the canopy surface area, trunk circumference and post-harvest pruning weights from these vines were measured and recorded. Linear regressions were fitted to the relationships between PCD and the three indices of vine vigour (Fig. 1a,b,c).

The 2003 relationship described in Figure 1a was used to produce an image of the block showing the spatial distribution of canopy surface area (Fig. 2b). Using this image and visual assessments, areas within the block were identified where vines were generally considered to be either excessively vigorous or too weak. Mindful that changes in the application of water via the





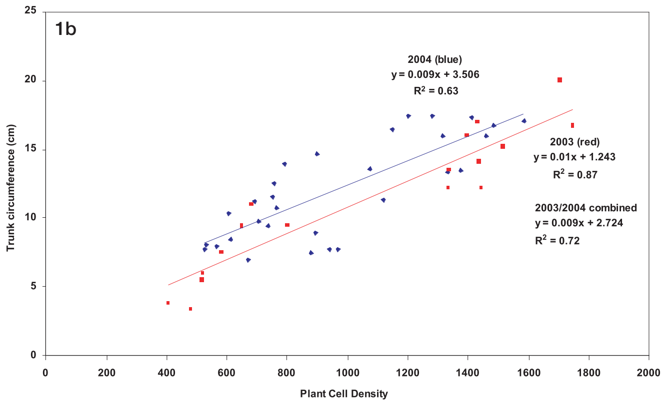


Fig. 1. Correlations between plant cell density and (a) canopy surface area (m^2), (b) trunk circumference (cm), and (c) pruning weight (kg) for 2003 (■) and 2004 (◆) growing seasons. Data is for Cabernet Sauvignon.

drip irrigation system could only be done within the constraints of the irrigation design, three different zones (A, B and C) were identified.

In 2003, irrigation water had been applied uniformly across the block. In 2004, the amount of water applied during the growing season was different in each of the three zones. Compared with 2003, the amount of applied water was reduced in zones B and C and increased in zone A in order to improve the management of vegetative growth. The amount of water applied to each zone during the later part of the growing season was approximately 64l/vine/week, 42 l/vine/week and 32 l/vine/week in zones A, B and C respectively. A comparison of the images derived for 2003 (Figure. 3a) and 2004 (Figure 3b), together with the change in canopy surface area summarised in Figure 3c, shows that the application of less water in zones B and C generally reduced vegetative growth whilst the application of more water in zone A generally increased vegetative growth, thereby making the whole block more uniform (Figure 3b).

From an economic perspective, the 2004 costs associated with canopy and fruit manipulation in zones B and C were reduced when compared with ▶

2003 due to less machine leaf plucking at $250/ha, machine shoot trimming at $140/ha and hand crop thinning at $300/ha. In addition, the smaller canopy in the vigorous zones B and C improved aeration and spray penetration which reduced the risk of botrytis which had been a significant problem in previous years. The smaller canopy also improved fruit exposure to sunlight, thereby hastening the rate of ripening so that fruit quality across the whole vineyard block was more uniform in 2004.

Labour at pruning

For the same vineyard, the 2003 PCD imagery was used to identify zones of high, medium and low vine vigour in a 8.3ha block of Shiraz with the aim of reducing pruning costs and ensuring that all staff pruned an equal number of vines of varying vigour and hence degree of difficulty. The block was planted in 1998 and the vines are currently cane pruned.

Piece rates per vine were determined for each zone according to the amount of time allocated to work on vines within that zone. After pruning had been completed, the total cost of the operation using the zonal management approach was compared to the total expected cost had the traditional uniform management approach been implemented (Table 2).

It is estimated that there was a cost saving of approximately $2,400 (11.6%) by implementing a zonal management approach. In addition, all pruning staff made similar amounts of money which ensured that morale remained high and staff truancy remained low.

Table 2: Piece rates and total pruning costs in an 8.3 ha block of Shiraz using both zonal management and uniform management methods.

Pruning method	Vine no.	Lopping cost/vine# ($)	Pulling cost/vine* ($)	Wrapping cost/vine+ ($)	Total pruning cost@ ($)
Uniform	12,445	0.42	0.40	0.85	20,783.15
Zonal					
High vigour	2,578	0.44	0.42	0.92	4,588.84
Medium vigour	5,562	0.37	0.35	0.76	8,231.76
Low vigour	4,305	0.31	0.30	0.68	5,553.45
Total					18,374.05

refers to the cost of selecting canes to retain and cutting the canes to remove.

* refers to the cost of pulling the cut canes out from the canopy and foliage wires.

+ refers to the cost of cutting the retained canes to the correct number of buds and wrapping the cane to the fruiting wire.

@ the cost shown using the uniform management approach is approximate since this methodology was not actually implemented.

Forecasting crop yield

The uncertainty in predicting crop yield costs the industry millions of dollars each year due to discrepancies between the forecast tonnage and the actual tonnage of fruit delivered to wineries. Surveys have shown that nationally, yield forecasts differ from actual yields by ±33% (Dunn and Martin 2003).

Crop forecasting is often based on a random sampling approach whereby samples are taken at random from within whole vineyard blocks regardless of the spatial variation in vine performance. In some cases, the number of samples taken has been determined statistically in an attempt to achieve an acceptable degree of error. Whilst this approach to crop forecasting has improved in recent years with the introduction of tighter statistical sampling protocols, and the development of better training materials (see Dunn and

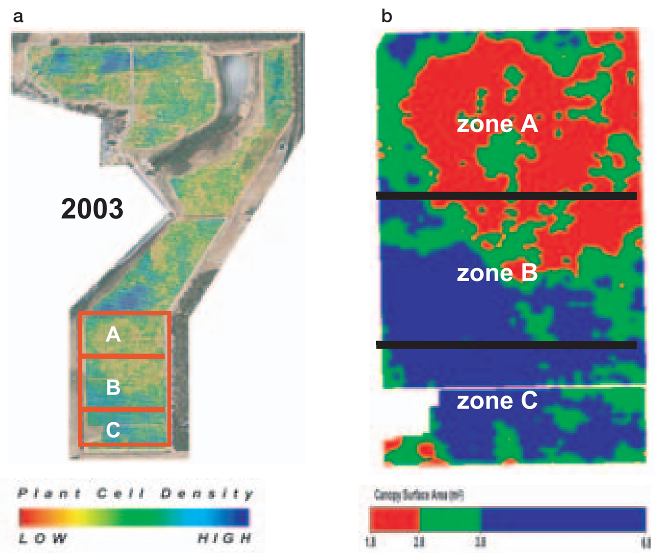


Fig. 2. (a) Plant cell density across the whole vineyard property at veraison 2003. The boundary of the Cabernet Sauvignon block and the irrigation zones are delineated by the red rectangles. (b) Canopy surface area across the Cabernet Sauvignon block at veraison derived using the 2003 correlation between plant cell density and canopy surface area. The three different irrigation zones of contrasting vine performance are identified as A, B and C.

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Martin 2003), the strong spatial structure of variation commonly seen in vineyards suggests that an alternative sampling approach is worthwhile exploring.

In this study, crop yield was estimated for a 2.54ha block of Cabernet Sauvignon located in McLaren Vale two weeks before the expected harvest date using both a random sampling approach and a zonal viticulture approach. The vineyard was planted in 1983. For the random sampling method, 30 vines were selected across the block using a computer 'random number generator'. The number of samples was not determined statistically to satisfy a pre-determined degree of error, but was based on the amount of time that could be allocated to the task of providing a crop estimate. For the zonal viticulture method, three zones of characteristic vine performance within the block were identified from PCD images. These were identified as having high (0.71ha), medium (1.8ha) and low (0.03ha) vine vigour. Ten vines were then selected from within each zone using the computer random number generator. For both methods, crop yield for each of the 30 selected vines was determined by removing, counting and weighing all the bunches.

In the random sampling method, crop yield for the block was estimated using the mean yield per vine (mean number of bunches per vine multiplied by the mean bunch weight per vine) and the total number of vines within the block. In the zonal viticulture method, crop yield within each zone was estimated using the mean yield per vine for each zone and the number of vines within each zone. Crop yield for the block was determined by summing the estimated yields for each zone (Table 3).

Using the random sampling method the block yield was estimated to be 26.26t compared to 23.57t using the zonal viticulture method. The actual tonnage delivered to the winery was 21.3t. This represents an overestimate of 4.96 t (23.3% difference) using the random sampling approach and an overestimate of 2.28 t (10.7% difference) using the zonal viticulture approach. The random sampling method when compared with the zonal viticulture method predicted a 12.2% greater mean number of bunches per vine and a 7.9% greater mean bunch weight (Table 3).

Table 3: Vine yield, components of yield, and vine numbers used to estimate crop yield in a 2.54 ha block of Cabernet Sauvignon using both zonal and random sampling methods.

Sampling method	Mean yield/vine (kg)	Mean no. bunches	Mean bunch weight (g)	Vine no.	Estimated crop yield for the block or zone (t)
Random	7.39	176.8	41.8	3553	26.26
Zonal					
High vigour	8.17	167.0	48.9	991	8.10
Medium vigour	6.08	153.9	39.5	2514	15.28
Low vigour	3.91	145.0	27.0	48	0.19
Total					23.57
Mean of 3 zones	6.05	155.3	38.5		

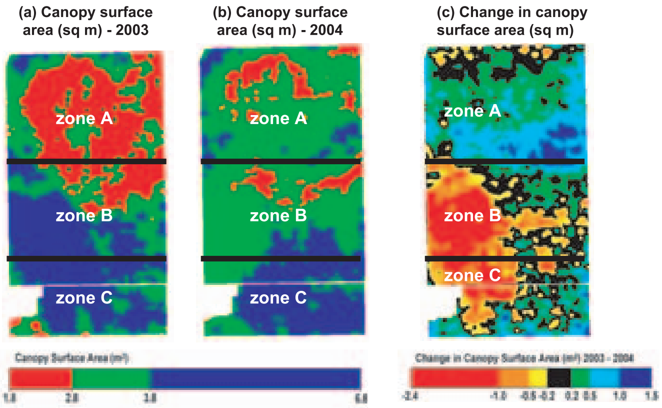

Fig. 3. Canopy surface area across the Cabernet Sauvignon block is 2003 (a) and 2004 (b) determined from correlations between plant cell density and canopy surface area. The change in canopy surface area between the two years as a consequence of different irrigation management practices within the three zones is shown in (c).

Since the area (and hence the number of vines) associated with the medium vigour zone represents 71% of the total block, it is not surprising that the mean yield per vine determined for that zone is similar to the mean yield determined from the three zones together (Table 3). In other words, 10 samples taken from the medium vigour zone alone in order to determine yield per vine would have given a block estimate very close to the actual tonnage delivered (ie. 21.6t predicted compared to 21.3t delivered). This observation highlights the benefit of getting as good an estimate of the mean as possible (ie. removing both high and low extremes from the estimate results in an improved estimate).

A few other points emerge from this study. Firstly, it is worth questioning whether the low yielding zone warranted separate delineation given that it represents only about 1% of the total number of vines in the block. Secondly, in allocating the 30 vines equally between the three zones, bias was introduced into the mean estimate since a 10 vine sample in each of the three zones represents a sample size equivalent to 1%, 0.4% and 21% of the total number of vines in the high, medium and low vigour zones respectively. Thus, whilst, the results point to the merit of zonal-based sampling, they also suggest that the number of samples allocated to each zone should be proportionate to the zone area (or vine number), relative to the total for the block. If this had been done, then there would have been eight sample vines in the high vigour zone, 21 sample vines in the medium vigour zone and 1 sample vine in the low vigour zone. Therefore, when using zonal-based sampling, it is recommended that this proportional allocation of samples to the different zones is adopted. Further work in this area is warranted. Thirdly, in situations such as this where one zone is dominant, it may be possible to confine sampling to a single zone. Fourthly,

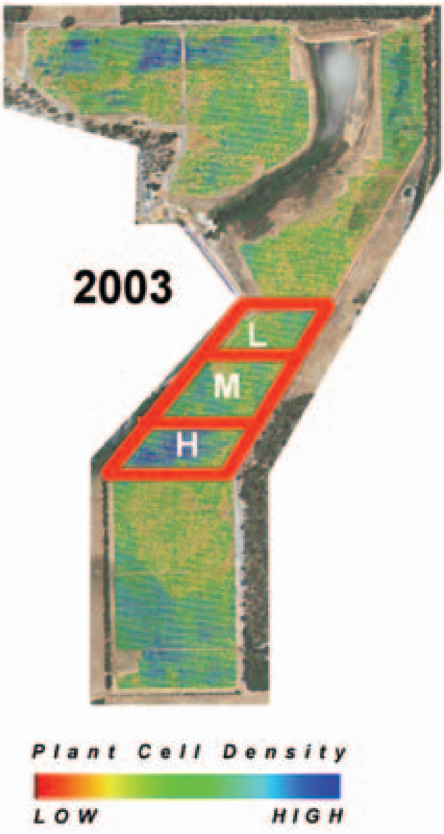

Fig. 4. Plant cell density across the whole vineyard property at veraison 2003. The boundary of the Shiraz block is delineated by the red rectangle. The three different pruning zones of contrasting vine performance are identified as high (H), medium (M) and low (L).

juice characteristics (baumé, pH, titratable acidity and colour) were also recorded from bunches sampled from the targeted vines in each zone (data not shown). The three zones exhibited differences in these parameters and is therefore a result which is likely to be of interest to winemakers.

In conclusion, a number of studies have now demonstrated that zones (identified using either airborne imagery or maps generated from yield monitors) within individual vineyard blocks do exhibit differences in vine performance. For example, Bramley and Hamilton (2004b) have shown for three consecutive years that these differences can be statistically significant. Several studies have also demonstrated that the adoption of a zonal vineyard management approach can have considerable economic benefits.

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For further information on Precision Viticulture and its application in vineyards or acquiring airborne digital imagery, please contact Tony Proffitt at AHA Viticulture (08-97568011) or Andrew Malcolm at SpecTerra Services (08-92279644).