The role for EM mapping in precision agriculture in the Mallee

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Abstract

This paper investigates eelectromagnetic induction (EM) mapping in terms of its potential to provide cost-effective spatial information for the implementation of site-specific management by Mallee grain growers. EM measurements and soil analysis on 39 Mallee paddocks show that this readily available tool is typically able to map soil variation of importance to yield potential and fertiliser management in the low-rainfall Mallee environment. Strong correlations are common between EM measurements and EC1:5 (median R^2 0.88) and associated soil water content typically at or near Crop Lower Limit (R^2 0.71). An important finding is the stability of EM-based soil maps over multiple seasons and temporal changes in soil water. On the focus field sites, relationships between yield and EM were evident in the dry 2006 and 2007 seasons. Simulated yield responses over a much wider range of season types further indicate the potential benefits of site-specific management, and the role for low-cost EM mapping in the Mallee.

Key Words

Site-specific management, variable rate, electromagnetic induction, adoption

Introduction

The technology that makes precision agriculture and site-specific management feasible is rapidly becoming cheaper and readily available to farmers. The ability to identify and take advantage of any potential benefits of site-specific management is largely dependent on information and the relative cost of that information (Bullock and Bullock 2000). Beyond the technical equipment aspects of precision agriculture and variable rate application, widespread implementation of site-specific management will generally require two key types of information. Firstly, cost-effective spatial information that can identify different land classes that cause substantial and understandable differential responses to management. Secondly, the information needed to determine what management can be implemented on those land classes each season in order to achieve a desired overall economic outcome. Essentially, the latter is no different to what is required for paddock-scale 'land classes', and a similarly diverse range of individual approaches will be used by growers.

Electromagnetic induction (EM) measures the apparent electrical conductivity of the soil. This is influenced by a combination of soil properties including soluble salts, clay content and soil water (see Corwin and Lesch 2005). EM mapping has become readily available to Mallee growers in recent years at costs often below $5/ha, with a number of contractors and agronomy service providers providing EM survey services and the necessary supporting soil tests. Rising fertiliser costs together with greater recognition of the importance of salt-related chemical constraints in determining crop water use efficiency on Mallee soils (Sadras et al. 2002) has led to increased interest in variable rate fertiliser applications and the potential application of EM-derived spatial information for paddock zoning. In this paper we focus on characteristics required for EM mapping to be a cost-effective source of spatial information for Mallee grain growers using tests of reliability, stability and the relationship with key drivers of crop yield.

Methods

EM database

A database of calibrated electromagnetic (EM) surveys from 39 unique Mallee paddocks has been used to gain an overview of the reliability and typical accuracy of EM38 in mapping key soil characteristics. This includes data from the current and previous Mallee Sustainable Farming projects involving EM since 2001 (e.g. O'Leary et al. 2004). Most paddock surveys have been conducted in summer-autumn by commercial contractors using methodology consistent with the industry protocol (see O'Leary et al. 2006). Several (usually 10) soil core locations were chosen post-survey, covering the range of apparent electrical conductivity (ECa) measures across the paddock. At each location a soil core was taken, usually to at least 1m in four horizons with soil $EC_{1:5}$ and volumetric water content being measured on each sample. A point ECa measurement was obtained for each calibration core location. In the analysis, the average $EC_{1:5}$ and total water for the core to 1m were fitted to models of ECa (linear fit to ECa, linear fit to log(ECa) and power fit to ECa.). The measure of fit (R^2) of the best-fitting model was used as an indication of correlation between ECa and $EC_{1:5}$ and soil water, with Root Mean Square Error also calculated.

Focus paddocks

As part of the Mallee Sustainable Farming project, farmer-managed paddocks were EM surveyed prior to the season break in early April 2005 and maps showing ECa variability were produced. Each paddock was extensively soil sampled, including characterization in EM-based zones for plant available water capacity using the pond method for drained upper limit and near-harvest soil measurements for crop lower limit. Point ECa measurements were also taken at each time of sampling with the instrument calibrated at the original reference point. Multiple fertiliser treatment areas running across the extent of the ECa range were applied to paddocks in 2006 and 2007 using farmer machinery. All fertiliser was applied at seeding, consistent with the practices of the farmers at the sites in the seasons presented here. Yield was measured using farmer yield mapping equipment. Results from the most extensively sampled paddocks at Carwarp (Vic.), Cowangie (Vic.) and Loxton (SA) (see also Jones et al. 2008) with typical Mallee dune complex landforms are presented in this paper, with yield results presented from Carwarp.

Yield simulation

To look further at variation in yield potential and response to variable rate N strategies over a wide range of season types, each paddock was classified into 3 EM-based classes, the soils in each characterized, and simulations of wheat yield run using APSIM (see also Whitbread et al. 2008). The areas of each soil class from Low EM to High EM at Carwarp were 65ha, 32ha and 24ha. Yield performance in each of the classes was simulated using weather records from the previous 50 seasons. In the examples presented here, the simulations are reset each year so that soil N and organic matter start at the same (relatively low) levels in each year. Wheat (cv Yitpi) was always sown between April 25 and July 15 with sowing triggered by 10 mm rain over 5 days and at least 10 mm of available soil water in the profile.

Results and Discussion

Reliability of EM mapping

EM mapping is shown to reliably map variables known to influence crop yield potential in Mallee soils. The results from 39 paddocks across the South Australian, Victorian and New South Wales Mallee (Table 1) show that for the median paddock approximately 88% of the variability in $EC_{1:5}$ can be explained by the ECa measurement with an average root mean square error of 0.1dS/m (median paddock $EC_{1:5}$ 0.4 dS/m).

Table 1. Correlations between ECa measurements and EC1:5 and soil water for 39 Mallee paddocks.

	Median R^2	% with $R^2 > 0.7$	% with $R^2 < 0.5$	Median RMSE

$EC_{1:5}$	0.88	87	5.1	0.12 ds/m
Soil water	0.71	51	26	22 mm

It should be noted that the correlation with the soil water present at the time of EM surveying is not necessarily a result of soil water having a large direct influence on the EM signal, but is generally a result of the association between salt and/or texture and residual water content. In additional regression analyses (not presented in this paper), $EC_{1:5}$ alone is shown to explain a dominant proportion of the variation in the EM measurement in the majority of the paddocks. This makes the use of EM to detect temporal changes in soil water across a paddock problematic (see Corwin and Lesch 2003 and description of 'hyper-electrolytic' characteristics by McBratney et al. 2005), however, it does help to explain the stable nature of the EM maps over time.

Stability of EM maps

Examples of the stability of the EM measurement over time with different levels of soil water are shown in Figure 1. EM measurements taken over 2 years later are shown to explain 95-98% of the variation in the original paddock EM survey, with slopes very close to 1:1. This means that the resulting EM maps will appear near identical. The May 2007 measurement was at time when average paddock total soil water content (0-110mm) was considerably higher at each of Carwarp (112mm 2005:156mm 2007), Cowangie (131mm:204mm) and Loxton (132mm:157mm). Using November 2007 ECa measures (i.e. close to Crop Lower Limit) instead of May 2007 ECa values produces R^2 values of 0.97-0.98. Other examples from different sites over different time periods show similar relationships. The correlation of 2005 ECa measures with $EC_{1:5}$ and soil water (at or near Crop Lower Limit) at Carwarp were 0.75 R^2 (EC1:5) and 0.75 R^2 (water), and higher at Loxton (0.93;0.96) and Cowangie (0.96;0.87).

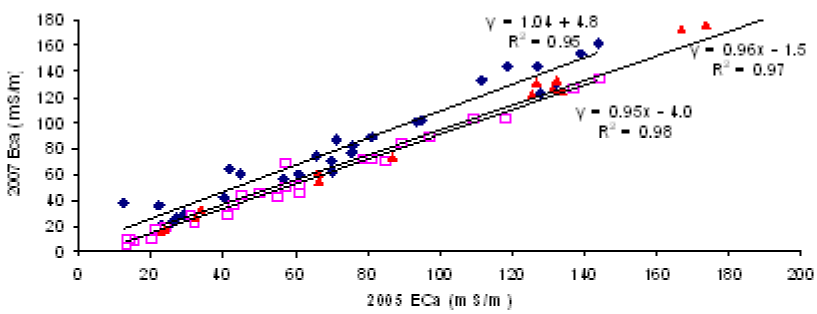

Figure 1. Relationship between ECa values measured in May 2007 (point measures) and April 2005 (values extracted from kriged paddock map) at Carwarp ♦, Cowangie ▲and Loxton □

Relationship with yield

A comparison of ECa and crop yield in 2006 (barley) and 2007 (wheat) at Carwarp together with elevation is shown in Figure 2. Using 3 EM-based classes, in 2007 average yields were 1.32 t/ha in the Low EM class and 0.77 in the High EM class. In 2006 yields were 0.60t/ha (Low EM) and 0.21t/ha (High EM). Both were dry seasons (119mm GSR 2007) with almost no rainfall received in spring during the finish of the crops. In these seasons, the soil characteristics that are typically mapped by EM (texture and salts) have a large influence on yield. The very dry season and the presence of relatively high starting N and P levels in 2007, meant that zero fertiliser was most profitable on all EM-based zones.

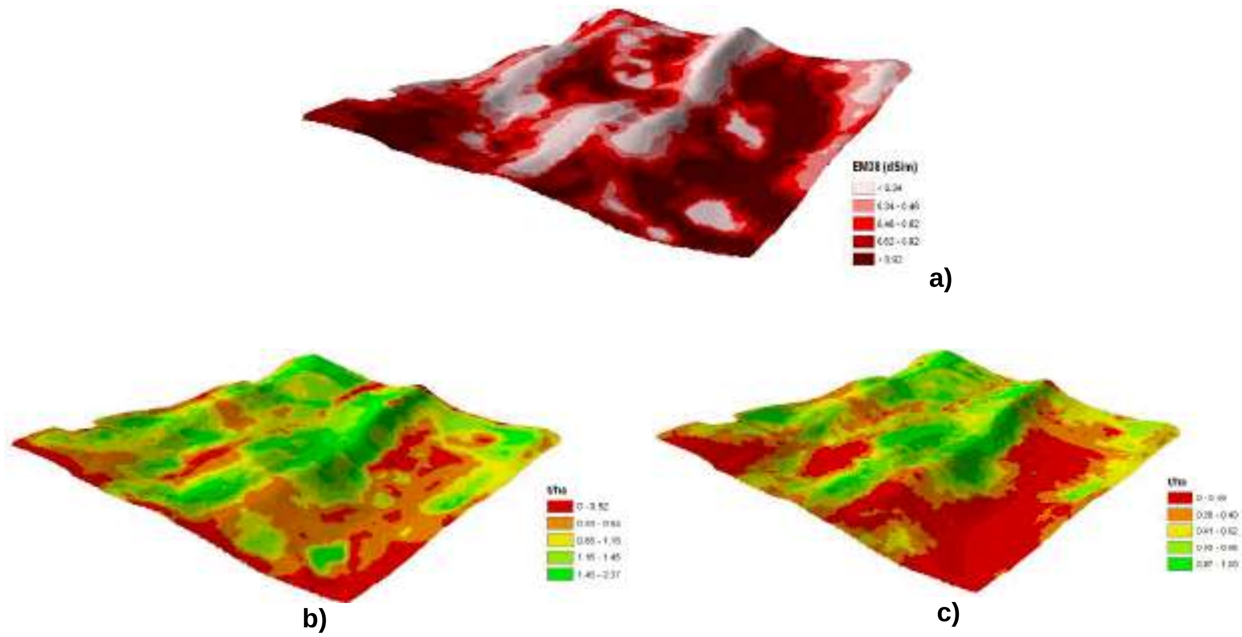

Figure 2. Maps of Carwarp paddock showing (a) ECa (from 2005 EM38 survey); (b) 2007 wheat yield and (c) 2006 wheat yield. Differences in elevation (enhanced) also indicated.

Performance of EM-based zones over a range of season types using APSIM

While the differences in median simulated yield between zones at Carwarp are less than that experienced in 2006 and 2007, over the 50 season types the Low EM zone out-yielded the High EM zone by over 60% (Table 2). Over the 50 simulated seasons there were only 5 years (all with high spring rainfall) in which 'flip-flops' occurred, that is, where the high EM (high subsoil constraint) zone out-yielded the low EM zone.

Table 2. Median wheat yield (t/ha) on EM-based zones from 50 simulated seasons, the potential rooting depth (cm) as determined by sub-soil chemical constraints, and the plant available water capacity (mm) for each zone.

	Carwarp		
	Yield (t/ha)	Rooting depth (cm)	PAWC (mm)
Low EM	1.51	140	107
Medium EM	1.25	110	91
High EM	0.94	60	65

Of most economic interest is whether zonal soil variation justifies variable fertiliser strategies compared to uniform applications. Shown in Table 3 are simple gross margin calculations based on simulated yields for a range of N rates applied to different zones at Carwarp, indicating possible average gross margin gains in each zone from spatially variable N rates. Using the most profitable N rate in each zone (Table 3) would increase average paddock gross margin by $8.50 compared to a flat rate of 30 kg N/ha.

Table 3. Average indicative gross margins ($/ha) over 50 simulated seasons for N rates (kg N/ha) applied to 3 EM-based paddock soil classes.

		Carwarp	
N rate	15	30	60
Low EM	258	292	274
Medium EM	177	196	217
High EM	201	186	171

(nb using gross margins based on $300/t grain, $1.70/kg N; $100/ha non-fertiliser variable costs).

The results support the argument that there is potential for increased gross margins by using variable N rates. Because of the assumptions used in the simulations these should be just seen as an indication of whether differences in the optimal N strategy for each zone are likely rather than an indication of actual optimal N rates in an ongoing rotation. It should also be kept in mind that the analyses presented here have used only relatively crude zoning based only on EM. Incorporation of farmer knowledge of other spatial factors likely to influence yield potential can improve zoning. The results presented here have also only included strategic 'fixed' N rates applied at seeding on each soil class. The potential for tactical N application in response to seasonal information to further improve returns from variable rate application is the subject of further analysis. Further work is also being conducted to compare the cost-effectiveness of EM-based spatial information with other sources such as elevation and farmer 'mud-map' approaches.

Conclusion

EM surveys conducted on a typical Mallee paddock are now low-cost and have a high probability of effectively mapping soil characteristics that are important in determining yield potential. The variation mapped at the time of the survey is likely to be based on relatively stable soil characteristics affecting plant available water and crop yield potential. These levels of reliability (of gaining useful information from investment in mapping) and stability (of the spatial information over a longer term) are important in evaluating the value of EM mapping as a cost-effective spatial information source.

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