POTENTIAL OF HIGH RESOLUTION AIRBORNE VIDEOGRAPHY FOR RAPID ASSESSMENT AND MONITORING OF VEGETATION CONDITIONS IN AGRICULTURAL LANDSCAPES

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ABSTRACT

Timeliness and up-to-date information on the status of different landscape components are a key issue for decision makers, land planners and farmers involved in the adoption of remedial measures to ameliorate land degradation and increase profitability in agricultural areas. Rapid access to these data can be achieved via an information management system capable of integrating various data types for assessment and monitoring. But, to be useful to farmers and land planners, the system should offer simple, easy to use, image products for monitoring crop and soil conditions, the impact of phenomena such as hail or frost, weeds, soil variability and the effect of fertilisers or spray applications at a paddock level.

Accordingly, this paper examines the potential of airborne videography as a remote sensing tool in a project aimed to develop a rapid and cost-effective system for assessing and monitoring the conditions of crops, native forest and re-vegetated areas in the agricultural region of Western Australia. This implies a close examination of existing techniques for low cost/high resolution data capture, as well as identifying value-added products easy to be used and understood by farmers and land planners interested to know where and why field variations occur in their paddocks. Mapping the occurrence of such variations would enable farmers to identify the causes of variability and to decide on appropriate management practices to correct the problem, if it is economically feasible.

1 INTRODUCTION

Timeliness and up-to-date information on the status of different landscape components such as soils, crops, pastures, native forest and re-vegetated areas are a key issue for decision makers, land planners and farmers involved in the adoption of remedial measures to ameliorate land degradation and increase profitability in agricultural areas. Rapid access to these data can be achieved via an information management system capable of integrating various data types for assessment and monitoring. To be of real utility to farmers and land planners, the system should offer simple, easy to use, image products for monitoring crop and soil conditions, the impact of phenomena such as hail or frost, weeds, soil variability and the effect of fertilisers or spray applications at a paddock level.

Rapid image turnaround and near-real time delivery of information are critical to retrieve pertinent crop and soil information relevant to farm management (Moran *et al*., 1997). For instance, decisions on optimum times to spray or to fertilise need to be taken within a short time span (e.g. usually not longer than a week). Additionally, high value crops have critical times during which they need frequent coverage to identify and minimise crop stress conditions. To this end, digital airborne video systems delivering multispectral, metre- or sub-metre resolution imagery of agricultural fields have a unique role for monitoring seasonally variable crop and soil conditions, and for time-specific and time-critical crop management. Current multispectral Earth observation satellites, with fix revisiting cycles, coarse temporal (e.g. not better than 16 days) and spatial resolutions, are unable to cater for these monitoring needs. Although conventional aerial photographs offer flexibility in data acquisition, high temporal and spatial resolution, they present two drawbacks: a) lack of spectral resolution and b) hardcopies that requires scanning of the films to enable data processing and analysis in a digital environment, which in turn implies longer times in data availability.

Airborne videography emerged in the 1960s and early 1970s, with works by Robinove and Skibitzke (1967) and Mozer and Seige (1971), but it was not before the 1980s that main research and operational applications in mapping and resource management began (Mausel *et al*.,1992; King, 1995). Airborne videography has been tested and applied for detection and mapping of crop types and conditions, including weed infestation and diseases, and the effect of soil salinity (Richardson *et al*.,1985; Wiegand *et al*., 1994; Cloutis *et al*., 1996; Wiegand *et al.*, 1996). Other applications in agricultural areas include identification of site-variability in cropped areas (Yang and Anderson, 1996; Moran *et al*., 1996). These works have demonstrated the potential of DMSV as a non-invasive and rapid method of generating geo-referenced maps that helps, for instance, the control of GPS-equipped mobile weed spraying or fertilizing units, or the identification of areas within a field that need different treatments in order to improve yields. Forestry applications of videographic data comprised prediction of habitat complexity (Coops and Catling, 1996); mapping forest species (Everitt *et al*., 1986; King and Vlcek, 1990, Thomasson *et al*., 1994), detection of signs of stress and structural damage in natural and revegetated areas (Levesque and King, 1996 and 1999).

Accordingly, this paper examines the potential of airborne videography as a remote sensing tool in a project aimed to develop a rapid and cost-effective system for assessing and monitoring the conditions of crops, native forest and re-vegetated areas in the agricultural region of Western Australia (Metternicht *et al*., 1999). This implies a close examination of existing techniques for low cost/high resolution data capture, as well as identifying value-added products (e.g. vegetation indices) easy to be used and understood by farmers and land planners interested to know where and why field variations occur in their paddocks. Mapping the occurrence of such variations would enable farmers to identify the causes of variability (e.g. waterlogging, insufficient fertilisers, weeds, etc.) and to decide on appropriate management practices to correct the problem, if it is economically feasible.

2 METHODOLOGY

Remote sensing of changes in vegetation condition requires knowing the spectral behaviour of the landscape components of interest in the range of the spectrum the sensor gathers information (e.g. the visible and near-infrared for the DMSV system). Likewise, it is important to know what constitutes remote sensing evidences of vegetation damage, and what are the effects on spectral reflectance (Murtha, 1978), so that techniques to interpret and assess the condition of vegetation can be derived. Thus, the research approach comprises: a) Identification of crop, pasture and native forest stress indicators that can be used as early signs of changes in condition; b) Selection of test sites and on-ground assessment of the condition of remnant vegetation, crops and pastures; c) Acquisition of the digital multispectral video data; d) Creation of a spectral library of the main land cover types; and e) Correlation between indicators of change and the digital multi-spectral video bands, and vegetation indices.

2.1 Identification of changes on vegetation condition using remote sensing

2.1.1 Evidences of physiological and morphological changes: changes in plant morphology (e.g. defoliation, stunted growth, loss of branches in trees, cellular collapse) are indicated by variations in texture and shape, whereas physiological changes such as decrease in photosynthesis, deterioration of chloroplasts, interruption of translocates including water, are associated with changes in spectral reflectance patterns. Because morphological damage affects spectral reflectance only when new surfaces are exposed (e.g. increased shadow component in the vegetation canopy), they are better described on the basis of form, texture and boundary patterns (Murtha, 1978).

A generalised spectral reflectance curve of a healthy plant shows a peak in the green (500 to 600 nm) region and a lower level reflectance in both the blue (400 to 500 nm) and red (600 to 700 nm) regions, and a considerably higher level of reflectance in the near-infrared (700 to 900 nm). Chlorophyll and other leaf pigments (e.g. carotene, xanthophyll) absorb light energy in the blue and red regions of the spectrum and reflect in the green (Hildebrant, 1976, Murtha, 1978, Curran, 1985). The high reflectance of vegetation in the near infrared is dominated by the internal structure (cell walls) of the vegetative materials. Variations in water content in the vegetation further influence the overall ‘height’ of response curves beyond the chlorophyll absorption band at 650 nm (Harrison and Jupp, 1989). Although the exact levels vary according to the plant and its surrounding characteristics, it is the deviation from this generalised curve from which changes in vegetation conditions may be detected.

Remote determination of chlorophyll content constitutes a useful tool for detection of physiological states and stress in plants (Gitelson and Merzlyak, 1996). Chlorophyll content in leaves changes throughout the different stages of plant development, with the content of leaf pigments being affected by exposure of terrestrial vegetation to various kinds of natural (e.g. water stress, senescence, waterlogging, soil salinity), and anthropogenic stresses (e.g. release of toxic substances such as heavy metals into the soil, herbicides) as reported in previous works by Carter (1993 and 1994) and Gitelson and Merzlyak (1996). Investigating the responses of leaf spectral reflectance to plant stress agents of biological (e.g. plant competition, senescence) and physicochemical (herbicide, salinity, ozone) origin, Carter (1993), found the visible (e.g.535 to 640 nm, 685 to 700 nm) rather than infrared reflectance, to be the most reliable indicator of plant stress.

An early indication of deteriorating plant health is a decrease in the actual wavelength at which reflectance increases between red and near infrared. This change is called the 'red shift' and occurs before a change in condition is visible in the plant itself. But since the shift occurs over a very small spectral range it requires very narrow spectral channels for detection (Harrison and Jupp, 1989). Continuing chronic damage causes deterioration of the chloroplasts (e.g. yellowing of the foliage) perceived as a shifting of the green peak towards the red wavelength. The final generalised change is the reddening of the dead foliage, accompanied by a continuing shift of the visual peak towards red (Murtha, 1978).

2.1.2 Interpreting variations in the vegetation condition using vegetation indices. Based on the positions of the spectral bands relative to the spectral features mentioned above, specific band ratios and indices can be applied to assess the conditions of vegetation in agricultural landscapes. An advantage of using ratios is the normalisation of data, reducing the influence of illumination conditions, topography, etc. Discrimination of crop growth and plant status (e.g. disease, crop nutrient deficiency, water stress) is generally accomplished by computing a ratio or linear combination of visible and near-infrared reflectance such as the done in the NIR to red ratio (VI), the normalised difference vegetation index (NDVI), the soil adjusted vegetation index (SAVI), and other indices for chlorophyll assessment such as proposed by Gitelson and Merzlyak (1994a, 1996), Carter, (1994). Thorough reviews of vegetation indices can be found in (Cohen, 1991; Jackson and Huete, 1991; Moran *et al*., 1997;).

The responses of land cover to four vegetation indices, namely plant pigment, photosynthetic vigour, plant cell density and normalised difference vegetation index are assessed in this study. Three indices use the green region (550 nm) as a 'reference' band because of its lower soil-green vegetation reflectance contrast, as mentioned by Tucker (1977). The indices are described hereafter:

a) The plant pigment ratio: $PPR = (R550 - R450) / (R550 + R450)$ (1)
This index produces an output image where strongly pigmented foliage present a high PPR (i.e., a light tone in a grey scale), while weakly pigmented foliage has a low PPR, thus appearing dark. The higher the pigmentation in the leaves, the stronger the absorption in the blue band, translated as lower digital numbers in this channel. Conversely, weakly pigmented leaves, absorbing less energy, will present higher reflectance values in this band.

b) The photosynthetic vigour ratio: $PVR = (R550 - R650) / (R550 + R650)$ (2)
This index is high for leaves or green canopies with strong chlorophyll absorption, that is, photosynthetically very active, with strong absorption of energy in the red band; and low for weakly active vegetation. The use of this ratio may be compared to the observation of yellowing off of plants with nutrient deficiency or under stress due to some plant diseases, or with onset of senescence. In a grey-scale image, this index will show light values for photosynthetically very active vegetation, darkening as the chlorophyll content of the vegetation canopy decreases (e.g. chemical stress, plant senescence).

c) The plant cell ratio: $PCR = (R750 - R550) / (R750-R550)$ (3)
This ratio measures the quantity of leaves in a pixel and the density of healthy plant cells in the leaves, as the response of vegetation in the NIR is dominated by the cells' structure. Thus, for instance, moderately sparse distribution of very healthy plants may show a PCR similar to a dense distribution of plants with less leaves and/or less healthy cells in the leaves. In a grey scale image, the healthy plant tissues will reflect strongly in the NIR, exhibiting light grey values. Deterioration of the plant cell structure will translate in darker image values.

Moreover, Gitelson and Merzlyak (1996) report this index as a good indicator of chlorophyll contents in yellowish-green to dark-green vegetation. They found the reflectance near 700 nm and in the range from 530 to 630 nm to be highly sensitive to chlorophyll variations. Thus, taking into account that the range of $(550nm)^{-1}$ is directly proportional to chlorophyll, and that the NIR region virtually does not depend on chlorophyll, they developed a so called 'green NDVI' to assess chlorophyll contents.

d) The Normalised Difference Vegetation Index: $NDVI = (R750 - R650) / (R750 + R650)$ (4)
This index is said sensitive to vegetation parameters such as green leaf area index, and percent of the ground surface covered by green vegetation (Jackson and Huete, 1991). The index represents the aggregation of two phenomena, the high reflectance in the NIR due to healthy plant cells, and the low reflectance in the red region due to chlorophyll absorption (Honey, 1997).

2.2 The test site

The flat to slightly undulating Toolibin catchment area, selected as the test area for this study, lies between latitudes 32°40' and 33°S and longitudes 117° 20' and 118°E, and is situated 240 km south east of Perth city, in the SW of Western Australia. The 44,760 hectares are dominated by dryland agriculture base on crops such as wheat, barley, oats, lupins and canola, and pastures mainly for sheep. Small stands of remnant native vegetation occupy around 15% of the catchment (Baxter, 1996). As result of the extensive clearing of natural forest for agricultural purposes by settlers at the beginning of the 1900s, the area is being affected by incipient salinisation problems.

The climate is Mediterranean with cool wet winter growing season and warm to hot summers. Rainfall varies from 375 mm in the eastern section of the catchment to 425 mm in the west part of the catchment. The catchment lies within the 'Zone of Ancient Drainage' described as broad flat valleys of low gradient with salt lake chains at their lowest points, gently sloping valley sides, some rock outcrops and large areas of yellow sandplain.

2.3 Data acquisition

2.3.1 Videographic data: The Specterra Systems Digital Multispectral Video System (DMSV) which captures high resolution images (e.g., resolution ranges from 0.25 m up to 4 m, depending on the flight altitude) of the same area simultaneously through four narrow spectral channels (25 nm) located in the visible and near infrared region of the spectrum was used for this study. The four nominal bands lie close to the principal reflectance spectra features of vegetation:

- Band 1 (blue): the pigment absorption around 450 nm;
- Band 2 (green): the relatively higher reflectance and transmission near 500 nm;
- Band 3 (red): the strong chlorophyll absorption in the 650 – 670 nm range; and
- Band 4 (NIR): the high infrared reflectance beyond the 750 nm.

These bands are registered digitally to produce a single four-band image file. Frames are captured as 740 by 578 line BIP (band interleaved by pixel) image files along GPS controlled flight paths. Each individual frame is geometrically and radiometrically corrected to eliminate camera induced distortions such as a 'zipper' effect across each frame due to the CCD's (charge couple devices) odd-even interlaced field readout mechanism, band to band misalignment and lens barrel distortions.

The DMSV data was acquired on the 16 Septermber 1998, at 2 m resolution over a 2 km wide transect, running 17 km in a northeast-southwest direction, and covering diverse agricultural and natural land cover types, with variations in their conditions. The frames were georeferenced to a digital orthophoto at scale 1:25,000 and a digital mosaic was generated afterwards. The radiometric corrections were carried out using and in-house developed software, based on inversion of a bidirectional reflectance distribution function model (Honey, 1997).

2.3.2 Field data was collected concurrently with the DMSV flight. Color aerial photographs at scale 1:25,000, along with an analogue copy of the cadastre were used for location purposes and land use data recording. The land use investigated included canola, lupins, wheat, pasture and pasture on stubble, that is, paddocks harvested in season prior to 1998. At the time of the data acquisition, most of the crops were in early flowering. The attributes recorded for these land uses were location, height, maturity, and dry weight equivalent (DWE). To determine the dry weight equivalent (DWE), a $1/10^{th}$ m^2 quadrant was placed over three or four sample locations within a paddock in order to gather an average DWE for that land use. The vegetation density was noted for each sample (by visual comparison to the paddock average, in terms of high, medium or low). The samples were cleaned and then oven-dried over 1 or 2 days. The dry vegetation samples were weighed, and the weight recorded in grams per $1/10^{th}$ m^2, that was converted to an average tons/ha, as shown in Table 1.

The average tons/ha resulting for each land use are characteristic values for the study area. Canola, although a tall and dense looking crop, is a very thin plant and most of its weight corresponds to the flowering canopy. Lupins are also a dense looking crop with thin stems. They are seeded at an average density of 40 plants/m^2 in comparison to wheat, which is generally seeded at 100 plants/m^2. The pasture paddocks were not being grazed at the time of field data collection. Pasture in the paddock cropped prior to 1998 was invaded by capeweed, a bright yellow flowering weed (hue color similar to canola crop). The weeds were removed during the drying period, thus decreasing the DWE for that pasture (see table 1). The second pasture paddock provided an expected result for the time of year and current land use management practices.

Table 1: Land use samples and their associated Dry Weight Equivalent

Land use and maturity	Vegetation density	DWE (grams per $1/10^{th}$ $m^{2)}$	Tons/ha	Land use and maturity	Vegetation density	DWE (grams per $1/10^{th}$ $m^{2)}$	Tons/ha
Lupins: early flowering	Low	22.06	2.2	Pasture on land cropped prior to 1998	Low	7.9	0.8
	Medium	40.82	4.1		Medium	24.66	2.5
	High	69.85	7.0		High	36.41	3.6
Canola: Early flowering	Low	9.68	0.97		Very High	46.25	4.6
	Medium	30.77	3.1	Pasture	Low	24.96	2.5
	High	49.24	4.9		Medium	43.82	4.4
Wheat: Early flowering	Low	63.34	6.3		High	56.84	5.7
	Medium	63.68	6.4				
	High	90.95	9.1				

3 EXPERIMENTAL RESULTS

Spectral signatures of the areas sampled in the ground were collected using the SEED function of Erdas Imagine software (ESRI, 1999), with spectral and spatial constraints determine by the user. The standard deviation of the plots in the four bands was, on average, around one. The mean value of the cover types sampled was used to plot the spectral signatures and to extract the image values on the four vegetation indices tested. Vegetation indices were computed using equations (1) to (4) discussed in section 2.1.2, and the output value scaled to 100.

3.1 Spectral signatures

The results are presented according to crop density, crop type and variations in the conditions of crops observed in the field.

3.1.1 Crop density: the spectral signatures of the crops sampled (e.g. canola, lupins, wheat and pasture) show that increase in plant density influence the amount of energy absorbed in the red, and to a lesser extent, the blue bands; while increasing the reflectance in the NIR region (Figure1). Bands 4 and 3 appear to be the more sensitive to changes in crop density. Low density wheat and canola canopies show a very low absorption of energy in the red band, that may indicate low chlorophyll contents. Band 2 appears insensitive to changes in crop density.

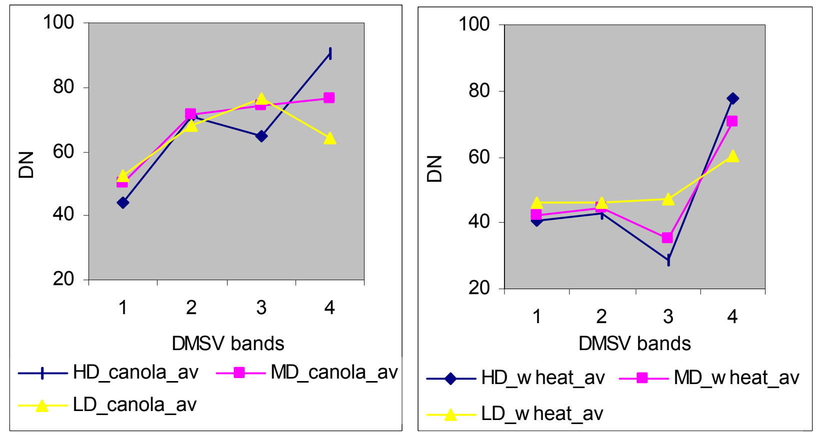
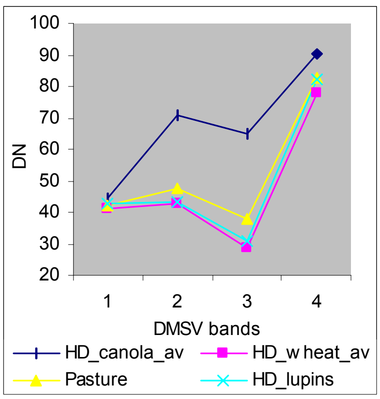


Figure 1: Spectral signatures of canola and wheat crops, as a function of their density (see table 1).



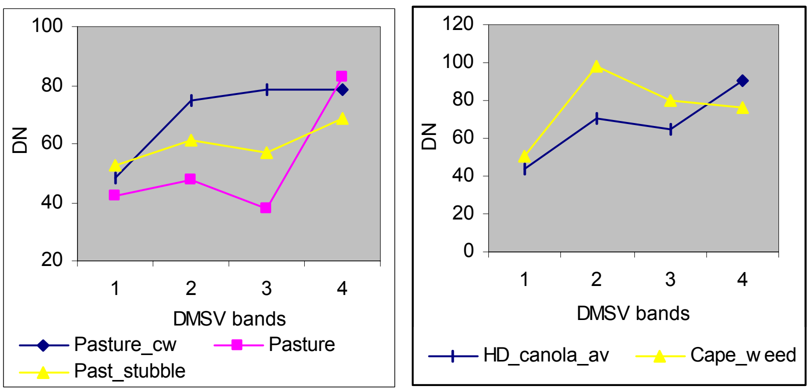


Figure 2: Spectral signature by crop types. Figure 3: Variations in crop conditions and their associated effect on reflectance.

3.1.2 Crop type: Canola paddocks were flowering at the time of the DMSV data acquisition. Thus, the spectral response of the canopy appears dominated by the yellow flowers, evidencing a highly reflective spectral curve, with lower absorption in the red and blue bands that relates to green biomass, as compared to the responses of lupins, wheat and pasture canopies (see Figure 2). The color of the canola flowers also dominates the shape of the spectral curve (which resembles senescent vegetation), with similar amounts of energy absorbed in the green and red bands. Wheat and lupins and, to a lesser extent, pasture show strong absorption in the red band, with a curve shape typical of healthy, photosynthetically active green vegetation (Figure 2). Band 3 shows the best discrimination among crop types.

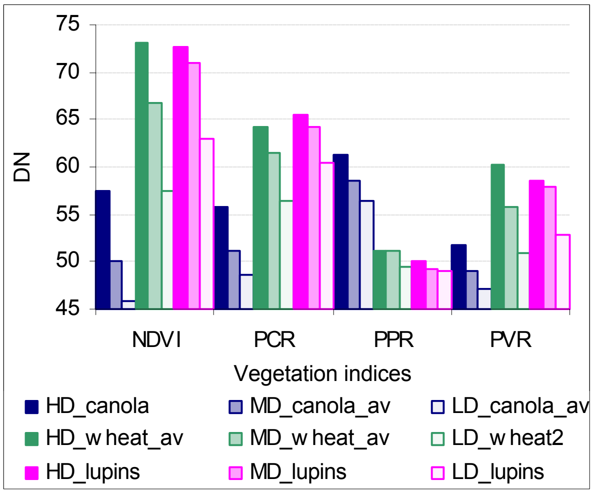
3.1.3 Variations in crop conditions: The inclusion of dead vegetation (e.g. stubbles) decrease the reflectance on the NIR region, while increasing the reflectance in the chlorophyll-related band 3 (Past_stubble in Figure 3). Standing dead vegetation produces a linearisation of the shape of the pasture curve. Capeweed, an invasive plant with yellow flowers, commonly associated to pasture, causes a change in the shape of its spectral curve (Pastu_cw in Figure 3) as well. This change is expressed as a higher reflectance in the green and red bands of the spectrum, due to the yellowish color of the flower.

Both, canola crop and capeweed show a yellowish color in the natural color composites derived using the blue, green and red bands of the DMSV (see Figure 5). It appears that they are spectrally distinct in the green, red and NIR bands, where capeweed exhibits overall higher reflectance values in the visible region of the spectrum, with a decrease in the NIR.

3.2 Vegetation indices

Series of bar graphs were used to compare the digital values of different crop density, crop types, variations in crop conditions in the four indices.

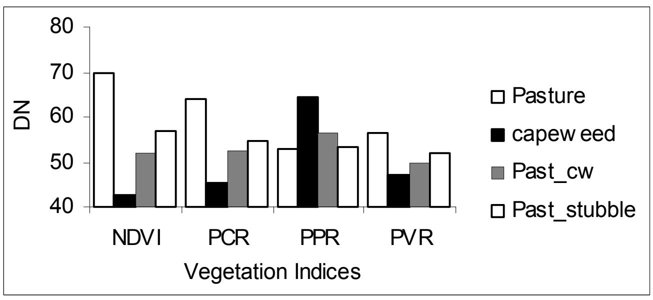
3.2.1 Crop density and type: Figures 4 and 5 compare the performance of the four vegetation indices to distinguish crop density. NDVI and the plant cell ratio (PCR) correlate best with variations in the density of crop canopies and the DWE computed in Table 1. For instance, medium and low density canola, exhibit the lowest NDVI and PCR. Both indices show similar values for high canopy density of lupins and wheat. A comparable relation is shown between canopy density and the Plant Vigour Ratio (PVR), the highest values corresponding to medium and high canopy density of lupins and wheat. The highest PVR, related to healthy, photosynthetically active vegetation, corresponds to high density wheat, while the lowest values are recorded for the yellow canopy of canola.



The strongly pigmented yellow canopy of canola dominates the spectral response of this crop in the plant pigment ratio (PPR). Lupins, wheat and pasture present similar plant pigment ratio.

Assuming that PCR measures the quantity of leaves in a pixel, it is expected the index to show low values for canola canopy, mostly composed of flowers, in comparison to the higher amount of leaves present in the canopy of wheat and lupins (see Figure 5). Figure 5 also shows that in all indices the lowest values correspond to native forest. Patches or isolated trees of remnant of native forest (e.g. eucalyptus and mallee trees) are clearly distinguished in all indices, suggesting that semi-automated procedures for their identification and mapping could be developed in the future.

3.2.2 Variations in crop conditions. Figure 6 shows that presence of capeweed or standing dead vegetation affects the spectral response of pastures in the four indices. Clear evidence is shown in the plant pigment ratio, where the index value of pasture increases as result of the invasion of capeweed (see Past_cw in Figure 6). The chip corresponding to the PPR of pasture in Figure 5, shows an elongated red line in the bottom right and isolated red spots in the lower left corner of the image. Ground verifications showed these to be capeweed, exhibiting higher pigmentation than pasture (Figure 6).



Conversely, the presence of capeweed and standing dead vegetation decreases the digital values of pasture paddocks in the plant vigour ratio that relates to photosynthetically active vegetation.

This findings suggest that plant pigment ratio (PPR) may be used to derive 'weed maps' helping the farmers to identify the spatial distribution, and roughly the density, of invasive plants in their crops. But further research is needed to confirm whether this would apply to a wider range of weed types, as well as earlier stages of plant development.

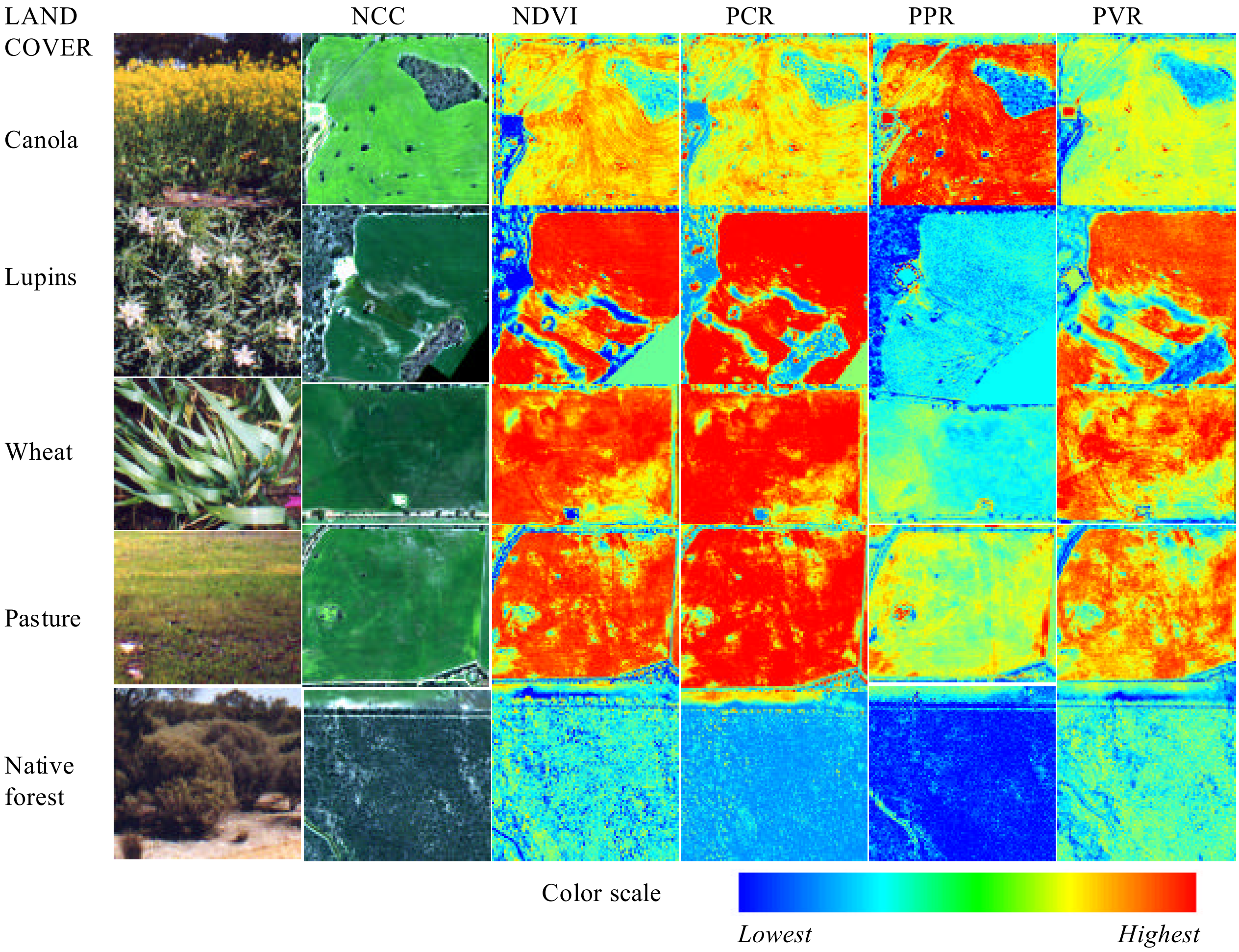


Figure 5: Chips illustrating the ground conditions and image outputs of natural color composite (NCC bands 3,2,1), the Normalised difference vegetation index (NDVI), the Plant Cell Density Ratio (PCR), the Plant Pigment Ratio (PPR) and the Plant Vigour Ratio (PVR), discussed in section 2.1.2. The lowest ratio values correspond to a blue color, while red relates to the highest values recorded for a particular index (or ratio).

4 FINAL REMARKS

Mapping and analysing variability in field conditions, and linking such spatial relationships to management action, places high resolution multi-spectral videography and GIS applications at the cutting edge of agricultural production. The ultimate goal of managing field variability is to reduce costs and increase production levels, while improving environmental benefits. To this end, high resolution video data can reduce the amount of field data collection, such as laboratory analysis of soil fertility or the use of yield meters required in precision farming. These data are generally costly , and therefore could be limited to management units pre-defined on the video imagery. Preliminary results of using DMSV data indicate:

- high accuracy for discrimination of high-value crops in the agricultural region, such as canola and lupins,
- within-field identification of crop variability due to, for instance, the presence of dead standing vegetation and weeds,
- a good correlation between the plant vigor ratio and canopy densities, and the plant pigment ratio and weed distribution in pasture paddocks;

- remnant native vegetation, either isolated trees or elongated patches along roads, are clearly distinguished in all indices and color composites. Further research is needed to evaluate the possibility of discriminating amongst species and their conditions.

Although the results are promising, there are several issues that need further investigation. Firstly, optimal time of data acquisition to identify changes in crop conditions that may affect yield (e.g. weeds, deficiency of fertilisers), so that timely image products can be deliver to the farmers for the adoption of remedial measures. Secondly, further analyses to correlate canopy density and dry weight equivalent to variations in the spectral bands used in this study.

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