Vineyard Monitoring and Management Beyond 2000

Precision Viticulture: A workshop investigating the latest technologies for monitoring and managing variability in vineyard productivity

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Table of Contents

Introduction

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Rationale for the workshop: CRCV Project 1.1.1 Precision Viticulture

The recent introduction of global-positioning systems (GPS) and GPS-equipped yield monitors on winegrape harvesters in Australia, enables growers/managers to quantify spatial variations in yield across vineyards and to accurately map regions according to yield. This technology, together with the emergence of computer-based geographical information systems (GIS), and the capability to process and map spatial relationships between any productivity-related attributes, has facilitated the rapid growth in what we know as *precision agriculture*. In the context of the grape and wine industry, *precision viticulture* may be defined as monitoring and managing spatial variation in productivity-related variables (yield and quality) within single vineyards. Geo-referenced information on vineyard performance may be integrated in a GIS and might include information on a range of soil, vine and fruit indices as well as climatic economic and cultural (management) data. Using this information, subsequent management may involve either minimising, maximising or simply accounting for spatial variations in a particular variable according to desired production outcomes.

In response to the needs of the Australian grape and wine industry for an evaluation of precision viticulture technologies, the Cooperative Research Centre for Viticulture (CRCV) and the Grape and Wine Research and Development Corporation (GWRDC) jointly funded a research project, commencing July 1999, for an initial period of 3 years subject to annual review. The project, entitled "Precision Viticulture - Investigating the utility of precision agriculture technologies for monitoring and managing variability in vineyards" (CRCV 1.1.1) involves research staff of Charles Sturt University's National Wine and Grape Industry Centre, CSIRO Land and Water, CSIRO Plant Industry and Department of Natural Resources and Environment Victoria. The stated objectives of the project are

- To quantify the nature and extent of within-vineyard variation in grape yield and associated fruit and vine characteristics in two vineyard sites;
- To analyse soil and associated vineyard properties to identify possible causes of such variation with a view to assessing the feasibility of crop response to targeted management;
- To investigate the utility of high-resolution remote sensing as a means of directing timely in-field sampling to ascertain causes of detected variability in soil properties (pre-establishment) and vine vigour (pests, diseases, available moisture);
- To develop methods for targeted in-field sampling and experimentation for assessing response to management;
- To scope the opportunity for adoption of precision agriculture technologies in the wider Australian grape and wine industry.

A key component of the project is the continuous and wide-ranging process of communicating research outcomes throughout the grape and wine industry. Already, outcomes have been widely published in a range of industry publications, scientific and industry conferences and via the public media.

About the workshop

The purpose of this workshop was to provide an update on the latest in PV research, both here in Australia and overseas, and to listen to industry concerns about the future directions of PV research.

The workshop, held at the National Wine & Grape Industry Training Centre, Charles Sturt University on 8th August, 2000, contained two sessions: Morning & Afternoon. The Morning Session comprised a set of formal presentations designed to bring the participants up to date on the status of a range of precision-viticulture (PV) practices and technologies. While most of these practices/technologies are the subject of ongoing research projects throughout the country and overseas, presenters were, in the main, commercial providers of PV services.

The Afternoon Session was an interactive workshop, involving both Morning Session presenters and workshop participants. The interactive workshop aimed to produce a list of perceptions / feedback / recommendations from participants that addressed the following issues:

a: the level of industry awareness of existing PV practices/ technologies
b: limits to the adoption of PV practices/ technologies by the wider industry (small and large growers alike)
c: areas in PV which require (further) investigation
d: scope / opportunities for greater industry participation / collaboration in PV Research & Development.

Workshop participants were assigned to one of three groups, based on their particular interest / expertise. Workshop facilitators collated participant views and responses into a summary list of recommendations.

Workshop timetable

PROGRAM:

MORNING SESSION:
8.45 - 9.00 REGISTRATION

9.00-9.15 OPENING Jim Hardie, CRCV

9.15-9.45 Application of vineyard sensing to the Californian wine-grape Industry. Lee Johnson, California State University.

9.45-10.15 Measuring within-vineyard variability in yield and quality attributes. Rob Bramley, Precision Agriculture Research Group, CSIRO Land & Water.

10.15-10.45 MORNING TEA

10.45-11.10 Practical applications of new technology to vineyard irrigation management. Michael Murtagh, MRV Management.

11.10-11.35 Airborne remote sensing-instrumentation and applications in grape-growing. Garth Morgan and Wolfgang Lieff, Airborne Research Australia (ARA).

11.35-12.00 Applications for airborne hyper spectral imaging systems in viticulture.
Sedat Arkun, Ball Advanced Imaging and Management Solutions.

12.00-12.25 Application of electromagnetic soil surveying in vineyards. Terry Evans. Southcorp.

12.25-12.50 Applications of airborne multi spectral imaging in grape-growing.
Frank Honey. SpecTerra Systems.

12.50-1.45 LUNCH

AFTERNOON SESSION
1.45-2.45 Parallel interactive workshop sessions:

GROUP A: SOILS AND IRRIGATION
Facilitator: Terry Evans and Michael Murtagh

GROUP B: REMOTE SENSING APPLICATIONS:
Facilitator: Garth Morgan, Sedat Arkun and Lee Johnson.

GROUP C: SPATIAL VARIATIONS IN YIELD AND QUALITY ATTRIBUTES.
Facilitators: Rob Bramley and James Taylor.

2.45-3.15 AFTERNOON TEA

3.15-4.00 Workshop facilitators present key outcomes and recommendations of their workshops (15 minutes per Group summary).

4.00-4.30 Summary & Concluding remarks. David Lamb. CRCV 1.1.1 Project Leader.

Workshop attendance

The workshop was attended by 78 people comprising growers, researchers and PV-related service/technology providers. An audience survey revealed an approximate proportion of each group (Figure 1), favouring growers.

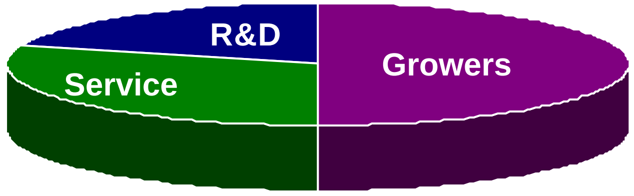

Figure 1. Approximate breakdown of workshop participants.

Acknowledgments

The CRCV would like to acknowledge the contributions of the following people in presenting seminars at the workshop.

Lee Johnson, California State University
Rob Bramley, CSIRO Land & Water
Michael Murtagh, MRV Management
Garth Morgan & Wolfgang Lieff, Airborne Research Australia
Sedat Arkun, Ball Advanced Imaging and Management Solutions
Terry Evans, Southcorp
Frank Honey, Specterra Systems

The CRCV would also like to ackowledge the Phylloxera & Grape Industry Board of South Australia who sponsored Lee Johnson's visit to Australia.
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PART I : Technology Update

Measuring within vineyard variability in yield and quality attributes

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Precision viticulture provides a suite of tools for improved viticultural management

Precision agriculture (PA) emerged in the grains industries of the US about 10 years ago. Since then, other forms of agricultural production have acquired the capacity for precision management through the development of crop-specific yield monitoring systems. The development of precision viticulture (PV) is a part of this general progression and has become possible through the recent commercial availability of a grape yield monitor. Since the development of these and supporting technologies (yield and quality monitors, remote sensing tools, GIS etc…) is an on-going process, PV is expected to similarly evolve over time. The key point is that PV provides a suite of tools for the improved, more targeted, management of vineyards – it does not, however, replace existing good management.

Some guiding principals

Research being conducted in the Viticulture CRC (CRCV) draws on the idea that viticultural production can be described as an input-output process (Figure 1). Thus, there is a relationship between the inputs to the system (water, fertilizers etc…) and the outputs (ie. grapes and wine). Whilst there are some things in the system (noise) that we cannot control (eg. rainfall, sunshine, the soil types that occur in the vineyard), we can control the use of a range of inputs such as irrigation water, fertilizers, sprays and can control the use of practices such as canopy management, pruning and harvesting. Through the use of yield mapping and other vineyard monitoring tools, we can start to understand the relationship between the inputs and outputs. By recognising that this relationship can vary within the vineyard, improved and more targeted management becomes possible.

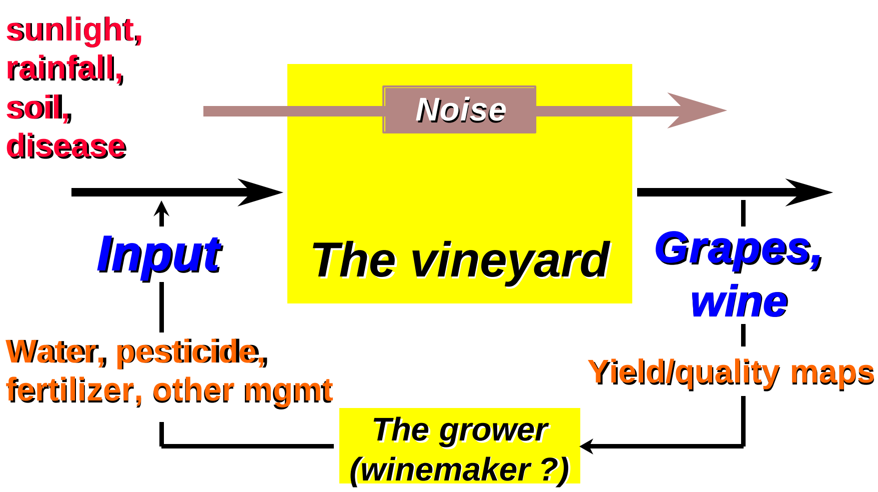

Figure 1. Viticultural production as an input-output process.

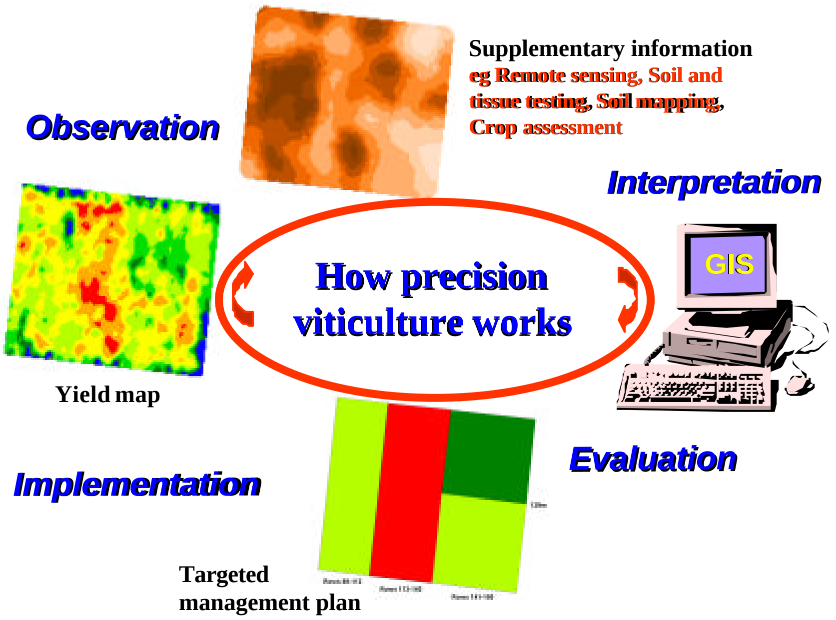

Figure 2. The adoption of PV implies a continuous cyclical system of data collection (observation), interpretation and evaluation with a view to the implementation of more targeted management, followed by further observation, interpretation and evaluation (was the targeted management successful ?)…

How might PV work and what might its benefits be ?

In Figure 2, we illustrate how the adoption of PV might work with a real example from the Coonawarra. The use of a yield monitor illustrated that vineyard productivity was highly variable. In this case, the variability in yield was seen to be closely related to variation in soil depth which was assessed using EM38 sensing (see below) and it appeared reasonable to divide the vineyard into 3 zones of similar performance. The fruit in these were harvested into separate bins and separate wines were made.

The CRCV project team think that there are a number of reasons why the grape and wine industry might benefit from the adoption of this sort of management approach. These include:

- More efficient use of inputs (sprays, water, fertilizer, etc) leading to
  - Improved cost effectiveness,
  - Enhanced sustainability, and
  - Demonstration that best-practice has been used;
- Separation of the crop at harvest according to expectations of quality and/or yield;
  - ie. ensure that the premium wines are not only that, but are also as premium as possible !
- Harvesting to quality specification;
- Improved harvest scheduling;
  - possibly related to issues such as winery storage capacity;
- More accurate/better targeted sampling of vineyards as an aid to making management decisions
  - for better pest/disease monitoring

- for crop forecasting;
- An improved basis for payment to growers; and
- Improved vineyard design.

No doubt other opportunities will emerge as PV develops.

Progress in CRCV precision viticulture research

Our research, which is being conducted at sites in Coonawarra and Sunraysia, is focussed on understanding the input-output relationships depicted in Figure 1, the nature and extent of within vineyard variation, and the identification and evaluation of tools such as remote sensing through which growers might acquire useful information to assist in the interpretation and evaluation of yield and quality maps (Figure 2). At each site, we have a large number of target vines on which a number of measurements of both vine and fruit characteristics have been made, together with analysis of soil properties. Whilst this work remains on-going, our results to date suggest that:

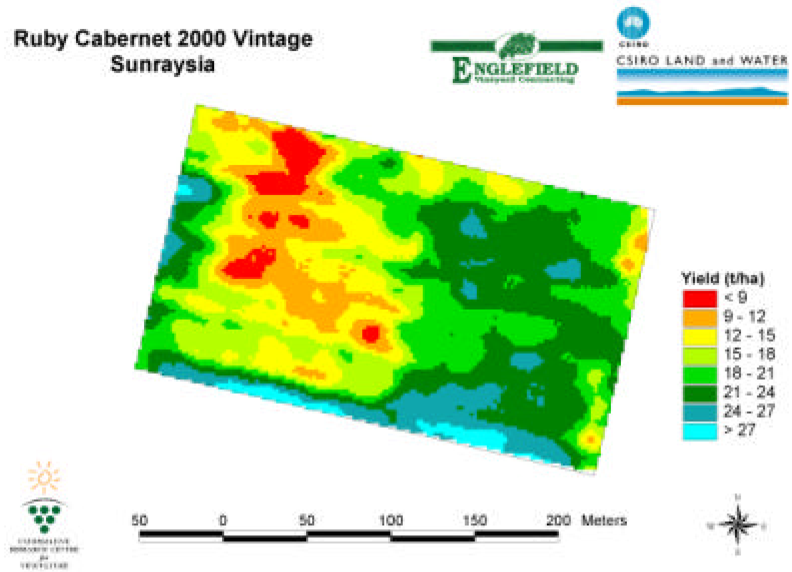

Figure 3. Variation in the yield of Ruby Cabernet at a 4.5 ha site in Sunraysia. The vines were planted on their own roots in 1989.

- Yield variation in the two vineyards is substantial (eg. Figure 3)
- On the basis of 2 years data from 2 sites in Coonawarra and Sunraysia, the pattern of vineyard variability appears to be fairly stable from year to year (eg. Figure 4), even though actual yields in the two years differed markedly.
- Correlations between the various measured grape and vine properties were generally poor when the data were treated as a set of repeated measures, but there were similarities in the spatial structure of the data between some properties (eg Figures 5 and 6). However, covariation of soil and vine/grape indices was not constant in space.

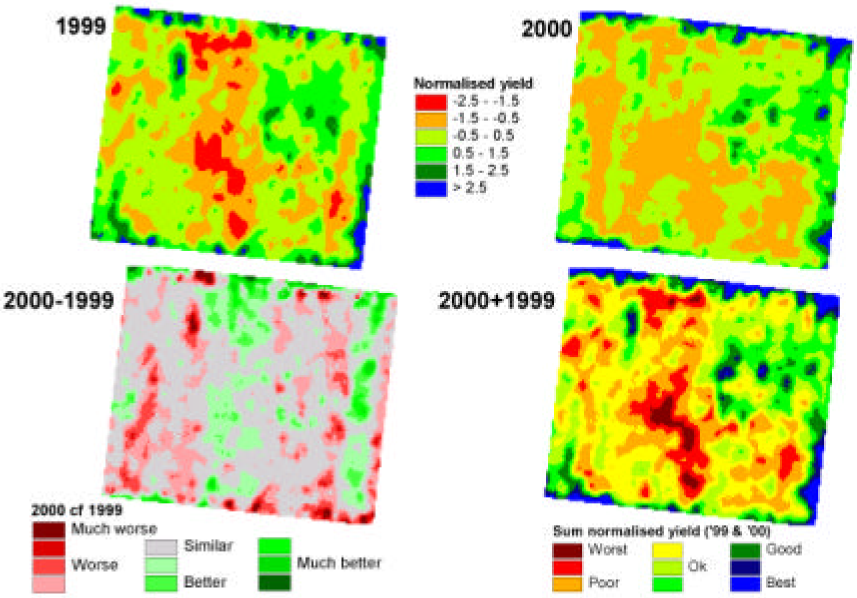

Figure 4. Comparison between vineyard performance over two years in a Coonawarra vineyard under Cabernet Sauvignon. In this figure, the yield data for the two years have been normalised to a mean of zero and standard deviation of 1 (top two maps). The bottom left map shows the difference between this normalised yield over the two years and indicates that even though the actual yields were markedly different in the two years (2000 was significantly lower yielding than 1999), the pattern of yield variation was similar in each year - the map is dominated by pale pink, grey and pale green. Adding the top two maps together (bottom right) enables identification of the relative performance of different parts of the vineyard over the two years and therefore promotes the identification of possible management zones for which different management strategies might be appropriate.

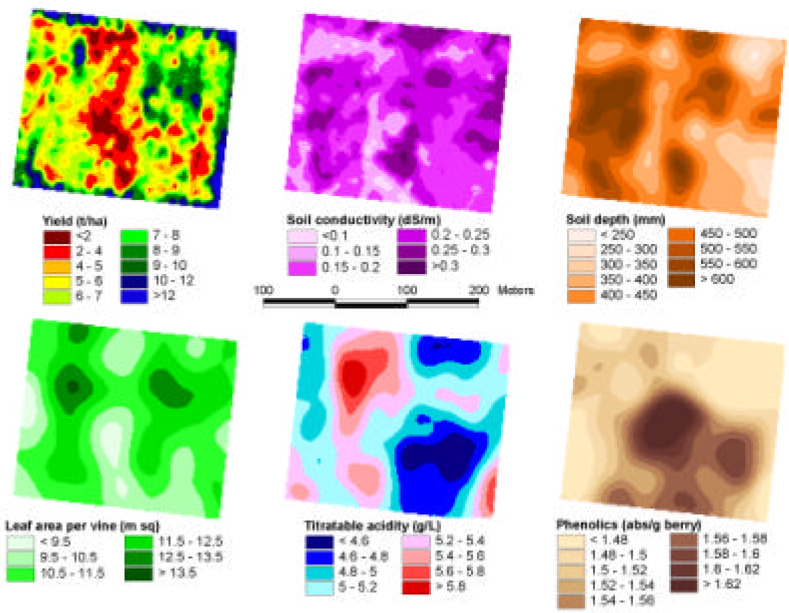

Figure 5. Variation in selected grape, vine and soil properties in a Coonawarra vineyard under Cabernet Sauvignon (1999).

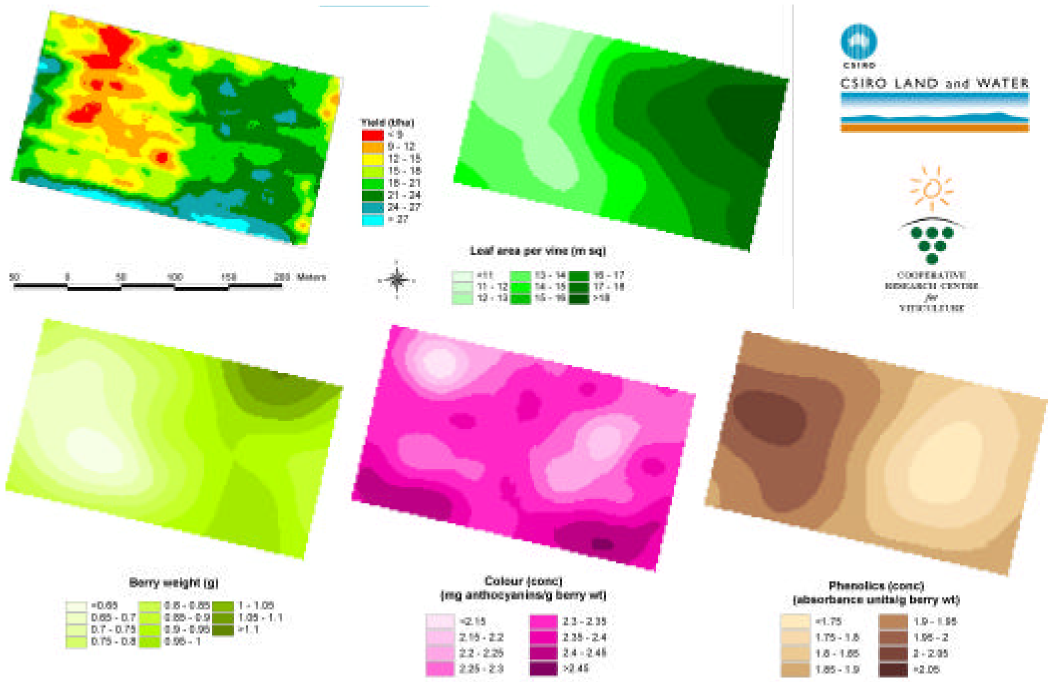

Figure 6. Variation in selected grape and vine properties in a Sunraysia vineyard under Ruby Cabernet.

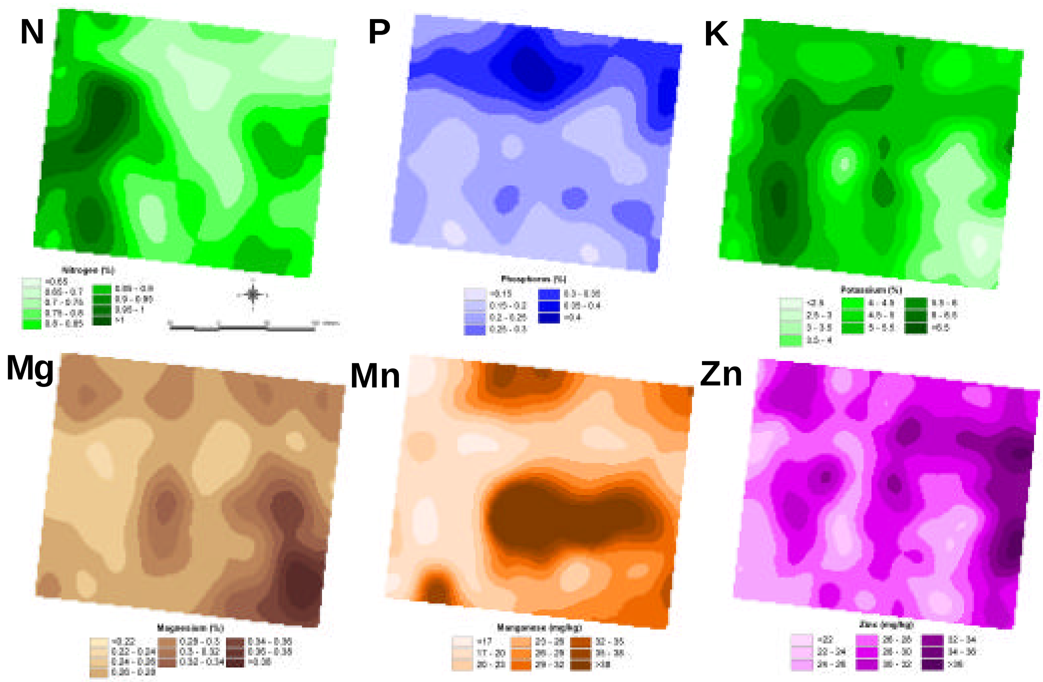

Figure 7. Variation in the levels of selected petiole nutrients at flowering in a Coonawarra vineyard of Cabernet Sauvignon.

- Variation in petiole nutrients suggests the importance of crop nutrition (eg. Figure 7).

- Soil depth variation appears to drive yield variation at both the Coonawarra and Sunraysia sites, with EM38 reconnaissance shown to be a useful indicator of soil depth in the Coonawarra (Figure 8).
- Airborne remote sensing tools also show promise (Figure 9, refer to next article).
- Yield monitoring, together with map production and some supplementary analysis and interpretation can be expected to cost approximately $4-5/tonne.

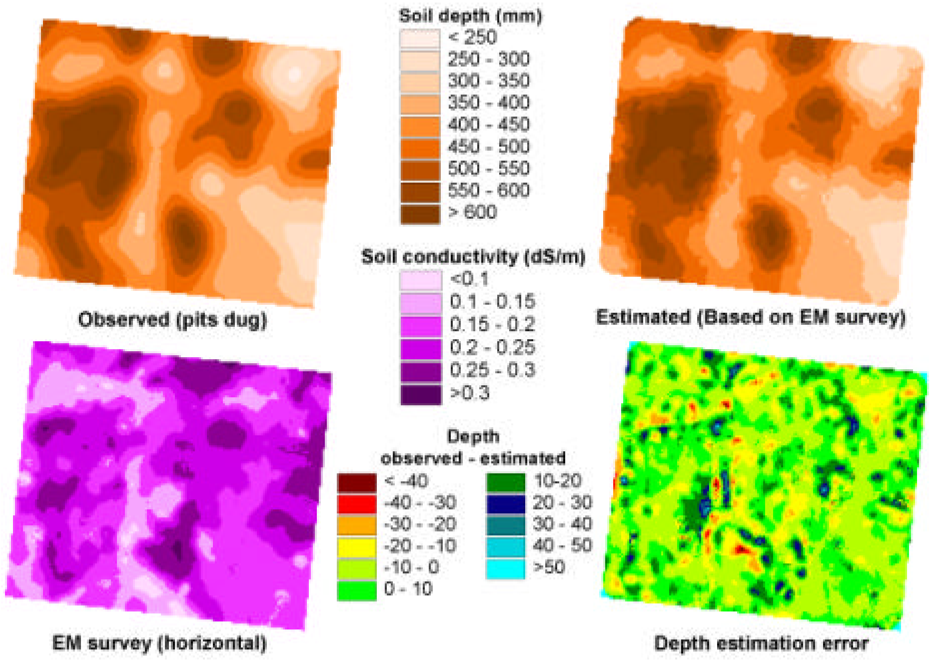

Figure 8. EM38 as a tool for soil depth sensing in Coonawarra. Soil depth was assessed at 190 points within the vineyard and mapped (top left) and an EM38 survey conducted at the same time (bottom left). A moving window regression tool was used in GIS to relate soil depth and soil conductivity as determined by the EM38 sensor and this was used to estimate soil depth on the basis of EM38 data (top right). Comparison between the observed (top left) and estimated (top right) soil depth maps, suggests that in Coonawarra, EM38 can be expected to provide a useful tool for inferring soil depth.

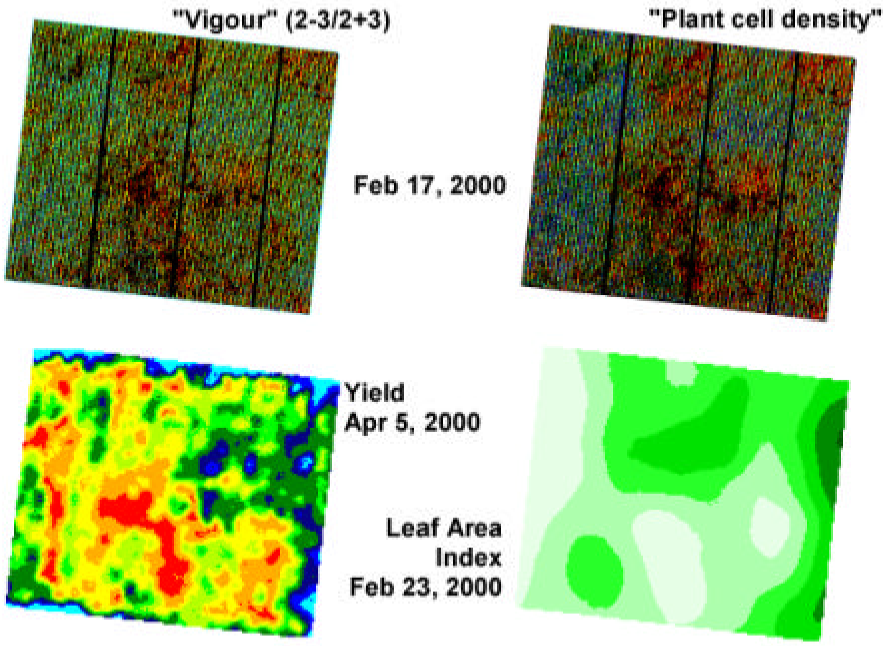

Figure 9. Comparison between yield, leaf area index and two enhanced images obtained by airborne digital multispectral video imaging in the Coonawarra. (Courtesy F. Honey, SpecTerra Systems, Perth)

Conclusions

There is a marked spatial variation in vineyard performance in terms of both yield and quality and limited evidence supports the view that this variation is reasonably stable in time. Consequently, we conclude that the adoption of precision agriculture technologies by the grape and wine industry could produce significant benefits. We see PV as providing a cheap source of valuable information which could lead to marked improvements in the way in which viticultural production systems are managed. Whilst PV is new, a range of tools (EM38, remote sensing) are already available to support activities such as yield monitoring; we consider their continued development to be warranted. Finally, we believe that careful soil management may promote greater control over variation in grape yield and quality. In this connection it is important that growers understand that getting crop nutrition right may be just as important as getting irrigation right; their management should reflect this. However, because covariation of soil and vine/grape indices is not constant in space, an improved understanding of the input-output relationships in grape production systems will be required if targeted management is to be successful.

Airborne remote sensing of the vine canopy

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Introduction

Remote sensing has long been used to monitor and map variability in vegetation canopies based on changes in their spectral signature. However, in the study of land-use and degradation in Australia, the transition from research to operational use has been slow, and in the late eighties there was a perception that remote sensing had failed to fulfil its promise (Johnson and Barson 1990, Bryceson and Marvanek 1998).

The emergence of precision viticulture in Australia has provided new opportunities for technologies capable of mapping spatial variability of productivity-related parameters within what has traditionally been the basic viticultural management unit; the vineyard. The recent introduction of precision yield mapping technology in viticulture, an increasing understanding of the link between vine spectral signatures and biophysical parameters, improvements in spectral sensitivity and spatial resolution, and the availability of low-cost sensors have all contributed to an increased interest in applying aerial imaging to routinely monitoring the health and development of vineyards as well as for acquiring base data for vineyard management plans.

How does it work ?

Airborne imaging systems utilize the sunlight reflected off ground targets, in this case vines, cane, covercrop and soil. A typical spectral reflectance profile of vine leaves and bare cane is given in Figure 10 (adapted from Lamb 1999). Typical of most chlorophyll-containing vegetative surfaces, vine leaves reflect strongly in the green portion of the spectrum (≈ 530 nm) and have low reflectance (associated with strong chlorophyll absorption) in the blue and red wavelengths. It is for this reason that photosynthesising targets appear green when viewed in visible wavelengths only. However, a significantly greater proportion of the sunlight is also reflected in the near infrared band of the electromagnetic spectrum, wavelengths that are beyond the limit of human perception. The strong reflection of near infrared radiation by plants is primarily associated with the cell structure of the leaves (Campbell, 1996).

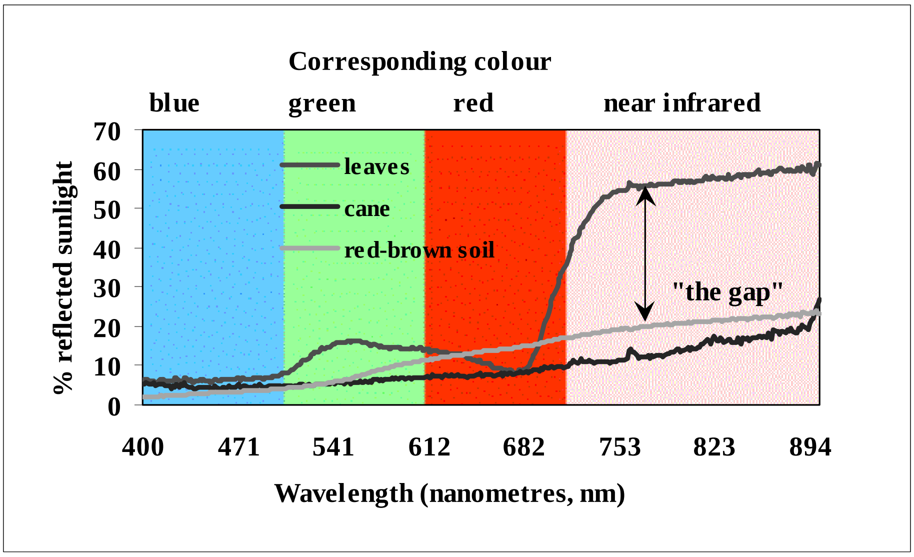


Figure 10. Reflectance profile of cane and young leaves on a Cabernet Sauvignon vine showing "the gap" where huge differences in the amount of reflected sunlight exist between the leaves and the cane (Adapted from Lamb (1999)).

By comparison, bare cane, and in this case red-brown soil, exhibit a smooth increase in reflectance with increasing wavelength, and no significantly higher reflectance in the green or the near infrared wavelengths.

The improved contrast between leaves and cane or soil in near infrared wavelengths makes the measurement of near infrared reflectance an important parameter in delineating relative amounts of plant biomass against a cane or soil background in a vineyard. Furthermore, it has been demonstrated that the near infrared reflectance of vegetation is more sensitive to changes in plant health than in the visible wavelengths (Campbell 1996). Generally, the influence of vine diseases, pests, nutrition and available moisture will affect vine biomass or leaf spectral characteristics, or both.

Unlike human eyesight or conventional colour imaging, aerial imaging systems record separately the different waveband (or 'colour') components of a target. This allows the overall colour of a target to be quantitatively analysed in terms of the amount or relative proportion of specific wavebands. Digital images, unlike print photographs, are formed by a 2-D array of image pixels. Each pixel carries a number of values; one per corresponding image waveband. For example, in an image acquired using a four waveband imaging system (such as a blue/green/red/near infrared system), each pixel will contain four numbers; representing the brightness in each of the blue, green, red and near infrared wavebands, respectively. By looking for differences in the brightness numbers associated with each waveband of every image pixel, small differences in plant spectral signature are detected and processed by computer. Differences can be processed quantitatively, if the pixel values are calibrated to ground target reflectance or absolute radiance units, or qualitatively by calculating relative differences. Either way, differences in the spectral signature can be mapped over an entire image (surface of a target) using standardized image display formats.

Spectral vegetation indices reduce the multiple-waveband data at each image pixel to a single numerical value (index), and many have been developed to highlight changes in vegetation condition (for example Wiegand et al. 1991, Price and Bausch 1995). Vegetation indices utilize the significant differences in reflectance of vegetation at green, red and near infrared wavelengths. For example, Normalised Difference Vegetation Index (NDVI) images are created by transforming each multispectral image pixel according to the relation:

$$\mathrm{NDVI} = \frac{(\text{near infrared}) - (\text{red})}{(\text{near infrared}) + (\text{red})} \qquad \text{(Rouse et al. 1973)}$$

where 'near infrared' and 'red' are respectively the reflectances in each band. The NDVI, a number between –1 and +1, quantifies the relative difference between the near infrared reflectance 'peak' and red reflectance 'trough' in the spectral signature (refer to Figure 10 for an example), and is the most widely used indicator of plant vigour or relative biomass. For highly vegetated targets, the NDVI value will be close to unity, while for non-vegetated targets the NDVI will be close to zero. Negative values of NDVI rarely occur in natural targets. Other indices of potential use in viticulture include Plant Cell Ratio (PCR), Photosynthetic Vigour Ratio (PVR) and Plant Pigment Ratio (PPR) where

$$\mathrm{PCR} = \frac{(\text{near infrared})}{(\text{green})}$$

$$\mathrm{PVR} = \frac{(\text{green})}{(\text{red})}$$

$$\mathrm{PPR} = \frac{(\text{green})}{(\text{blue})} \qquad \text{(Honey 2000)}$$

In general, appropriate index or multiband colour-infrared images of agricultural crops are an important indicator of crop health and development.

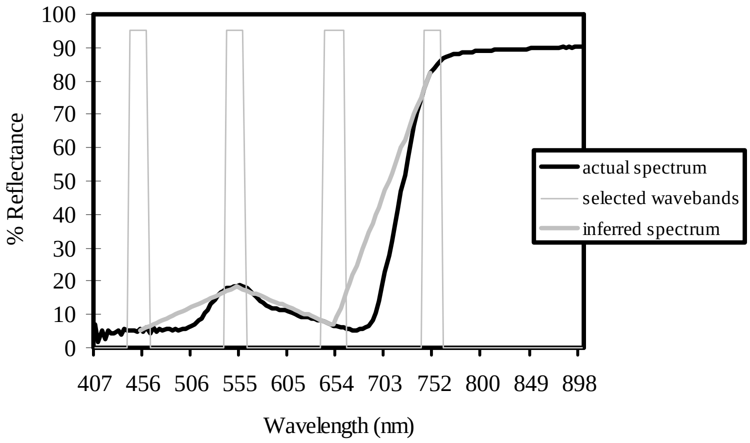
Spectral resolution –multispectral versus hyperspectral

The extraction of plant biophysical data from remotely-sensed imagery relies on the ability of the sensor to detect changes in the on-ground plant spectral signature. This ability is specified in the spatial, radiometric and spectral resolution of the instrument. The spatial resolution of the sensor is related to the number of image-forming pixels. A greater number of pixels per unit area of ground coverage means spatially smaller features on the ground can be distinguished from their surroundings. The radiometric resolution is the number of numerical steps available to each pixel to record brightness values in response to the intensity of incident radiation in a specified waveband; for example 0 (black) to 256 (white). The spectral resolution is the width (usually specified in nanometres) of each of the wavebands recorded. An important partner of spectral resolution is the number of wavebands of data that can be simultaneously recorded at each pixel.

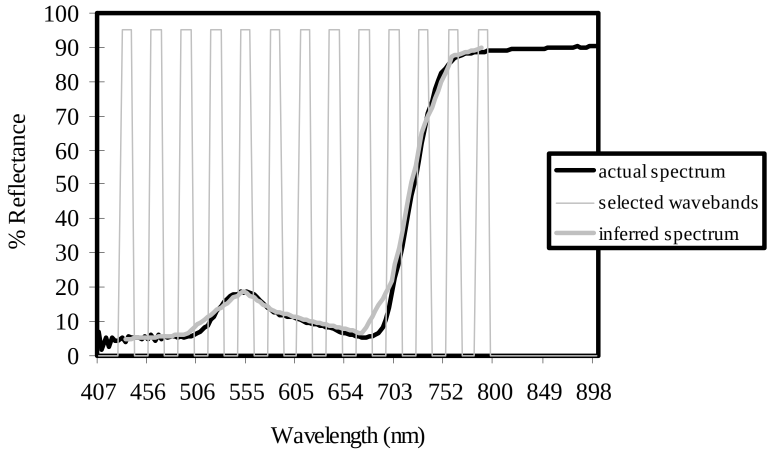
Assuming the spatial and radiometric resolution of the instrument is appropriate, the ability of a sensor to distinguish small differences in the spectral profile of an on-ground target is dictated by its spectral resolution. Figures 11(a) and (b) show the reflectance profile of a typical vegetated target. Superimposed on these profiles are a set of wavebands corresponding to the sensitivity of a hypothetical instrument and the reflectance profile that would be inferred from the response of that instrument to the ground target. In Figure 2(a) the hypothetical instrument measures the spectral signature of the target in four wavebands. While an accurate measure of the target reflectance would be extracted at the four specified wavebands, the shape of the reflectance profile of the vegetated target is only poorly described. Using thirteen closely-spaced wavebands (Figure 11(b)), the reflectance of the target is recorded for each waveband and the shape of the entire spectral profile is more accurately described. In an application where the shape of the spectral profile is required, the higher spectral-resolution instrument (Figure 2(b)) would be appropriate.

A consequence of the upper limit on the amount of data that can be processed and stored in real-time by any remote sensing system is the compromise between spatial, radiometric and spectral resolution. In general, this equates to a trade-off between spatial and spectral resolution. The terms multispectral and hyperspectral are often interchanged, although they usually define instruments according to the number of wavebands of information that is recorded at each image pixel (spectral resolution). The more general adjective 'multispectral' is used to describe instruments which record information in only a small number of wavebands; typically 2-10. Hyperspectral instruments record information in a large number of wavebands, typically greater than 10.

Remote sensing systems which form an image of a target directly onto a 2-D array of charge-coupled device (CCD) elements tend to be multispectral due to the large amount of spatial data which is recorded at any one time. On the other hand, scanning instruments use one dimension of a 2-D CCD array to record a small slice of the image target and use the forward motion of the remote sensing platform and consecutive "scans" to form a 2-D image. The second dimension of the 2-D array records spectral information as the incident radiation is directed through a dispersing medium such as a prism or diffraction grating. Because of the relatively small amount of spatial information recorded at any one time, a greater amount of spectral information can be recorded. Scanning instruments are typically hyperspectral instruments (for an excellent discussion on multispectral and hyperspectral instruments, refer to Campbell, 1996).



(a)



(b)

Figure 11. Comparison between an actual vegetation reflectance profile and an inferred reflectance profile using (a) 4 wavebands (multispectral), and (b) 13 wavebands (hyperspectral) (Adapted from Lamb (2000)).

Airborne versus satellite remote sensing for vine monitoring

Remote sensing can only be used for monitoring vines when;

(i) appropriate biophysical parameters influence the spectral signature of the vine canopy, and

(ii) the remote sensing instrument has the appropriate spatial, spectral and radiometric resolution to detect variations in spectral signature.

The remote sensing system itself must;

(i) provide cost-effective data,

(ii) be capable of acquiring and providing information in timely manner, and

(iii) have user-defined spectral characteristics to allow tuning to specific pre-defined vine indicators.

The spatial resolution requirements of imaging vines remains unspecified. Unlike crops with a complete surface coverage (such as cereal crops), the relative vigour of row crops is also often expressed in canopy dimensions as well as canopy spectral signature. Imaging vines with pixel-sizes greater than the row-row distance may actually be advantageous. Assuming a uniform background, spatial variations in canopy dimensions will affect the spectral value returned by mixed (vine and background) image pixels as the relative contribution of the vine and background spectral signatures will be different. This approach, however, may be confounded if the background varies across an image, as often in the case when cover-crop or significant changes in soil type/structure exists. This is the subject of ongoing research.

Satellites have a limited operational flexibility compared to aircraft. In a capability study undertaken to assess aircraft reconnaissance against commercial satellite imagery for military purposes, Heric et al. (1996) found greater flexibility of scheduling in favour of aircraft reconnaissance in any 96-hour window. The growth and management of agricultural crops is dictated by local weather conditions and this demands a high scheduling flexibility for any monitoring system.

The next generation of commercial satellites will offer improved spatial resolution and improved data turnaround times (for example Fritz 1996). However the ability of an airborne sensor to operate below a cloud ceiling is an important advantage in any winter cropping season.

Airborne imaging systems

The use of airborne colour and colour-infrared photography for monitoring crops in Australia was established in the early 1970's (for example, by Harris and Haney 1973), and later extended to detect weeds in crops and pastures (Barrett and Leggett 1979, Arnold et al. 1985). However, limitations of aerial photography for crop monitoring include the absence of a quantitative data acquisition capability, the high cost and availability of colour infrared film and processing, and the requirement for manual scanning or digitising in order to incorporate into a geographic information systems package (GIS). Airborne imaging systems, incorporating in-flight or post-flight image digitisation can provide sub-metre resolution images of crops at any revisit frequency and in a timely and cost-effective manner. These systems provide user-selectable spectral bands, some as low as 2 nm bandwidth, in the visible, near infrared and mid-infrared bands.

Due to the significantly different spectral signatures of vine canopies and underlying cane or bare soil, colour-infrared imaging provides both a qualitative and quantitative tool for the analysis and mapping of relative amounts of canopy biomass (Johnson *et al.* 1996, Lamb 1999). Researchers have demonstrated the potential of airborne multispectral imaging for identifying and mapping regions of long-term stress associated with phylloxera (Figure 12) (Johnson *et al.* 1996) and for prior- and mid-season estimation of yield in phylloxera-infested vines (Baldy *et al.* 1996). and for estimating irrigation demand (Figure 13).

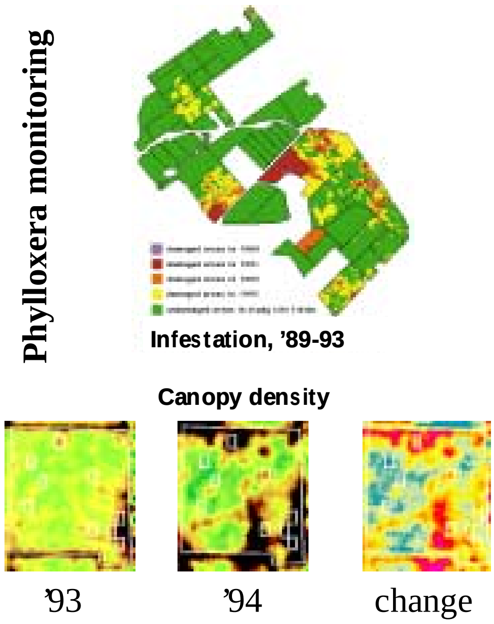


Figure 12. Monitoring changes in canopy vigour associated with phylloxera in Napa Valley (USA) vineyards (Courtesy, VINTAGE & L. Johnson).

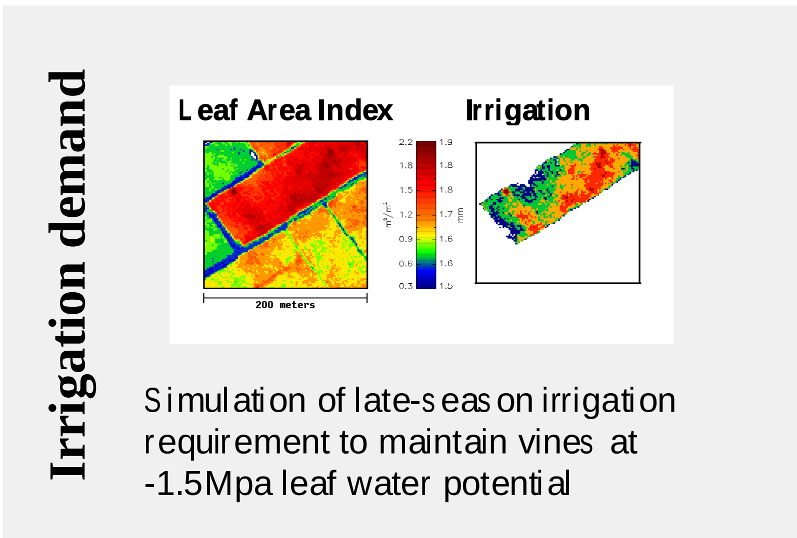


Figure 13. Estimate of irrigation demand from modelled relationship between leaf area index (LAI) and canopy transpiration. (Courtesy, VINTAGE & L. Johnson)

However in the Australian context, the general robustness of the correlations between spectral signal and on-the-ground status requires further investigation, especially since much of the previous research was conducted over vines with a senesced cover-crop or bare soil on the vineyard floor. It would be expected that the spectral signature of a healthy cover-crop would confound the ability to discern canopy boundaries, and hence to estimate canopy biomass, although to date this has not been quantified. An example of spectral reflectance profiles of vines and the background cover-crop throughout a given season is given in Figure 14. Here it is evident that the progressive growth and subsequent senescence of the cover-crop results in significant changes in the background spectral signature throughout a season.

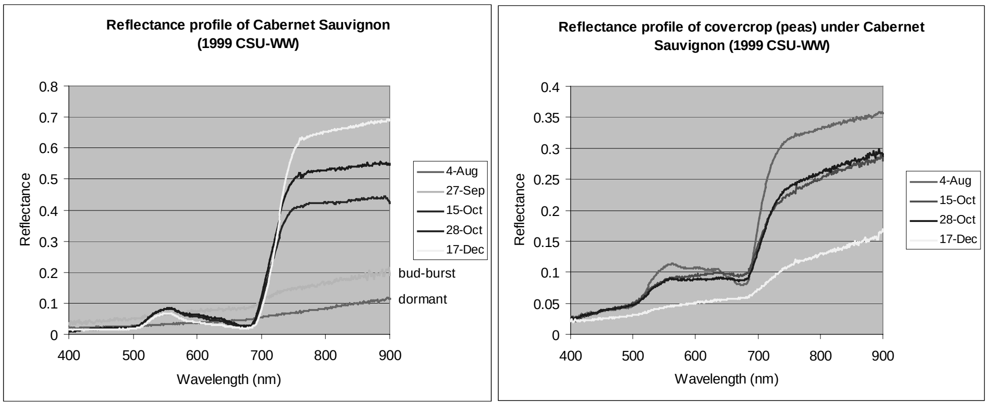


Figure 14. Spectral reflectance profiles of Cabernet Sauvignon vine canopy and underlying cover-crop during the 1999-2000 growing season (Riverina) (Courtesy, NWGIC & D. Lamb).

Nevertheless, it is possible that the confounding influence of a spatially and temporally varying cover-crop may be negated with the use of multi-temporal imagery of the same vineyard block (Figure 15). However, to date the link between the vine canopy and grape yield and quality variables is not fully understood, primarily due to the complex interactions between climatic conditions, vine genetics, vineyard management practices and the influence of pests and diseases (Dunn and Martin 1998).

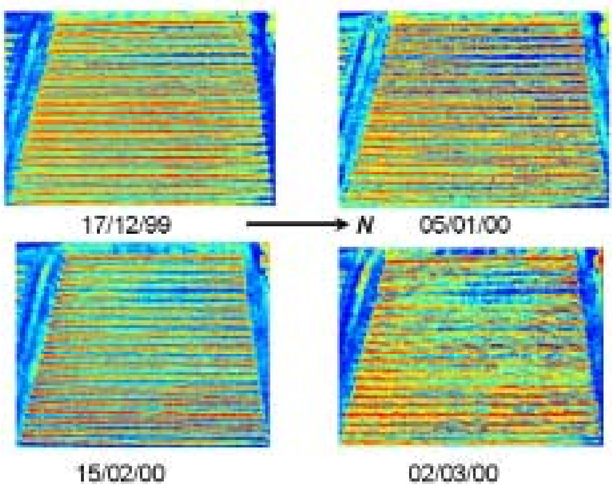


Figure 15. Time sequence of four pseudo-colour NDVI images of a 1 ha Cabernet Sauvignon block (Riverina) generated using a multispectral image (Four wavebands - near infrared, red, green and blue). Red = strongest live-vegetation signature, Blue = absence of live vegetation. Image resolution = 25 cm. Note the patches of bare soil (blue) in the cover-crop viewed between the rows of vine canopy. In these images it is possible to contrast the canopy against the varying cover-crop. (Courtesy, Charles Sturt University Farrer Centre & A. Cush).

While remote sensing offers an insight into canopy growth and development, robust extrapolation to grape yield and quality attributes will likely require integration of remotely-sensed canopy biophysical data with some form of vine physiological growth and development model. This, again, is the subject of further research in the CRCV.

Notwithstanding limitations associated with extracting quantitative biophysical information from vine canopies and the issues of varying cover-crop, qualitative airborne imaging has many uses. For example, hyperspectral imaging has been used for identification of varieties based on differentiating small differences in vine spectral signatures (Figure 16). Provided imagery is geo-rectified, that is converted to a faithful representation of the ground surface using correction procedures and on-ground map coordinates, accurate measurement of surface areas planted to vines can be made (Figure 17).

While the link between soil properties and vine vigour may be complex, qualitative multispectral imagery highlighting areas of different vine vigour can be a surrogate indicator of spatial variations in underlying soil properties. In Figure 18, an NDVI image of a vineyard acquired using a trispectral scanner (3 wavebands - near infrared, red and green), the anomalous area of low NDVI (arrowed) coincides with an area that was too aggressively levelled during site preparation. Much of the fertile top-soil had been removed from this region.

Figure 16. Grape varieties identified using hyperspectral imaging (Courtesy, Ball Advanced Imaging & Management Solutions).

Figure 17. Areal estimates provided from a geo-rectified image on a vineyard site. (Courtesy, Ball Advanced Imaging & Management Solutions).

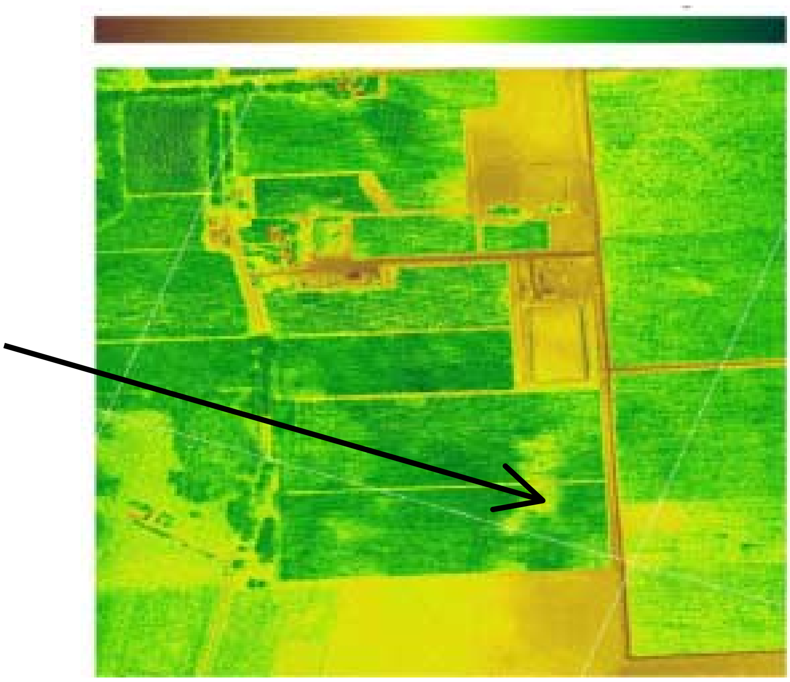
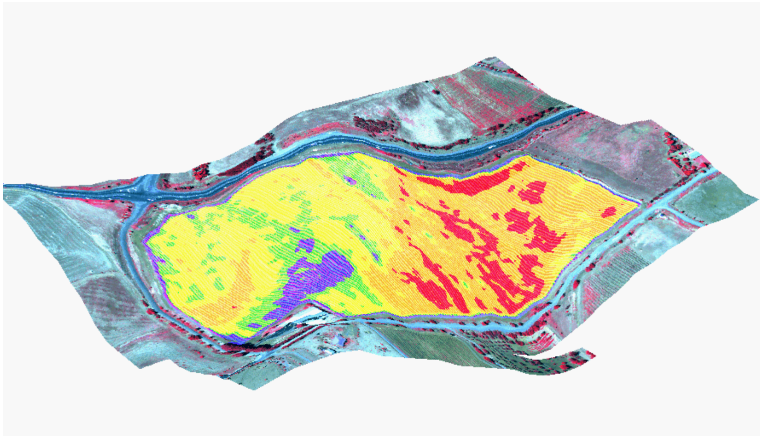


Figure 18. NDVI imagery of vineyards generated from a trispectral scanner image. The anomalous patch of low NDVI (arrowed) coincides with an area that had been too aggressively levelled. Top colour bar indicates an NDVI range from 0 to 1 (brown to green). (Courtesy, Airborne Research Australia).

Like any digital dataset with spatial coordinates, imagery can be combined in a GIS with other datasets to allow processing of multiple data layers to generate management plans (Figure 19) including segmenting harvest (Johnson *et al*. 1998) (Figure 20).



Vineyard Image draped over a digital elevation model

Figure 19. A vineyard stress-image "draped" over a digital elevation model of the same vineyard. In this example, the impact of local topography on vine stress can be visualised. (Courtesy, Ball Advanced Imaging & Management Solutions).

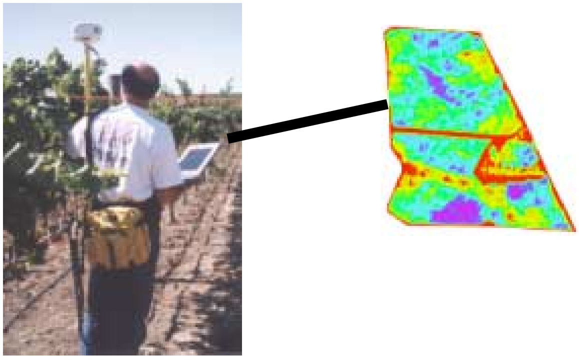


Figure 20. Segmenting a vineyard block based on the persistence of estimated vigour levels from airborne imagery (Courtesy VINTAGE & L. Johnson).

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PART II : Workshop feedback, conclusions and recommendations

Workshop feedback, conclusions and recommendations

The following summarizes the feedback generated during the interactive workshop in response to the following primers:

a: the level of industry awareness of existing PV practices/ technologies
b: limits to the adoption of PV practices/ technologies by the wider industry (small and large growers alike)
c: areas in PV which require (further) investigation
d: scope / opportunities for greater industry participation / collaboration in PV Research & Development.

Industry awareness

The level of industry awareness of PV-related issues generally appeared to be linked to the level of local research and development activities. Regions such as the Coonawarra/Barossa had a higher level of awareness, ostensibly because of a comparatively larger amount of PV-related research and development activities conducted in a number of local vineyards, and also because of the PV presence at field days such as Vititec, grower meetings etc. Smaller, more physically-isolated, growers expressed concern about being left out of the loop.

1.1 Recommendation/Conclusion: PV-related research and development activities should be distributed across Australia, not only to increase the geophysical relevance of the research but also to increase local awareness of PV issues/practises. The establishment of a number of strategically-located "extension or demonstration sites" on completion of the basic CRCV 1.1.1 project is recommended. These should not be restricted to sites "sponsored" by larger companies.

1.1 Implication/Relevance to current CRCV Project 1.1.1: Since commencement of CRCV Project 1.1.1, the number and location of sites has expanded from two to four. Sites are currently located at Padthaway (Coonawarra), Nangiloc (Sunraysia), Wagga Wagga (Riverina), and Hanwood (Riverina).

1.2 Recommendation/Conclusion: A survey of existing attitudes of the industry to precision viticulture be commissioned.

1.2 Implication/Relevance to current CRCV Project 1.1.1: A survey of attitudes to precision viticulture was distributed to participants of Murray Valley Grapegrowers Council Seminar (Mildura), 2000 (Bramley). Results were collated and a report submitted to the GWRDC. A new survey, incorporating elements of this earlier survey has been assembled (Appendix 1) for distribution via CSU's educational network and arrangements for distribution via the CRCV's mailing list are currently in progress.

The need for an active process communication of research outcomes through symposia, field-days and industry publications, as well as scientific reporting mechanisms was discussed. Given the technological nature of PV, standardised terminology as well as established protocols for acquisition and analysis of PV-related spatial data, both from researchers and commercial providers was recommended.

1.3 Recommendation/Conclusion: An active program of communication should be adhered to. Reported research outcomes, related to the acquisition and analysis of PV-related spatial data, should include reference and conformity to standard terminology and operational protocols.

1.3 Implication/Relevance to current CRCV Project 1.1.1: In the 12 month-life of the project, outcomes have been widely reported to the industry via field days (2), conferences (2), tabloid media (numerous), industry publications (3) and scientific journals (1). Draft protocols for the generation of grape yield maps are currently under review for wider dissemination to the wider industry (Bramley) and a review paper on the use of remote sensing in viticulture is currently in the final stages of preparation (Lamb). The preparation of a discussion paper on the use of electromagnetic survey in viticulture is also planned (Lamb).

Limits to adoption

Incentives for adopting PV practises were identified, including increases in productivity, more efficient uses of inputs (water, fertiliser, pesticides) and more effective time spent in the vineyard. However, participants voiced concerns over a possible lack of formal training infrastructure for PV. While it was recognised that hardware providers (eg Gregoire or Harvestmaster) can provide limited training support in the use of yield mapping hardware, growers in particular felt general training in interpretation and management of spatial data was important.

2.1 Recommendation/Conclusion: The CRCV should work with partner educational institutions like CSU to develop appropriate educational packages related to the use of spatial data in viticulture.

2.1 Implication/Relevance to current CRCV Project 1.1.1: Experiences gained in PV are already being used in developing/modifying existing teaching subjects offered by CSU to accommodate the spatial nature of vineyard data.

A summary of outcomes of a recent symposium on precision agriculture in Australia (Australian Centre of Precision Agriculture, August 2000) was presented. A lack of agronomic support and experience in interpreting spatial variability in productivity-related variables was listed by cereal farmers as a significant limit in the adoption of precision farming technologies in the grains industry. A similar concern related to viticultural support for PV was voiced at this workshop. The importance of making PV an integrated package of data acquisition and analysis, and practical viticultural advice was established. While possible with larger corporations, smaller growers may find themselves in the position of being able to access data but little in the way of practical viticultural knowledge. PV R&D will create opportunities for a new generation of viticulturists.

2.2 Recommendation/Conclusion: Where possible, practising viticulturists should be included in PV R&D, rather than simply being involved in extending outcomes. They need to have a working knowledge of the characteristics of the data itself as well as the viticultural ramifications of the data assemblage.

2.2 Implication/Relevance to current CRCV Project 1.1.1: The project is structured around four commercial vineyard sites and utilises the skills of numerous practising viticulturists from Southcorp and McWilliams. Further involvement of practising viticulturists in subsequently established extension sites (R/C 1.1) would occur.

A survey of workshop presenters, specifically those involved in remote sensing, revealed that, while highly qualified and experienced in aspects of their own technologies, they had a limited knowledge of the grape and wine industry and viticulture. A consequence of this is the fact that technology providers are offering a product to an area they no little about, and viticulturists/growers are evaluating a technology they know little about.

2.3 Recommendation/Conclusion: CRCV researchers new to the grape and wine industry should be identified and encouraged to participate in orientation activities similar to that offered to postgraduate students.

2.3 Implication/Relevance to current CRCV Project 1.1.1: Outcomes of the project will be reported in technology-orientated media as well as industry-related media. A critical review of the world-wide status of remote sensing in viticulture is currently in preparation (Hall & Lamb) for submission to the *Australian Journal of Grape & Wine Research.* A similar review is also in preparation for submission to *Remote Sensing of Environment*. A paper on the strengths and limitations of PV technologies (Lamb & Bramley) has been submitted to *Journal of Natural Resource Management.*

Participants felt that the occasional inconsistent terminology and jargon from the different workshop presenters highlighted the importance of uniformity in formatting and describing spatial data related to PV. This could become an important issue if growers were contemplating using spatial data as part of ISO accreditation (eg ISO 14000).

2.4 Recommendation/Conclusion: Establishment of, and compliance with, protocols for generating and reporting spatial data related to PV should be an integral part of evaluating PV technologies.

2.4 Implication/Relevance to current CRCV Project 1.1.1: Draft protocols for the generation of grape yield maps are currently under review for dissemination to the wider industry (Bramley) (I/R 1.3). The preparation of a protocol discussion paper on the use of electromagnetic survey in viticulture is also planned (Lamb).

Identified requirements for PV research and development

The following areas were identified as being of sufficient interest to participants to warrant additional research and development activities.

1. Remote and/or proximal sensing of vine nutrient status to replace existing methods of petiole sampling and subsequent analysis.

2. Remote or proximal sensing of soil structure and nutrition/water status through the use of electromagnetic (e/m) survey and ground-penetrating radar.
3. Remote and/or proximal sensing of bunch parameters (physical and chemical)
4. Vine growth and development modelling (for example as conducted by CSIRO Plant industry, Merbein Vic) and integration with GIS to account for spatial variability
5. Decision support including data integration (GIS) for viticulture

3.1 Recommendation/Conclusion: Areas identified as warranting additional research and development be communicated to the Grape & Wine Research and Development Corporation and the CRCV Board for future strategic evaluation.

3.1 Implication/Relevance to current CRCV Project 1.1.1: Elements of points 1, 2 and 4 are currently under investigation in this project.

Industry participation

Participants identified a number of avenues to encourage and facilitate broader level of participation by industry members in PV research.

1. Include contract harvesters, either provided with yield-mapping hardware for short-term use, or encouraged to purchase yield-mapping hardware.
2. Form closer information links with the Viticare network
3. Provide wider access to databases such as that contemplated for assembly in the SA Grape & Phylloxera Board Phylloxera Project.
4. Maintain a high-profile in the industry via workshops and in-vineyard demonstrations.
5. Establish locally 'controlled' study/extension sites involving local growers.

APENDIX 1

Appendix 1

COOPERATIVE RESEARCH CENTRE for VITICULTURE

Survey of Attitudes to Precision Viticulture

What is Precision Viticulture ?

Variations in soil type, nutrient and water status, vine nutrient and water status, their management, and the incidence of pests and diseases all contribute to variation in fruit quality and yield across and within vineyards. The emergence of geographic information systems (GIS) and global positioning systems (GPS) allows vineyard data to be referenced according to their location in a vineyard. On-the-go yield monitoring technology is also now available to grapegrowers. The integration of geo-referenced data allows growers to visualize and quantify the magnitude and nature of spatial variations in parameters affecting productivity. Precision viticulture (PV) encompasses the measurement and mapping of these parameters, the process of making management decisions based on interrelationships between them, and the implementation of these management decisions in the vineyard.

While precision agriculture technologies have been utilized in other agricultural systems like the grains industry, precision viticulture (PV) is new. The purpose of this survey is to seek your views and to ensure that PV research conducted by the Cooperative Research Centre for Viticulture (CRCV) is targeted to address the needs of the grape & wine industry, and ultimately to maximise the opportunities for you in the industry to benefit from its adoption.

Your help in filling out answers is greatly appreciated. Unless otherwise indicated, please clearly mark with an **X** the response that is most similar to your views.

If, on further consideration, you wish to change a response please draw a horizontal line through the original response and mark with an **X** the new response (eg ~~YES~~ NO)

---

1. Are you concerned about variations in productivity (yield and/or quality) within vineyards ? YES NO

2. Do you think your production system would be improved if you had a good understanding of the nature and cause of variability within vineyards ? YES NO

3. If precision viticulture technologies were accessible to you, would you be interested in utilizing them ? YES NO

4. A geographical information systems (GIS) is a computer package that allows you to create maps of any number of attributes/themes of your vineyard and analyze relationships between them. In order of priority (**1 – 10**), label those attributes you would like to be able to map within your vineyard:

Attribute/theme	Rank (**1-10**)
Grape yield	
Grape quality (eg Brix)	
Vine stress (any number of times in a season as required)	
Soil type, structure or depth	
Vine nutrient status, eg nitrogen (**maximum of twice per season**)	
Vine water status (any number of times in a season as required)	
Grape variety, rootstock	
Vine management, eg pruning, PRD irrigation	
Other (specify)….	
Other (specify)….	

5. Collecting data to generate attribute maps can be time-consuming and expensive. "On-the-go" automated methods could significantly reduce time spent and cost of acquiring such data. Which particular "on-the-go" technologies are you interested in ?
(select preferred options (**X**); you may select more than one)

YIELD MONITORING | SOIL SURVEYING | AIRBORNE IMAGING

GRAPE QUALITY MONITORING | DISTRIBUTED MOISTURE SENSORS

OTHER, please state ……………………………………………………

6. We have identified the following as potential benefits of PV. Do you agree that PV offers these benefits, or do you see PV as being of little value in the suggested areas ?

	select preferred option (**X**)		
• More efficient use of inputs (pesticides/fungicides, water, fertilizer, etc.)	Benefit	No value	Undecided
• The ability to demonstrate best-practice, compliance with QA guidelines/ISO standards	Benefit	No value	Undecided
• Improved quality control	Benefit	No value	Undecided
• Harvesting to quality specification	Benefit	No value	Undecided
• Improved harvest scheduling/grape delivery to winery	Benefit	No value	Undecided
• Targeted sampling or inspection of vineyards as an aid within-season management decisions	Benefit	No value	Undecided
• An improved basis for payment to growers	Benefit	No value	Undecided
• Improving vineyard design	Benefit	No value	Undecided

7. Have we missed anything in the above list ?

8. The following table lists current costs (approximate) associated with setting up or accessing various attribute monitoring/mapping capabilities currently in existence…

Technology/capability/attribute	Costs
Yield mapping at harvest	To set up yourself: $26,000, or estimated at $5.00/tonne or $15.00-$30.00/Ha over 5 years
Airborne imaging of vine stress	Contractor: 50c – 2.00/Ha
E/M soil surveying for texture/structure	Contractor: $15.00-$30.00/Ha

Do you think such costs are an impediment to you adopting elements of PV ?
(select desired response (**X**))

YES NO

9. With your current understanding of PV, do you think small growers could equally benefit from PV technologies or would the benefits be confined to large companies ?
(select desired response (**X**))

SMALL GROWERS CAN BENEFIT   BENEFITS CONFINED TO LARGE COMPANIES

10. If you were going to invest time and/or money in PV technologies/practises, would you consider undertaking a short course (eg 1-few days) or even more formal training (TAFE/University) to become acquainted with issues in using spatial data and PV ?
(select desired response (**X**))

YES NO

11. How worthwhile do you consider PV research to be ?
(select desired response (**X**))

VERY WORTHWHILE   POSSIBLY USEFUL   UNLIKELY TO BE USEFUL   A WASTE OF RESOURCES

12. Would you be interested in participating in PV research ?
(select desired response (**X**))

YES NO

13. As our research into PV progresses, how would you like to be informed or our findings ?
(select preferred options (**X**); you may select more than one)

INDUSTRY JOURNALS eg Aust Grapegrower & Winemaker, Aust Viticulture

SCIENTIFIC JOURNALS eg Aust Journal of Grape & Wine Research, Vitis

NEWS MEDIA eg National Grapegrowers   WORKSHOPS & FIELD DAYS

CRCV NEWSLETTER   WORLD-WIDE WEB eg CRCV website

OTHER, please state   ……………………………………………………

14. Your occupation can best be described as….
(select desired option (**X**))

GROWER/VITICULTURIST   WINEMAKER   CONSULTANT

RESEARCHER   CONTRACTOR

OTHERWISE INVOLVED IN THE INDUSTRY   NOT INVOLVED IN THE INDUSTRY

15. Please mark the region of Australia where you reside/work. (**X**)

Thank you very much for your input
Please place completed survey in the stamped/addressed envelope and post it to us !

David Lamb & Rob Bramley
Cooperative Research Centre for Viticulture
Project 1.1.1 Precision Viticulture