Airborne remote sensing of vines for canopy variability and productivity

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Grape yield-mapping in numerous districts of Victoria and South Australia, completed in the 1999 and 2000 vintages, demonstrated significant (some as large as between 4- and 10-fold) variations in yield within single vineyards (Bramley & Proffitt, 1999; Bramley, 2001). Limited data suggests the locations of high- and low-yielding zones within vineyards may be stable in time, and that soil structure/condition appears to play an important role in this (Bramley et al, 2000). When confronted, post-harvest, with information concerning spatial variability in productivity, a natural question of vineyard managers is whether there was something that could have been done during the growing season to identify these regions, if not to direct some mid-season management, then at least tell them where to look as part of their routine vineyard sampling.

Airborne remote sensing is being used as a means of identifying areas of differing levels of plant vigour in many agricultural crops (Lamb, 2000) because in many cases, especially "uniform-cover" crops like wheat and canola, plant vigour is often directly linked to productivity. However, little use is being made of the technology in the grape and wine industry. This is likely because vines are a row crop and the extraction of biophysical data from images is more complex than from images of uniform-cover crops. In uniform-cover crops, different levels of plant vigour are often manifested as differences in the crop density which can be identified from the relative contributions of the spectral signatures of the crop and underlying soil. Generally, a region of healthy crop has high biomass and that particular region in an image is total crop signature. Conversely a weak crop has lower biomass and has a greater component of underlying soil signature mixed in with the crop signature since the crop canopy is very thin if not non-existent. Grape vines, however, express vigour not only in terms of the density of the canopy, but also in the spatial extent of the canopy itself. In uniform-cover crops, often the crop biomass is quite strongly related to crop yield, and this forms the basis of many yield prediction services available to growers. However, the relationship between spatial variations in vine vigour and spatial variations in vine productivity (yield and quality) is not quite as straight forward and little in the way of outcomes have been reported in this area.

Like any crops, remote sensing of vines has the potential to identify and map specific factors that influence vine vigour, provided the physical characteristics of growing vines such as canopy size, leaf density and leaf pigment (hitherto referred to as vigour indicators) are directly attributable to those specific factors. In practise, there are many long term and transient factors which may influence vigour, including soil water and chemical status (linked strongly to soil physical characteristics), pests and diseases and hail damage etc. Long-term causes of variability in vine vigour indicators such as the influence of soils may be manageable by whole-season strategies of irrigation, nutrient applications etc. However, transient causes of variability such as pests and diseases (Phylloxera is one in particular attracting considerable attention), faulty irrigation equipment (blocked or broken tubes/sprinklers) or hail/rain damage are all examples where managers may require timely information of location and extent. Importantly, establishing links between remotely-sensed canopy vigour indicators and vine productivity would offer managers an insight into spatial variability in productivity in the forthcoming vintage. All of these elements are the subject of a detailed investigation by the Cooperative Research Centre for Viticulture (CRCV).

Spectral signatures in the vineyard

Remote sensing systems, in particular those used for acquiring images in visible light and/or near infrared wavelengths, utilise the sunlight reflected off ground targets, in this case vine canopies, covercrops and soil. The amount of sunlight reflected off a target is described in terms of the target's reflectance profile. In figure 1 the spectral reflectance profiles for Cabernet Sauvignon vines, underlying covercrop (chick-peas) and bare soil are given. These profiles indicate the amount of sunlight these targets reflect as a function of the wavelength (or colour). Here relative reflectance may be converted to percentage of sunlight reflected my simply multiplying by 100. All photosynthesising plants, including vine canopies and covercrops, do not reflect much light in blue or red wavelengths because chlorophylls (and related pigments) absorbs much of the incident energy for the process of photosynthesis. However these targets reflect a significant amount of light in the green wavelengths, again due to chlorophylls and related pigments, and this is why such targets appear green when viewed by the human eye. However, in the near infrared wavelengths (wavelengths greater than about 700 nm) photosynthesising plants reflect large proportions of the incident sunlight (in excess of 65%). These wavelengths, to which the human eye is insensitive, are capable of being detected by appropriate instruments. The amount of sunlight reflected in these wavelengths is very sensitive to leaf cell structure and this is influenced by water content. An instrument capable of measuring leaf reflectance in both visible and near infrared wavelengths is therefore an instrument sensitive to changes in leaf pigment (influenced by plant/leaf chemistry and water content) as well as leaf cell structure. Figure 1 also illustrates that soil, covercrop and vine leaves have different reflectance properties, especially in the infrared wavelengths. It is therefore possible to discriminate soil from covercrop and vine leaves based on these differences.

Remote sensing basics

Remote sensing defines any activity that involves measuring parameters from a distance (as opposed to proximal sensing). In the traditional context this involves combining some measurement of the spectral characteristics of a target with its spatial characteristics, ie forming an image. One comparatively cheap class of remote sensing instrument is that which forms an image of a target onto a 2-D array of sensors as contained in a digital video camera. An image is then stored as an array of pixels where the pixel size is governed by the distance between the sensor and the target. As depicted in figure 2, the further the sensor is away from a target the greater the area of ground covered in each image. However, given there is a fixed number of image-forming pixels in an image, this results in each individual image pixel covering a larger area too. A consequence of this is a reduction in spatial resolution. Conversely, the closer the sensor is to the target, the smaller the overall image coverage, but now smaller features on the ground can be distinguishable from neighbouring features, ie an increase in spatial resolution.

Multispectral imaging instruments form an image of a target in a small number of separate wavebands (typically 2-4), therefore carrying both spatial and spectral information. Computers readily combine these wavebands to form composite-colour images, for example as depicted in figure 3. By having the colours recorded separately it is therefore possible to compare relative amounts of each colour and hence use this information to discriminate features by differences in their spectral signatures in those particular wavebands. Furthermore, different image wavebands can be combined in mathematical equations tailored to discriminate features such as plant vigour or biomass. In an example where a sensor records an image of a target in both red and near infrared wavebands, the normalised difference vegetation index (NDVI), an equation linked closely to vigour/biomass in a target, can be calculated where

$$\text{NDVI(pixel)} = \frac{\text{near infrared(pixel)} - \text{red(pixel)}}{\text{near infrared(pixel)} + \text{red(pixel)}}$$

Such a calculation is performed on every individual image pixel using the near infrared and red wavebands of the stored image. An example of an NDVI image is given in figure 4.

What is the best spatial resolution ?

The false-colour and NDVI images of the Cabernet Sauvignon block in figures 3 and 4 have a spatial resolution of 20 cm and a coverage of 1.7 Ha. These images have sufficient spatial resolution to show clearly the individual vine rows. Close examination of these images, in particular the NDVI image, shows some regions where the vine canopy appears thinner, for example the top-right quadrant of the block. However, quantifying the difference in vigour/biomass that our eye perceives in this imagery is difficult since vine vigour manifests itself as differences in canopy size and density- both of which are affecting the spectral signature detected by the sensor. Figures 5 (a), (b) and (c) are images of the same vineyard block at different spatial resolutions; 20 cm, 1 m and 3 m, respectively. The vine row spacing in this block is 3 m. Following figures 3 and 4, the 20-cm resolution image shows clear detail of the vine rows and, importantly, note the inter-row spacing is effectively all shadow thereby masking any small changes in covercrop signature resulting from different covercrop/soil densities. Even with the covercrop obscured, one is confronted with the need to take into account different canopy widths as well as spectral signature (the latter manifested in the NDVI value) when identifying regions of high or low vigour. When the spatial resolution is decreased to 1 m (figure 5(b)), a large proportion of the row detail is missing, and aliasing occurs (diagonal lines running from top-left to bottom-right in the block) due to the regular nature of both the vine rows and the lines of image pixels. Nevertheless, the region of lower vine vigour/biomass in this block becomes clearer as vine and inter-row spacing (shadows) signatures are now being combined in larger pixel footprints. When the spatial resolution of the image is now decreased to 3 m, matching the 3-m vine row spacing, the individual rows and adjacent inter-row spaces are now merged into each 3m x 3m image pixel and each pixel carries information about both canopy density and size (figure 6). The NDVI image of figure 5 (c) clearly shows regions of differing vigour (density and canopy size).

Can spatial variations in vine vigour point to spatial variations in productivity ?

Figure 7 now shows the 3-m resolution NDVI images of the Cabernet Sauvignon block acquired at flowering, veraison and immediately prior to harvest. In all images there appear regions of vastly differing levels of vine vigour. In figure 8, the veraison image is compared to a yield map of the same block generated from a simple (1st-order polynomial bilinear) surface interpolation involving 60 point measurements of vine yield (kg grapes per vine). A reasonable level of visual correlation exists between the veraison vigour image and subsequent vine yield map. Indeed an examination of figures 5 and 7 suggests the veraison image to have the closest visual correlation with the yield map. This is not surprising given that canopy, root and trunk development rates slow considerably after veraison in favour of a significant increase in the rate of grape development (Jackson 1994). In short, the vigour of the canopy at veraison could conceivably provide a snap-shot of the level of subsequent grape development to be expected at each location within the block. A detailed investigation of these data, and indeed similar data acquired from an additional three other vineyard blocks in currently in progress.

The way ahead

Airborne images of vineyard blocks do show regions of varying levels of vine vigour as expressed by canopy density and size. Extracting such information may be quite complex if data such as canopy dimensions, density, leaf-health are required separately. However, if such data can be simplified by integrating canopy vigour indicators then relatively low-resolution imagery of vineyard blocks may prove useful not only for indicating levels of vine vigour throughout a vineyard, say as a means of assisting in vine management against pests and diseases, but if acquired at the right time in the growing season, such as veraison, may provide an insight into vine productivity variations within vineyard blocks too.

It is likely, however that more detailed information extracted from the higher-resolution imagery will only improve possible links with not only yield but also quality indicators. This is the subject of a PhD project within the CRCV (a component of Project 1.1.1, Precision Viticulture). This particular project aims to find the most appropriate parameter(s) to extract from imagery which can be used to correlate with traditional vine biophysical, grape yield and grape quality indicators. Candidates under investigation include vine canopy size (feature size), peak pigment concentration (peak spectral indicator) and total pigment signal (feature size x spectral indicator).

In the meantime, this particular research does move towards answering the question of "What can simple processing of multispectral imagery provide in the form of highlighting zones of differing vigour/biomass and even productivity" ?

References

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Lamb, D. W. (2000). The use of qualitative airborne multispectral imaging for managing agricultural crops– A case study in south eastern Australia, *Aust.J.Exp.Ag.* **40** (5): 725-738

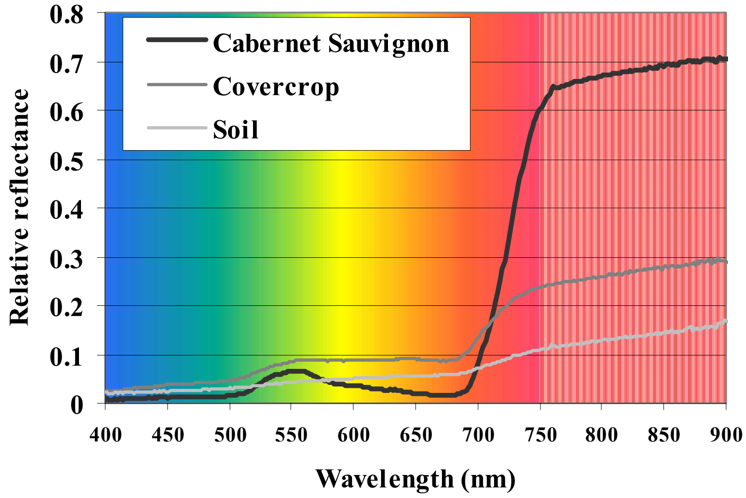


Figure 1. Spectral reflectance profiles for Cabernet Sauvignon, covercrop (chick-peas) and exposed red-brown soil. (Percentage of reflected sunlight = 100 x Relative reflectance). Data acquired from Charles Sturt University's vineyard in Wagga Wagga, NSW.

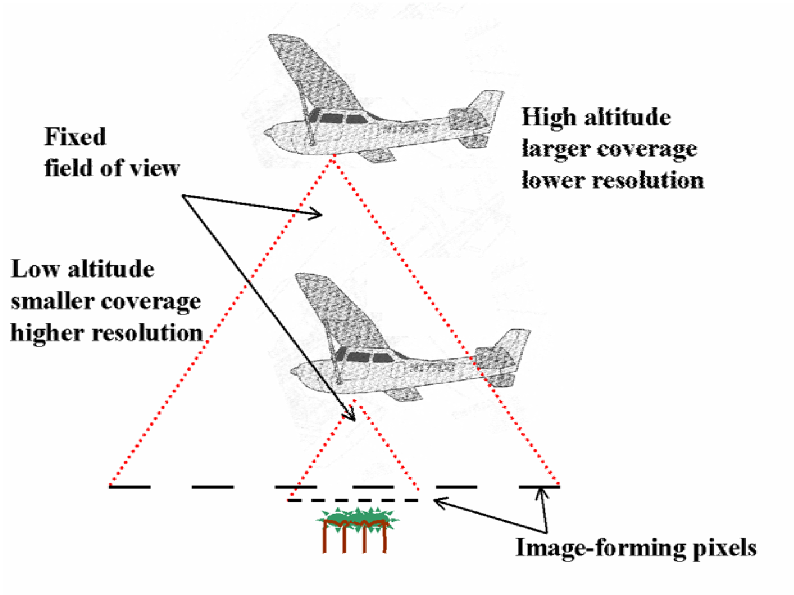


Figure 2. The coverage and spatial resolution of an imaging instrument is governed by sensor altitude above ground. The closer the sensor to the target, the smaller the coverage but the more image-forming pixels per surface area (greater spatial resolution).

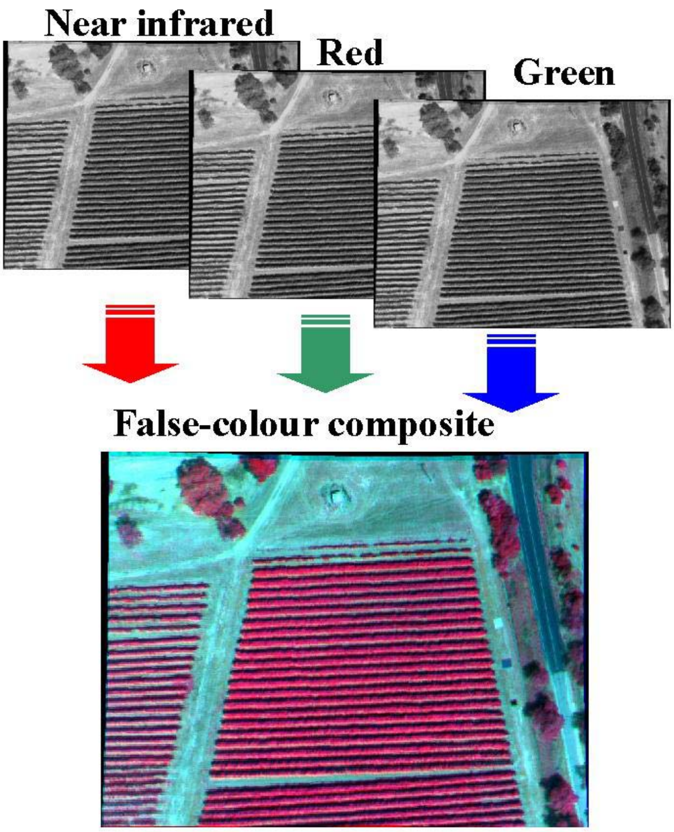


Figure 3. Composite images (here a standard "false colour" image comprising near infrared, red and green images) are generated when multiple bands are combined. In false colour images, red signifies a strong near infrared reflectance and blue/green a weak infrared reflectance. The red portions of this image are healthy vigorous vines while the blue/green regions are bare soil/dead grass.

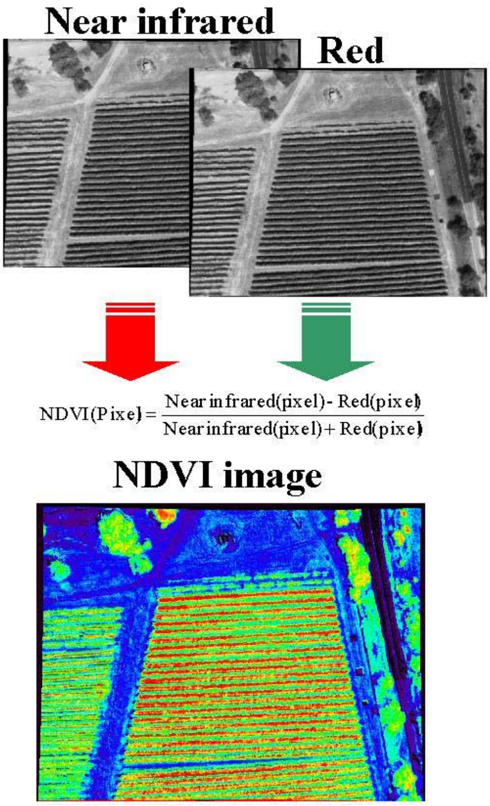
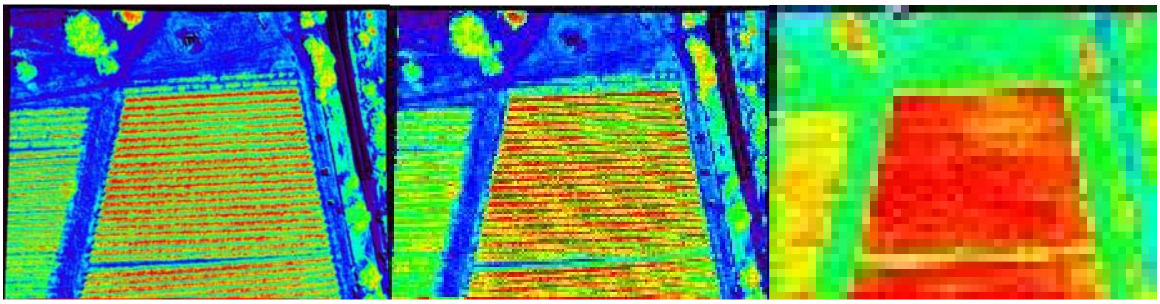


Figure 4. NDVI image, here in pseudo-colour, calculated from infrared and red images. Here red is ascribed to high values of NDVI (corresponding to most healthy/vigorous vegetation) and blue to low values (corresponding to least vigorous vegetation/dead grasses and soil).



(a) (b) (c)

Figure 5. NDVI images of a Cabernet Sauvignon block with different spatial resolutions. (a) 20 cm, (b) 1 m, and (c) 3m. Vine row spacing = 3 m.

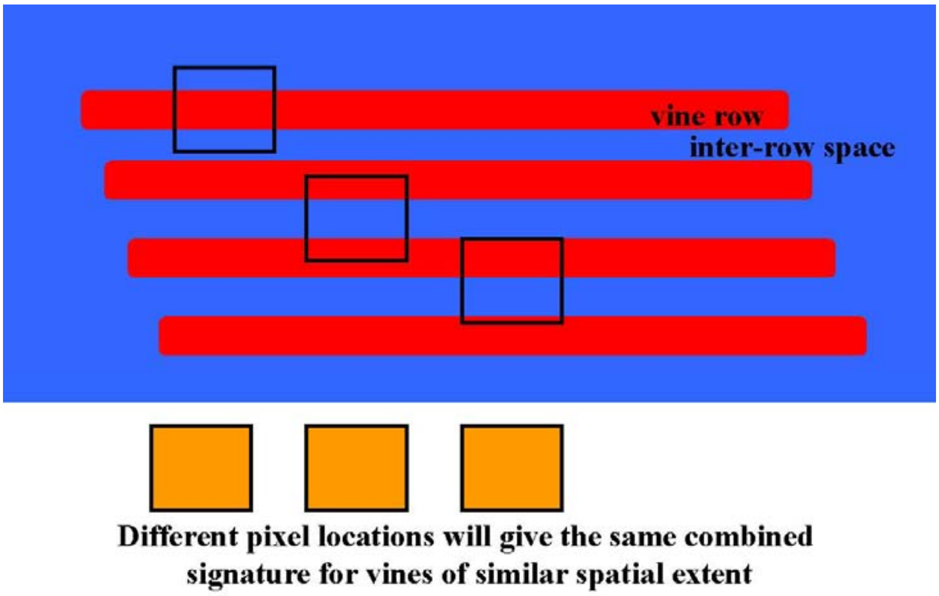


Figure 6. Synthetic NDVI image of a block of vines having the same spatial characteristics and vigour. Pixels with dimensions equal to the vine-row spacing will have the same values regardless of where they lie relative to vines or inter-row gap.

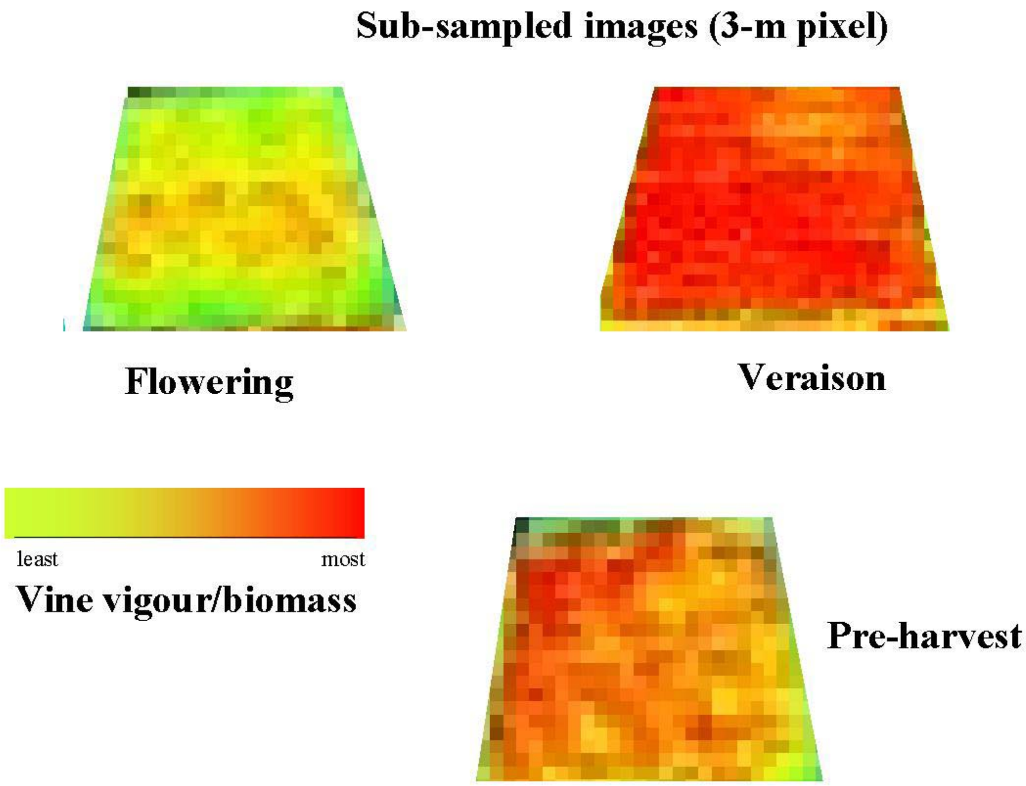


Figure 7. NDVI images (3-m pixel) of a Cabernet Sauvignon block acquired at three different stages of vine development; flowering, veraison and immediately prior to harvest.

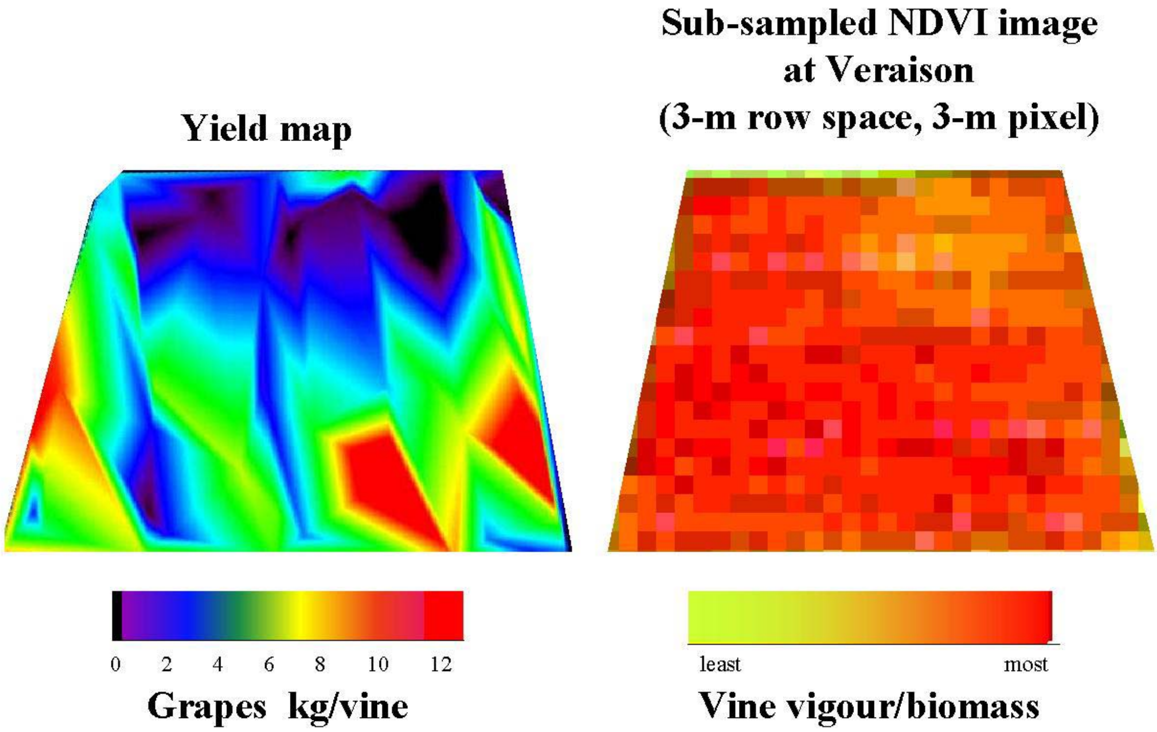


Figure 8. NDVI image (3-m pixel) of a Cabernet Sauvignon block acquired at veraison and the subsequent yield map generated by interpolating (simple 1st-order) hand-harvested yield data sampled from 60 points within the vineyard.