Spatial Aspects of Vineyard Management and Wine Grape Production

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ABSTRACT

Grapes and wine are natural products whose special characteristics rely on both environmental conditions and the skills of the grapegrower & winemaker. Viticulture has a strong association of place (e.g. region, Marlborough) and time (vintage). This paper demonstrates that the spatial and temporal variables associated with the growth of grape vines and management of vineyards are ideally suited to the application of spatial information systems. This is clear by recognising that the key factors influencing results vary from regional to intra-vineyard scales. Precision agriculture and site-specific farming have demonstrated the successful application of spatial information systems in primary production, crops from the land, and management & use of resources. The paper highlights those aspects distinctive to viticulture that are amenable to support from spatial systems. Issues that are addressed include scale variation, significance of location, factors which affect production & quality, vintage, the annual cycle of the vine and harvest of fruit, extreme events, risks (eg. frost, pests, diseases), trans-seasonal & intra-seasonal cycles, sustainability, quality & integrity of the final product, traceability and the reputation and value of the final product.

***Keywords and phrases*:** wine, viticulture, precision viticulture, vineyard management, spatial information, GIS

1.0 INTRODUCTION

Wine is the natural product from grapes, the crop of the grape vine, *Vitis vinifera*. It is made from many different varieties (Riesling, Chardonnay, Merlot, etc.), in many styles (dry, fruity, oaky, for drinking young, for maturing, etc.) and in many countries and regions. The aim of the grape grower or viticulturist is to produce grapes, to a quality and price that will meet the requirements of the winemaker and the business manager. The aim of the winemaker is to make wine from the grapes, also to a quality & price, that naturally reflects its origins and vintage, and is appreciated by the consumer. In New Zealand the aim is to produce distinctive wines that reflect the characteristics of the land and its clean green image, promoted by the wine industry as "the riches of a clean green land" (Wine Institute of NZ Annual Report, 1999).

The grapes are the crop which goes to winemaking - the supply of juice, from the vine, the soil, the environment of the vineyard, to the winery, to the bottle, to the glass, for the ultimate enjoyment of the drinker. This is achieved through many stages by a team of people. Information for all these stages must be integrated and shared if the production of wine is to be successful. It is this information which is analysed and used by these people to make decisions which influence the final quality of the product. Vineyard decisions are made along with winemaking decisions, marketing and overall management of the business of the producer.

Many variables affect the growth of grapes, some according to place, some by time. For each factor there is information, much of it specific to the location of the vine. To take advantage of the complexities of variation, and to control the detrimental ones, a flexible information system which allows spatial reference and spatial

analysis is required. This paper argues that spatial information systems can be used effectively for the benefit of producers; that decisions in the vineyard are only as good as the information available; that information can be referenced to spatial location; and that relevant information can be analysed and correlated by spatial reference.

2.0 VINEYARDS & INFORMATION

The establishment and ongoing management of a vineyard requires information. Decisions made by the viticulturist call on information – about the vines, their growing conditions, the seasonal progress, etc. The quality of available information is an important factor determining the quality of decisions made and, therefore, the quality of results – of the grapes produced and, ultimately, profitability. Over 100 years ago Romeo Bragato recognised the importance of quality and reported on the prospects of viticulture in New Zealand: "It is vastly more profitable for a grower to make wine of a fine quality, thus securing individuality and a reputation for himself, than to produce an inferior quality wine, although in large quantities." (Bragato, 1895)

Much of the information relates to location, so spatial (geographical) relevance is a significant aspect of data, information for the growth of the vine, development of fruit, its attributes and quality. The relevance and applicability of spatially related and analysed information is the main focus of this discussion, because many of the variables affecting grape quality are inherently spatial in nature. Grape growers may refer to several kinds of maps of the vineyard, and to many categories of information. Behind every map, however, is a wealth of additional or more detailed information not included on the printed map. Paper based maps are static, single theme, current only at the time they are drafted, with no underlying database and unable to be 'queried'. Computerised maps can have multiple thematic layers with extended databases, and can overcome these limitations of paper maps. Figure 1 illustrates these points by depicting a collection of maps comprising a 'spatial database' – the major resource of any spatial information system. These systems allow the exploration of spatial correlations, associating attributes and features to support the analysis of patterns and processes across a landscape.

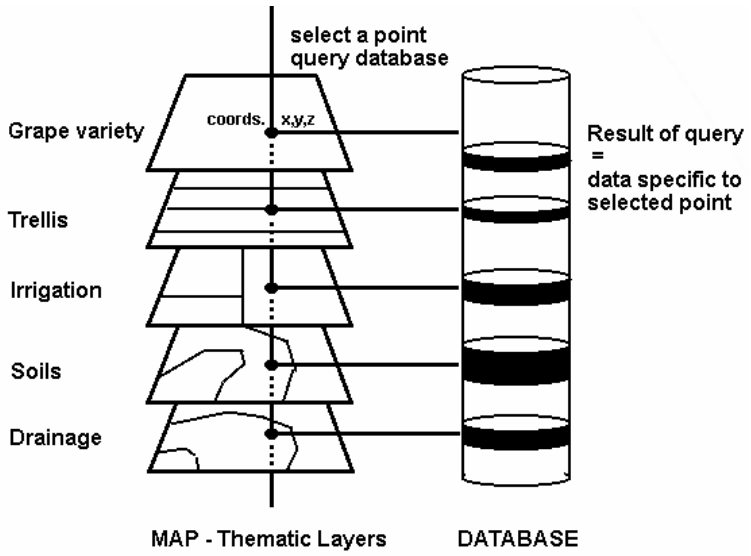

Figure 1: Map Query, of space and related data.
(other query options would be – select an area, or zones of proximity)

Spatial information systems can be integrated and applied with management information systems for inventory purposes and for decision making. They assist in understanding how things act and respond to natural influences and to managed inputs and controls, in the space around them. Integration in this context is the combination of shared data and analysis systems where information used and decisions made in one area affect what happens in another, eg. financial information related to vineyard decisions.

The power of spatial information systems derives from the integration of spatial data with descriptive data pertaining to spatially distributed phenomena – whether these are naturally occurring phenomena or cultivated/manufactured resources. Data describing the management, development, yield and other characteristics of resources is typically integrated with data related to climate, soil, topography and other geographic phenomena. Whelan et al. (1997) state that with the advent of tools such as the differential Global

Positioning System (dGPS), Geographical Information Systems (GIS), and miniaturised computer components, agricultural enterprises are now capable of gathering more comprehensive data on production variability in both space and time. In the case of wine production, both these characteristics are evident and the interaction between natural phenomena and vineyard management practices is known to have significant effect on the quality of the end product. A spatial information system for viticulture should, therefore, support analysis which will lead to viticulturists gaining greater understanding of fruit responses to management practices under varying natural conditions (Smith & Firns, 1998). This will require the integration of data from a variety of sources within a well designed spatial database.

Spatial database design includes the specification of geometric representations of resources as well as attribute data design. A spatial representation of a vineyard would require geometric objects corresponding to growing blocks, rows of vines and the location of individual vines as well as data representing trellis systems, irrigation networks and other infrastructure. Attribute data of interest includes characteristics of the vines, rootstock, grape quality and yield, management practices (eg. fertilisation, pest spraying, pruning & irrigation) and quality of the final product. Natural phenomena of interest would include climatic information (temperature, rainfall, sunshine, wind – both climate data monitored within the vineyard and long-term macro-climate data), topographic & soil-type data. While much of this data may derive from paper maps, its integration within a well-designed spatial database provides a value-added resource for decision support systems in management and research.

Another important capability of spatial information systems for viticulture is the analysis of spatial extents of common characteristics, phenomena or similarities (or alternatively, of specific differences). This includes proximities, buffer zones, etc. from multiple integrated sets of information. Analyses produce aggregate/compound maps (Figure 2), or images (vector and/or raster), presenting specific reports to the viticulturist or vineyard manager for appropriate decisions and actions. For example, to identify potential premium quality grape blocks based on spatial patterns identified from previous high quality growing areas and to understand the contributing factors.

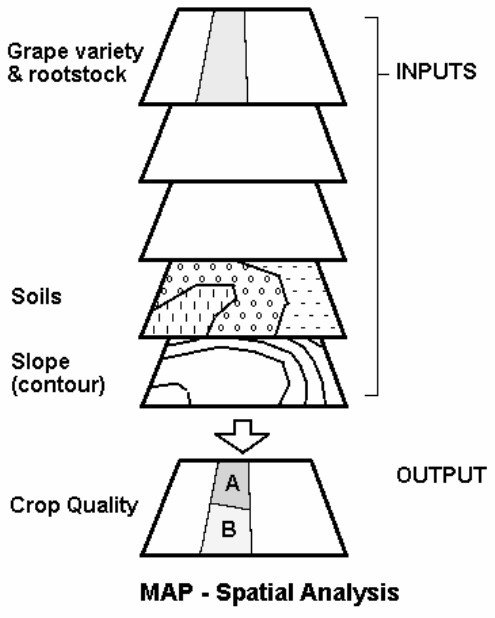

Figure 2: Spatial Analysis

2.1 Agriculture, horticulture, and information uses

Precision agriculture or site specific farming have demonstrated the success of spatial information systems in agriculture, forestry, horticulture, etc. (Buick, 1997; Clark, 1997). As agricultural producers get smarter and more efficient in their operations, they are using more information in a wide variety of contexts (Anderson, 1997). They are using them to vary and target their management to suit the characteristics and needs of specific areas of the land, identified through spatial and temporal analysis. For example, Schulmann (1997) stated that "GIS (Geographic Information Systems) allow farm operators to successfully manage and fine-tune specific sites. The data being collected enable them to see what is occurring in smaller sections of the field. With this

knowledge, farmers can control water, fertilizer, crop selection, planting density, and pest-disease control programs".

Some examples of precision farming in agriculture include:

- Definition of fields or paddocks, based on similar or uniform characteristics (soil types, topography, etc). Farm survey of paddocks, physical features and infrastructures, to provide maps with linked spatial features and associated attributes.

- Recording data on land use, stock & crops, associated with particular locations.

- Aerial images (colour photos, IR or multi-spectral, etc.) for analysing vegetation characteristics, and crop or pasture performance at various stages of year. Identifying potential or actual problems, pests, diseases, including stress, vigour and growth variations.

- Yield monitoring, by capturing and mapping harvest data, and showing spatial variations. "The more exciting opportunities have been pointed to by the use of global positioning systems connected to yield monitoring equipment in broadacre cropping. This sort of use is now a reality in vineyards." (Robinson et al., 1999)

- Targeted and variable rate applications of fertiliser, sprays for disease or pest control, irrigation (eg. applying water to suit soil variables and minimising leaching or salinity problems); site specific work operations. "..it has allowed farmers to understand better the variation across their fields and, in some cases, to vary the inputs to take account of this variability." (Robinson et al., 1999)

2.2 The wine industry

The wine industry in New Zealand has developed dramatically in the last two decades. Vineyard area has increased more than 50% in 10 years and growing regions have spread throughout the country (Wine Institute statistics). The emphasis has shifted to production of quality premium wine grapes, with an international reputation and success (Wine Institute of NZ Annual Report, 1999).

Strategies for progress into the next millennium include improvements to quality of grape growing and wine making (Wine Institute, 1992). To achieve this, the right decisions must be made in viticulture, based on reliable and relevant information. Objectives should therefore include adoption of applications of spatial information systems in vineyard management, and their integration with other management information systems.

An often quoted fundamental in the quality of wine is the quality of the grapes. This is determined by their environmental and growing conditions, referred to as 'terroir' by the French (Robinson, 1996). Terroir generally means a combination of vineyard location, soils, climate, and other environmental factors, as well as choice of grape varieties, viticulture practices, and the strategies or philosophies of the producers. Location or spatial references are important to many of these factors.

Growing grapes and producing wine are natural processes, manipulated by the grape grower and wine maker. Environmental influences affect the grape crop, as well as the decisions and actions of the grape grower and winemaker. Grape growers take advantage of natural factors – soils, climate, drainage, aspect, etc. – by selecting suitable sites for particular grape varieties. They control or manipulate other factors – irrigation, pruning, vine training, spraying, etc. – through management procedures. These factors may be spatially variable through the vineyard, and it is assumed that management procedures could also be varied. With the assistance of a spatial information system, it may be possible to analyse the factor variations and apply a variable approach to each vineyard block, rather than managing it homogeneously (average approach).

Wine makers achieve greater control over the product by selecting, fermenting and blending batches of grapes with suitable ripeness and flavours. It may be possible to give them more choice, by defining sub-blocks within the vineyard. Batch selection could be decided with the assistance of spatial analysis of data related to grapes in the vineyard and environmental factors affecting their development, instead of picking whole blocks as single batches. Wine makers would have access to specific information about the origin of each batch when making blending decisions and when assessing the blended product (Johnson et al., 1998).

2.3 Grape growing

The growth of vines and grapes is a natural process, governed by the annual cycle of seasons (vintages), through bud burst in spring, shoot & vegetation development, flowering, fruit set, ripening, harvest, and finally pruning before the next cycle begins (Figure 3). The crop is influenced by the physical conditions where the vine is growing (location, topography, soil, etc.), the climatic environment, and manipulated by vineyard management (decisions and actions of the grower/viticulturist, and other inputs). The interaction between vines, natural phenomena and vineyard management practices has significant effect on the quality of the end product.

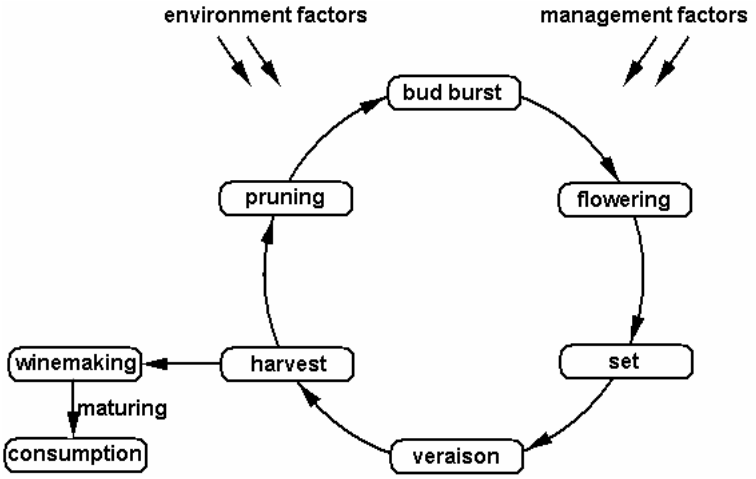

Figure 3: Grape growing cycle

The main factors affecting vines, their development and annual cycle of growth, and the crop produced each year include:

Physical Environment:

- Global: The main places on earth where wine grapes are grown are in a latitude band in each hemisphere (the temperate zones between 10^0C & 20^0C mean annual temperature), with regional differences within these bands (Jackson & Schuster, 1997).
- Regional & local: Geography & land form, altitude, shape, slope, aspect, natural features (river, lake, sea, etc.), built environment (urban areas, roads, etc).
- Site: Land, availability of suitable land, history of viticulture use or agriculture use, proximity of other land uses including agriculture & viticulture, reputation or proven performance of land for similar uses.
- Soils (eg. clay, chalk, limestone, gravels), including subsoils, physical, structure, nutrients.
- Water, ground water table, water quality, availability of water for irrigation, drainage, runoff.

Natural phenomena:

- Regional climate & local variations, seasonal variations, macro conditions.
- Latitude, continental & maritime effects.
- Longer term cycles & fluctuations, El Niño, La Niña, extreme events (eg. cyclones), global warming.
- Local climate & weather patterns, average temperatures, daily fluctuations, heat summations (for example growing degree days (GDDs)), frost risk, hail, wind (Norman, 1996).

- Site climate variations & relation to regional climate. Variations in air, sun & rain make different seasons producing different vintages (McDavitt, 1999).

Viticulture & vineyard management:

- Selecting sites.
- Design & layout of vineyard, consideration of significant spatial variables (soils, nutrients).
- Selecting varieties, rootstocks.
- Vine spacing.
- Training of vines, trellising, pruning, shaping the vine.
- Infrastructures, fencing, shelter, water supply, drainage.
- Cultivating, irrigating, fertilising, use of cover crops, weed control.
- Pests & diseases management.
- Managing/controlling growth & development of the vine, limiting numbers of buds or shoots to control vegetative vigour, limiting flower & bunch sets, trimming canes & leaves.
- Removing bunches, thinning, restricting or determining yield (quantity) of crop.
- Monitoring fruit development and deciding harvest.
- Harvest.
- End of season maintenance, removal of damaged or diseased material, pruning & training for next season, replanting.

Wine making: (and participation of the winemaker in decisions on grape production, style of wines, market, cost, etc.)

- Crop selection, by monitoring & control of particular areas of vineyard, and selection at harvest.
- Blending of separately vinified batches of grapes, to achieve style & complexity.
- Analyses (monitoring results), feedback & control.
- Record keeping and audit trail of results, from place of origin through to consumption.

Each of these factors has some relationship with location and variability from place to place.

2.4 **The Season In The Vineyard** (Ecclesiastes 3:1)

☼ Each new season in the vineyard begins in spring with the first signs of new growth – buds of new vine shoots. This is preceded by preparation during winter, when the vines are dormant – pruning, training, replacing damaged or diseased vines, repairing trellis systems, doing any cultivation and soil adjustment, etc. (Jackson & Schuster, 1997).

Bud burst is triggered by factors which vary with each season (early spring warmth, longer winter) and in different locations (regionally, and within the vineyard). Availability of soil moisture and nutrients also vary and the characteristics of vine variety and rootstock mean they respond in different ways.

This event sets the time frame for later events such as flowering, ripening, and harvest. The time it occurs varies according to location, variety and onset of conditions. The nett results of the previous season also leave a legacy to the new season's development.

Variations in the site climate (mesoclimate), in soil & moisture patterns and in vine health, mean that bud burst and vine development is not uniform throughout the vineyard, although vineyard management may adjust the variations.

As the vine develops, the viticulturist may control growth by removing buds or trimming shoots to maintain balance between the vine's health, vigour, potential to ripen its crop, and its growing conditions. This will depend on the aims of fruit quality, quantity and economics. "The decisions of the grower will be dictated by climate, tradition, economics, and the pursuit of quality." (Halliday & Johnson, 1992)

☼ The shoots develop and vegetation spreads, spurred on by the growing conditions for each vine. The conditions may also be ideal for the occurrence of diseases or infestation of pests (especially mildew and fungus brought on by warm wet conditions). As the shoots extend they are trained on the trellis. Diseases and pests are likely to threaten the vine throughout the season, requiring monitoring and remedial action by the viticulturist. Monitoring and control of such problems is a part of management throughout the season. Some growers spray by the calendar in anticipation of problems. Others monitor conditions and spray only as needed. Responses will be different each season and in each location.

☼ A key event in development of the crop is flowering. The success of flowering and fruit set is sensitive and crucial to the rest of the season. Any setbacks may reduce the size and quality of the crop and give more management problems to the viticulturists. Prolific flowering and set will also add to efforts to control the crop. If crop load is excessive, fruit may be removed to maintain balance and ability of the vine to ripen the fruit to desired quality.

☼ Sunshine, warmth, soil moisture & nutrients and management of the vine contribute to veraison (the first change of colour of the grape) and ripening. Variations in these mean variations in fruit quality. The viticulturist continues to monitor (eg. grape sugars, acids, pH, flavours, ripeness) and adjust management practices. The winemaker also monitors to assist with management and to know what fruit will be available for making the wine. Balanced growth gives optimum fruit (Howell, 1999). Vigorous vegetative growth takes energy away from fruit and diminishes ripeness. Insufficient leaf area fails to capture enough photosynthesis power. If there are too many bunches for the ability of the vine then fruit does not fully develop and ripen. This could be compensated by some removal of bunches, or a hope that the season will continue long enough to ripen the full load. It varies from vine to vine. "For any given location or site there is an upper limit of crop yield, even under the conditions of an 'ideal' growing season for that climatic zone, if one is to achieve desired fruit and wine quality." (Howell, 1999)

☼ Harvest is the culmination of the vines growth and production of a crop and the result of the vineyard work and management. Traditional celebration of harvest time shows how significant this event is. It is also the time at which main effort is handed over from viticulturist to winemaker. Until now most work and control has been located at the vine. It is now transferred to the winery to make the best of this natural crop to produce the final result: wine. "Great wine is made in the vineyard…", (Hansen, 1998). The ability to select blocks for batches of grapes of consistent quality depends on how well the vines and their growing conditions have been monitored and managed. Records kept through the season, and of longer term performance of the vineyard, help both the viticulturist and winemaker understand the processes and results achieved at all stages from vineyard to bottle.

☼ The crop is picked, the vine has achieved its result and loses leaves as growth shuts down in autumn, prior to winter dormancy. The vine is a rampant weed and if left to grow wild would produce some fruit but put most energy in to its vegetation. However in most vineyards the growth is pruned back during winter to prepare the vine for another season and to suit the trellis system used in each location. The method of pruning & training is chosen to get best performance from each vine in its growing conditions and to suit management operations.

2.5 Spatial aspects of season, events, and other variables

Many of these previous factors and seasonal events vary from place to place, and year to year. Some can be measured/monitored but cannot be controlled, such as topography, soils and climate, and so will be specific to the vineyard location. Others are the result of grape growing and wine making methods and can be varied or controlled, depending on style & management objectives. (Bramley & Proffitt, 1999) Management inputs and control could be very detailed, adjusted for each vine. But how much is worthwhile? The viticulturist has to decide on the scale of detail that is needed and the frequency of observing, monitoring, recording, analysing, making decisions, and taking actions. Too much detail is expensive, wasteful and may be confusing. Too little detail may miss out on significant spatial variations.

Some possible opportunities include:

- Identification of vineyard blocks or sub-blocks for targeted or site specific management, including:
  - Decisions on clone or rootstock, canopy management, pruning, bud removal, bunch thinning, leaf trimming, etc. Can we vary them to suit the conditions, rather than take an average approach?
  - Targeted application of sprays for disease and pest control (spraying only where necessary and in variable rates to suit the level of problem or canopy density), thus leading to efficiencies, reduction of waste and less risk of residues. Integration with a temporal system which, instead of spraying on a calendar rota, achieves spraying only when needed. An example of this is the increasingly used NZ Winegrowers Integrated Winegrape production (IWP) scheme. (Creasy, 1999, pers. com.)
  - Irrigation & fertigation. Water & fertiliser applied to the vines needs, supported by soil moisture monitoring and soil maps. (ibid; Smart, 1997).
- Remote sensing and monitoring tools, aerial photos and multi-spectral images. (eg. infra-red)
  - To determine spatial variations in vegetation balance, vigour, health, soil moisture, and for correlation with maps of soils, microclimate, topography, etc., and when the harvest is in, compare variations of yield & ripeness with the variations in influencing factors. (Cunningham, 1998)
- Disease & pest management.
  - Identify and show areas prone to disease or other problems and analyse the spatial variables to find and manage the key factors that cause those problem-prone or problem-free zones. Would a humidity map help us? What are the spatial variations of soils & nutrients? Perhaps a map of soil vigour potential would help determine why there is too much or too little vigour. Could we use aerial images to show spatial variations?
  - Monitor disease & pest problems, like the spread of phylloxera, using aerial imagery and ground survey. Produce a map each year to show the extent of damage, which over time can be used to support the understanding of the factors which lead to outbreaks and therefore their control.
- Selection of blocks or sub-blocks for separate harvesting, giving more choice and blending options to winemakers.
  - Grapes selected on ripeness, or flavours, or degree of noble botrytis, etc., (Johnson et al., 1998)
- Yield mapping. Plot a map of yield & ripeness variations determined by monitoring the harvest, from the bin or off the harvester chute. It may surprise growers to see how much spatial variation occurs in crop yield (eg. tonnes per hectare), revealed by the yield maps, when until now they have measured average yields. (Bramley & Proffitt, 1999; Taylor & Whelan, 1999) This could influence future management decisions for

different blocks or sub-blocks, potentially allowing the majority of effort to be directed to those areas which create the best quality product. Alternatively, inputs could be adjusted spatially, in order to achieve consistent quality efficiently throughout each defined block. (Creasy, 1999, pers. com.)

- Traceability of product, through a record system that can identify sources of components of the blend back to their locations within the vineyard. As the clean green image becomes more dominant, the ability to trace a product from the 'paddock to the plate'/'soil to the glass' will become essential.

- Information sharing and transparency of knowledge are vital for the support of long term strategic goals. Decisions are not taken in isolation - records of actions and why they occurred allow knowledge of site-specific practices to be collected and shared with others, thus avoiding the issue of people 'containing all of the knowledge' and losing this knowledge when people move on.

- Profitability, through improved control of inputs and quality.

- Resource Management

    - Use of water resources, minimising consumption by allocating water only where it is necessary during the growing phases: This could be based on mapping of soils, moisture measurements, vineyard and vine factors (NZ WineGrower, Autumn 1998).

    - Accountability. Spatio-temporal records of management practice are insurance against environmental impacts (eg. if water quality downstream is degraded then who is to blame?).

- Integrated Winegrape Production: Managing the use of chemical sprays to minimise costs and environmental effects, by selective timing, targeting and variable application rates and demonstrating to planning and regulatory authorities that growers are using environmentally responsible techniques (Smith, 1998). Besides assisting management decisions, spatial information systems could produce reports for presentation to these authorities.

- Historical analysis of vineyard performance. The relationship between site conditions, management and product quality is a long term process. Information systems allow the activities and environmental factors that occurred some years in the past to be understood in terms of product quality (eg. when the bottle is opened).

The spatial spread of vines across the landscape and the spatially variable factors that affect the development of the vine and quality of the crop are fundamental to the management of vineyards. The use of spatial information systems, as occurring in agriculture & horticulture, provide the grape growing and wine making industry with new tools to analyse spatial aspects and variables and manage vineyards.

3.0 SUMMARY OF USE OF SPATIAL INFORMATION IN THE VINEYARD

The quality of information available for management of a vineyard will always be an important factor determining the quality of decisions made and, therefore, the quality of results – of the grapes produced, environmental effects and of course profitability. The assistance of spatial information systems should make it possible to analyse the factor variations, allow viticulturists a greater understanding of fruit responses to management practices under varying natural conditions, and apply a variable approach to each vineyard block.

There are potential pitfalls. Data gathering and management can be very expensive. A GIS does not on its own provide a ready to use system that would meet the needs of the vineyard manager. A simple application of a spatial information system does not yet appear to have been developed for vineyards, one that will provide a practical interface (Robinson et al., 1999). There is a risk that costs will be incurred, viticulturists' time distracted from core activities and benefits not realised.

Key opportunities with the use of spatial analyses in spatial information systems appear to exist in these ways:

- Identification/delineation of spatial blocks with similar characteristics (ie site selection) for specific management. Design of blocks and establishment of new plantings, for optimum results.

- Specific measuring & monitoring of zones.

- Targeting management procedures to controllable factors.
- Analyses of results, in grapes and wine, compared to variables of location.
- Selection of grapes at harvest, based on spatial similarities.

Precision viticulture provides the winemaker with more specific information on the origin of the grapes, for choices in the selection of batches, and for blending. These factors are based on an understanding of spatial variables, the relationship between these variables, and their patterns over time.

4.0 CONCLUSIONS

There are many opportunities to use information, particularly spatial information, throughout the process of growing grapes for winemaking. The identification of significant factors that influence the development of fruit, which vary spatially, and are included in an information system will provide growers and producers with better information and therefore support better decision making and quality of results.

Some final comments, adapted from (Roberts, 1999):

- Site selection is the most important decision in wine quality.
- Developing the site to its potential requires thorough knowledge of soil & climate, and spatial variables.
- A soil classification system can be used for comparing sites, and for choosing rootstocks and vine spacing.
- Influence of soil & climate interaction with the vines varies spatially.
- Climatic conditions, soil characteristics, topography, water availability are examples of interactive natural factors that vary spatially; management of irrigation, fertilisers, and crop load are examples of controllable factors that vary spatially.
- The proof of wine quality is in the bottle. The reasons for quality may be explored in the spatial information system.

"With more thoughtful and precise vineyard management, the winemakers of the 21st century should have significantly better grapes to work with than their 20th century counterparts" (Halliday & Johnson, 1992).

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