Further developments in Precision Viticulture and the use of spatial information in Australian vineyards

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Introduction

Following the introduction of Precision Viticulture (PV) technologies to the Australian wine industry in the late 1990's, and the associated research during the intervening years, an increasing number of grape and wine producers are recognising the value of understanding the inherent biophysical characteristics and performance of their vineyards for improved viticultural management and decision-making. By definition, PV is viewed as a continuous cyclical process of observation, evaluation and interpretation leading to the implementation of a targeted management plan, followed by further observation and refinement of the management plan if required (Proffitt et al., 2006). The rationale behind this process is that through the use of spatial information, any given viticulture decision has an increased likelihood of delivering the desired or expected outcome compared to a similar decision made in the absence of such information. However, it is important to realise that the use of spatial information alone also provides an opportunity to improve viticultural knowledge and management decision-making. Whilst this is not strictly PV, the use of spatial information in this way should be highlighted as the data is often acquired using the same technologies.

At an earlier Bragato conference, Bramley (2005) presented some of the first case studies of the use of PV in Australian vineyards. These included selective harvesting to improve the uniformity of fruit quality, salinity and irrigation management to improve productivity and long-term sustainability, and whole-of-vineyard designs as a basis for improving field experimentation. This paper provides an update on the adoption of PV in Australian vineyards and the increasing use of spatial information, both as a decision-making tool and for wider research purposes. Throughout the paper reference is made to examples that have been documented elsewhere in the literature.

Technology adoption

Since the Australian grape and wine industry first looked at PV technologies more than a decade ago, major progress has been made in its availability and affordability. In addition, research has continued to investigate new tools and to discover new uses for existing technologies. A useful review of PV is provided by Bramley (2009).

Whilst some would argue that the rate of adoption has been slow, the leaders have embraced PV and have incorporated the acquisition and analyses of spatial information into their business models. This is demonstrated by the fact that high resolution maps are no longer viewed only at vintage to help make harvest decisions, but are now being referred to throughout the year for a range of viticultural activities. Philosophically, as time goes by, there should be little difference between 'viticulture' and 'precision viticulture' and in the case of these leaders, perhaps they are approaching that point.

An increasing number of service providers offer various technologies and data acquisition, management, processing and viewing packages using geographical information systems (GIS). Within the range of PV tools currently available for the assessment of variation in vine performance, remote sensing of vine vigour and yield monitoring are the most readily available. Remote sensing using light aircraft as opposed to satellites is generally the ‘entry point’ for new adopters due to the potential high rate of return on investment; such imagery is available to Australian growers for about A$30-37 per ha. Digital multi-spectral imagery (DMSI) is being acquired and used in vineyards for a range of applications including selective harvesting to improve the retail value of wine, the differential application of inputs to reduce vineyard heterogeneity and to reduce/maintain costs of production, the sampling of vine and soil related parameters to improve the accuracy in the measure of interest, and for vineyard design and field experimentation.

One major company that provides DMSI, acquired data from 1,800 ha of vineyard in 2004. The area covered increased to 10,700 ha in 2006 and then stabilised to between 7,000 and 9,000 ha in subsequent years. The same company has airborne sensors available in Spain, France, Portugal, Argentina and Chile. Chileans, in particular, are strong adopters of the technology with the total area of vineyard flown increasing from 3,000 ha in 2007 to 7,500 ha in 2008 (Proffitt and Winter, 2008).

Given the low additional cost of yield monitoring over and above the cost of harvesting, there has been a steady increase in the number of contractors and winegrape producers who have installed yield monitors on their mechanical harvesters. The leading manufacturer of this technology in Australia has developed a weighing system that fits all harvesters and sales have been increasing steadily. It is estimated that between 30 to 40 yield monitors get some use, with about 25 of these fully functional and being used regularly. The area of vineyard being mapped has increased from about 850 ha in 2004 to about 3,000 ha in 2009. In general, yield maps are being used in the vineyard in the same way that imagery is being applied. However, one of the main advantages that a yield map has over imagery, once it has been adjusted to match the tonnage recorded at the winery, is that it does not require ground truthing.

The acquisition of high resolution soil and elevation data is also becoming increasingly popular to help understand and better manage soil and topographical influences on existing and potential vine performance. The acquisition of such data is now at a spatial resolution and price which is often more cost-effective than using traditional manual methods. A range of proximal soil sensors are commercially available (e.g. electromagnetic induction via tools such as the EM38, gamma ray spectrometry and ground penetrating radar) which, when used in conjunction with a real-time kinematic global positioning system (RTKGPS), allow maps displaying changes in soil properties to be draped over three-dimensional digital elevation models (DEM) at scales which are relevant to vineyard managers (Figure 1). These data layers are being used for a range of applications including vineyard, irrigation and drainage design, soil amelioration, and the placement of vineyard infrastructure and equipment.

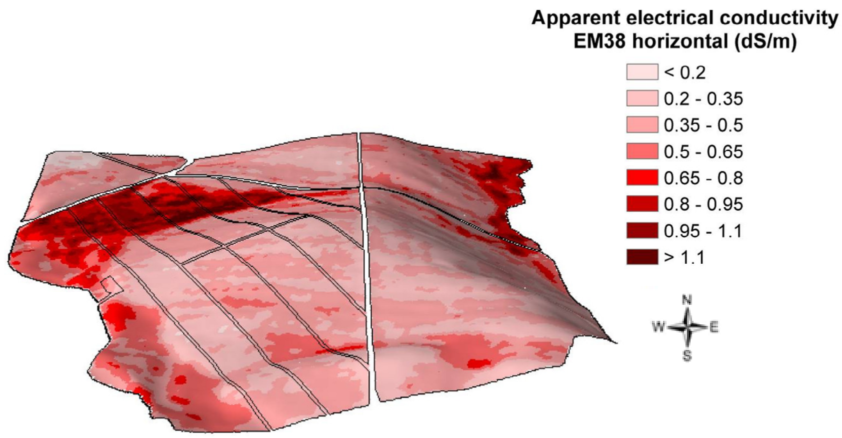

Figure 1. An example of an EM38 soil survey (horizontal dipole, 0-75 cm soil depth) and digital elevation model (DEM) for a 86 ha vineyard in the Clare Valley, South Australia. The survey highlighted differences between soils in the vicinity of streams (to the north and south) compared to those on higher ground, and also identified an area of different (higher clay content) soils in a low-lying area to the north west.

Applications in the vineyard

Harvesting

Selective sampling was one of the first applications of PV in Australian vineyards and, in the context of promoting uniformity in parcels of fruit delivered to wineries, continues to deliver significant commercial benefits. Selective harvesting is defined as the differential picking of grapes at harvest according to different yield and/or quality criteria with consignment to different product streams in order to exploit the observed variation in vineyard performance. Recently, there have been refinements in yield monitoring software. During vintage 2009 for example, operators of mechanical harvesters were able to view pre-defined ‘harvest zones’ on the console, thereby negating the need for identification markers in the vineyard (Figure 2).

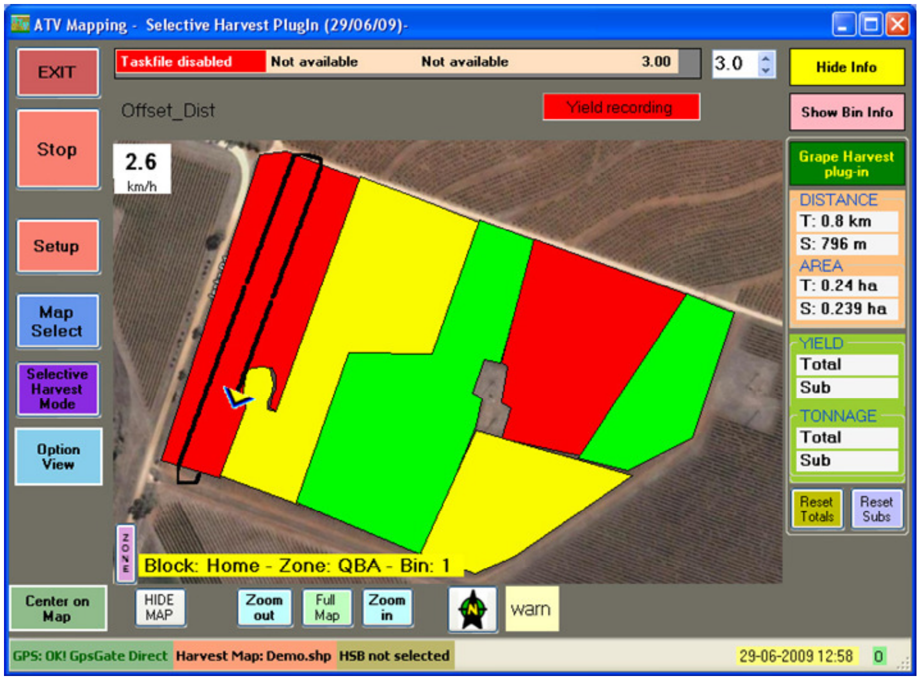

Figure 2. Spatial information can now be displayed on yield monitoring consoles or ultra mobile personal computers (UMPC) to aid selective harvesting. As well as displaying information such as area covered, distance travelled and tonnage (shown on the right), different harvest zones can be displayed (i.e. the red, yellow and green areas) where the fruit is to be kept separate in the vineyard by changing receival bins. The position of the harvester is identified by the yellow triangle with the route taken shown as a black line. Other features are available as additional plug-ins.

Numerous commercial examples of selective harvesting exist that demonstrate an increased profitability using this approach (Smart, 2005; Proffitt et al., 2006). The economic benefits for four case studies are shown in Table 1.

Table 1. Economic benefits of selective harvesting for grape production and/or wine production. Note that the benefits shown are based on the harvesting of fruit from different zones of the vineyard on the same day. Increased benefits are sometimes realised by harvesting zones on different days. Data of Bramley et al. (2005).

Region	Variety	Income benefit (A$) - grape production	Income benefit (A$) - wine production
Clare Valley, SA	Riesling	54,904 (+77.8%)	
Padthaway, SA	Shiraz	4,657 (+3.2%)	272,971 (+20.5%)
Margaret River, WA	Shiraz	12,300 (+12.5%)	
Margaret River, WA	Cabernet Sauvignon		139,480 (+19.2%)

Yield monitor data in conjunction with a knowledge of the costs of grape or wine production has also been used to construct gross margin maps (Bramley and Proffitt, 1999; Bramley, 2009). These are powerful and under-utilised tools for identifying and addressing poor and/or variable financial performance in vineyards.

Case study 1

As part of a PV extension project involving a group of grapegrowers near Griffith in New South Wales, a 33 ha block of Chardonnay was used to acquire yield monitor data at harvest. During the growing season production costs were also recorded for this block. By integrating the yield and cost of production data, a map showing the gross margin for the vineyard block was produced (Figure 3a). Whilst the average cost of production (+/-A$15 per tonne) resulted in gross margins in the A$500-A$1,000 range, the effective cost of production in areas returning a loss was more than A$45 per tonne higher than the average for the block. Areas returning more than A$1,500 per tonne had effective costs of production that were more than A$45 per tonne below the block average. The grower was particularly interested in addressing the areas of the vineyard that were operating at a loss or generating returns that were considerably less than what was required of the vineyard.

Figure 3b shows a map of apparent electrical conductivity for the same block obtained using an EM38 sensor. When the gross margin and EM38 maps are clustered together (Figure 3c), the poorly performing areas of the vineyard block appear to be those in which the values recorded by the EM38 are significantly higher ($p<0.05$) than in the remainder of the block. Although this does not prove that a soil constraint is limiting production, it does suggest that an examination of vineyard soil properties is warranted and that a targeted soil amelioration program may be economically beneficial.

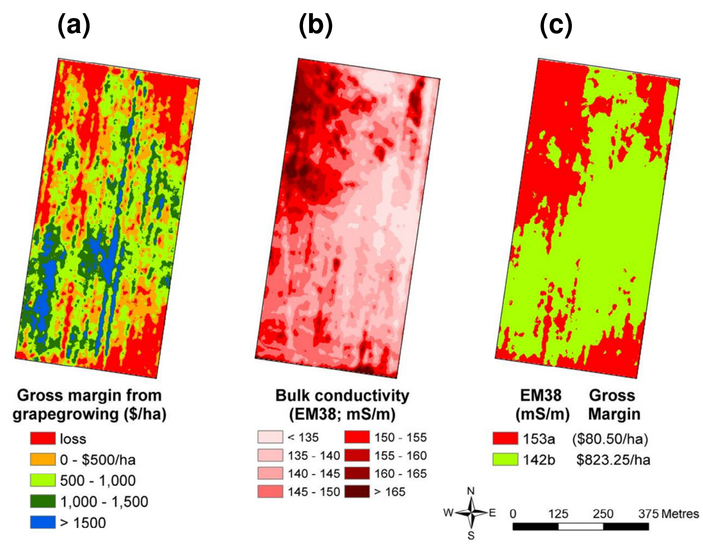

Figure 3. Variation in (a) gross margin obtained from producing Chardonnay, and (b) bulk electrical soil conductivity as determined using an EM38 sensor in a 33 ha vineyard near Griffith, New South Wales. In (c), the map layers shown in (a) and (b) have been clustered together to identify two zones. The areas returning a loss are those with high conductivity suggesting that a soil constraint may be limiting productivity in these areas.

Targeted management

Selective harvesting may not always be the appropriate response to vineyard variability. For example, the available product/brand line might be limited or there may be logistical winery constraints such as processing and storage capacity. The opportunity therefore exists for viticultural inputs (e.g. irrigation water, fertilizers, soil amendments, sprays and labour) to be applied differentially (or 'targeted') to particular areas across vineyard blocks in order to improve the overall uniformity in crop yield and/or quality.

Broadacre cereal farmers have predominantly used high resolution spatial information in this way by means of variable rate application (VRA) technology. However, managing inputs has not been the major objective for winegrape producers who have generally concentrated on managing outputs (i.e. yield and quality). This is beginning to change due to the development of new technology, increasing production costs and environmental constraints such as the lack of irrigation water. Two examples of targeted management are described in Proffitt et al. (2006). The first involves the differential application of irrigation water to manage vine vigour as a means of improving the overall quality of fruit across a vineyard block and reducing canopy management costs. The second involves the setting of pruning wages based on vine vigour in order to reduce costs and to improve staff morale. Input costs were estimated to be reduced by A$700 per ha in the first example and by A$290 per ha in the second. Both studies used airborne imagery to delineate zones of so-called 'high', 'medium' and 'low' vine vigour. Other examples of targeted management have recently been observed in vineyards, including the differential removal of vine leaves (leaf plucking) by hand to increase fruit exposure, and the differential application of fertilizer, lime and mulch by increasing or decreasing tractor or PTO speed. In all these cases, management zones have either been identified on the ground using markers or on-the-go by using maps that have been imported on to personal digital assistants (PDA) or UMPC's attached to GPS equipment.

Sampling and monitoring

Sampling and monitoring are key activities that are required in vineyards for much of the year and include crop yield forecasting, fruit maturity assessment, tissue and soil collection for nutritional analyses, fruitfulness assessment via bud dissection, and pest, disease and vine health assessment. It is critical that the sampling methodology employed for each of these activities is representative of the whole vineyard block because spatial variation in vine and/or soil characteristics may introduce a bias in the results. The traditional approach has been to target vines or areas within a block using a random sampling strategy and in some cases, the number of samples taken is determined statistically in an attempt to achieve an acceptable degree of error.

The commercial availability of high resolution spatial data allows alternative approaches to be used. One example involving crop forecasting is described in Proffitt et al. (2006) in which a vineyard was divided into sampling zones based on vine vigour derived from airborne imagery. This strategy realised a 5% improvement in crop estimate compared to the traditional random sampling approach. However, more research is required to determine how PV technologies can improve crop forecasting since this is a topic of national importance (Hall and Hardie, 2008). Using other sampling strategies based on spatial information, winemakers have observed improvements in fruit maturity assessments; an example is documented in Bramley (2001). Spatial information is also being used to improve sampling strategies when selecting vine material for bud fruitfulness assessment (bud dissection analyses). This is considered to be critical since the relationship between potential fruitfulness and actual fruitfulness recorded in the vineyard varies according to vine vigour (Wisdom et al., 2004).

Pest, disease and vine health monitoring is an important activity that is required to be undertaken in the vineyard for much of the year. Once again, high resolution spatial information is being used to improve surveillance strategies. An example of this is the work that continues to be undertaken in monitoring and detecting phylloxera (*Daktalosphaira vitifoliae*) (Edwards et al., 2004; Renzullo et al., 2004). Similarly, the use of spatial data is proving to be valuable for research work investigating relationships between pests and their environment.

Case study 2

The garden weevil (*Phlyctinus callosus*) is a vineyard pest that is a particular problem in the south western region of Western Australia. The larvae are protected within the soil and emerge as flightless adults which feed on the leaves, flowers, buds, rachi and fruit of young and mature grapevines. Up to 70% reductions in crop yield have been reported as a result of their nocturnal feeding habits. In addition, they are responsible for increasing botrytis infection through damage to individual berries. The garden weevil is therefore considered to be a significant economic threat to grapegrowers within the region. A systems approach is being used to help improve knowledge about the pest's life cycle and physiology, the economic injury level and cost to the wine industry, and the interactions between management strategies and the environment that may help to reduce the threat of this pest.

Anecdotal evidence suggests that there is a relationship between soil type, ground cover species in the vineyard and the occurrence of high populations of garden weevil. A 4 ha block of Chardonnay in the Margaret River region has been established as part of a research project aimed at addressing this issue. 192 vines were selected across the block and georeferenced using a differential GPS. During the 2005/2006 season each vine was fitted with a waxed, cardboard weevil trap around the trunk, and the number of weevils caught in each trap were counted weekly over a 11 week period starting in December 2005 and finishing in March 2006. Damage to vines by weevil activity was assessed in late December 2005 using a 11 point damage scale.

Changes in the weevil population across the vineyard during the monitoring period are shown in Figure 4. Weevil numbers were low in December 2005 with little variation across the vineyard block (Figures 4a, b). However, the population started to increase in January, particularly towards the perimeter of the block (Figures 4c, d). This pattern continued during February (Figures 4e, f) and March (Figures 4g, h) suggesting that the pest was either moving into the vineyard from outside or that the pest preferred some aspect of the environment (e.g. plant species, soil type) closer to the edges of the vineyard block. The spatial distribution of plant species and soil properties across the vineyard are currently being acquired and will be correlated with weevil numbers, vine damage, crop yield and indices of fruit quality using clustering techniques and GIS.

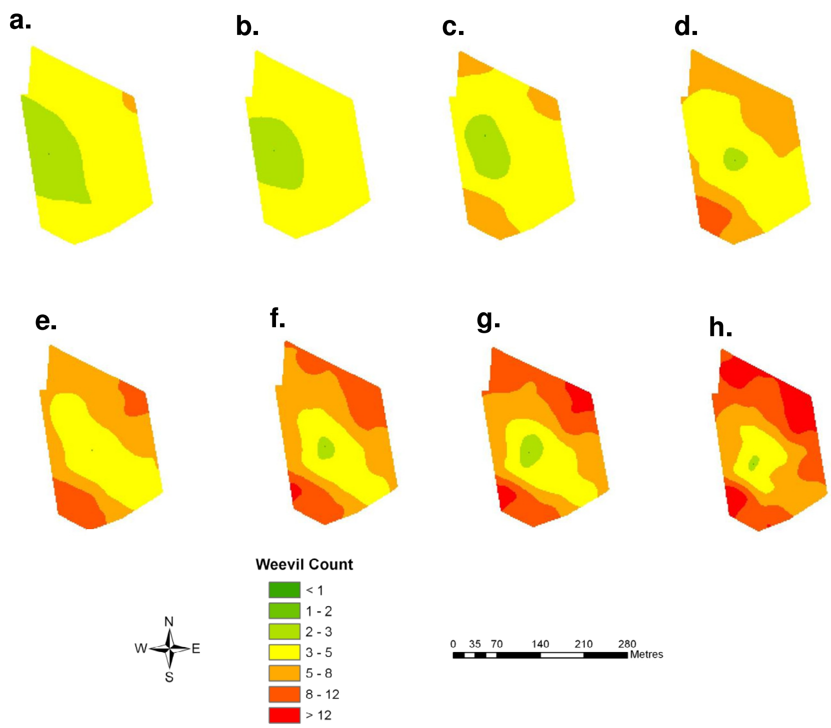

Figure 4. Monitoring the spatial distribution of garden weevil in a 4 ha block of Chardonnay in Margaret River, Western Australia. Changes in weevil numbers monitored weekly on vines between December 2005 and March 2006 are shown in maps (a) to (h) which correspond to fortnightly recordings. Unpublished data of Mark Gibberd, Curtin University of Technology, Margaret River.

Vineyard design

Variation in soil and topography is likely to have a substantial impact on variation in vineyard performance. As Figures 1 and 3 illustrate, high resolution soil maps generated through the use of proximal sensors are proving to be useful in providing insights into the spatial variation in soil properties at scales which are relevant to those responsible for designing new vineyards or re-developing older vineyards. The information is frequently being used as an alternative, usually cost-effective methodology to position inspection pits compared with the standard, lower resolution 75 m grid approach. This approach does not replace the need for skilled soil surveyors, but does provide a means of assisting them to target their efforts (Bramley et al., 2009). Accurate boundaries delineating changes in soil properties, coupled with topographical information, assist with matching grape varieties to desirable soil types, designing irrigation and drainage systems, and locating infrastructure (e.g. roads, dams, frost fans and buildings) and instrumentation (e.g. weather stations and soil moisture/salinity monitoring devices).

Case study 3

The management team at Penfold's Robe vineyard has been using high resolution spatial data in a variety of ways over the past six years to fine-tune vineyard practices. The vineyard is located close to the coastal township of Robe about 320 km south-east of Adelaide in South Australia. It covers an area of 235 ha and produces about 2,000 tonnes of premium red and white fruit. Frost damage to vines and the subsequent loss of fruit has become an increasing problem in recent years.

This case study demonstrates the use of spatial information to locate frost fans as a strategy to reduce the risk of crop loss in high value blocks. The basis of the capital cost evaluation was an expectation of two major and two minor frost events over a 10 year period resulting in 80% and 20% crop damage respectively.

An RTKGPS was used to map elevation and the acquired data then used to construct a DEM (Figure 5a). Windbreak positions and areas exhibiting different degrees of frost damage to vines in the previous year were georeferenced using a GPS. Loss of fruit and the degree of damage as a result of frost events was determined in the vineyard by undertaking intensive counts in each affected block. This data, together with the predicted air movement across the vineyard, were superimposed over the DEM (Figures 5b, c). Air movement was derived using GIS routines that predict water flow across the landscape and for the purposes of this work, it was assumed that air flow dynamics are similar to fluid dynamics. An examination of Figures 5b, c identified several tree lines that were required to be removed to enhance the drainage of cold air. Fruit value was determined from grape purchase costs and estimated crop yields.

When coupled with the manufacturer's recommendation that a single fan will cover approximately 6 ha, the spatial data enabled identification of the optimum sites for the placement of four diesel powered frost fans (Figure 5d). The location of each fan was based on a number of factors including the incidence and severity of previous crop damage, the value of fruit in each block and windbreak locations in relation to airflow movement and susceptibility to frost damage.

The total cost of the project was A$250,000 which included the purchase and installation of the frost fans in 2007 (A$53,000 each), the purchase of a diesel tank and trailer, the construction of bunding, the modification of some trellis, and the removal of tree lines. Within 10 days of the fans being installed, a frost event occurred. An 11 ha block of high value Sauvignon Blanc fruit which was totally destroyed by frost in the spring of 2006 was protected and only received minimal damage on the fridges of the frost fan protected areas during the 2007 frost event. Indeed, the amount of fruit saved in 2007 across all protected blocks was estimated to be of a value similar to the total cost of the project. The frost fans therefore paid for themselves in the first year and consequently, plans to purchase an additional four frost fans were implemented.

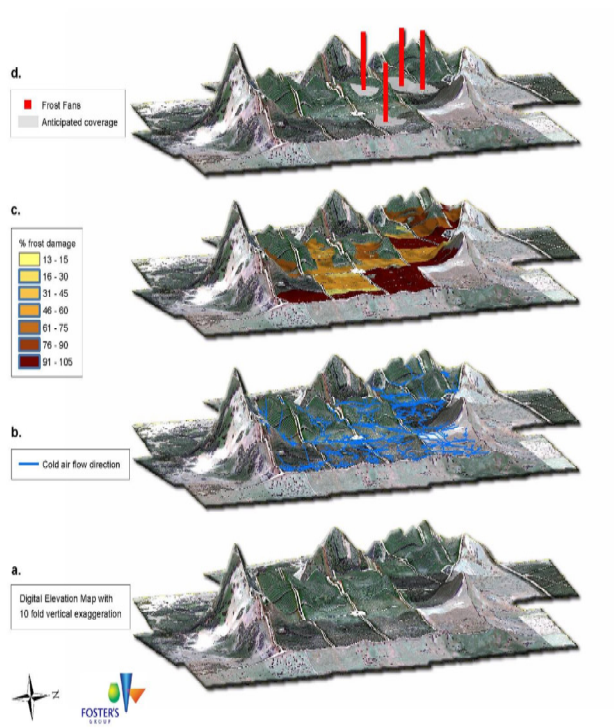

Figure 5. Using spatial information to locate frost fans at Penfold's Robe vineyard in South Australia. Unpublished data of Richard Hamilton and Suzanne McLoughlin, Foster's Group. Refer to the text for further explanation.

Field experimentation

The marked spatial variability that has been shown to exist in vineyards presents problems for researchers and winegrape producers wishing to conduct viticultural field experiments. It also presents issues for vineyard managers faced with the problem of deciding how their management practises should be targeted within variable blocks. The classical approach to viticultural experimentation is to use randomised designs which attempt to accommodate the effect of underlying spatial variation by randomly allocating treatments to a number of plots. However, the merits of this approach are questionable given that the management units to which the results will be applied are likely to be variable. For an experiment conducted in the block shown in Figure 3, the problem is where to locate the plots in such a way that the results are relevant to the two different zones that were identified. The commercial availability of high resolution spatial data, coupled with geostatistical methods, has led to new experimental approaches being utilised which assist in addressing this question.

Case study 4

Conducting experiments over whole blocks is an alternative approach to the plot-based one and several examples have been existence for a number of years in vineyards located in South Australia. Recently, an important advance has been made to the method of analysing such experiments which relies on some complex geostatistics (Bishop and Lark, 2006). A number of viticultural management strategies have been investigated including a range of mid-row and canopy management techniques (Bramley and Lanyon, 2005; Panten et al., 2008; Panten et al., 2009) and the treatment of powdery mildew (Bramley et al., 2007).

Figure 6 illustrates an example in which the merits of a range of vineyard floor treatments for enhancing vine vigour were examined in an organic vineyard in the Clare Valley, South Australia. The vineyard manager was concerned that vine performance in this block was being constrained by inadequate nutrition and/or competition for soil water from the inter-row sward. A highly replicated design was implemented by vineyard staff with the manager being very positive about the opportunity it afforded him to see how responses to the treatments varied across the vineyard block. Whilst the analysis of such experiments is complex, Figure 6 shows that it promotes robust evaluation of differences between possible management strategies over the entire area in which they may be applied. In contrast to the classical approach which seeks to determine whether one treatment is better than another treatment, the whole-of-block approach recognises that a particular treatment may deliver benefits in some parts of the block whilst another treatment may be more effective in other areas. If these treatment effects can be associated with a key variable (e.g. clay content, soil moisture), this approach also increases the opportunity for extrapolating the results to other vineyard blocks. It is hoped that further work will promote the adoption of this approach through the production of easy-to-use protocols and analytical software.

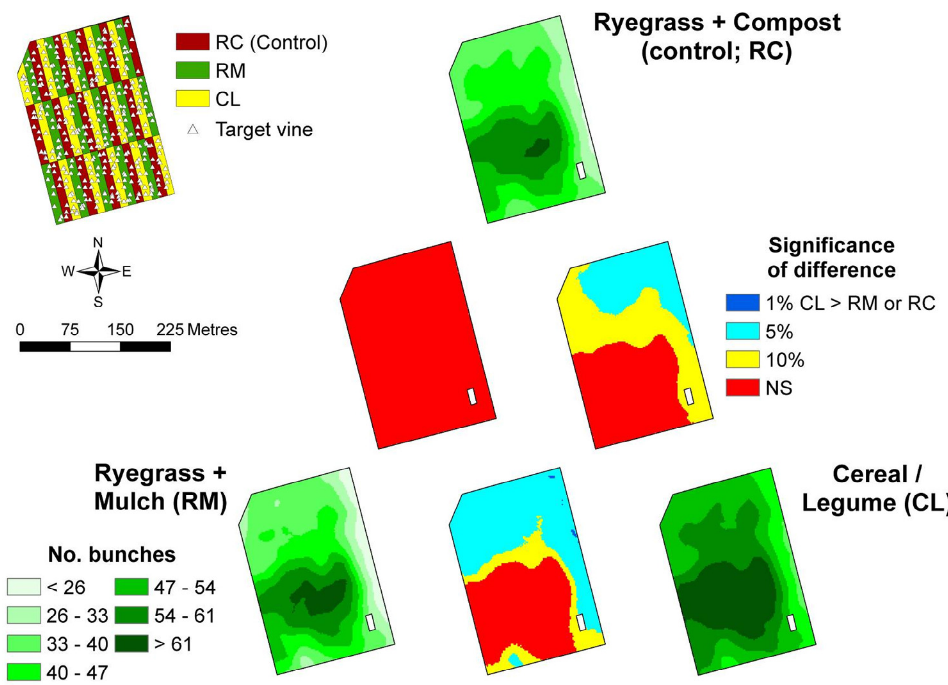

Figure 6. A whole-of-block experiment in which a replicated design (top left) was applied in 2004 over a 4.8 ha block of Merlot to assess the merits of three mid-row management strategies (RC, ryegrass + compost; RM, ryegrass + mulch; CL, cereal + legume). Treatment responses are shown in terms of bunch number per metre of row on 378 target vines for vintage 2006. Significance of difference between the treatments is shown in maps positioned between each treatment map. Data of Panten et al. (2009).

Conclusions

Through the acquisition of high resolution spatial data Australian grape and wine producers are recognising that the inherent variability of land (predominantly topography and soil properties) results in variation in its potential productivity (i.e. crop yield and fruit quality). Its subsequent use in the vineyard has much to offer as a way forward to increasing knowledge about the integration of soil and land attributes on vines and seasonal impacts on grape and wine production. This knowledge, when coupled with appropriate experimental approaches, is helping to improve our understanding about a range of vineyard issues which, in turn, is helping to fine-tune management practices and business models as well as improving our ability to make proactive decisions.

One would surmise that variability is particularly noticeable in New Zealand because of its relative youth in geological terms. Potential adopters of PV and spatial information, whether for production purposes or as a research tool, should be aware that all they need to start with is a single layer of information and to begin thinking about the meaning of that information and its relationship to variability in the vineyard.

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