Photo Richard Merry, CSIRO

Practical applications of precision viticulture

Rob Bramley, *CSIRO Sustainable Ecosystems*

Selective harvesting in Margaret River

In general, the main goal of Precision Agriculture (PA) is to gain control over a variable production system so that there is an increased likelihood that the outputs from the production system are the desired ones. Whilst intuitively very similar, Precision Viticulture (PV) differs markedly from PA in terms of the objectives of their early adopters. Broadacre cereal producers have overwhelmingly used yield mapping and other tools, such as high resolution soil survey (eg EM38) and elevation modelling, to promote the variable rate application (VRA) of inputs to the production system. In contrast, the early adopters of PV have placed much greater focus on the use of remotely sensed imagery, with or without yield mapping, as a basis for 'selective harvesting'.

the gross retail value of production was estimated to be increased by approximately $139,480

Selective harvesting is the split picking of fruit at harvest according to different yield/quality criteria, in order to exploit observed variation – generally in fruit quality. Rather than focussing on differential management of production inputs, selective harvesting involves the differential collection of outputs.

In this example from the Margaret River region of Western Australia, an evaluation of selective harvesting was conducted in a 3.3 hectare section of a much larger Cabernet Sauvignon vineyard. The vineyard manager and winemaker were interested to see whether there was a cost benefit from selective harvesting.

Figure 2a is a remotely sensed image of the study area acquired in 2002 at veraison, the time when grapes begin to soften, colour and ripen. The image was acquired using airborne digital multispectral video imagery, the most common commercially available form of vineyard remote sensing in Australia. Veraison has been shown to be the most informative time for acquisition of such imagery enabling variation

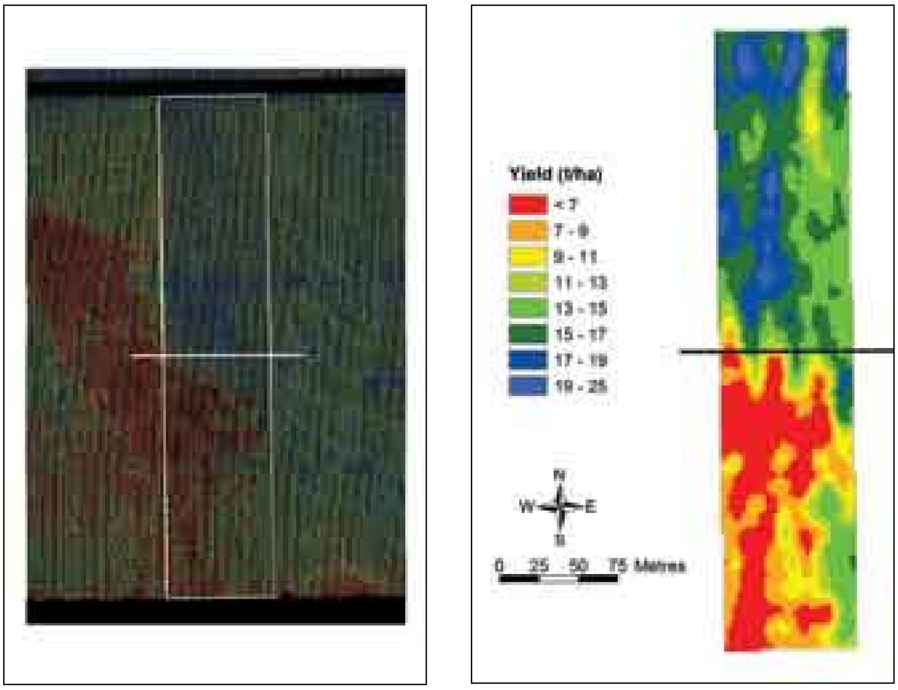

Figure 2 a&b. *Performance of a 3.3ha area of Cabernet Sauvignon in Margaret River in terms of (a) PCD at veraison 2002, and (b) vintage the same year. In (a), blue indicates relatively higher vigour and red indicates low vigour. The horizontal line in both figures delineates the lower and higher yielding zones, the fruit from which was selectively harvested into separate bins.*

in photosynthetically active biomass (PAB) to be identified. Remote sensing provides a surrogate estimate of PAB – in this case through the so-called 'plant cell density' index (PCD), which is calculated as the ratio of reflected infrared to red light. A large PAB (ie higher values of PCD) is a reflection of a large, healthy (ie vigorous) canopy, whereas a low PAB reflects either that the canopy is small and/or that it is under stress (low vigour). As Figure 2a indicates, this particular vineyard has a more vigorous (high PCD) northern section and a less vigorous (low PCD) southern section. Note that the rows run north-south, which means that a single row may express the full range of vigour seen in the whole block.

Two weeks prior to the expected harvest date, vines in areas of low and high PCD were assessed for canopy vigour, and samples of fruit were analysed for sugar (baumé), pH and titratable acidity (TA). Sensory assessment of the fruit by the winemaker was also carried out. The results confirmed that differences in PCD translated into real differences on the ground.

Accordingly, the block was divided into northern (high PCD/high vigour) and southern (low PCD/low vigour) zones. It was subsequently selectively harvested using a mechanical harvester fitted with a grape yield monitor and differential GPS. Two chaser bins ran alongside for the separate collection of fruit from the two zones. The yield map produced (Figure 2b) showed that whilst the average yield for the whole block was 13t/ha, the higher vigour northern zone had an average yield of 16t/ha whereas the southern zone yielded 8t/ha. The variation in yield across the block was found to resemble closely variation in PCD.

The two parcels of fruit were processed separately in the winery. After vinification, differences in wine quality between the wines from the two zones were deemed large enough to justify allocation of the wines to different end products.

Wine made from fruit harvested from the northern zone was allocated to the 'Classic Dry Red' brand (retail price approximately $19/bottle), while wine made from fruit harvested from the southern zone was allocated to a varietal Cabernet Sauvignon brand (retail price approximately $30/bottle).

If the block had been harvested as a single unit, the resulting wine would have been allocated to the lower end-use product. Based on these wine prices, the tonnage of fruit harvested from each zone, and the assumption that one tonne of fruit produces 750 litres of wine, the gross retail value of production was estimated to be increased by approximately $139,480 over the 3.3 hectares using selective, as opposed to uniform harvesting. This is equivalent to $3,653/t fruit harvested or $42,267/ha. The additional costs involved in selective harvesting were confined to the costs of running the second chaser bin/tractor. Winemaking costs associated with the two products were the same.

In 2003, this block was again split into the two zones and harvested differentially. However, instead of picking each zone on the same day, the more vigorous northern zone was harvested nine days later in order to enable the fruit to become more physiologically ripe. This strategy had the additional benefit of removing the requirement for the second chaser bin during harvest, reducing the cost of selective harvesting. While wine made from the less vigorous southern zone was again allocated to the varietal Cabernet Sauvignon brand, wine made from fruit harvested from the northern zone was allocated to a higher end product than in 2002 (a Cabernet Merlot blend with a retail value of approximately $22.50/bottle), because of the enhanced fruit ripeness.

In 2004 and 2005, the block was again selectively harvested. As in 2002, each zone was picked on the same day but fruit was separated during harvest using one tonne capacity bins mounted on a four bin trailer (4t total). Individual bins were used to separate the low and high PCD fruit by simply changing the filling position on the picking trailer. This strategy, as in 2003, removed the requirement/cost of running a second chaser bin/tractor, but still allowed selective harvesting to be carried out in a single harvest event.

Research conducted over several years in other vineyards by Richard Hamilton and I, along with colleagues from CSIRO, CRCV and Foster's has shown that patterns of spatial variation in vineyard productivity (yield, vigour) tend to be fairly stable in time – as was the case in this example. The research also strongly suggests that patterns of variation in fruit quality follow patterns of variation in yield. So, until on-the-go fruit quality sensing technologies are available, the use of remotely sensed imagery and yield monitor data appears to be an appropriate basis for delineation of zones for pre-vintage fruit quality assessment and subsequent selective harvesting.

Of course, whether inter-zone quality differences are large enough to move the resultant wines from one price point to another, as in this Margaret River example, is something that will need to be determined each year. Nevertheless, selective harvesting offers both grapegrowers and winemakers the opportunity to take advantage of variability within their production systems.

Improved natural resource management in the Clare Valley

The Clare Valley has limited supplies of good quality water; much of the groundwater is salty and annual average rainfall is only 650mm, with most falling in winter when vines are dormant. In order to secure a supply of irrigation water for the growing season, many vineyards have installed surface water dams. However, this strategy increases the risk of soil salinisation as a consequence of the raised saline water table in the vicinity of the dam. The manager of the 24 hectare vineyard in which this study was conducted wanted to know whether, and to what extent, such salinisation was impacting on vineyard performance.

An EM38 soil survey was carried out at the site in December 2000 and the following vintage the block was yield monitored (Figure 3). An elevation model of the site was also produced following survey with a real time kinematic GPS (RTK) (normally done with the EM38 survey). While the differential GPS, as used for yield mapping and EM38 survey, is accurate to about ± 50 cm in the horizontal planes, its accuracy in the vertical plane is several metres. In contrast, RTK is accurate to 2-3cm in both the horizontal and vertical planes.

Soil samples collected from positions chosen to cover the full range of variation in the EM38 signal (Figure 3a) were analysed for a range of soil properties, including electrical conductivity (EC), clay content and exchangeable cations. Note

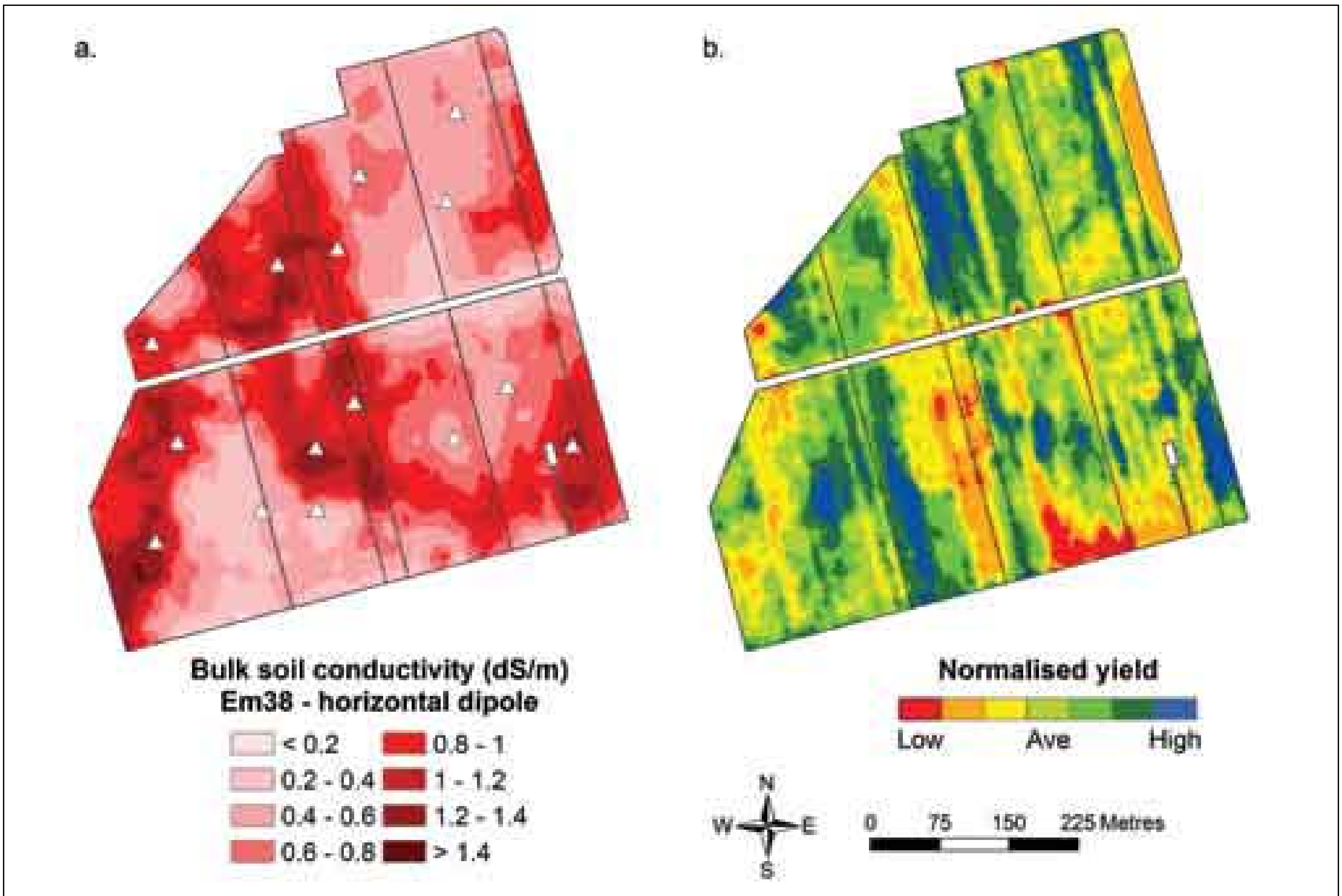

Figure 3. *Variation in (a) bulk electrical soil conductivity and (b) yield (vintage 2001) in a 24 ha vineyard in the Clare Valley, South Australia. The triangles in (a) indicate the location of soil sampling sites used for ground-truthing the EM signal. Different varieties are grown in each of the sub-blocks making up this vineyard. To account for between-variety differences in yield potential, the data were normalised (mean = 0, standard deviation = 1) on a per variety basis prior to mapping. There is a large surface water dam on the north-western side of this vineyard.*

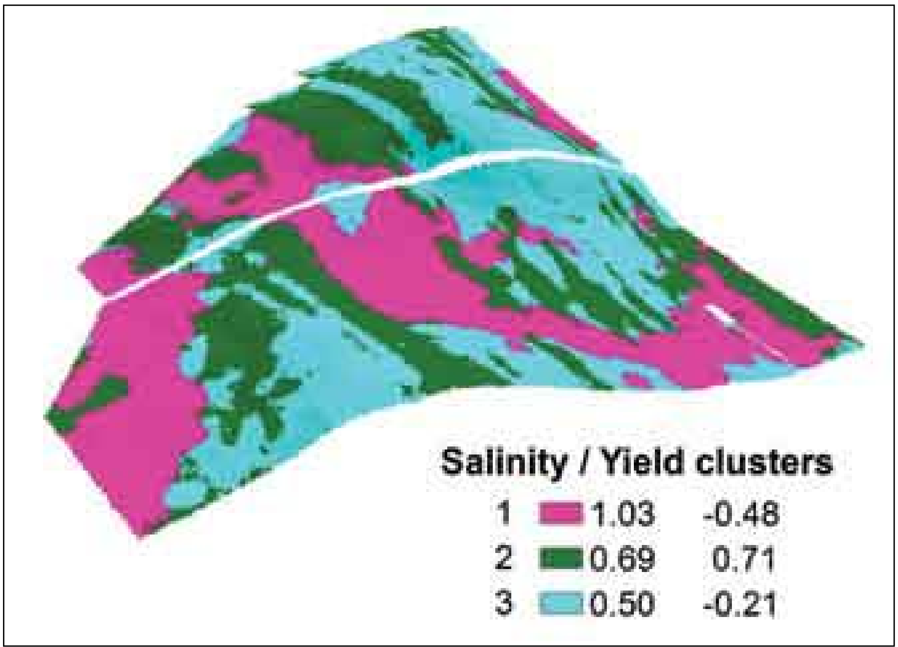

Figure 4. *Results of clustering salinity (EM38) and yield (vintage 2001) data in a 24ha Clare Valley vineyard. For each cluster, the first value in the legend represents the mean bulk electrical soil conductivity (dS/m) in the cluster, whilst the second value is the mean cluster yield. For this analysis, the yield data were normalised to account for differences in yield potential between the six varieties grown in block. The range in elevation from the lowest to highest point in the block is approximately 13m.*

that conductivity arises in soil as a consequence of the presence of salt, the type and amount of clay, and the amount of water and organic matter. Calibration of the EM38 signal (bulk electrical conductivity in the soil, against soil analytical data) demonstrated that the EM38 signal was dominated by soil salinity. Therefore, for all practical purposes, Figure 3a can be regarded a soil salinity map. This conclusion is strongly supported by the fact that when the EM38 map is draped over the digital elevation model derived from the RTK survey, the areas of highest apparent salinity occur in the lowest lying areas (Figure 4) – the expected result in a salt-affected landscape.

As Figure 3 shows, both yield and electrical conductivity varied markedly within the 24 hectare study area, with most of the apparently saline areas corresponding to areas of lower yields. This is especially apparent when the yield and EM38 data are clustered into zones using a statistical procedure known as k-means clustering (Figure 4).

- Cluster 1 is made up of areas which are characterised by both low yields and high soil conductivities (ie high salinity),
- Cluster 2 separates out above-average yielding areas characterised by moderate soil salinity,
- Cluster 3 is made up of lower yielding areas in which salinity, as measured by EM38, is not expected to be yield limiting.

The latter suggests that Cluster 3 areas may be subject to a yield limiting factor not reflected by the EM38 signal. Cluster 1 occurs mainly in the lower lying areas, especially in the western part of the block close to the dam, where the groundwater table may be expected to be closest to the soil surface.

salinity in this vineyard is reducing yield by 5-27%

Further analysis of the data underlying Figures 3 and 4 suggests that salinity in this vineyard is reducing yield by 5-27%. Accordingly, it was suggested to the vineyard manager that a re-design of the irrigation system and re-location of the surface-water dams to higher parts of the landscape may deliver substantial benefits in terms of the productivity and long term sustainability of this vineyard.

In addition to providing quantitative evidence that soil salinity has a detrimental impact on vineyard productivity, this case study demonstrates that the application of PV does not have to be confined to optimising production outcomes. These results strongly support the view that a PV approach to assessment of vineyard constraints offers a means of providing growers with knowledge of the precise location and extent of the constraints, and the basis for targeted ameliorative management.

Whole-of-vineyard experimentation in Langhorne Creek

When conducting experiments, researchers have traditionally used random location of treatments in small plot trials to overcome the effects of spatial variation. However, as the two previous examples illustrate, spatial variation in paddocks tends not to be random. So is there a better way of designing agricultural trials? Might there be an advantage in doing the experiment over the whole management unit? At CSIRO/CRCV we have been addressing this question as a part of our Precision Viticulture research. The following example is based on work carried out at Langhorne Creek, SA by Dean Lanyon. It demonstrates the management related benefits gained by using whole-of-block rather than plot designs.

The manager of this Langhorne Creek vineyard was concerned that production was being limited by poor soil conditions. On ground sampling had identified that the soil volume explored by vine roots was constrained by the combined effects of wheel track compaction in the inter-row, and in an inhospitable sodic subsoil containing toxic concentrations of boron. Since the soils at this site vary in clay content and depth to the B horizon, the response to soil amelioration treatments was expected to be variable.

A highly replicated trial design was applied across the whole 6.8 hectare Shiraz vineyard block with treatments applied in strips four mid-rows wide (ie 12m). The experimental treatments used were aimed at increasing access to stored soil moisture. They comprised of ripping the wheel tracks to a depth of 40mm, and use of a composted grape marc applied as a surface mulch at a rate of 150m3/ha. The ripping was intended to improve root penetration into the mid-row; the mulch was intended to suppress evaporation of soil water. (Figure 5).

Figure 6 shows the results obtained from this experiment in 2004. The highly replicated design coupled with the use of a yield monitor at vintage enabled construction of treatment-specific yield maps for the whole block (Figures 6a-c), even though in this case, the treatments were effectively only applied to a third of block.

On first inspection, comparison of the three treatment-specific maps (Figures 6a-c) suggests little difference between them. However, subtraction of the control map from those for ripping and mulch reveals that the response to the imposed treatments was highly variable, delivering both benefits and penalties with respect to yield in excess of 1.5t/ha (Figures 6d-e). The final map 6f indicates where the greatest benefit will be gained from applying either or both treatments.

Given the large difference between the cost of ripping ($185/ha) and applying mulch ($2,500/ha), the manager had a strong preference for ripping and a desire to only use mulch where it was likely to deliver a benefit greater than that likely from ripping.

Figures 6d-e provides the vineyard manager with a powerful basis for decision making. In particular, they allow construction of Figure 6f which shows those areas where there was both a treatment benefit with respect to the control, and where each treatment delivered a greater benefit than the other; here 'benefit' is defined in terms of a yield difference of 0.5t/ha or greater. The areas in Figure 6f where ripping is recommended are those where there was both at least a 0.5t/ha yield benefit from ripping compared to the control (Figure 6d) and at least a 0.5t/ha greater yield following ripping compared to mulch (Figure 6e).

Of course, Figure 6f may be constructed with respect to any yield benefit of the manager's choosing. This is important because the statistics of classical experiments

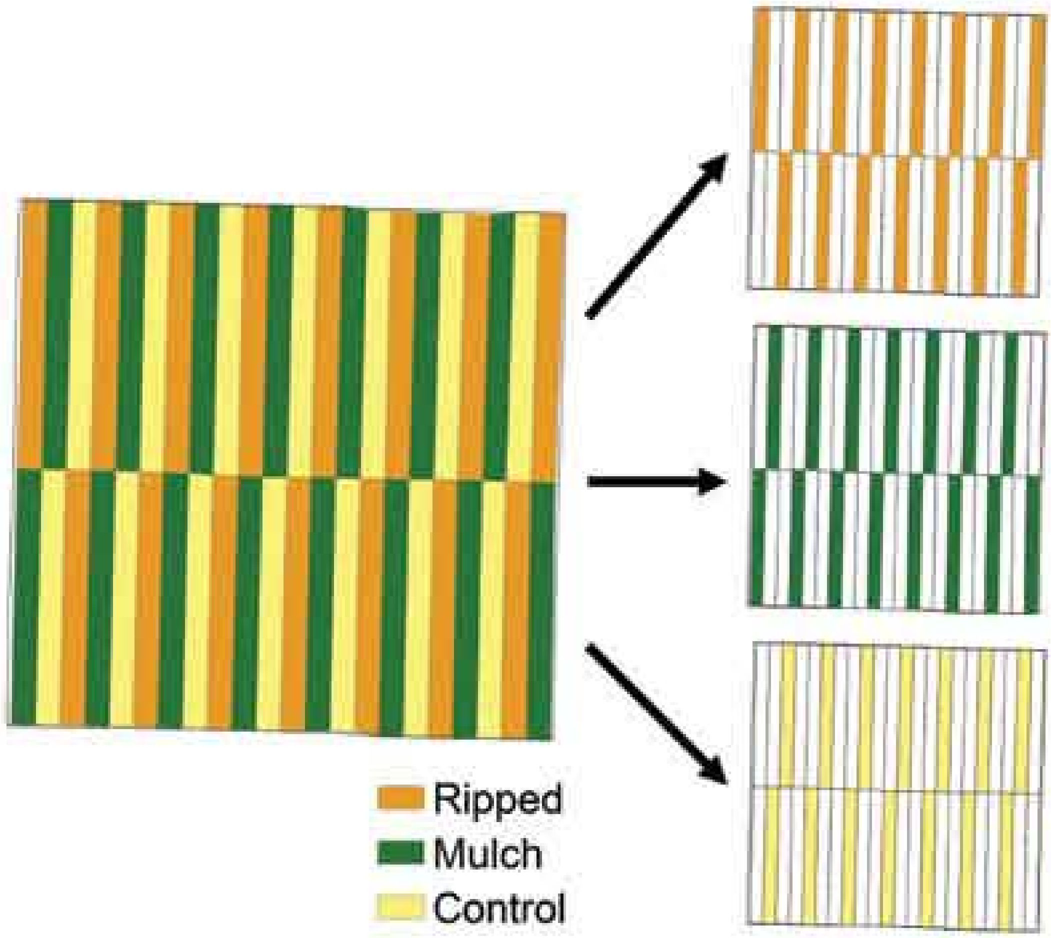

Figure 5. *Design for a whole-of-block experiment used to explore options for improved soil management in a 6.8ha Langhorne Creek vineyard. Use of such a highly replicated design, coupled with GIS-based analysis, allowed yield maps to be produced for each treatment over the whole of the block and promotes a spatially based analysis of results.*

determine whether or not a treatment delivers a benefit on the basis of the statistical significance of the difference between the treatment and the control. Whilst this is mathematically robust, I have yet to meet a vineyard manager (or any other kind of farmer) who makes their decisions on the basis of statistical significance. More typically, the decision as to whether a new practice should be adopted is made on the basis of considerations such as the magnitude of the response (eg t/ha), the benefit:cost trade-off, or whether the benefit is large enough to justify the additional effort required in doing something new, among a whole raft of other possible considerations.

Another benefit of note in this approach is that through the use of an indicator variable, in this case clay content, the results can be more robustly translated to similar areas than is possible in the case of more traditional experimental approaches.

However, arguably the most important thing to emerge from this research is the fact that the vineyard manager had no problem either with the idea of giving the whole block over to experimentation or with the pragmatics of implementing the treatments. The managers of several other blocks in which whole-of-block designs have been used for experimentation have been similarly comfortable with the idea. In other words, even in the absence of variable rate application, these managers have not seen the complex nature of the experimental design as an impediment to its implementation. Further work being done by Kerstin Panten seeks to explore improved designs for such experiments. Kerstin will be reporting on this work in a future issue of Precision Agriculture news

Acknowledgments

This work was funded by CSIRO, Vasse Felix Wines, Southcorp Wines (now Foster's Wines) and Australia's grapegrowers and winemakers, through their investment body, the Grape and Wine Research and Development Corporation. The invaluable input of colleagues at CSIRO, Vasse Felix and Foster's is gratefully acknowledged.

Note: This article is based on a paper presented at the 11th Romeo Bragato Conference, held in Gisborne, New Zealand, 25-27 August, 2005.

For more information
Dr Rob Bramley (08) 8303 8594, Rob.Bramley@csiro.au
or visit www.csiro.au/csiro/content/standard/ps1xy,,.html

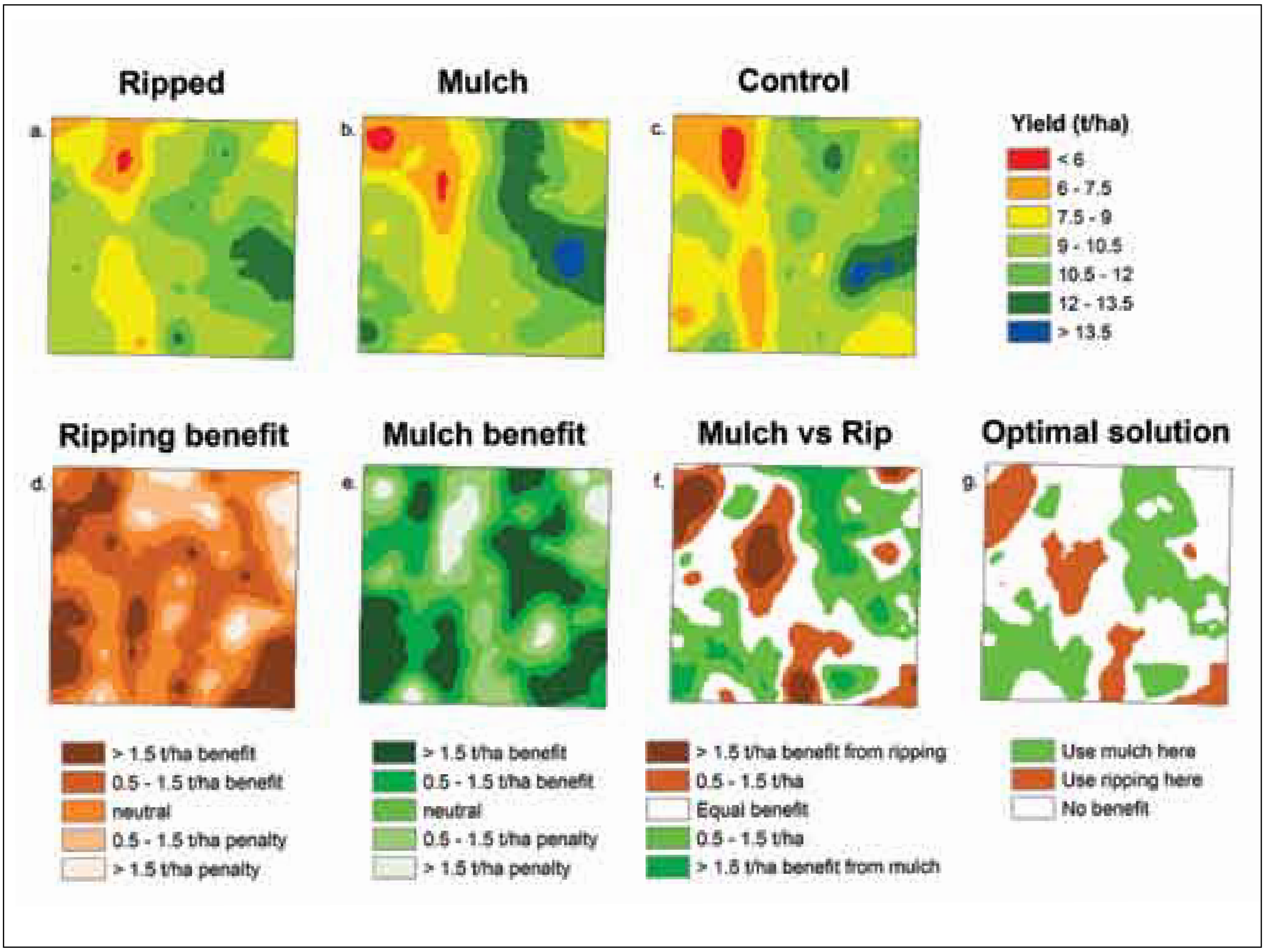

Figure 6. *Variable yield response of 6.8ha of Shiraz to two soil amelioration treatments.*