Chapter 1: General Introduction to Precision Viticulture

1.1 Introduction

This introductory chapter is not intended to be an in depth analysis of the philosophy and applications of Precision Agriculture (PA). Rather it is a brief introduction to the ideas and approaches being used in precision agriculture and how they apply to viticulture or precision viticulture. For more detailed descriptions of the PA philosophy and its application and implementation in modern agriculture the reader is directed to the conference proceedings of the International and European conferences on Precision Agriculture that have been staged over the past decade.

Precision Agriculture (PA) is no longer a new term in global agriculture. It has been the subject for numerous International and European conferences for the past decade as well as Australian symposia for the past 8 years. Its acceptance in the United States of America has been formally recognised by the passing of a bill on PA by the US Congress in 1997. Unfortunately other governments, including Australia, have been more backward in coming forward.

Many definitions of PA exist. Currently the best definition, in my opinion, is that proposed by the US Congress that PA is "an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment". The key to this definition is that it recognises that PA is a management strategy that utilises information technology and the aim of management is to improve production and minimise environmental impact. It also refers to the entire farming system which in modern agriculture includes the supply chain from the farm gate to the consumer. This definition also distinguishes between agriculture and agronomy. Whilst the PA philosophy has been expounded primarily in cropping industries it is important to remember that precision agriculture can relate to any farming system. Site-specific crop management (SSCM) as defined by Robert (1999) is only part of the PA spectrum. Agriculture is much broader, incorporating animal industries, fisheries and forestry. In many of these cases PA techniques are being implemented without being identified as such, for example the tailoring of feed requirements to individual milkers depending on the stage of their lactation in dairy enterprises.

Simplified, PA is the application of new information technologies together with production experience to site-specifically:

i) maximise production efficiency
ii) maximise quality
iii) minimise environmental impact
iv) minimise risk

This is not a particularly new concept in agriculture, being expounded as early as 1731 by Jethro Tull (Figure 1.1). What is new is the scale at which we are able to implement these aims. Prior to the

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industrial revolution, agriculture was generally conducted on small fields with farmers often having detailed knowledge of their production system without actually quantifying the variability. The movement towards mechanical agriculture and the profit margin squeeze due to economies of scale has resulted in the latter half of the 20th century being dominated by large-scale uniform "average" agricultural practices. The advance of technology, especially georeferencing systems, in the late 20th and early 21st centuries, has allowed agriculture to move back towards site-specific agriculture whilst maintaining large-scale operations compatible with economies of scale.

Like many new concepts, PA is dogged by misconceptions. Firstly PA is often confused with yield mapping. Yield mapping is a tool used in PA and is generally the first step towards implementing a PA management strategy. PA involves the use of any emerging information technology not just yield sensors. Secondly PA is sometimes misinterpreted as sustainable agriculture. PA is a tool to help make agriculture more sustainable however it is not the total answer. PA aims at maximum production efficiency with minimum environmental impact. Initially it was this potential for improved productivity (and profitability) that drove the development of PA. In recent years the potential for this technology as a tool for the environmental auditing of production systems has become more prominent. However environmental auditing is not environmental management. The large amount of fine-scale data being collected in a PA system should be beneficial for on-farm risk assessment. This information needs to be incorporated into sensible sustainable practises and a whole farm plan if farm production is to remain viable in the long term.

Also central to the PA philosophy are the concepts of Total Quality Management (TQM) and Vertical Integration (VI) in the agricultural sector (Bishop, 1998). Traditionally farmers lost contact with their produce once it left the farm. Now with traceability of products, farmers are able to follow the movement of their produce into the market place (Praat *et al.,* 2003). Nowadays a farmer is concerned not only with quality at the farm gate but also the quality at the point of sale and how his product meets consumer demands. This will bring premiums and also will probably be used for environmental auditing.

1.2 Variability and the Production System

PA, and of course Precision Viticulture (PV), is dependent on the existence of variability in either or both product quantity and quality. This variability may be both spatial and/or temporal. Most production variables fall into one of two categories - either temporally stable but spatially variable or both temporally and spatially unstable. The first can be referred to as seasonally stable properties and include soil physical properties. The second are seasonally variable and include soil moisture and pest/disease/weed infestations (Moran *et al.,* 1997). Some variables may also be temporally variable but have a stable spatial pattern, for example climatic variables such as incident radiation or temperature. If spatial variability does not exist then a uniform management system is both the cheapest and most effective management strategy and PA is redundant. In cropping situations the magnitude of temporal variability appears much greater than that of spatial. Given this large temporal variability, relative to the spatial variation, there is a need to determine if uniform or differential management is the optimal risk aversion strategy (McBratney and Whelan, 1999).

Broadly speaking "variability of production and quality = PA opportunity". Having said this the nature of the variation is also important. For example the magnitude of the variability may be too small to be economically feasible to manage or variability may be highly randomised across the production system making it impossible to manage spatially with current technology (Pringle *et al.,* 2003). The implementation of PA is limited by the ability of currently available variable rate technology (VRT - machinery/technology that allows for differential management of a production system) to cope with highly variable sites and the economic inability of sites with a low magnitude of variability to increase profitability enough to offset the cost of PA adoption. It is important to note that these costs are considered mainly from a short-term economic perspective. If we were able to express environmental costs in a fiscal sense even areas with a small magnitude of variation in production may be viable for PA management. Variability may also be due to a constraint that is not manageable such as localized storms in large wheat paddocks.

Due to these constraints PA is at present operating on a zonal rather than a completely site-specific basis (Figure 1.2). As VRT improves, the capital cost PA technology decreases and the true environmental value is calculated, the minimum size of management zones and the minimum magnitude of variation needed to effectively implement PA will decrease till eventually a truly site-specific management regime is possible.

1.3 Why Precision Viticulture?

In Australia several aspects of the vititculture industry lend themselves to the adoption of PA technology. Viticulture is intensive, highly mechanized, has high value-adding potential and is dominated by large companies. Thus the incentive, ability and capital is available. Viticulture is one of the first horticultural crops in Australia to which PA methodologies have been applied. While many of the lessons learnt from broadacre cropping can be utilised, Precision Viticulture also offers new challenges.

Viticultural systems, and horticultural systems in general have fixed perennial plants. Thus there is a long-term scale involved compared to the annual nature of broadacre cropping. Vines are cloned eliminating intra-varietal differences. This puts the emphasis on variability on the site-specific clone-environment-management interaction. Viticultural system is more intensively managed allowing for more detailed ground-truthing and data collection. Management decisions are also capable of having a much larger impact on yield in viticulture, for example pruning and training strategies affect yield (Morris *et al.,* 1985). A large proportion of Australian vineyards are irrigated, minimising the impact of rainfall, or lack of rainfall, on crop production in Australia. Minimising this influence provides the grower with greater control on the yield and quality of production.

Finally the most compelling argument for the adoption of PV is the variability that has been shown in vegetative, yield and quality mapping over the past few years (Bramley, 2001, Ortega *et al.,* 2003, Hall *et al.,* 2002) (Figure 1.3). Since variability exists in quantity and quality there is an opportunity for site-specific management to improve the efficacy and profitability of production.

The objectives of precision viticulture will differ depending on the market for the wine. In Australia there is an enormous potential for PV in vineyards aimed at producing temporally similar "brand" wines. Likewise, in France, areas of *vin de pays* wines will benefit from better characterisation of the production environment for a more consistent vintage. However for appellation or premium quality wines where production practices are heavily regulated, the emphasis may be on environmental au-

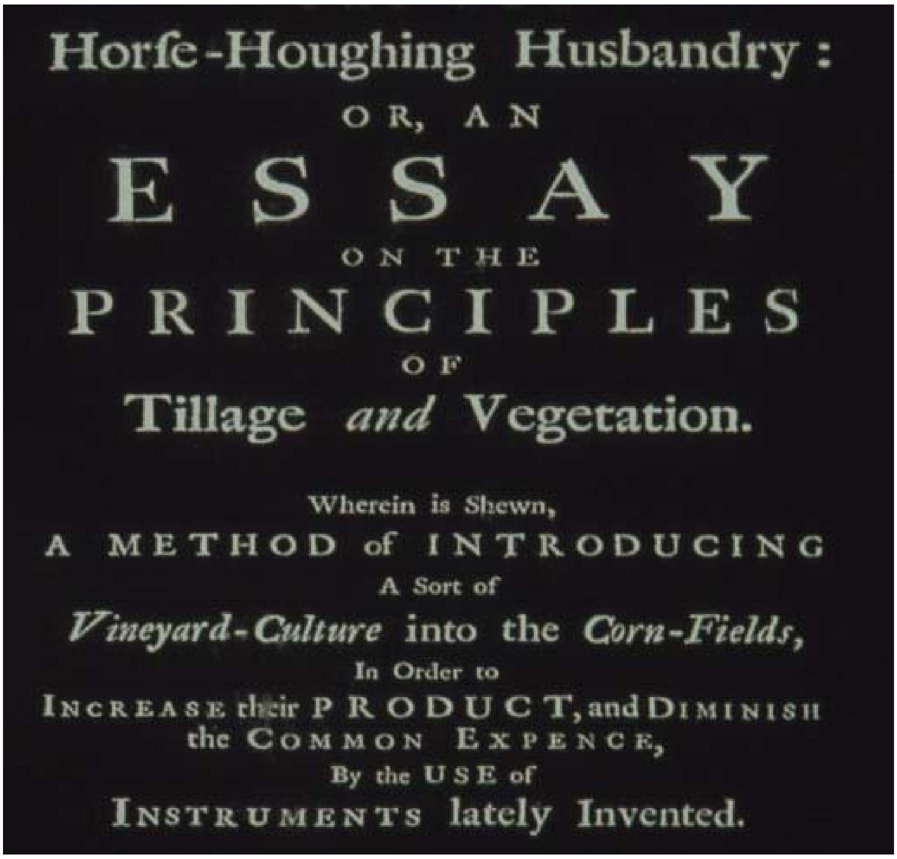
Horfe-Houghing Husbandry:
OR, AN
ESSAY
ON THE
PRINCIPLES
OF
Tillage and Vegetation.
Wherein is Shewn,
A METHOD of INTRODUCING
A Sort of
Vineyard-Culture into the Corn-Fields,
In Order to
INCREASE their PRODUCT, and DIMINISH
the COMMON EXPENCE,
By the USE of
INSTRUMENTS lately Invented.

Figure 1.1: Title page of Jethro Tulls 1731 essay on tillage and vegetation advocating the benefits of a more site-specific approach using new technologies (courtesy of Prof. A McBratney, The University of Sydney).

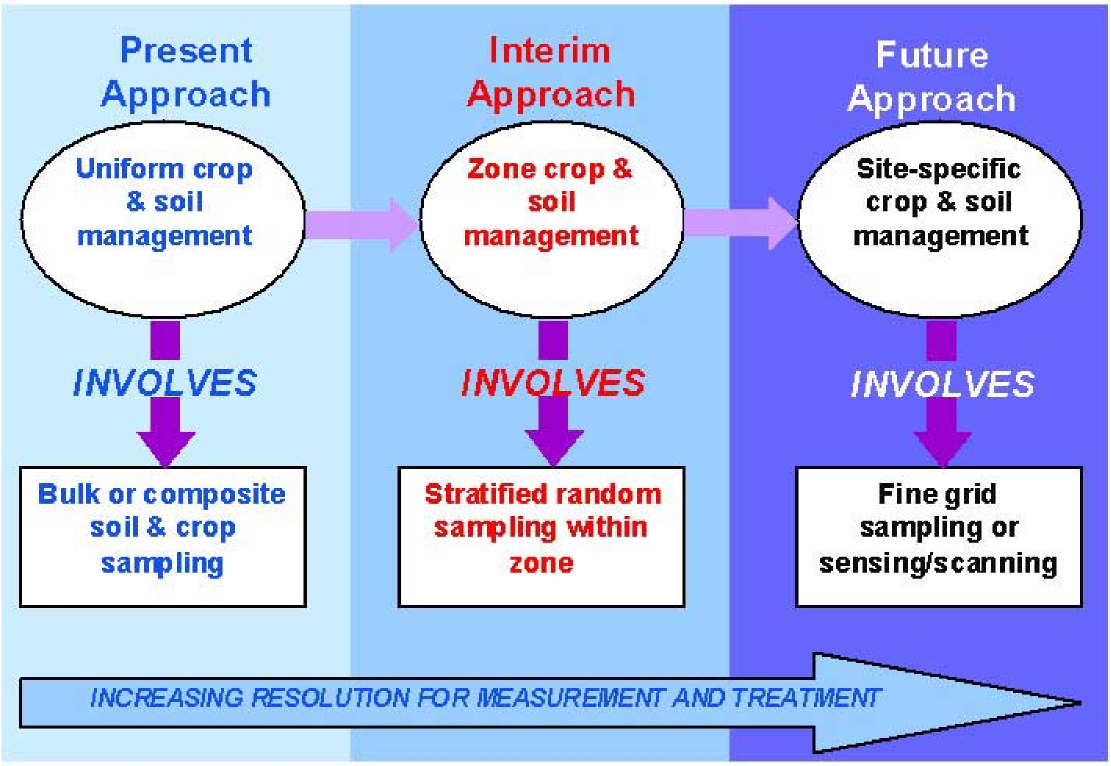

Figure 1.2: The evolving timeline of precision agriculture from a uniform to a totally site-specific approach (courtesy of the Australian Centre for Precision Agricultue www.usyd.edu.au/su/agric/acpa).

diting and product tracking to prove the environmentally friendly nature or authenticity of the wine to ensure a premium price. Selective harvesting may also be utilised to optimise quality (Bramley *et al.*, 2003).

1.4 Making PV work

At the start of this introduction four main objectives of PA were listed, and before we proceed any further it is pertinent to relate these to PV.

1.4.1 Maximising Yield and Quality

In viticulture quality is perhaps a more important parameter than yield in determining the value of the crop. There is generally considered to be a trade off between yield and quality in viticulture (Johnston and Robinson, 2001). As noted above a viticulturist is able to exercise considerable control over the yield and quality of the crop. Heavy pruning and applying water stress can decrease yield but increase quality. However studies (Sinton *et al.,* 1978) have shown that this trade off is not always necessary and both good quality and good yield can be achieved simultaneously. The aim of PV must be to maximise both yield and quality without compromising the other.

In general the aim of SSCM is to differentially maximise return across a field not, as is sometimes construed, to produce a uniform crop. Variability is not a bad thing if we can manage it. If the variability can be identified then differential harvesting is possible to maximise quality and quantity at each site or within each “zone”. The production of a uniform production level is often very difficult and counter intuitive as the production will be restricted to the level of the worst part of the production system. In viticulture the ideal of a uniform crop is very appealing as variability in grape quality can degrade overall quality. In vertically integrated industries Kilmer *et al.* (2001) demonstrate that decreased variability in input quality (grapes) can increase expected output. Given this differential harvesting would appear to have a strong chance of succeeding in viticulture and preliminary studies have already shown that there are benefits. (Johnson *et al.,* 1998, Tisseyre *et al.,* 2001, Bramley *et al.,* 2003)

The first and potentially the biggest step in managing yield and quality and understanding the vine-environment interaction is the initial placement of vines. The long-term nature of a vineyard results in this becoming crucial for future management decisions. If vines can initially be planted in zones of similar environment or “digital terroir” it may reduce the need to differentially manage them later, that is by differentially planting we can uniformly manage. This is much more economical than the reverse of uniformly planting and differentially managing. Unfortunately the latter is the more common situation facing existing growers entering into PV today. The benefit of planting varieties to soil type has already been recognised by the industry with soil surveys standard with new plantings. These surveys (usually on 75m grids) may not be detailed enough to provide the accuracy required for PA (Booker, 1997). Existing PV work (Bramley 2001, Johnson *et al.,* 1998, Hall *et al.,* 2002) shows variation at scales finer than this. The use of remotely and proximally sensed data may provide better information for more precise plantings and irrigation layout in the future.

Over the past few decades there has been an increase in consumer awareness of quality and government legislation on quality assurance. This has forced farmers to produce within defined accreditation standards and at a consistent quality. To help regulate this on a global scale the International Organisation for Standardization (ISO) has developed a set of quality management standards, ISO 9000, for a wide variety of industries. (These are not product standards but management standards and are often incorporated into national standards). ISO 9000 has been developed to meet customer quality requirements thus an accredited company is tailoring the quality of their product/service to the customer and gaining an advantage over their competition. In terms of quality product standards many wineries are now using HACCP (Hazard Analysis Critical Control Points) which became mandatory for all processed food businesses, including wineries, in 2000. Currently HACCP is not applied to a vineyard situation (Small, 1999).

1.4.2 Minimising Environmental Impact

Vineyards have two main environmental impact concerns - irrigation and the use of chemicals. Irrigation salinisation is currently one of the biggest concerns in Australian agriculture (Haw *et al.,* 2000) and as a major user of irrigation water viticultural industries need to be aware of the potential dangers of over irrigation. A general movement to drip rather than broadcast sprays will help but there is a need to continuously monitor water table levels and adjust management accordingly. There may also be an opportunity for vineyards to employ differential watering regime to further maximise the irrigation efficiency and minimise loss to ground water.

Vineyards have a heavy reliance on chemicals, using upwards of 10 sprays a season to combat disease, weed and insect pressure on the grapes. The potential impact of chemicals on human and environmental health from spray drift and ground/water contamination has raised concern amongst consumers and a preference among a majority of consumers for more “organic” solutions (Anderson *et al.,* 1996) even at the expense of “picture perfect” foods (Lynch, 1991). Most of this preference has been directed towards whole fruits rather than highly processed goods such as wine. This is now changing with consumers in the UK strongly advocating for “clean green” foods and foodstuffs (Reedman, 2001). A better understanding of the spatial distribution of pests/disease incidence and severity and identification of areas most prone to outbreak may allow for a differential application of chemical that is more cost effective and less environmentally damaging (Mochado *et al.,* 2002)

Generic ISO 14000 standards have been developed for environmental management however the adoption and adaptation of these standards to agriculture is very limited. For example Denmark has some 50 accredited farms (Langkilde, 1999) while in 1999 there was only one accredited cotton farm worldwide, which is in Australia. The Australian viticulture industry is currently developing an Environmental Management Systems protocol to incorporate industry codes of practice, such as ISO 14000, industry Best Management Practices (BMP) and benchmarking tools like total quality management (TQM) (Baker and Boland, 2001). By being pro-active in developing and adopting such standards, opportunities exist for increasing profits through product differentiation based on environmental or health qualities. However to achieve this level of integrated management a higher level of information on both the production and environment systems is required (Greiger and Armstrong, 2001). PV technologies are capable of generating this information.

1.4.3 Minimising Risk

Risk management is a common practice today for most farmers and is considered from two points of view - income and environmental. Moreddu (2000) identifies the main forms of income risk minimisation available to farmers as;

i) Diversification of income - both on- and off-farm to achieve a more even cash flow
ii) Pooling of risk - either as an individual through insurance or as part of a collective via co-operatives and marketing boards
iii) Forward selling - either on futures markets or through contract to minimise price variability
iv) Transferral of risk along the food chains through vertical integration and
v) Use of Government programmes such as subsidies

The more that is known about a production system the faster a producer can adapt to changes in market forces and his own production. For example accurate mid season yield predictions will give a grower more room to move with forward selling options. With improved communication and information transfer, farmers in the future will hopefully have more data, on both their production and market movement, and a better chance of optimising the use of economic risk management options.

In a production system farmers practice risk management by erring on the side of extra inputs (income risk is seen as greater than environmental risk) (Harris, 1997). Thus a farmer may put an extra spray on, add extra fertilizer, buy more machinery or hire extra labour to ensure that the produce is produced/harvested/sold on time thereby guaranteeing a return. This is contrary to the concept of PA. PA needs to provide a better management system, to aid in risk management, to substitute for these extra physical inputs (Harris, 1997). This better management strategy will come about through a better understanding of the environment-crop interaction and a more detailed use of emerging and existing information technologies, such as overseas crop reports, short and long term weather predictions and agroeconomic modelling.

1.5 The PA cycle

PV in Australia has barely learnt to crawl yet alone walk. At such an early stage it is important that the concept of PA is not misunderstood as it has been in other industries. PV is not a case of "whacking" a yield monitor onto a harvester and taking off at 100 miles an hour. To make PV work all areas of the PA wheel model (Figure 1.4) need to be addressed. Currently most of the research is directed at data acquisition, environmental monitoring and attribute mapping to quantify variability in the system to determine if PA is applicable. If viticulture is to avoid the current bottleneck in Decision Support Systems (DSS) being experienced by the grains industry there is a need to formulate a PV approach that encompasses all aspects of the PA wheel model. The general background into the present state of research and development for each section on the PA wheel model is discussed briefly below. A more detailed review of certain aspects is provided in subsequent chapters.

1.5.1 Georeferencing

Differential Global Positioning Systems (DGPS) are now common place on many farms and the technology is appropriate for use in viticulture. Horizontal accuracy is usually sub-metre allowing differentiation of rows. As vineyard rows are fixed and known, algorithms can be applied to "straighten" any errors. One aspect that does need further refinement however is the accuracy of

DGPS in the z (or elevation) plane. At a 95% confidence interval DGPS-corrected positioning accuracy is of the order of 4-6m in the vertical component (Rizos, 2001). The use of Digital Elevation Models (DEM) in farm situations is increasing and so is the value of this z information. In vineyards (or farms) with little relief, errors of up to ±6m are too great to map elevation with enough precision. Combining multiple surveys can improve the prediction (Bishop 2003) however the use of Differential carrier-phase receivers is currently the most accurate way of mapping elevation on-the-go. Such systems provide accuracy in the decimetre range in the x, y and z dimensions but at a much greater cost (Rizos, 2001). The degree of precision afforded by the Differential carrier-phase systems is greater than that needed for farm management thus it is generally cheaper to contract elevation surveys especially for small areas. The wide base of potential GPS application has resulted in the majority of research being driven by corporate ventures. It is hard to imagine GPS technology doing anything except become more precise and cost effective in the future.

1.5.2 Crop, Soil and Climate Monitoring

Many sensors and monitors already exist for *in-situ* and on-the-go measurement for a variety of crop, soil and climatic variables. The challenge for PA and PV is to adapt *in-situ* sensors and develop new on-the-go sensors. While the commercial potential of these sensors will mean that private industry will be keen to take up the engineering aspects of research and development, research bodies have an important role to play in the development of the science behind the sensors. Market concerns often lead private industry to sell sensors prematurely to ensure market share. This may lead to substandard sensors and a failure to adequately realize the potential of the sensor. Scientists also need to determine what and how multiple crop and production indicators can be measured. For example a NIR Brix^{o} (sugar) sensor is currently being developed for commercial release. However NIR may also be used to measure other important must characteristics such as terpenes, or further characterise sugar content into sugar types. It is also important to utilize other sensors, for example ion-selective field effect transistors, to simultaneously measure other must characteristics such as pH and K. The use of multiple sensors also creates new problems in the area of data fusion and decision making, an area which has received little research in agriculture. The opportunities for information technology in viticulture will be explored in more depth in Chapter 3.

1.5.3 Attribute Mapping

For several decades geostatisticians and pedometricians have been researching ways of describing and representing spatial data that accurately interprets the raw data. Historically most of this has been done with low density point data. While PA and PV can utilize this previous work it offers new problems. Yield data is often mixed within the harvester and needs to be post-processed (deconvoluted) before it can be used. PA also produces large dense data sets that are producing new challenges for interpretation and mapping. One of the largest problems is the determination of initial and future sampling schemes to ensure that the variability of the system is properly characterised. These challenges have seen many geostatisticians and pedometricians move into the area of PA. PV can benefit from the work already done however differences in the production system between viticultural and broadacre crops means some research will be needed to adapt and expand these methods.

The other challenge is to bring together data from different sources and present it on a common platform. The development of Geographical Information Systems (GIS) is allowing this to occur

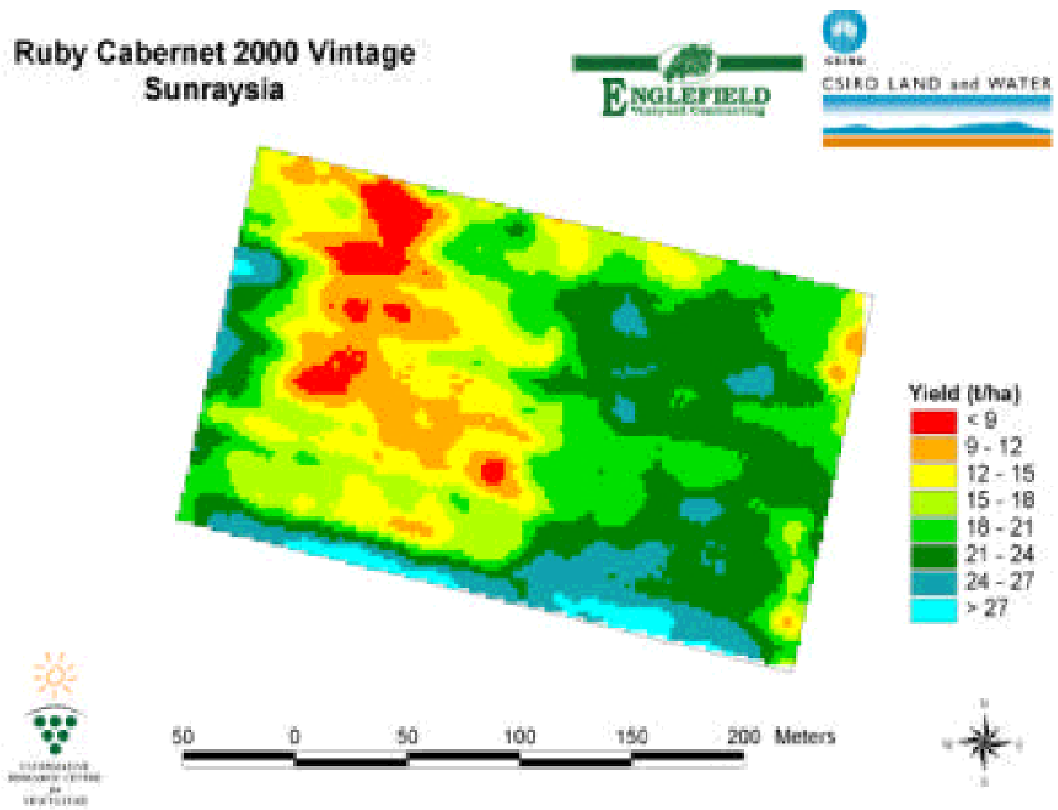

Figure 1.3: An example of yield variability in winegrapes (reproduced from Lamb, 2000).

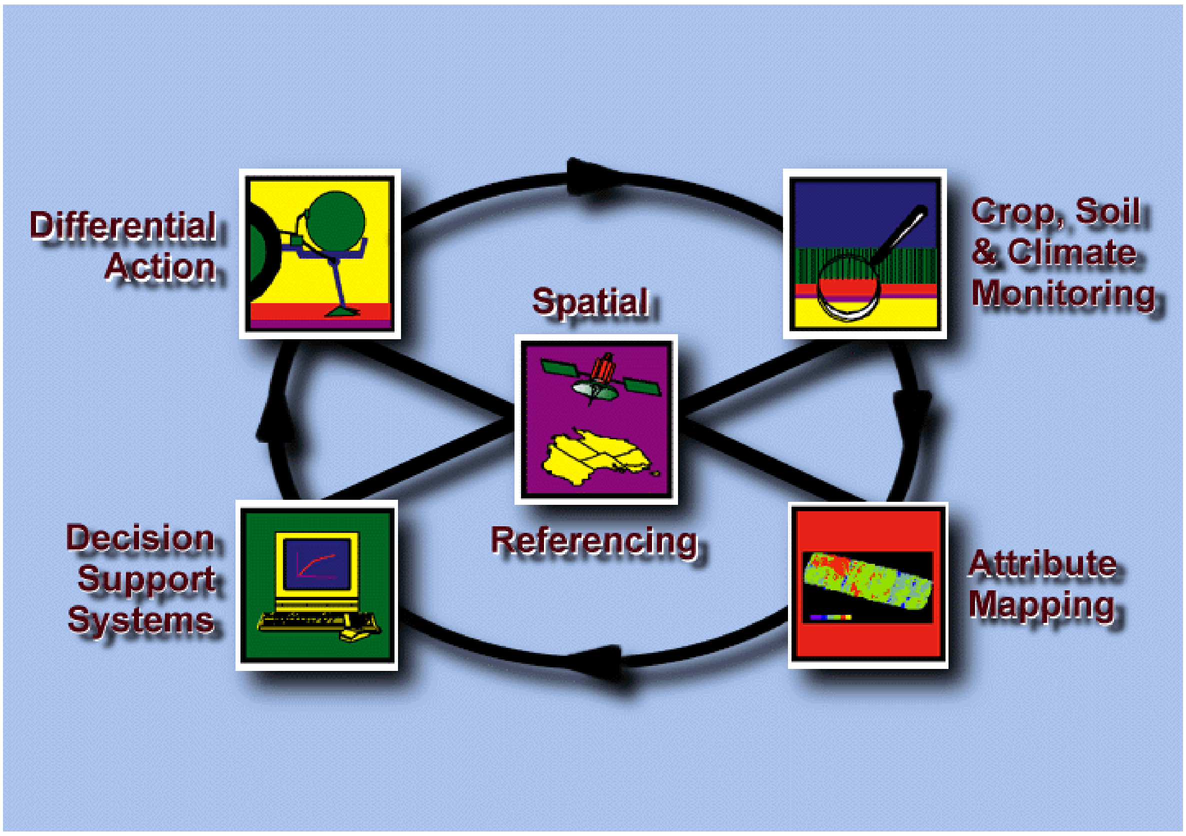

Figure 1.4: The Precision Agriculture wheel model showing the five main processes for a site-specific management system (courtesy of the Australian Centre for Precision Agricltrue, http://www.usyd.edu.au/su/agric/acpa).

however the adaptation of this technology to farm scales is still in its infancy.

1.5.4 Decision Support Systems

Techniques for data presentation and storage, such as Geographical Information Systems (GIS), developed in other industries are also applicable with some modification to viticulture. However Decision Support Systems (DSS) are not so flexible and it is in this area that real research needs to be done. The majority of engineering companies currently supplying PA technology are not interested in and are unable to produce DSS. Thus the onus will fall on the industry and to a lesser extent the government to fill the gap. Initially it may be sufficient to adapt existing viticultural DSS such as AUSVIT to site-specific situations. In the long run a viticulture DSS that is able to site-specifically model vine-environment interactions in terms of yield and quality will be needed. This will need to be flexible enough to incorporate all aspects of the new information technologies, accept feedback from other parts of the PA cycle and be able to conform to standards such as ISO 9000/14000.

1.5.5 Differential Action

The production of variable rate technology (VRT) is essentially an engineering problem. Due to the commercial potential of VRT much of this engineering development will again be driven by the private sector. The main input from an agronomic point of view is the provision of accurate information on application rates (derived in the DSS) and interpretation of the results of the differential action for feedback into the DSS. VRT in the mid 1990s was probably the best developed part of the PA cycle (Searcy, 1995) and development of new methods of differential input application still appears to be a pet project of many research and commercial entities around the globe. In recent international conferences papers on auto-steering, machine vision and variable rate applicators have focused prominently in the proceedings.

The potential for VRT in vineyards will also be discussed in more detailed in chapter 3 however currently there is little VRT application in vineyards.

1.6 The state of play of Precision Viticulture

1.6.1 Australia

Australia is at the forefront of global precision viticulture. At the 2001 European conference on Precision Agriculture, of the three PV papers presented, two originated from Australia and one from France. At the 6th International Conference on Precision Agriculture held in Minneapolis USA in 2002, again, two papers were presented on PV from Australia and one from France. No work was presented from the USA.

From an Australian perspective academic research into precision viticulture is concentrated in two main centres, the Australian Centre for Precision Agriculture (ACPA) and the CRC for viticulture (CRCV). The Precision Viticulture program within the CRCV contains two main sections; 1) application of aerial imagery to PV (supervised by Dr David Lamb, formerly Charles Sturt University and now University of New England) and 2) investigation of yield/quality variability and its causal factors (supervised by Dr Rob Bramley, CSIRO Land and Water, Adelaide). This project represents the sum investment of the industry into PV. Research within the ACPA centres on the application of new technologies in describing and modelling vineyard variability. The work is supported by the University of Sydney and the ACPA. PV research has also begun recently at the University of Melbourne under the guidance of Professor Snow Barlow.

Commercially several companies are offering aerial and satellite imagery services for viticulture. The spectral and spatial resolution offered differs between suppliers, however currently there is little if no support offered with the data. Much of the satellite data being sold is heavily processed and growers are offered only vegetative indices such as a Normalised Differences Vegetative Index (NDVI) or Plant Cell Density (PCD) image rather than raw data.

A number of soil surveyors are now offering EM38 survey services to aid in vineyard design and EMI surveys prior to vineyard establishment are becoming a common occurrence in Australia. Again however there is little support offered to the data and little understanding of how to best extract and utilise the information in the data. The maps of soil apparent electrical conductivity (EC_a) are used primarily to identify areas of salinity and for some basic site-directed soil surveying. Currently no method exists to standardize these surveys and incorporate them into existing soil survey protocols.

1.6.2 International

France and the USA are the two main countries involved with precision viticulture outside of Australia. The French machinery manufacturer, Pellenc, Pertuis, France, is actively involved with researchers at the Institut National de la Recherche Agronomique (INRA), Montpellier, France, in the development of a yield/quality sensor. As well as the design of yield monitors, the group at Montpellier, headed by Dr Bruno Tisseyre, is involved in the development of a sensor to detect canopy size and density as well as investigating the spatial variability in the vineyard (Paoli *et al.*, 2003).

In recent years there has been little published research come out of the USA. However in the mid to late 1990s research was conducted into the use of aerial imagery for site-specific viticulture. This was a joint effort between a large viticultural company and the National Aeronautics and Space Administration (NASA) (Johnston *et al.,* 1998). More recently the Centre for Spatial Technologies and Remote Sensing (CSTARS) at UC Davis, USA, have become interested in mapping vineyard canopy density remotely (Dobrowski *et al.,*, 2002). Further research has been undertaken at the University of Washington, Oregon, into the use of digital cameras to detect disease (Lang *et al.,* 2000) and investigations into yield variability and precision management (Wample *et al.,* 1998).

The recent commercialisation of a load cell based yield monitor and its subsequent testing in Spain has seen an increase in PV on the Iberian peninsula in the past 18 months. As well there has been interest from Chile in the establishment of a PA and PV research centre and preliminary work is now emanating from there on spatial variability of grape quality and quantity (Ortega *et al.,* 2003). At the recent European Conference on Precision Agriculture there was also a contributed paper on the adoption of precision viticulture in Slovenia (Lakota *et al.,* 2003)

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