Chapter 9: General Discussion and Future Work

More than 270 years Jethro Tull subtitled his dissertation on tillage (Horfe-Houghing Husbandry) with " A METHOD OF INTRODUCING A SORT OF VINEYARD-CULTURE INTO THE CORN-FIELDS". Today the trend is being reversed and technologies, first utilised in broadacre crops, are being "introduced" back to viticulture with some exciting prospects. The ability to measure productivity site-specifically within a field has given growers back the intimacy with their production systems that was lost with the agricultural revolution in the 1950s -1970s. It has also produced a potentially powerful new tool for implementing sustainable agricultural practices.

The potential of these emerging information technologies to revolutionise agriculture is widely acknowledged, the adoption of these technologies may be retarded, however, if i) they do not produce what is promised or ii) there is no support to interpret and act on the information. To generalise, the first point comes down to how much snake oil is being sold with the information and the second is an issue regarding how much research (and the quality of the research) that is being committed to understanding the agronomic significance of the information. Hopefully the outcomes from this thesis will contributed to improving the second situation.

The first objective of this thesis was to identify the amount of variability that is being recorded in viticultural production systems. This was primarily limited to an analysis of yield data as real-time quality sensors are not yet commercially available. The premise for site-specific management is that there is, i) a significant magnitude of variation in the target variable and ii) sufficient spatial structure to the variation to permit differential management given current limitations in machinery technology. The analysis of 75 fields from 3 vineyards containing 6 different varieties (primarily Shiraz, Cabernet, Chardonnay and Semillon) showed a large range in both the magnitude and spatial structure of the yield variation. This confirms that the opportunity for site-specific management is itself field-specific. To ensure that the maximum short-term benefit is achieve, differential management strategies should be directed at those fields that exhibit a large magnitude and a strong spatial structure to the variation.

In general the magnitude and spatial structure observed in this study was lower than that recorded in a previous study of broadacre crops. However the ability to manage smaller areas more intensively in viticulture means that some blocks would appear to suit and benefit from differential management. Further research into this area is required to understand exactly how the spatial statistics used relate to potential agronomic intervention. Currently growers are able to rank their production units (fields) however threshold values, to help producers determine if a site-specific or uniform approach is preferable, do not exist. A collaborative study between researchers in Australia, Chile and France has also been initiated to investigate if the level of variability observed in this study is consistent with other national and international grape growing regions.

For grape quality only a perfunctory investigation into the spatial variability was performed as data is currently restricted to hand-harvested surveys. The commercialisation of a quality sensor will precipitate further research into this area (and hopefully this occurs sooner than later). Different grape quality properties exhibited different spatial patterns and different ranges of autocorrelation. This is consistent with other findings. The difference in spatial variation has significant implications for site-specific management as wine quality is a factor of multiple must qualities. The management of multiple quality factors spatially will require a well designed decision support system.

The yield data was analysed with both classical statistics and spatial statistics. The classical statistics were shown to be suboptimal when applied in a spatial context. The majority of viticultural and agricultural scientists and consultants are only trained in classical statistical analysis. For site-specific management to be successful the capabilities of existing scientists and consultants need to be upgraded as well as future researchers and consultants trained in spatial data analysis. Incorrect data analysis will result in improper use of the information and result in impeded technology adoption.

The second objective was to update the current methods of vineyard soil survey with new technologies (e.g. the Geonics EM38 that is used for soil electrical conductivity mapping and RTK-GPS that is used for elevation surveys) and new methodologies (including pedotransfer functions and multivariate interpolation techniques). To bridge the gap between the current point map approach and more advanced multivariate interpolation techniques a protocol has been developed for univariate interpolation of soil properties. This allows the point data on existing maps to be displayed as continuous raster maps. Central to this approach are recent advances in pedotransfer functions that permit the conversion of qualitative soil survey data into quantitative units. However univariate interpolation is only viewed as an interim step and the ultimate goal is to utilise ancillary data (like EC_a and elevation data) in the interpolation of soil properties. Despite results to the contrary in this study, multivariate interpolation (e.g. regression kriging) has been shown to generally outperform univariate interpolation (e.g. ordinary kriging) (Odeh *et al.,* 1995, McBratney *et al.,* 2000). The statistical failure of regression kriging in this study may be due to a lack of validation points or poorly chosen validation points. Further analysis will be undertaken once the number of independent validation sites has increased to check if this was the cause of the poor performance of regression kriging. Alternatively the original soil survey data could be jack-knifed to form a validation set and the accuracy of the univariate and multivariate interpolation tested. Despite the poorer statistical performance visually the mulitvariate interpolation showed more detail and delineated soil boundaries more clearly.

Although not investigated in this thesis, there are also concerns about the continued use and preference for grid surveys by vineyard soil surveyors. Site-directed surveys have been shown to outperform grid surveys when some knowledge of soil variability is known (Pocknee, 2000). If soil EC_a and elevation surveys are performed prior to the soil survey then this data should be used to optimise the level of information gained from the soil survey. This is not to say that ancillary surveys should replace the soil survey but rather be used in conjunction with it. An ancillary survey that is not ground-truth can be misleading. The lack of ground-truthing that accompanies present soil EC_a surveys has already lead some users to distrust the data (McKenzie, 2000).

Site selection and subsequent vineyard design are perhaps the most critical points in determining the potential performance of the vineyard (Gladstones, 1992). The perennial nature of the crop and the high cost of planting precludes a rapid turn over of plants, thus errors made in the initial vineyard site selection and/or design will impact on production over several decades. The objective of interpolation (either uni- or multi-variate) is to produce data layers, on a common raster, that can be not only easily visualise but also modelled. Chapter 7 was an attempt to put these data layers to use to predict digital terroir at a sub-vineyard level. Predictions of digital terroir using multivariate clustering, a common approach in broadacre cropping, were not particularly successful when compared to yield and canopy response. A lot of research has been directed at methods for zoning data for precision agriculture without really producing anything useful. Algorithms for zoning are available however statistics for determining the optimum number of zones/classes, or significant differences between zones/classes are still lacking. The MPE/FPI approach has been used previously however results from this study using this approach were not encouraging.

While the clustering approach was not successful the proposed "local site index" did show promise when compared to plant response. Adapted from a regional model this provides a single layer that incorporates a variety of climatic and soil factors which influence vine production. Condensing the information into a single layer makes the interpretation easier however all available layers should be examined to ensure that there are no anomalies that need to be accounted for in the vineyard design.

The goal of vineyard design should be to minimise variability within individual production systems. If variation can be minimised by planting smartly, without compromising the efficiency of vineyard operations, then less effort is required for ongoing differential management. When average must properties are the same for different grape sources then wine from areas of low grape variability have been shown to produce superior wines (Sinton *et al.,* 1978). The key question that has yet to be addressed is for what production variables (e.g. yield, must pH, sugar content etc.) should we be trying to minimise the variation. It is likely that the variable of interest will differ between varieties, between regions and on the end use of the grapes.

The final vineyard design is very much an "expert" orientated system with the layout determined using knowledge gained from past experience and current surveys. The data resulting from the proposed mapping protocols and the derived LSI should help "experts" to better design vineyards to minimise within block variability. The advantage to these data is the ability to define areas of similar "digital terroir". How the grapevine will respond the digital terroir and how it should be managed are agronomic issues that require either expert analysis or decision support tools (which are currently nonexistent).

The issue of decision support tools is the reason behind the final objective and research chapter. Without tools to act on the information the data are just digits or pretty images (and expensive ones) In general the limiting factor to the adoption of precision agriculture is not the quality of the data or the ability of machinery but the knowledge to interpret the information. In all cropping enterprises a bottleneck is forming at the decision support nexus of the PA cycle. Viticulture has an opportunity to learn from the current experiences in broadacre cropping and implement DSS research sooner rather than later. The recent amalgamation of AusVIT, a whole vineyard decision support system, with PAM, a PA orientated software package, is a good first step. It is essential that the industry continues to take these steps. The ability to merge data layers, to produce an output to which a management response can be gear to, should be a major objective of future work.

Chapter 8 has presented a framework for merging a variety of field-tested grape must quality parameters. It recognises that wine quality is a function of multiple must characteristics that need to be examined holistically not individually. Soft-computing techniques offer a way of merging different data layers, including expert knowledge, into a decision support system. The individual grape quality characteristics have been converted into a "total" grape quality value using a fuzzy logic model. This has produced a map of where bulk, commercial and semi-premium wine quality grapes may be found in the vineyard. The "total" quality map showed more spatial continuity than the individual quality characteristics and a good opportunity for differential harvesting. However this research was performed retrospectively post-harvest and a selective harvest and micro-vinification was not performed to validate the model. The research was done initially to demonstrate the potential of soft computing techniques and the need for DSSs. Research into this area is very minimal in agriculture in general but is urgently needed. However the model now exists and it is hoped that a collaborator will be found who is willing to trial the model on a selective harvest. The opportunity also exists to expand the model to include other quality characteristics e.g. colour, anthocyanin content etc., as these characteristics become more easily measured. The current model was developed for Shiraz grapes in the Hunter Valley. For other varieties and regions it is likely that the model will need to be adjusted to account for varietal and regional differences in plant productivity. There is also no reason why the model cannot be adapted to a real-time situation rather than a post-harvest model.

The model presented in Chapter 8 provides a continuous prediction of "total" winegrape quality. Fuzzy models however offer more flexibiliy in the model output. By extracting the level of membership of each sample to the 5 potential outputs before defuzzification, then a measure of the "certainty" of prediction can be made. Unfortunately the software used to model the fuzzy inference system does not allow these memberships to be extracted thus this "certainty" map has not been produced here. A "certainty" map would provide some extra information to the grower/winemaker in delineating grape quality and is an area where further research can be undertaken.

The development and commercialisation of a grape quality sensor is the next major technological step that is required for precision viticulture. In general the opportunity for product development and sales will drive sensor technology. The most commonly used sensor technology used in viticulture is the multi-spectral digital camera (either satellite or plane mounted). With the research emphasis placed on this technology it is disconcerting to see the lack of support for the interpretation of the data in the general community.

Although not discussed in this thesis future research in Precision Viticulture should also incorporate on-farm (vineyard) experimentation and product auditing/tracking. Every vineyard is different. To be serious about site-specific management the production system needs to be understood on a per vineyard or block basis. The collection of this information can only occur through on-vineyard experimentation. To do this growers need protocols for experimental design and analysis that will allow them to quantify the variability in their production and to determine the crop response to a target variable(s) without impacting on the profitability of the production system. A variety of on-farm experiments have been designed and analysed from strip plots to checker boards to "egg carton" to zonal designs (Pringle, 2002). Viticultural can take advantage of these previous studies and use them as a stepping stone to expedite the adoption of on-vineyard experimentation. It is promising to see the recent appointment of a Post-doctoral position with the CRC for viticulture (CRCV) to examine this issue.

The current success of Australian Viticulture is built on export markets. It is imperative that the industry protects these markets to ensure that there is a not a major "boom and bust" cycle in viticulture. Apart from maintaining quality and value for money the opportunity exists to value-add to the wine by on-selling information with the wine. Precision agriculture technologies provide a means to measure and thus audit inputs into the production system. Product tracking technologies also exist to ensure the integrity of the product as it travels along the supply chain. Consumers, particularly European consumers, are increasingly beginning to demonstrate their environmental concerns through their spending dollar. If the industry can demonstrate that wine production is "clean and green" and product integrity then it will gain a considerable market advantage. The current strongly vertically integrated structure of the wine industry should promote these technologies however research is still needed to determine how to use the technologies most effectively and how to distribute the data for maximum gain.

In the time it has taken to produce this document precision viticulture has gone from humble beginnings with a few prototype yield sensors and research contracted aerial images to becoming a commercial reality and a multi-million dollar industry. The continued funding and support for precision viticulture projects indicates that the industry is also committed to this "new revolution". Hopefully, as scientists, we can provide the protocols and decision support necessary to ensure that in future years precision viticulture becomes general viticultural practice.

9.1 References

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