Terroir and precision viticulture: are they compatible?

Terroir et viticulture de précision : quelle compatibilité ?

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Abstract: The concept of *terroir* or *sense of place* is almost as old as the wine industry. It is generally used as an all-encompassing term to reflect the effects of the biophysical environment in which grapes and their resultant wines are produced on the character of those wines. Historically, *terroir* has generally been considered at the regional or property scale. However, the recent development of Precision Viticulture promotes acquisition of a more informed *sense of place* by providing detailed measures of vineyard productivity, soil attributes and topography at high spatial resolution. Whilst associated research into vineyard variability lends weight to the concept of *terroir* in terms of biophysical impacts on grape and wine production, it also raises questions as to the scale at which *terroir* is a useful concept. These issues are explored using examples from the Padthaway and Sunraysia grapegrowing regions of Australia.

Key words: Vineyard variability, spatial scale, Australia

Introduction

Recent research conducted in Australian vineyards has demonstrated that within a single vineyard block under conventional (ie uniform) management, yield can be expected to vary by approximately 10-fold (ie 2-20 t ha^{-1}), with this variation showing a marked spatial structure (Bramley and Hamilton, 2004). Fruit quality has also been shown to be variable; its patterns of spatial variation tend to follow those for yield (Bramley, 2005a), although not necessarily in the same rank order (Bramley and Hamilton, 2005). This work, and the associated development of Precision Viticulture (Bramley and Proffitt, 1999), strongly suggests that not only is uniform management a sub-optimal strategy, but that targeting management in recognition of underlying variability may deliver significant benefits with respect to both profitability and natural resource management (Bramley, 2005b; Bramley and Hamilton, 2005; Bramley *et al.*, 2005).

It is not unreasonable to ask whether we should be surprised by these results ? After all, the fact that land is variable, irrespective of the scale of inspection, is well understood. Thus, no two vineyards are the same, no two wine regions are the same and neither, of course, are any two wine producing countries (figure 1). One consequence of this variation is that some connoisseurs of wine are readily able to discriminate between wines of differing origin. Herein lies at least a part of the basis for the concept of *terroir* (eg Seguin, 1986) or *sense of place* (eg Goode, 2005) - the English equivalent gaining increasingly common usage - and in particular, its use as a means of establishing a point of difference in an increasingly competitive marketplace.

Of course, at the local and property scale, grapegrowers and winemakers have known that vineyards are variable for as long as they have been growing grapes and making wine. But in the absence of the tools of Precision Viticulture (PV), which now allow them to observe, quantify, precisely locate and react to the variation, they have had to treat it as « noise », and so have managed large blocks as though they were uniform. The wine industry therefore faces an interesting paradox. On the one hand, and in spite of some acknowledgment of the importance of issues of scale to *terroir* (Vaudour, 2002; Deloire *et al.*, 2005), much is made of the gross variations between vineyards and regions (eg Laville, 1990) which lead to relatively subtle differences between wines; this is especially so in so-called « Old-World » winegrowing countries such as France. On the other hand, what may be quite large variations at the local, vineyard and block scales have tended to be ignored or masked.

Work conducted in France (Tisseyre *et al.*, 2001), Spain (Arno *et al.*, 2005), Chile (Ortega and Esser, 2003) and the USA (Cortell *et al.*, 2005) suggests that vineyard variability is not a peculiarly Australian phenomenon. Indeed, the work of Taylor *et al.* (2005) suggests that there are strong similarities between the

a. b.

Figure 1 - Contrasting vineyards from (a) the Marlborough region of New Zealand and (b) the Eden Valley, Australia.

vineyards of Europe and Australia in terms of their spatial variability. This should be no surprise given that in all the aforementioned (and other) Australian examples, variation in vineyard performance has been closely related to variation in topography and/or soil properties (Bramley, 2003; Bramley and Hamilton, 2005 and references therein), a finding which raises questions as to the utility of the concept of *terroir*.

Clearly, the traditional view of *terroir* being reflective of soil and land attributes (Seguin, 1986; Laville, 1990; van Leeuwen *et al*., 2004) is appropriate; but at what scale is it appropriate ? For example, does the wine produced from the vineyard shown in figure 1a most reflect the *terroir* of this particular vineyard, or of either the region (Marlborough) or country (New Zealand) in which it is located ? If, as some purists might argue, the answer is « this particular vineyard », it is then legitimate to ask whether the wine reflects this vineyard in terms of its dominant gravely soils, the silty hollows which dissect them, or some integration of the two ?

Similarly, given that there is more than 100 m difference in elevation between the top and bottom of the slope shown in figure 1b, it is legitimate to ask in what respects wines produced from the uppermost, or lowest blocks on the slope, are reflective of the *terroir* of the Eden Valley as a whole ? Clearly, the vineyards shown in figure 1 are markedly different, but is it sensible to ignore the differences *within* them ? This latter question is the main focus of this paper and is considered using examples from the Padthaway and Sunraysia grapegrowing regions of Australia.

Materials and Methods

Two vineyards were used for this work. The first is a 4.3 ha vineyard in the Padthaway region of South Australia which was planted to Shiraz (own roots) in 1971. This site is characterised by a 1.8 m deep «hollow» (approximately 0.8 ha) in its centre, which is thought to be due to a « sink-hole » in the underlying limestone. The soils at this site are a mix of red and black sandy clay loams; the black soils predominate in the hollow, whilst the red soils, which are somewhat similar to the *terra rossa* soils of the Coonawarra region, predominate throughout the remainder of the block. The mean daily maximum and minimum January temperatures for Padthaway are 28.1 and 12.0°C, whilst the mean annual rainfall is 502 mm, most of which falls in winter when the vines are dormant. Accordingly, the vineyard is irrigated on an « as-needs » basis, typically receiving 0.4 ML irrigation ha^{-1} y^{-1} *via* a drip system.

The second vineyard is a 12 ha vineyard in the Sunraysia region of north-west Victoria which was planted to Cabernet Sauvignon in 1994. Of particular interest in this study is an 8.2 ha section which was planted on own roots; the remaining 4 ha is on a range of rootstocks and was not used for this study. Sunraysia is considered to be a warm, dry region, with mean daily maximum and minimum January temperatures of 32.0 and 16.5°C. Mean annual rainfall is only 289 mm and irrigation is therefore essential; approximately 5 ML ha^{-1} y^{-1} is applied. Soils at this site are duplex, comprising sandy topsoils of varying depths (20-70 cm) over calcareous clay subsoils.

A mix of spatial data were collected at both sites. Remotely sensed digital multispectral video imagery (Hall *et al*., 2002) was collected at veraison (Lamb *et al*., 2004) for the Padthaway site in 2001, 2005 and 2006 (figure 2) and for the Sunraysia site in 2004, 2005 and 2006 (figure 3). In both cases, the so-called « Plant Cell Density » index (PCD) was used; that is, the ratio of reflected infrared:red light which gives a surrogate measure of vine vigour (Hall *et al.*, 2002). Yield mapping was carried out at Padthaway in 1999 and 2004 (Figure 2), and in 2004 and 2005 in Sunraysia (figure 3), using mechanical harvesters fitted with a differentially corrected global positioning system (dGPS; accurate to approximately ± 50 cm in the horizontal planes) and either a HarvestMaster™ or Farmscan™ yield monitor, or a modified HarvestMaster™ system in which the sonic beam yield sensors were replaced with a weigh frame and load cells. Both sites were also surveyed with a real-time kinematic GPS (RTK; accurate to approximately ± 2 cm in both horizontal and vertical planes) from which digital elevation models were derived. Details of the methods of spatial and statistical analysis used in this work are given in Bramley and Hamilton (2004) and Bramley (2005).

Immediately prior to vintage, measurements were made of a number of vine and fruit attributes on a 1 m section of row centred on the trunks of a selected number of geo-referenced « target vines ». In Padthaway (vintage 2004, 2005 and 2006), 10 randomly-chosen target vines were identified in both the « hollow » and remainder of the block and measurements made of yield, bunch number and the mean berry weight (from which mean bunch weight and the number of berries per bunch were calculated). Baumé, juice pH, titratable acidity (TA) and the concentrations of colour and phenolics were also analysed using standard methods (Iland *et al.*, 2000). The two sets of samples were collected on the same day. In Sunraysia (vintage 2005 and 2006), a different sampling strategy was used. Here, the target vines were located in « zones » of characteristic performance (Bramley and Hamilton, 2004, 2005; Bramley 2005) identified by *k*-means clustering of the data underlying the yield maps and PCD imagery obtained in 2004 and 2005. In this way, low vigour/low yield and high vigour/high yield sites were identified in which a number of target vines were located. Twelve bunches were randomly sampled from each target vine with 6 taken from either side of the row. These were analysed in a similar way to the Padthaway samples. In addition to the vine and fruit sampling at the Sunraysia site, a 200 kg sample of fruit was harvested from within each zone and used for small-lot winemaking (50 kg ferments in triplicate) following a standardised winemaking protocol. For both the target vine and winemaking samples, sampling in the low vigour/low yield and high vigour/high yield zones was done with a view to sampling at a constant target maturity of 24 °brix (13.3 °Bé). This meant that in both 2005 and 2006, sampling of the high vigour/high yield zone took place approximately one week after sampling of the low vigour/low yield zone.

Results

Both the Padthaway and Sunraysia vineyards were spatially variable with respect to both yield and vigour (figures 2 and 3). Consistent with earlier work, which shows soil and topographic variation to be a key driver of vineyard variability (Bramley, 2003, 2005a,b; Bramley and Hamilton, 2004, 2005), the patterns of variation were closely associated with the underlying topographic variation (figure 4) and, as a consequence, were stable in time (figures 2 and 3). Thus, at Padthaway, higher yields and greater vine vigour was seen in the hollow (figures 2 and 4a), which acts as a natural drainage feature in which the black soils remain moist for longer into the season than the red soils in the remainder of the block. In addition to increased yield and vine vigour, vines in the hollow were also characterised by significantly greater bunch and berry weights compared to the rest of the block (table 1), and had less mature fruit at vintage with significantly lower concentrations of colour and phenolics. Of greatest significance however, was the winemaker's sensory assessment of the fruit immediately prior to harvest (table 1). This was such that fruit from the « hollow » was considered of sufficiently lower quality than that in the remainder of the block to warrant implementation of a selective harvesting strategy with fruit from the two zones assigned to different product streams. Bramley and Hamilton (2005) and Bramley *et al.* (2005) describe how this was done and discuss the economic implications of this strategy. Suffice to say here that it delivered significant economic benefits with respect to both grapegrowing and especially winemaking, given that in 2004 for example, the C grade fruit from the hollow could be expected to go into a product which sells for approximately \$14 bottle^{-1} whilst the wine made from the high-B grade fruit in the remainder of the block would sell for approximately \$24.50 bottle^{-1}. Had the block been harvested as a single unit, the fruit would have been assigned to a low-B grade product stream; that is, a wine with a retail value of approximately \$18 bottle^{-1}.

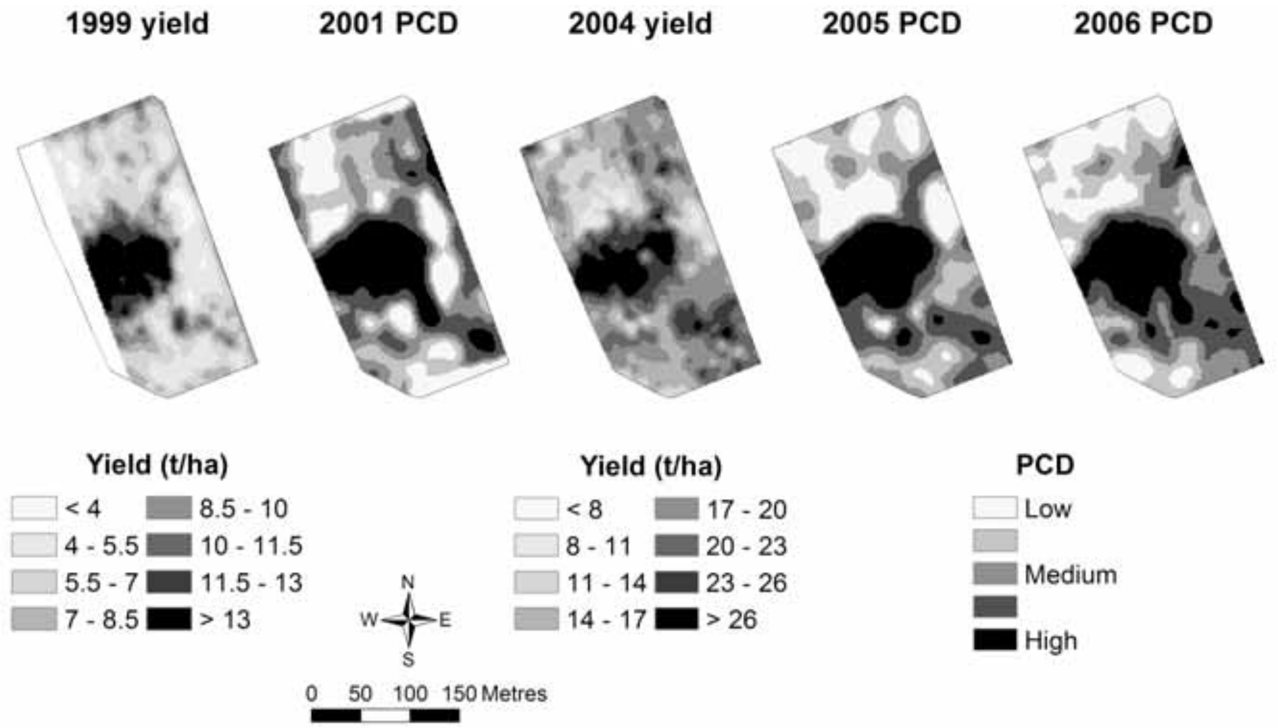

Figure 2 - Variation in a 4.3 ha Padthaway vineyard with respect to yield and vigour (PCD), 1999-2006.
In the case of the imagery, the colour ramp is stretched over the full range of PCD values in any given year. Thus, the absolute values for « low », « medium » and « high » will vary from year to year.

Table 1 - Zone-based means for selected vine and fruit properties at the Padthaway site sampled from the high yield/high vigour (H) and low yield/low vigour (L) zones shown in figure 4[A].

	2004			2005			2006		
	H	L	Sig[B]	H	L	Sig[B]	H	L	Sig[B]
Yield (kg)	12.4	8.5	**	9.5	4.3	***	6.0	4.3	*
No. Bunches	111	117	ns	109	83	*	86	80	ns
Bunch weight (g)	112.1	76.2	**	85.1	51.9	***	69.6	54.2	*
Berry weight (g)	1.30	0.90	***	1.40	1.06	***	1.18	0.99	***
Berries / bunch	86	83	ns	61	49	**	58	55	ns
Baumé	12.3	13.6	***	13.0	14.3	**	14.0	14.6	***
pH	3.93	3.33	ns	3.25	3.29	*	3.31	3.38	***
TA (g/L)	6.30	7.51	**	8.62	8.10	ns	6.86	5.77	***
Colour (mg/g)	1.13	1.82	***	1.26	1.89	***			
Phenolics (a.u/g)	0.81	1.21	***	0.99	1.35	***			
Winemaker assessment	C	high B		D	A				

[A]Data reported are the means of samples collected a few days prior to vintage from a metre of vine row centred on the trunk of target vines. Ten randomly located vines were sampled in each of the zones shown in figure 4a.
[B]Statistical significance based on Students t-test where ***, **, * and ns indicate p<0.001, p<0.01, p<0.05 and no significant difference (p>0.05).

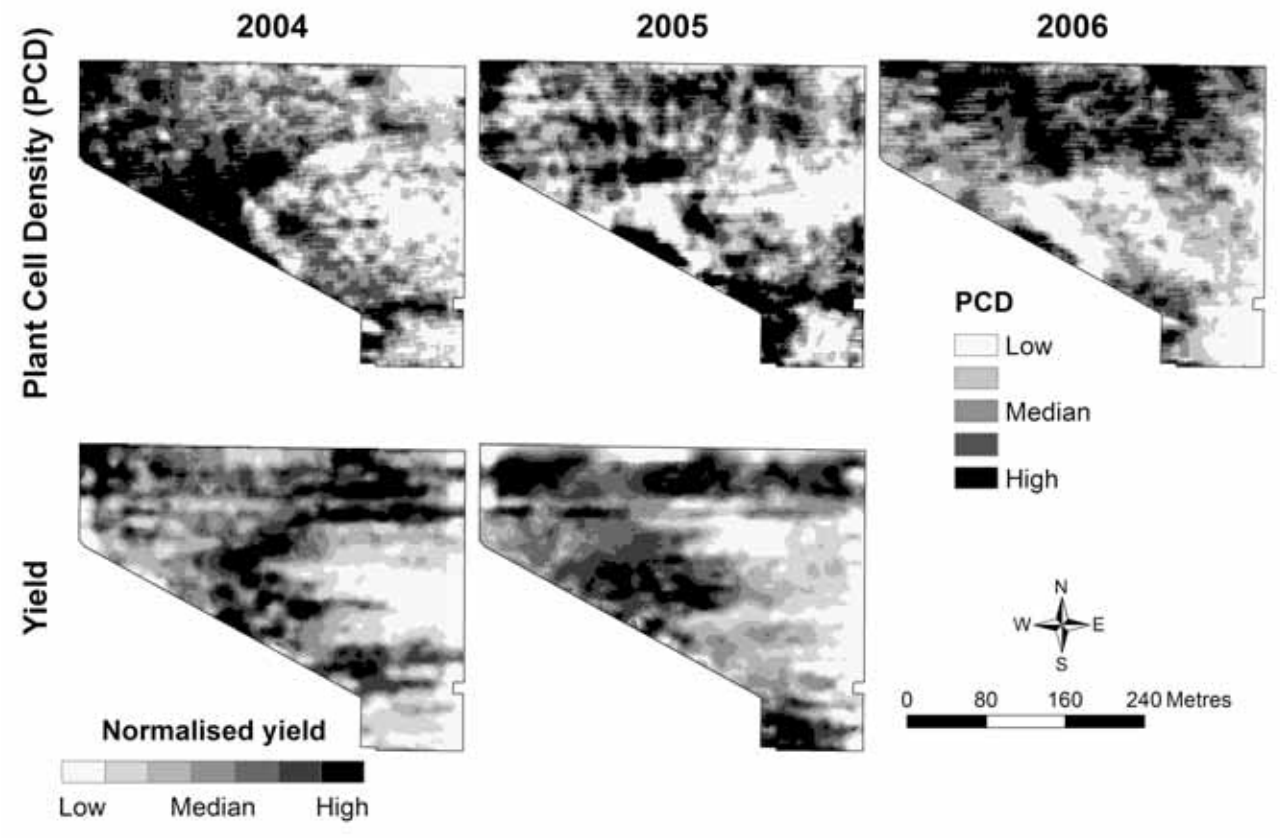

Figure 3 - Variation in an 8.2 ha Sunraysia vineyard with respect to yield and vigour (PCD), 2004-2006.
Note that the yield maps have been normalised (μ=0, σ=1) to accommodate the effects of inter-annual variation. The mean yields in 2004 and 2005 were 20.2 and 17.5 t ha^{-1}. In the case of the imagery, the colour ramp is stretched over the full range of PCD values in any given year. Thus, the median and absolute values for « low » and « high » will vary from year to year.

Table 2 -Zone-based means for selected vine, fruit and wine properties at the Sunraysia site sampled from the high yield/high vigour (H) and low yield/low vigour (L) zones shown in figure 4[A].

	2005			2006		
	H	L	Sig[B]	H	L	Sig[B]
Harvest date	Mar 7	Feb 27		Mar 2	Feb 21	
Bunch weight (g)	78.4	68.4	ns	111.7	79.7	***
Berry weight (g)	0.91	0.88	ns	1.05	1.03	ns
Berries / bunch	86	77	*	106	77	***
Baumé	13.4	13.9	**	13.6	13.6	ns
pH	3.56	3.47	*	3.54	3.53	ns
TA (g/L)	7.93	6.71	***	6.96	6.39	*
Colour (mg/g)	1.20	1.35	*	0.84	1.28	***
Phenolics (a.u/g)	1.13	1.24	*	1.05	1.40	***

[A]Data reported are the means of samples collected a few days prior to vintage from a metre of vine row centred on the trunk of target vines. Vines were sampled in each of the zones shown in Figure 4a. In 2005, the number of vines sampled was 6 (H) and 11 (L) whilst 13 vines were sampled in each zone in 2006.
[B]Statistical significance based on Students t-test where ***, **, * and ns indicate $p<0.001$, $p<0.01$, $p<0.05$ and no significant difference ($p>0.05$).

At Sunraysia (figures 3 and 4b), there were similar differences between the low and high yielding zones with respect to selected indices of vine performance and fruit quality (table 2). Furthermore, descriptive sensory analysis of the 2005 wines, conducted using a trained panel (Drs Ciarán Forde and Patrick O'Riordan, Food Science Australia – personal communication), indicates that the two zones produced markedly different wines. That from the low yielding, low vigour zone on higher ground with shallower, sandier soils was perceived to have greater colour intensity, « aroma impact », pepper, spice and tobacco flavours and a stronger after-taste or « finish » than the wine made from the high vigour zone. The latter was characterised as having a more « earthy » aroma and a much weaker after-taste.
Overall, one might summarise these results by saying that the *terroir* of both vineyards is spatially variable, and that this variability is matched by variation in the wines produced from different zones within them.

a. b.

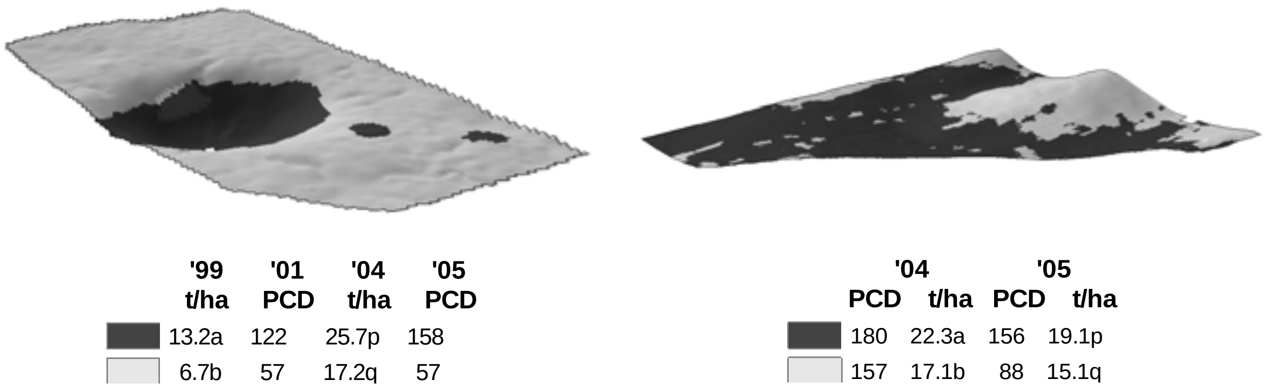

Figure 4. *Topographic variation in vineyards in (a) Padthaway (4.3 ha) and (b) Sunraysia (8.2 ha), and zones of characteristic performance identified through k-means clustering of yield maps and remotely sensed imagery. The legends indicate the mean values for yield and PCD in each zone and year. In the case of yield, numbers not connected by the same letter are significantly different (p<0.05). The range of elevation (lowest to highest point) was approximately 2.2 m in Padthaway and 4.6 m in Sunraysia.*

Discussion

Clearly, the performance of vineyards is variable whether yield, fruit quality, wine quality, wine style or value is the measure of interest. It is ironic that in « Old-World » countries where great importance is attached to *terroir*, and where considerable tradition is attached to both grapegrowing and winemaking, its impacts have, in the main, only been considered at regional scales (eg Laville, 1990), as a consequence of which, few « cause and effect » relationships between soil and land attributes and wine characteristics have been established. Indeed, the lack of importance attached to vine nutrition with respect to fruit and wine quality (Seguin, 1986) may be a direct consequence of investigating this issue at regional scale. Similarly, the pre-occupation with the effect of soil hydrological properties on wine style and quality (Seguin, 1986; van Leeuwen *et al*., 2004) may be, at least to some extent, an artefact of the prohibition of irrigation in many Old-World regions. On the other hand, « scant attention » has been paid to soil and its complex interaction with winegrapes in the « New World » (White, 2003), in spite of a more liberal approach to adoption of new technologies, such as soil moisture monitoring, and the associated opportunity for advancing understanding. Further work in this study will examine vine, fruit and wine differences with respect to specific soil properties and vine nutrient status.
As the present results indicate, the tools of Precision Viticulture enable both growers, winemakers and researchers to see that *terroir* may vary within vineyards. Indeed, vineyards producing wines that are deemed characteristic of a region, may in fact be capable of producing contrasting wines from different areas within the same management units. As White (2003) suggests, the true influence of *terroir* can only be satisfactorily studied for small areas mapped at large scale, an idea that is strongly supported by the results presented here. Furthermore, such studies, supported by the use of Precision Viticulture, may promote development of a more robust « digital terroir » function than the regionally derived « site index » of Tesic *et al*. (2002). Thus, whilst Precision Viticulture raises questions about the utility of the concept of *terroir* at regional scales, it has much to offer in promoting robust understanding of the impacts of soil and land attributes on grape and

wine production, and thus, how management practices might be modified to gain greater control over fruit and wine quality, and indeed, over at least some of the aspects of *terroir*. It may therefore also offer « Old World » producers the opportunity to refine wines from *terroir*-based classifications to more regularly meet the expectations for the region from season to season.

Acknowledgments: This work was funded by CSIRO, Foster's Wine Estates, the Wingara Wine Group, the Commonwealth Cooperative Research Centres Program under the aegis of the Cooperative Research Centre for Viticulture (CRCV) and Australia's grapegrowers and winemakers through their investment body the Grape and Wine Research and Development Corporation. Support from the latter was matched by the Federal Government. In addition to these organizations, we are most grateful to the management and staff of Foster's Wine Estates (Padthaway) and of the Wingara Wine Group (Sunraysia). In particular, the input and assistance of David Edwards and Sue Hodder (Foster's Wine Estates) and Craig Thornton (Wingara Wine Group) has been greatly appreciated, as have the contributions of Chris Day (Provisor) who made the Sunraysia wines, of Drs Ciarán Forde and Patrick O'Riordan (Food Science Australia) who conducted the sensory analysis of this wine, and of Susie Williams, Kerstin Panten, Jackie Ouzman and Rachel Hanlin who provided excellent technical assistance. The imagery used in this work was variously provided by the Phylloxera and Grape Industry Board of South Australia (Padthaway, 2001), Terrabyte Services (Padthaway, 2005) and SpecTerra Services (Padthaway, 2006; Sunraysia all years). Drs Tony Proffitt (AHA Viticulture) and Dean Lanyon (CSIRO Sustainable Ecosystems) kindly made helpful comments on an earlier draft of this paper.

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