Predicting plant available water by remote and proximal sensing

David Mitchell[1], Alan Palmer[1], David Duncan[2], Ian McGowen[3] and Jayne Jenkins[1]

[1]NSW Department of Primary Industries Trangie NSW 2823, Australia. Email: tonya12@tpg.com.au
[2]AGnVET Services Warren 2827/Sustainable Soil Management Warren NSW 2827, Australia.
[3]NSW Department of Primary Industries Orange NSW 2800, Australia.

Abstract
This paper explores the possibility of using relatively easily obtainable remotely sensed data such as electromagnetic induction, radiometrics, and air photo to assist in the prediction of plant available water for crop management decisions. The paper focus on readily obtainable remotely sensed data and demonstrates how the method of hand drawn polygons can be used to identify zones within the paddock that show some relative uniformity. Soil moisture can then be measured with the zone and extended across the zone with some understanding of the variation.

Key words
precision agriculture, EM 31, soil moisture

Introduction
Soils in the western plains of NSW, an area bounded by Dubbo, Nyngan and Coonamble, vary at a regional, farm and paddock scale. This region is also characterised by seasonally and spatially variable rainfall. The major soil types in this area have traditionally been grouped into red soils and grey soils and managed accordingly. The majority of the soils in the red soil group are hard setting, low plant available water content (PAWC), and can be sodic. However interspersed within this group is a range of soils with higher PAWC, non-hard setting and non-sodic. Compounding this variability is the presence of grey soils that range from the physically intractable with severe production constraints to some of the most productive soils in the district (McKenzie 1992).

In the past grain growers in this area have ignored this within paddock soil variation when they measured moisture or applied fertilizer. They have instead managed the paddock as a single entity. However this whole field management has now become viewed as inefficient with possible over application of inputs in areas of low production and sub optimal application in areas of higher production.

There is high spatial variation of grain yield in this region which is primarily due to variation in plant available water content of the soil (PAWC). This variation in PAWC is a product of the variability in soil, rainfall and nutrition. However the quantification of the spatial variation of stored soil moisture has not been addressed possibly due to the high number of measurements this would require. It is however reasonable to suggest that the spatial variation in soil moisture would be reflected in the spatial variation in crop response and yield. If reliable predictions of plant available water were available to grain growers this would greatly assist grain growers in this area to make more informed management decisions. They for instance could change inputs to better match the yield potential of the site, or delay sowing in areas within the field until further rain.

Grain growers are being encouraged to measure stored soil moisture at the beginning of the growing season to assist in estimation site seasonal yield potential. However due to the variable soils in this area this measurement may not be reliable. If however remote sensing can identify zones of similar properties then growers could then measure soil moisture at representative points in the paddock. The measurement of soil moisture would be could be more reliably extrapolated over the identified similar zone.

Remote sensing offers a relatively cheap method to capture spatially dense, geo-referenced data. This data may then relate to a biophysical property in the paddock. There are many forms of remote sensing some include surveys from ground borne frequency domain electromagnetic induction (EMI) instruments such as a Geonics™ EM 31 or a Geonics™ EM 38; radiometrics; a measure of the natural background gamma radiation signature from potassium, thorium and uranium from the earth's surface, and aerial photography in which areas of different surface soil colour can be distinguished.

Over the last 10 years in Australia there have been commercial agricultural services offering surveys of apparent electrical conductivity, usually by a Geonics™ EM 31. Government agencies offer spatial data such as air photo for land management purposes, and air borne geophysical surveys are available to assist with mineral exploration. The latter type of data is usually gamma radiometrics, gravity and magnetics. Maps of the grain yield from previous harvests are also available. As well as these measurements a direct sensing tool that measures soil strength, a single tyne dynamometer has been developed at Trangie Agricultural Research Centre, this instrument measures the strength of the soil by sensing the draft forces that act on a singe tyne as it passes through the soil at a known depth (100 mm).

The question posed was can this relatively readily available remotely sensed data be used by growers to assist in the prediction of plant available water?

The first step in using the remotely sensed data for the prediction of PAWC in the paddock was to define zones of similar properties eg ECa, yield or soil colour. Whelan and McBratney (2003) suggests several methods to define management zones from remotely sensed data such as hand drawn polygons, supervised and unsupervised classification of remote sensed imagery, areas of yield stability across seasons at fixed locations using statistical methods, fuzzy multivariate cluster analysis using seasonal yield maps, morphological filters or buffering, spectral filters using Fast Fourier Transform, multivariate analysis by hard k-zones. In this study management zones were defined by hand drawn polygons around areas that represented areas of a contiguous remotely sensed parameter.

Development of management zones by hand drawn polygons around zones that are representative areas provides a simple method to delineate management zones. It can be done in conjunction with a farm advisor, who can provide a technical input into the process, and the grower who may have a more intimate knowledge of the paddock. The map provides a focal point for discussion on the various factors that may influence the data.

Hand drawn polygons may not be suitable for every layer or for every type of remotely sensed data. Data that is derived from deeper in the profile may not present an obvious features, and hand drawing polygons over relies on the eye to select areas of contiguous data and this method may be highly subjective. If the paddock was extremely variable and no obvious feature dominated then this method may not be suitable. In such a situation large homogenous zones that are not contiguous may be subsumed by smaller areas that are homogenous and contiguous. However, this method presents itself as an initial starting point for more detailed analysis.

Methodology

Five fields in the western plains of NSW were selected to be part of this study. Site 1 Waverly is approximately 40 km south of Trangie NSW on a Bugwah formation back plain gilgai soil type (Hulme 2003), a Grey Vertosol (ASC 2003); site 2 Claremont is approximately 5 km west of Nyngan on a Marra Creek formation meander plain soil type (Hulme 2003), a Red Kandososl (ASC 2003); and site 3 consisting of three contiguous fields is located on Trangie Agricultural Research Centre (TARC) on a Trangie formation meander plain (Hulme 2003) soil type, a Red Chromosol (ASC 2003). All sites are zero till with stubble retained with controlled traffic permanent wheel tracks. For brevity only the data for the Waverly site is presented.

A 250 metre soil sampling grid was developed using the Trimble Pathfinder Office software. The points were identified by eye as approximately 250 m equidistant from each other, recorded as waypoints. The waypoints were uploaded into a Trimble TDC1 datalogger attached to a Trimble ProXL GPS linked to a Fugro Omnistar demodulator that provides differential corrections to the GPS. In the field the waypoints were located using the GPS and soil sampled.

The Waverly site was soil sampled to a depth of 1.5 m using a 3 point linkage hydraulic soil corer mounted on a tractor. The soil sample was divided sub sampled in to 8 intervals, 0-100 mm, 100-300 mm, 300-600 mm, 600-900 mm, 900-1200 mm and 1200-1500mm. The other two sites were sample to a depth of 600 mm and divided into depths of 0-100 mm, 100-300 mm, 300-600 mm.

Immediately after the soil sample was extracted from the sampling tube it was laid on a PVC pipe cut length ways and then divided into the respective depths. The soil was transferred to labelled jars and sealed. The container was then weighed and then oven dried at 105^{o} C for 48 hours then reweighed and the gravimetric soil moisture content was determined.

A Geonics™ EM 31 coupled to the Trimble ProXL GPS described above was mounted perpendicularly on the front of a four wheel motorbike approximately 1 m of the ground. The EM 31 was mounted with the dipoles in the vertical position. The bike was driven approximately 20 km hour. Transects were driven approximately 20 m apart along the existing controlled traffic tramlines. The GPS logged the EM31 data approximately every second.

The following air photographs were obtained from the NSW Department of Lands archive (LPI 2004) Waverly (Photo 55 run 3), TARC (Photo 9 run 7), Claremont (Photo 141 run 2). An unsupervised classification of the air photograph based on soil colour was performed in ARC View.

A single tyne dynamometer was built at Trangie Agricultural Research Centre (Kelly and Reeder 2000) was towed behind a 4WD vehicle at a constant speed of 15 km hours. The draft forces were logged to a computer in conjunction with the measured GPS position.

Yield maps were obtained by the participating co-operators. The Waverly yield map was produced by a John Deere Greenstar™ yield monitoring and mapping system.

A geo-referenced ternary tagged image format file (TIFF) of the Northern Parkes Sheet of total counts of potassium, uranium and thorium was obtained from the NSW Department of Mineral Resources (DMR 1995). The study sites were located by loading the image file into a GIS and overlaying the paddock boundary files.

Maps of gravimetric soil moisture, apparent electrical conductivity (ECa), soil strength and yield were generated in SURFER™ using the default griding settings. A map of the data was generated for with contours set at minimum, 25 th, 75 th centile and maximum values.

The paddocks were divided into zones by hand drawing polygons on a map. The polygons represent area of similar value of the remotely sensed data. This map was then compared by eye to the map of the measured gravimetric soil moisture.

Results

Waverly

The false colour bare soil photo showed two very prominent zones, one that included the red oblong zone in Figure 1. This area corresponds to an area of soil within the paddock that has a very prominent surface red colour. The rest of the field is combination of shades of soil from grey through to red. The patches of green on the photo are thought to be shadows caused by gilgais in the paddock. Two zones were defined from the photograph (Fig. 1), one around the prominent red oblong zone and the other zone was determined to be the rest of the field.

The EM31 survey data measured an apparent electrical conductivity range from 70 mS/m to 195 mS/m (Fig.2). The 25 percentile corresponded to 124 mS/m and the 75 centile was 148 mS/m. The mapped data shows that there is a large area in the centre of the map that is relatively uniform with the top and bottom of the map showing some variation in ECa (Fig.2). Two zones were defined from the EM31 survey (Fig 2), one around the uniform zone and the other, the rest of the field.

The data obtained from the mineral exploration database consisted of individual maps of the counts of potassium thorium and uranium as well as a ternary image of the three elements. The ternary image was examined however due to the wide line spacing of the original survey very little information could be generated. However the prominent red area noted in the bare soil photograph can be distinguished by the four brown coloured pixels in the north west of the image (Fig 3). This area was classified as a separate zone (Fig 3)

The data measured by the single dynamometer showed some variation, the obvious stripes in the data were originally thought to be an artefact of the direction of travel; however an additional survey was completed with the direction of travel perpendicular to the first survey (not shown). This data also reveal this stripping pattern. The deep red near the bottom of the map is an area the co-operator deep ripped in April 2004. It shows up as an area of low strength. The data revealed that similar to the other remotely sensed data that the area of prominent red surface colour had less variable soil strength than the rest of the paddock. This area was classified as a separate zone (Fig 4)

Figure 1 Aerial photograph Waverly

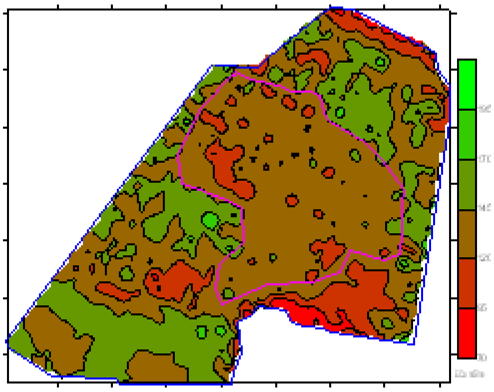

Figure 2 EM 31 Survey (mS/m) Waverly

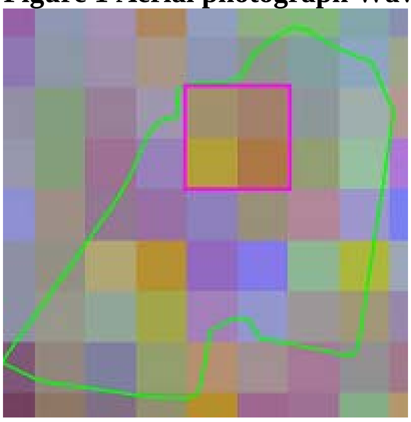

Figure 3 Ternary image (K U Th) Waverly

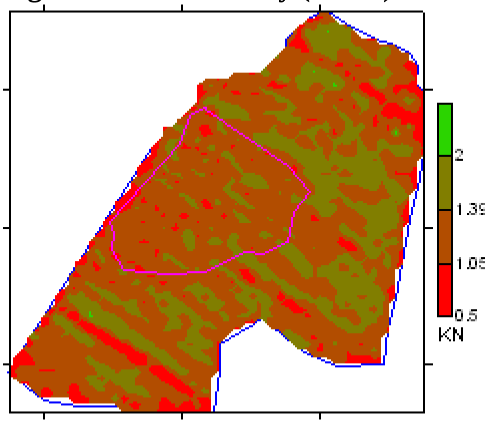

Figure 4 Soil strength (kN) Waverly

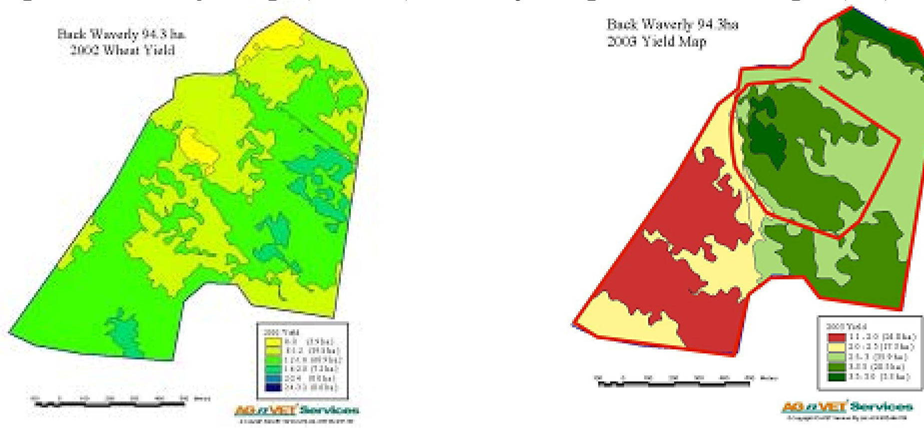

Figure 5 Wheat yield (t/ha) 2002 and 2003 Waverly

The yield maps for the 2002 and 2003 seasons from the Waverly site shows high variation in the measured wheat yield for both years 2003 (Fig.5). The yield data for 2002 showed the area associated with the very prominent surface red colour was the lowest area of yield, conversely this area had the highest yield was in 2003 (Fig. 5). This data was used to locate a zone around this area described (Fig. 5).

The measured gravimetric soil moisture data reveals the area described by the prominent surface red colour in the aerial photograph corresponds to the area of lowest gravimetric soil moisture content (Fig 6).

The measured gravimetric soil moisture content varied from 0.125 g/g to 0.175 g/g. The 25 th centile was 0.138 g/g and the 75 th centile was 0.159 g/g.

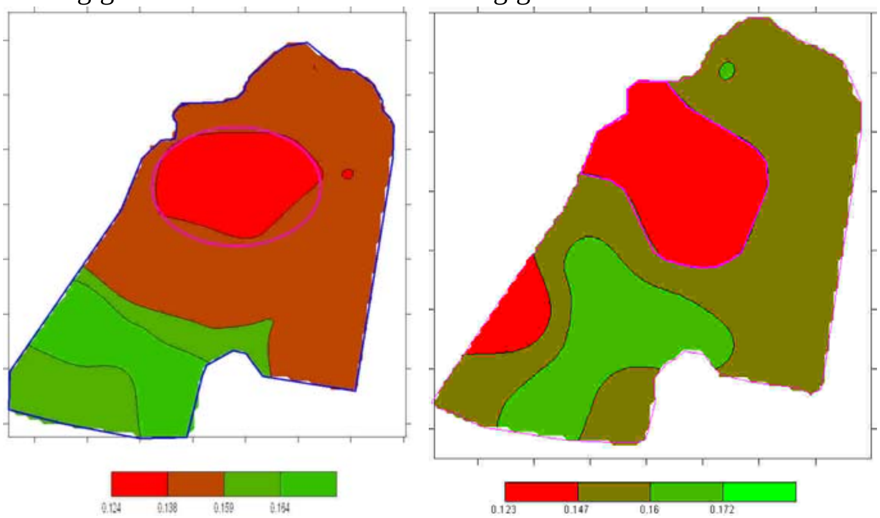

Figure 6 Gravimetric soil moisture content 0-100 mm 100-300 mm Waverly May 2004

The zones and field boundary were extracted from the data maps and the individual maps were compared by eye (Figs 7-14). It can be seen that all the remotely sensed data has some value in predicting the areas of similar gravimetric soil moisture content.

The best predictor of soil moisture appeared to be the aerial photography (Fig 7) and yield (Figs 11-12) then the draught measurement (Fig 10) and the radiometric data (Fig 9). The zones developed from the two yield maps (Figs 11-12) predicted the zones defined by the soil moisture well. Both the yield data sets suggest that the prominent area associated with the different soil type can exhibit high temporal variability in yield. As discussed above the area can oscillate between an area that produces highest in field yields (Fig 5) and lowest in field yields (Fig 5).

The EM 31 over predicted the zone of similar gravimetric soil moisture content (Fig 8) for the shallower measurement (0 -100mm) (Fig 13). The EM 31 appears to better predict zones of similar gravimetric soil moisture (Fig 8) for the deeper (100-300 mm) moisture (Fig 14), although the area the instrument did predict encompassed the same area as the other remotely sensed data. This is probably due to the response depth of the instrument. McNiell (1980) reports that due to the coil spacing of the EM 31 there is little response of the EM 31 to surface soil properties. The peak signal response of the EM 31 with the dipoles in a vertical orientation is 0.4 times the coil spacing or 1.44 m (McNiell 1980).

There is reasonably good agreement between the zones defined by the aerial photograph and the zones defined by the measured gravimetric soil moisture content. The 2003 yield map also shows quite good agreement with the measured gravimetric soil moisture content.

Initial management zones

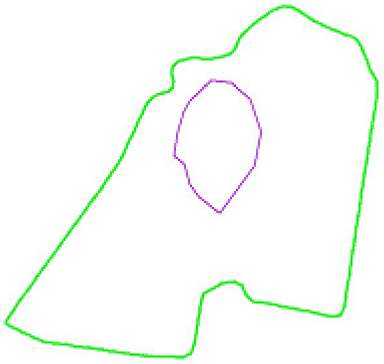

Figure 7 Zone developed from air photo

Figure 8 Zone developed from EM 31

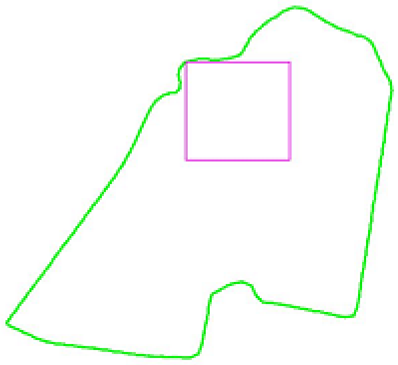

Figure 9 Zone developed from radiometrical data

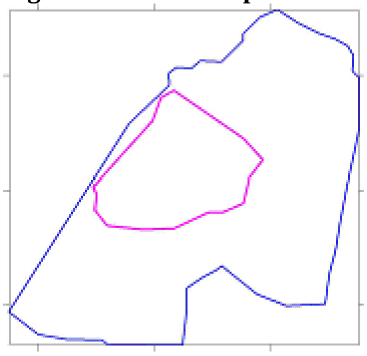

Figure 10 Zone developed from draft measurements

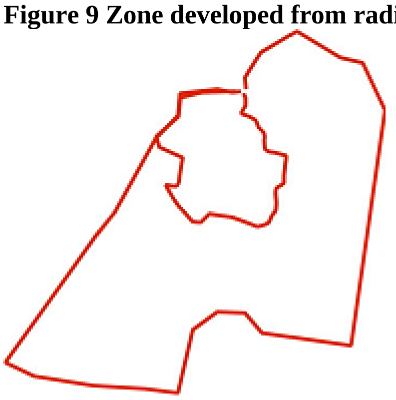

Figure 11 Zone developed from 2002 yield data

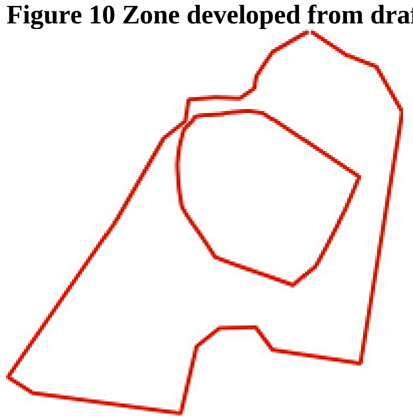

Figure 12 Zone developed from 2003 yield data

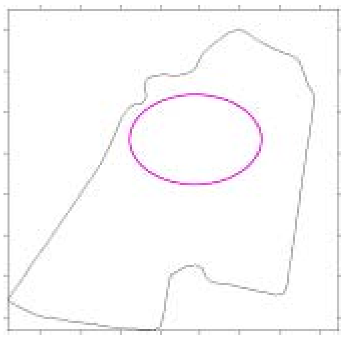

Figure 13 Zone developed from gravimetric soil moisture 0-10 mm

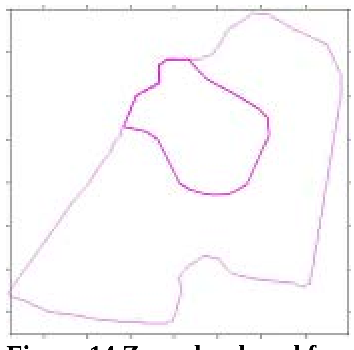

Figure 14 Zone developed from gravimetric soil moisture 100-300 mm

The analysis completed above suggests that aerial photography offers the greatest potential to define management zones and in turn predict plant available water. The addition of other data layers does not add any additional precision to the prediction; however the additional data layers provide supporting evidence to justify the prediction made. Alternatively a statistical analysis would provide objective evidence of the relationship between spatially distributed soil properties and soil moisture. The authors are currently exploring the use of co-kriging to assist in the prediction of soil moisture.

Conclusions

There is a wide range of remotely sensed data available for use in farm management decisions. This study has shown that if this data is coupled analysis, measurement of soil properties and yield data zones of similar gravimetric soil moisture content can be predicted. Grain growers then may be able to use this information to make more informed management decisions. This technique offers some potential to assist grain growers to obtain representative measurements of soil moisture. However this method does not take the place of a statistical analysis but can be used as an initial starting point to direct such an analysis.

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