THE COMMERCIALIZATION OF REMOTE SENSING AND GIS FOR VINEYARD MANAGEMENT: A SIMPLE BUT POWERFUL APPLICATION OF CHANGE DETECTION

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ABSTRACT

Remote sensing and GIS have been used for day-to-day vineyard management in a quasi-to-fully operational fashion in the Napa Valley area of California (Greater Napa, Sonoma, Lake and Mendocino Counties) and several other regions of the world for the past five to ten years. This paper reviews some of the key papers in the literature and describes the way in which the tools have been used in a fully operational environment. The focus is on their use as a special but simple case of change detection over time – both year to year and over a season. These applications have ranged from thermal sensing to identify areas prone to frost damage in the Niagara Region of Ontario, to the use of high resolution airborne imagery for viticulture research and management in the in the Napa Valley and Oregon wine regions of the United States and the Niagara Region of Canada. Monitoring changes over time has proven to be one of the most valuable contributions of remote sensing for vineyard management. Given the financially compelling reasons for using remote sensing in vineyard management in many regions of the world, the challenge in commercializing such services in other regions has been surprising.

INTRODUCTION

Remote sensing and GIS have been used for vineyard management in a quasi-to-fully operational fashion in the Napa Valley and several other regions of the world for the past five to ten years. Their more specific application, to studies of disease, for example, has been with us even longer. This paper reviews some of the relevant literature upon which the application is based, describes the way in which the tools have been used, and discusses some of the difficulties in commercializing their application along with the results that have been realized in both scientific and economic terms.

A BRIEF LITERATURE REVIEW

The application of imagery to the study of problems in the management of agricultural land is not new. As early as 1963 Myers et al used simple imagery to detect drainage and salinity problems. In a landmark publication in 1968 Schepis noted the value of multi-temporal imagery in agriculture. These two papers can be considered as having laid the base for what was to come later in the use of remote sensing in vineyard management – the concept of using imagery to detect problems and the use of multi-date imagery.

The application of remote sensing and imagery specifically to vineyards began in the mid-to-late 1970s. Ryerson (1974) carried out an empirical study with airborne thermal data that helped identify several management issues and corrective actions related to winter damage to the root stock and frost damage to emerging buds in the spring. Using the thermal imagery, meteorological data provided by the Canadian Weather Service, and other information Dr. John Wiebe of the Vineland Experimental Station developed the first grape-growing capability map of the Niagara Region of Ontario. This map led directly to a significant enlargement of the areas of the Region in which high quality wine grapes could be successfully grown, and started the rise of the area as a tourist destination linked to the wine industry. This map has been improved and further developed by Dr. Helen Fisher of the University of Guelph (Fisher and Slingerland, 2001).

Philipson et al (1980) reported on the use of remote sensing for vineyard management. Stephens (1984, 1991) applied sequential color infrared imagery of vineyards in northern New Zealand to identify phylloxera-affected areas in vineyards. The survey conducted in 1982 was repeated in 1983 to identify the rate of change. The 1982 imagery showed that 76% of all blocks showed some damage – with over 50% damage in 14% of the blocks. The ultimate goal was to identify where there was a requirement for replanting grafted resistant vines. Imagery from this work is accessible in Ryerson et al (1997 and 2003). While this application can be said to have been operational, it was not an application that could be considered routine and done at the farm or plot management level.

One of the problems in all of the work to this point from the stand point of making it technically feasible to be operational is that it is difficult to extract quantitative radiometric information from an analogue data source. Such quantitative information is essential to permit comparisons from place to place. For this reason, such analogue data are not recommended for operational applications. (Curran, 1980; see Ryerson et al,1997.)

While the availability of digital data from commercially airborne scanners was to eventually solve the problem of extracting quantitative information from imagery, there was another capability that was required to use remote sensing to do comparisons over time. One needed the development of a fully calibrated, low cost (or lower cost) airborne sensor. With digital and fully calibrated systems available such as the CASI System (Johnson, 1996), the opportunity for routine application of remote sensing to vineyard management became a possibility. That possibility was most thoroughly examined by Johnson whose numerous publications tell part of the story.

One of the most complete of the early publications on this subject area (Johnson (1996) began with the assessment of a phylloxera-infected plot at the Robert Mondavi Vineyard near Oakville, California in the Napa Valley using imagery acquired in 1993 and 1994. "Grape phylloxera is a tiny aphid-like insect that feeds on *Vitis vinifera* grape roots, stunting growth of vines or killing them." (http://www.ipm.ucdavis.edu/PMG/r302300811.html) Phylloxera can be observed in the top 18" of soil and attacks the roots of the grape vine, leading to deprivation of both water and nutrients which in turn leads to reduced vegetation, lower yields and poorer quality wine. Phylloxera, which moves quickly to infect the entire vineyard, cannot be controlled: vines must be replaced with resistant root stock at great cost and a loss of three to five years of production.

From the air Johnson (1996) noted that the “most pronounced symptom of phylloxera induced stress is decreased vegetation.” To assess changes in vegetation Johnson used the Normalized Difference Vegetative Index or NDVI as a surrogate measure of vegetation health. (See pages 533-541 in Hatfield et al (2004) for a thorough discussion of NDVI.) He then developed an NDVI “Image.” The consensus was that while the color infrared and NDVI maps contained similar details “the NDVI images were far easier to interpret than either the contrast enhanced color-infrared images or film-based color infrared photographs.” (Johnson, 1996: 4) The NDVI also permits comparisons across different vineyards under somewhat different management regimes. It was possible to see soil-induced changes, plan sampling of soils based on patterns found on the imagery, sampling for brix (sugar) content of the grapes. The most telling observation was that the NDVI imagery was used to “subdivide fields for harvest based on observed patterns.” Strong responses were the sites of grapes for reserve-quality wines. In 1994 the entire Napa Valley was covered by airborne imagery from this NASA-sponsored project.

A key conclusion of the work was that “the image processing steps outlined here are within the capabilities of commercial remote sensing and geographic information system (GIS) vendors.” (Johnson, 1996: p.5.) It was further noted that improvements in computer, display, GIS, and GPS technology would lead to greater application at the grower -consultant level. Recent advances in spatially enabled applications such as Google Earth, NASA World Wind and the like are significantly lowering the bar for people to interact with traditional GIS data. No longer is it just the consultant zooming, panning, turning layers on and off only to produce a paper map for a client. With these applications consultants can become data providers and set up applications for the client, albeit without the currency offered by groups that acquire data at the proper time, resolution and calibration. One company offering high quality calibrated, timely and high resolution data is GrayHawk. They have been offering a commercial service in the Napa Valley since the early 1990s using a state-of-the-art special-purpose-built proprietary sensor and supporting systems. (See http://www.grayhawk-imaging.com/ .)

The answer to the question posed in the title of the 1998 paper by Johnson et al – “Can geospatial technologies help produce a better wine” was a definite “yes.” Indeed, Robert Mondavi Winery was able to use the work by Johnson et al (1998) to produce reserve quality wines from a plot that had never before done so. The results that we have been told about in site visits to Napa and work by a co-author suggest that such results are no longer limited to research projects. GrayHawk has been helping deliver similar results to wineries (two of them with over 800 acres each), vineyard management companies, as well as smaller growers with vineyards as small as 2 hectares.

More recently, Johnson et al (2003) have used multispectral IKONOS imagery to develop uniformity maps at two resolutions – treating the field as a unit and another at .75 meter resolution through interpolation to look at within field variations related to yield and water balance. While these products showed some promise, additional validation, demonstration and technology transfer efforts were said to be required to take the methods to operational status.

In the Niagara Region of Ontario the emphasis has largely been on methods to combat spring bud damage and winter vine damage, including the placement of wind machines. Duncan (2008) has used visualization techniques, soil maps, previous land use information and 3-D modeling with a GIS and GPS to assess cold air drainage and the optimal site for wind machines. Figure 1 shows a progression of images that details the arrival at optimal location of wind machines. Brown has been developing similar approaches to those developed in Napa by Johnson with several wineries in the region. This work is based on low cost sensor systems to provide better information for management. Examples of imagery from the work by Brown of our team at the University of Guelph are given in Figure 2, below.

THE ECONOMICS OF REMOTE SENSING

Vineyards are expensive. In the Niagara Region of Ontario the Grape Growers of Ontario suggest that it costs $24,000 exclusive of land costs to bring one acre into production. Land in the Napa Valley is said to be among the most expensive agricultural land in the world. Recent real estate listings put a value in excess of $250,000 per acre on some vineyards. The emphasis on and importance of increasing reserve quality wines is easily explained in this context.

We begin with the yields in Napa that range upwards from 2300 bottles per acre – based on what in Napa are low grape yields of 5000 pounds per acre. (Yields can be double this amount.) High quality "reserve" wines typically sell at a significant premium over "varietal" or "district" wines and in many cases are sold only through the winery's store on site. As one Napa vineyard manager told the senior author in an interview "we can sell every drop of reserve wine in our store." The retail price for reserve wine is in the $35 range - and up. The varietal or district wine sells for $10-12 or less at retail or half that (or less) at wholesale. Since the finest reserve wines are sold on the estate – i.e. no middle man is paid to wholesale the wine, and there are almost no transportation fees, profits are high.

The difference per bottle between reserve quality grapes and others to the winery can be seen to be in the range of $25 to $30 per bottle – or a minimum of $57,500 per acre. The economics of the GIS/RS work becomes very clear. With a large vineyard of 800 acres, a 5% increase in reserve quality grapes turns into an extra $2.3 million profit. Even for a smaller vineyard of 30 to 40 acres, the additional income that flows to the bottom line can easily be well over $100,000. For a service that costs in the vicinity of $8-10 per acre for one image per year at veraison (the stage in the ripening process of grapes: the relatively short period during which the firm, green berries begin to soften and change colour), the economics are clear in a region where there is the potential to both produce and sell reserve quality wines. The RS/GIS work is a bargain. $400 can lead to additional profit in excess of $100,000.

Of significant interest in terms of commercial application is that the areas of each vineyard that produce reserve wines are not exactly the same each year, as is the fact that the imagery is often used to uncover other vineyard management problems that are manifested both at one time and over time. These management applications, along with some examples, are discussed below.

MANAGEMENT APPLICATIONS

It is primarily disease monitoring and harvest planning that have been detailed in the literature on remote sensing/GIS and viticulture cited here. While management applications have been mentioned, they have usually been considered almost in passing. In fact, remote sensing when combined with GIS has proven to be useful for a range of vineyard management issues. These tend not to be as well documented for two primary reasons: those doing the work are "too busy using the technology to write about it" or the work is considered to be giving the company a competitive advantage and those involved do not wish to give up that advantage. As noted below, this can cause problems in commercialization. Here we review some of the many applications we have uncovered in interviews conducted in the Napa Valley, the Niagara Region of Ontario, and New Zealand over the past two years.

The foregoing discussion suggests the need for an on-going and consistent monitoring year over year. The consistency of the data provided (and data provider) is important. Getting the acquisition date right is an issue – it has to be late enough to see stress, but at the same time be consistent in time of season. Most users in Napa get one image per year at between one and two meters resolution, although some do obtain multiple flights. Some acquire data at bud-break as well as veraison. Mid-spring imagery shows the vigour of the cover crop and where there was too much water. Too much moisture is a problem – often solved by planting a cover crop that will absorb it or by adding sub-surface drainage.

The monitoring over time (year to year) becomes valuable as changes and/or consistent patterns are seen from one year to the next. Where the vineyard is part of a larger corporate group the imagery and maps showing replanting information, re-grafting, wine quality maps, NDVI, and year-over-year changes are useful in securing support for replanting older vineyards, investments in irrigation, or other capital projects that must be approved by a management committee not located on site. The GIS and its outputs can also be used for forecasting for everything from marketing expenses to when old vines will be pulled out and what will be planted. Here the old adage "a picture is worth a thousand words" holds true. The image is used as a "report card" showing if the investments such as irrigation retrofits achieved the desired results.

One large vineyard identified a number of routine applications for the same NDVI data set. In high vigour crop growth areas and with location from GPS they assess where they should plant a cover crop to lower or slow the vine growth since it is better in some cases to hold the vines under a certain degree of stress.

Vineyard managers like to see stress on vines at appropriate times of the year to arrest vegetative growth and turn the vines' efforts to reproductive growth. This isn't to produce more grapes. Vineyards are unique in agriculture in that we are not trying to achieve maximum growth as in a grass seed farmer or corn farmer. Instead the goal of a vineyard manager is “balanced growth”. Excessive vegetative growth can decrease crop, but more importantly it increases undesirable flavor characteristics in the grapes. These flavors are commonly referred to “herbal” or green pepper flavors. Technically these flavors result from a group of chemicals called pyrazines.

Managers also plan pre-pruning in vigorous areas to cut the canes back 5 or 6 inches. They can also do an analysis of stem water potential and soil sampling based on the NDVI results. For example they use the NDVI to determine where they should take neutron probe measurements (for soil moisture measurement). In one case, they found an area where the vines were stressed for several years. It was found that there was a hard clay pan preventing the roots from growing deeper. They did a deep disc 18 inches from the vines to allow the roots to go deeper and the vigour returned. They also use the data to help estimate how much seed for cover crops to order. “All sorts of measures can be done quickly and easily” said the Chief Horticulturalist. Of course in the case of this vineyard the NDVI and other data in the GIS are used to help the wine maker decide where to sample and that in turn determines which grapes are harvested when and for what quality.

Vineyards have historically been farmed on a block by block basis. A block is defined as a contiguous planting of vines uniform in variety, rootstock and, if irrigated, irrigated uniformly. Using NDVI, vineyard managers can dissect a vineyard block, and come up with strategies to manage different parts of the block appropriate to the vines needs with the goal of creating uniform vine growth throughout the vineyard. Uniform vine growth throughout a block is highly desired by vineyard managers because with it, the block is more easily be managed and tuned to wineries specifications. In order to achieve uniformity a vineyard manager may look at fertility of the vine and soil in different vigor zones. Also, they may look at the vine-soil water relationship by using different tools such as leaf or stem water potential, soil moisture as measured with a neutron probe or c-probe. Further, soil physical characteristics and the impacts of past management decisions can be assessed. To remedy variation in a vineyard block the vineyard manager has a vast tool set. Modifying the irrigation systems to irrigate weak vines more may be as simple as adding additional water emitters or adding second irrigation lines. Differential disking of the cover crop can remove the competition for water in the weak zones while allowing the cover crop to compete with the stronger vines. Some vineyard managers are using GPS on their tractors that show the operator when they are entering a different vigor zone. There are many other tools only limited by the creativity and budget limitations of the vineyard manager.

Another group found that different slopes and soil characteristics tended to lead to wines resulting being reserve, grand cru and premier cru. Slope and aspect has also been linked in Napa and Niagara to frost pockets and winter kill. Another vineyard manager noted that there is some relationship to evapo-transpiration and the water regime within the plots. The NDVI is also tied to pruning weight ratios which is used as a stand-in for leaf area. The balance of the amount of crop to pruning weight is important, as noted above. “Most people on the fine wine side think that the information is worth it and are willing to pay for it,” said the manager. Another interesting monitoring application is the overview of neighbouring vineyards to look for evidence of stress that may “leap the fence” and cause problems down the road – or across it. Vine mealy bug is a notable current example of this. It transmits the leaf roll virus which is highly detrimental to vineyards. Herbicide damage is another example where someone sprays a herbicide on another crop next to a vineyard and prevailing winds blow the herbicide onto the vineyard. In Oregon’s Willamette Valley, where grass seed fields border vineyards, this is common.

ISSUES IN COMMERCIALIZATION

Napa is not an ordinary wine growing area. Unlike many old world vineyards where small plots have tended to evolve over the centuries into plots of similar production and quality characteristics, the Napa Valley area of California (Greater Napa, Sonoma, Lake and Mendocino Counties) is relatively young, has larger plots, and, as noted above it has considerable variability in each plot. The region now has over 100,000 acres of grapes (growing from under 5000 acres to its present size in just sixty years). While small (containing only a fraction of the total in California), it is an area where there is a tradition of creating fine, high priced wines, with a higher level of education and more interest in technology than in many other wine growing areas. It is made for the technology.

It seems strange then to hear the words of one commercial supplier, "Lee Johnson of NASA has worked for 15 years on the R&D. Six years ago it took off. It has taken 10-15 years to gain acceptance." While there are now several suppliers in Napa (operating at different levels of quality, sophistication and sustainability), this statement concerning the length of time it has taken to establish the market and gain acceptance must give one pause. Why has it taken this long to establish in Napa? How long might it take in other regions? What can one do to increase the likelihood of take-up of the technology?

In a study of commercialization of research Ryerson and Blair (2005) noted that one of the key elements in commercializing research was to involve industry from the very beginning – both users and suppliers of the resulting service and/or technology. This appears to have been done in Napa where both a winery and commercial supplier were involved at the outset with NASA. Furthermore, the technology seems to have migrated to other regions from Napa. In the Niagara Region where several members of this team have a contract to commercialize the research in remote sensing of Dr. Brown, users have been involved including Andrew Peller Ltd. who have contributed to this project, but there were at the outset no commercial suppliers. None existed: that is what we are attempting to develop.

The success in Napa has come in part from selling to both large users (such as Robert Mondavi) and large ***groups*** of users. In the words of one supplier, "it is hard to sell to groups – but it is important to do so." It may also in some respects be easier since the people managing the larger properties or groups of properties tend to have higher degrees in science. In addition, many vineyard/winery owners have had highly successful careers in other fields of business. They may not be experts on GIS or aware of NDVI, but when they are presented with a farm plan (essentially a business plan) they are aware that the inclusion of an NDVI represents a well thought out plan that makes use of advanced technology to make the best business decision. They don't necessarily need to be sold on technology, but they must have proof of the value.

The economic arguments and contributions to vineyard management presented above tend to be sufficient in most wine producing areas we have studied. With several large clients as a base, one can then add smaller groups of clients. Obviously one issue is that the service provider wants to bill (and deal with) as small a number of clients as possible. Under this model using a management company as client, one can (and often does) serve clients with holdings as small as an acre or two – but you need not invoice for such small holdings – they are captured in the management company who bills for a larger basket of services. For the management company then this is just another part of the service package that includes pest control, soil analysis, etc. For its trouble, the management company gets a cut of the sale value.

Another issue is the minimum acreage requirement. Most services will offer a service at $8 to $10 per acre with a 20 – 40 acre minimum cost. This can be a barrier to smaller producers. Also, currently people fly once a year. This results in 3-4 weeks of very busy work for the imagery provider, then a significant lull. What can be done during the off time? Flying more times per year, perhaps at each major physiological step in the vines growth (bud break, bloom, verasion and harvest) might be one solution – and adds more management information to the basket of services. Along these lines one issue with the "one-shot-per-season" is that stress patterns change over time. Imagine a vineyard with rows running up and down a steep hill. The soil may be fairly shallow at the top of the hill, deepening down the hill, and considerably deeper at the bottom of the hill. As the vine stress will likely be a function of available water, which is directly related to the soil depth, the vine stress will likely move its way down the hill over the course of the season. Similarly, if the lower areas become waterlogged, the reverse can hold true.

Translating this application to the Ontario context should in some respects be easier, and others far more difficult. First on the difficult side of the equation is the small size of the grape acreage: there are less than 17,500 acres in the entire province and of that only 14,000 are concentrated in the Niagara Region. (The other significant wine region in Canada in British Columbia is even smaller – at less than 8000 acres.) Second is the small size of most (but not all) of the wineries and vineyards: there are 74 wineries in Ontario (with almost 60 in the Niagara Region) – while Napa, with almost 6 times the acreage has but 200 – and several of these have 800 acres or more. In Niagara to make the application economic requires that a significant percentage – say 25% or more of all of the acreage be covered.

On the positive side is the fact that there is a Grape Growers of Ontario association representing all of the more than 600 grape growers in the province, and a Wine Council that represents all of the wineries. Like Napa there is a significant (if largely Ontario-based) tourist industry and a significant quantity of reserve wines are produced and sold on site. As noted above, we have also had some success in Niagara in terms of tests with specific wineries and vineyards. Furthermore, two of the largest wineries in Ontario are owned by companies which use remote sensing in their day-to-day operations on their large holdings in Napa. We therefore have two groups that might potentially act on behalf of their widely dispersed members, as well as two large individual players.

The Ontario commercialization first targeted the Grape Growers of Ontario and the Ontario Wine Council. The first expressed an interest, but that organization has subsequently decided not to seek the additional resources to participate since they are already using a rudimentary GIS system and are primarily interested in the production of grapes - not in reserve quality wines. The Wine Council was undergoing changes in senior management and in that period they too were reluctant to participate, but at the time of writing they have agreed to discuss our results and the information on successes elsewhere. We will also approach the two major players already using the technologies to gain a competitive advantage in Napa. As with all entrepreneurs everywhere we are hopeful – that is what it is to be an entrepreneur with an idea and service that we believe is ready to be used to make the world better for our clients. We hope to have a more definitive result and further comments on commercialization to present at the conference.

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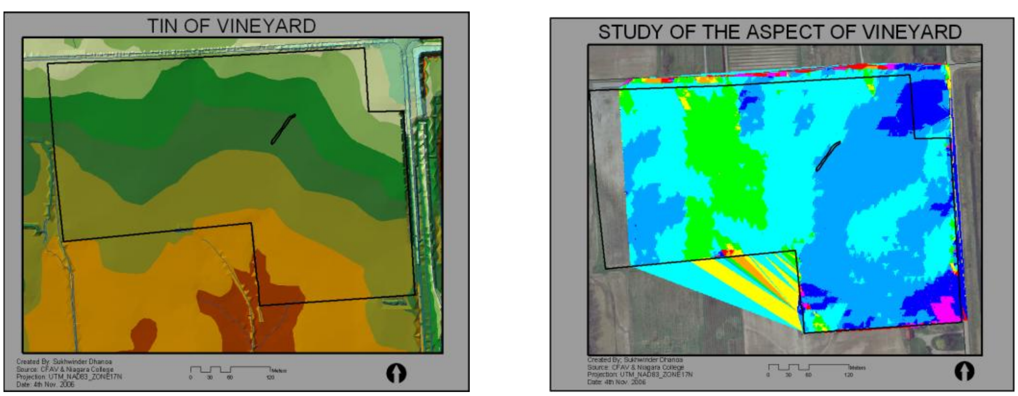
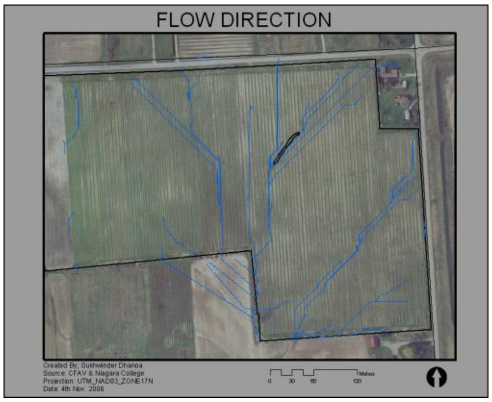
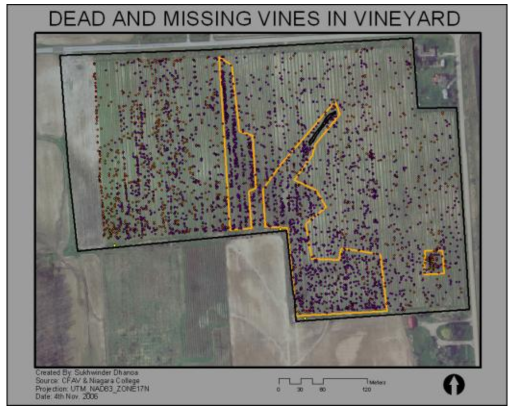
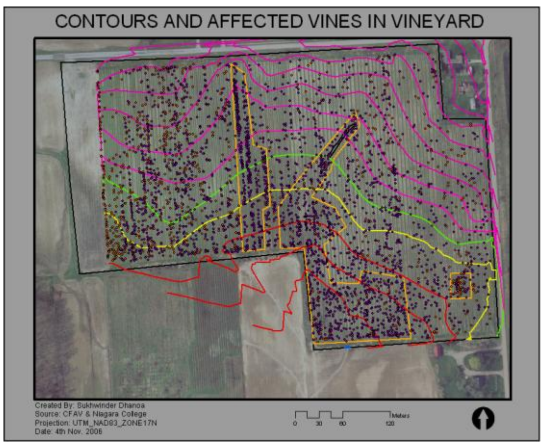


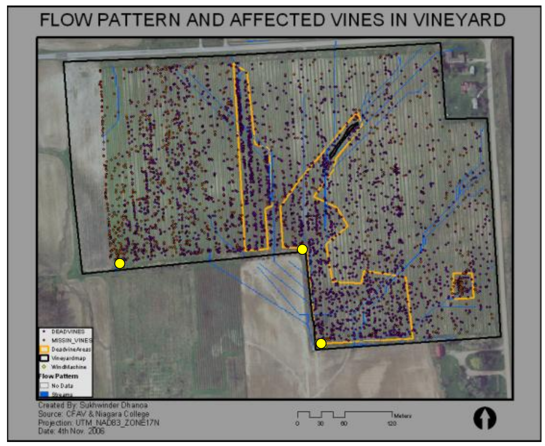
Figures 1a.and 1b. The TIN (elevation) of vineyard ranges from 175 meters (red bottom) to 191 meters (light green at the top). Slope of the aspect: green – slopes southeast; blue - slopes southwest; greenish-blue – slopes south. There is a V-shaped valley in the vineyard.



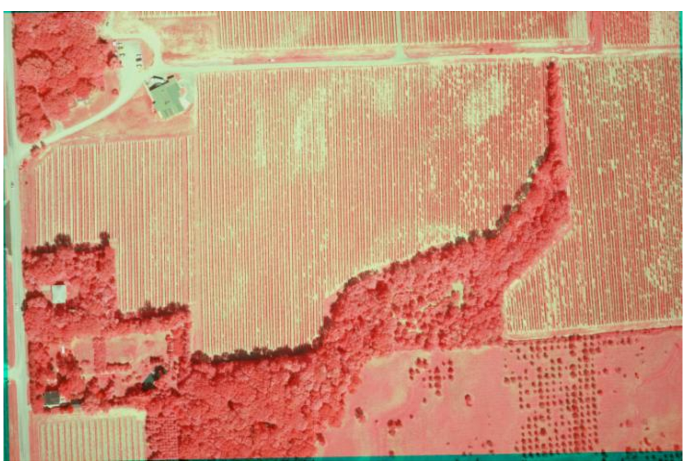


Figures 1c. and 1d. Flow direction of water and cold air and location of dead and missing vines.





Figures 1e and 1f. Here we discovered a soil drainage as well as cold air drainage problem. Location of wind machines suggested at south-west corner, middle corner, and south central corner (Yellow dots in 1f).



Figures 2a and 2b. 2a. Aerial image at high spatial resolution – visible & near-infrared imagery are obtained for grape canopy observation. 2b. Geo-referenced image links GPS location for decision making (blocking, managing, harvest planning, etc… note that rectangular blocks are for illustration only.)

Figure 2c. The user (consultant or vineyard manager) can input or extract spatial information from the imagery including area, length, location, missing vines, etc.

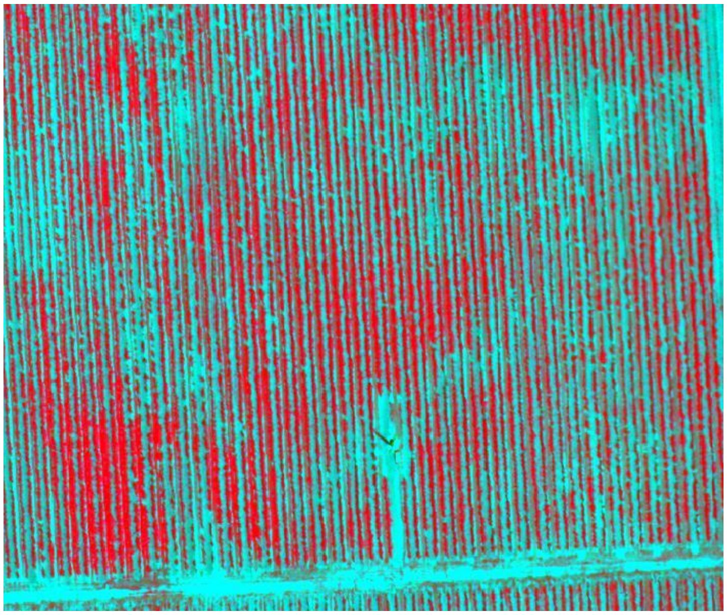


Figure 2d. Processed layers precisely show the location of: canopy problems (freeze damage, irrigation problems, water stress, wind machine effectiveness), wind machine zone of influence, potential positioning of new machines, factors affecting plans for replanting, requirements for direct scouting activities of problem spots, where to spray, do maintenance operations, and plan sampling for brix and harvesting to maximize production of reserve quality wine.