

Sodium, chloride, clay and conductivity: consistent relationships help to make EM surveys useful for site specific management in the Mallee

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Abstract

Farmers seek accurate soil property maps so that fertiliser is applied to soils where the crop needs it most, and sensitive crops are sown on suitable soils. In many SE Australian Mallee paddocks, electromagnetic induction (EM) surveys have calibrated well with EC1:5, and to a lesser extent soil water, chloride and boron. To understand the significance of EC1:5 and its relationship to other soil properties, detailed soil physical and chemical measurements were made at four paddocks across the Vic., SA and NSW Mallee with varying calibrations.

Across all samples, soil EC1:5 related almost completely to extractable sodium and soluble chloride ($R^2=99.2\%$). Variation in EC1:5 at low EC1:5 (<0.7 dS/m) was better related to sodium, and at higher EC1:5 (>0.7 dS/m) was better related to chloride. Sodium related to clay content ($r=+0.833$), as might be expected from retarded leaching, but chloride was less well related ($r=+0.690$). Soil water, crop lower limit and boron were best related to extractable sodium ($r=+0.780$, $+0.878$, $+0.875$). Silt, nitrate and sulphate were best related to soluble chloride ($r=+0.377$, $+0.413$, $+0.932$).

These relationships imply that chloride can act as a complicating factor when maps of clay content (and related variables) are sought from EM surveys. Surveys of paddocks with EC1:5<0.7 dS/m will generally map sodium and hence clay content. Good correlations with both soil water and EC1:5 are likely to indicate surveys that are good clay content maps. In paddocks where runoff and differential leaching have disturbed the texture-salt relationships typical of low-rainfall Mallee soils, EM surveys will map salt and not necessarily soil texture.

Keywords

Geonics EM38, soil nitrate, sulphate

Introduction

Farmers are interested in electromagnetic induction (EM) surveys as a method of mapping soils, with the aim of creating a stable 'base' layer to use in fertiliser management, and targeting of sensitive crops to particular paddocks. In many SE Australian Mallee paddocks, EM surveys have calibrated well with EC1:5, and to a lesser extent soil water, chloride and boron. Our current database of EM calibrations (an update of that presented in O'Leary *et al.* 2006) has 42 unique paddocks of greater than 20ha, of which 36 have $R^2>0.7$ for calibration with EC1:5, 18 of these also having $R^2>0.7$ for calibration with soil volumetric water. Only 2 of the paddocks have $R^2>0.7$ calibrations with water and not EC1:5. The observation of good calibrations with EC1:5 and variable calibrations with other soil properties is common in other semi-arid areas, where salt dominates variation in soil conductivity and hence the EM signal (Corwin and Lesch 2003). Calibrations in these areas can be understood in terms of theory relating the EM signal to soil extract conductivity, saturation percentage, bulk density and water content (*ibid.*), but the first two properties are not commonly measured. The key to interpreting Mallee EM surveys for farmer purposes appears to be understanding how the quantity that EM calibrates well to (EC1:5) is inter-related to other soil characteristics that might be of interest. To better understand the interrelationships, particularly with texture, detailed soil physical and chemical measurements were made at four paddocks across the Vic., SA and NSW Mallee with varying calibrations.

Methods

Four paddocks with varying degrees of EM calibration (10 0-1m cores, vertical dipole, best R^2 of linear, log and power fits to apparent EC) with soil EC1:5 ($R^2=0.68-0.97$) and water ($R^2=0.39-0.87$) were chosen from among Mallee Sustainable Farming focus paddocks: Bimbi, Carwarp, Loxton and Pinnaroo. Soil cores to 110cm (0-20, 20-40, 40-60, 60-80 and 80-110 cm horizons) were taken at randomly selected low, medium and high EM locations at each site (3 cores/site) before sowing in 2006, following a dry autumn. The samples were analysed for a range of chemical properties and soil texture. Soil chemical analysis was performed by CSBP Soil and Plant Laboratory, Bibra Lake, Western Australia. Extractable (exchangeable + soluble) cations were measured by the method of Gillman and Sumpter (1986), without initial pre-washing with solutions of ethanol and ethylene glycol to remove soluble cations. Cation estimates will therefore be higher than if only water-soluble cations were measured, but include some of the clay-associated exchange cations that also contribute to soil electrical conductivity. Chloride was measured in a 1:5 soil:water extract. Soil sand, silt and clay fractions were determined using the pipette method, after sieving to remove gravel. Crop lower limit (near-harvest soil core) and drained upper limit (pond method) were measured on cereal crops in 2006. Simple linear correlations between different soil measurements were calculated across the entire sample set, $n=60$, except for crop lower and drained upper limit (two missing samples, $n=58$).

Results

Soil EC1:5, sodium and chloride

Soil EC1:5 is an inexpensive and frequently measured soil test that often calibrates well with Mallee EM surveys and is closely related to total dissolved salts. In this dataset, sodium and chloride made the main monovalent contribution to extractable ions and were highly correlated with EC1:5 ([Table 1](#)). Calcium and magnesium were also numerically important (when displaced from clay particles by barium) but relatively poorly correlated, and potassium contributed little charge and was also poorly correlated.

Most of the variation in EC1:5 was related to variation in sodium below EC1:5 of about 0.7 dS/m ([Figure 1a](#)). Above about 0.7 dS/m, chloride was also related to variation in EC1:5 and the correlation with sodium was noisier ([Figure 1b](#)). Thus variation in EC1:5 is representing sodium at $EC1:5 < 0.7$ dS/m, and chloride in addition above that. The relationship was quite consistent across samples from different paddocks and paddock.depth combinations. A multiple linear regression of EC1:5 on extractable sodium and soluble chloride fitted 99.2% of the variation in EC1:5. The coefficient for extractable sodium, 0.060 dS/m/cmole⁺/kg (se 0.002), was about 40% of the coefficient for soluble chloride, 0.151 dS/m/cmole⁺/kg (se 0.007), reflecting the clay-bound component of sodium charge that does not contribute to EC in a 1:5 soil:water solution.

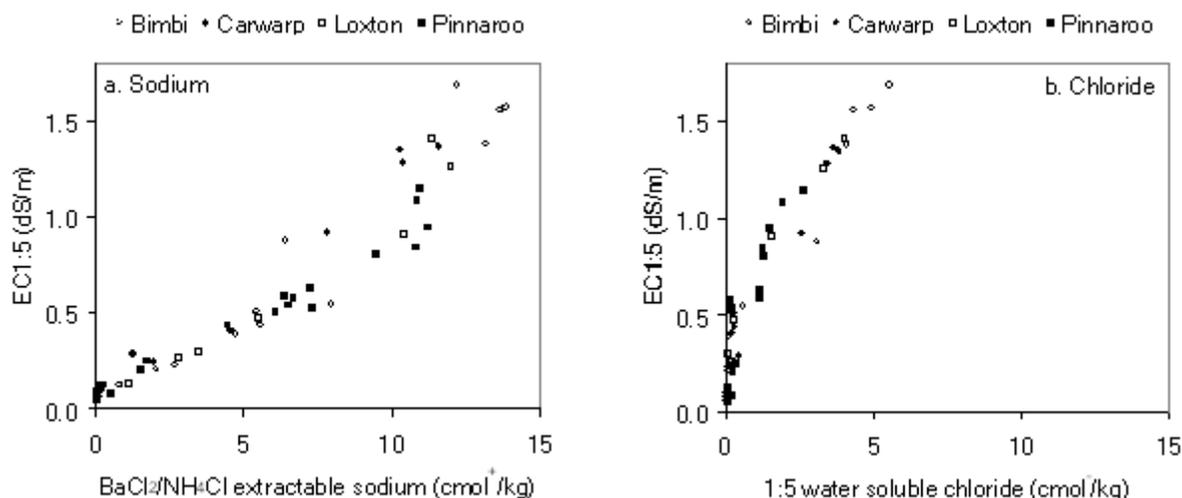


Figure 1. Relationships between soil EC1:5 and (a) extractable sodium and (b) chloride. The data are from individual samples (horizons) from 3 cores within each paddock.

Sodium, chloride, and other soil tests

If sodium and chloride are better related to different ranges of variation in EC1:5, and salt (measured by EC1:5) is the dominant cause of variation in Mallee EM surveys, then EM calibrations with other soil tests will depend on the range of EC1:5 encountered within a particular paddock, and whether the other soil tests correlate better with sodium, or chloride. Across these samples, extractable sodium was better correlated with clay, related physical properties and other cations (Table 1): magnesium, potassium, pH, boron (related to pH), sand, actual volumetric water content, and crop lower and upper limit. Soluble chloride was better correlated with other soluble anions; sulphate and nitrate, and less well correlated with texture-related measurements apart from silt. Note that linear correlations only were considered. The pattern of better correlation with sodium or chloride was generally reflected in better correlation with EC1:5 below or above 0.7 dS/m. In some cases (clay) correlation across the range of EC1:5 was better simply because this included both high and low clay and EC1:5.

Table 1. Simple linear correlation of soil test measurements with soil chloride and extractable sodium, EC1:5 and EC1:5 above and below 0.7 dS/m, across depths, cores and paddocks.

Measurement	Correlation ^a with (n)					over EC1:5 range	
	Chloride (60)	Sodium (60)	EC1:5 (60)	<=0.7dS/m (43)	>0.7dS/m (17)		
Chloride	+1.000 ***	+0.837 ***	+0.946 ***	+0.694 ***	+0.927 ***		
Sodium	+0.837 ***	+1.000 ***	+0.962 ***	+0.979 ***	+0.733 ***		
Calcium	-0.120	-0.355 **	-0.236	-0.291	-0.195		
Magnesium	+0.526 ***	+0.689 ***	+0.639 ***	+0.536 ***	-0.092		

Potassium	+0.239		+0.444	***	+0.388	**	+0.505	***	-0.540	*
pH(water)	+0.276	*	+0.643	***	+0.516	***	+0.808	***	-0.185	
pH(CaCl)	+0.459	***	+0.656	***	+0.609	***	+0.565	***	+0.340	
Boron	+0.517	***	+0.875	***	+0.743	***	+0.919	***	-0.144	
Gravel%	-0.061		-0.101		-0.072		-0.096		+0.272	
Clay	+0.690	***	+0.833	***	+0.796	***	+0.663	***	+0.406	
Silt	+0.377	**	+0.158		+0.277	*	-0.037		+0.488	*
Sand	-0.715	***	-0.791	***	-0.786	***	-0.578	***	-0.623	**
Water ^b	+0.633	***	+0.780	***	+0.733	***	+0.531	***	+0.411	
CLL ^b	+0.594	***	+0.878	***	+0.782	***	+0.868	***	+0.095	
DUL ^b	+0.531	***	+0.671	***	+0.630	***	+0.508	***	-0.216	
DUL-CLL ^b	-0.118		-0.342	**	-0.256		-0.321	*	-0.300	
Nitrate	+0.413	**	+0.185		+0.319	*	-0.170		+0.024	
Sulphate	+0.932	***	+0.857	***	+0.931	***	+0.676	***	+0.883	***

a. Stars indicate correlation significantly different from 0: *** p<0.001, ** p<0.01, * p<0.05.

b. Water = volumetric water. CLL = Crop Lower Limit. DUL = Drained Upper Limit. One sample from each of CLL and DUL was missing, hence n= n -1 and n=n-2 for DUL - CLL (both <=0.7 dS/m EC1:5).

Discussion

Pattern of EC1:5, sodium and chloride

The results show a remarkably consistent pattern of relationship between EC1:5, sodium and chloride, despite the mix of regional, local and depth-wise spatial variation. The pattern of variation in EC1:5 below about 0.7 dS/m being better related to sodium, and above 0.7 dS/m being better related to chloride, is likely to reflect the retardation of sodium leaching by negatively charged clay, and the relatively free leaching of chloride to the bottom of the root zone. In the Mallee both sodium and chloride arrive in rainfall, at a rate depending on distance from the sea, (Blackburn and McLeod 1983; Hutton and Leslie 1958). Sodium tends to remain associated with negatively charged clay particles and is thus quite well correlated with clay throughout the profile, whereas chloride leaches during large rainfall events to the

depth of dry soil (created by evapotranspiration) and remains there. Although there also tends to be more clay at this depth, the association is only approximate and hence correlations of chloride with clay and related variables are not as strong as with sodium. Shallow soil is leached of chloride and lower in EC1:5, mostly related to sodium and clay content. Deeper soil contains higher clay and sodium, but also leached chloride, and has higher EC1:5 that is related to both the sodium (and clay content), and the chloride.

Implications for EM calibrations with agronomic variables

These relationships have clear implications for EM calibrations, which in future work we hope to validate on the wider Mallee EM calibration database. In Mallee paddocks with lower EC1:5 throughout the profile (ie. <1.0 dS/m), good EM calibrations with EC1:5 will also be good calibrations with sodium, and hence clay content and other related variables such as boron, and crop lower and upper limit. In Mallee paddocks with higher EC1:5, chloride will act as a confounding factor in any relationship with clay content, and calibrations with clay-related variables may be poor. The good correlation between sodium and water at a time when the soil was likely to be dry suggests that calibrations with soil water are likely to be good proxies for calibrations with sodium and hence clay content, and can be used to diagnose useful EC1:5 – clay relationships in high EC1:5 paddocks.

Calibrations with other leaching anions, particularly sulphate, are likely to be better in higher EC1:5 paddocks. Calibrations with sulphate are likely to be better than calibrations with nitrate because the source in many paddocks is quite consistent (rainfall), and plant uptake and removal from the paddock are small in relation to the stock of sulphate in high EC1:5 paddocks.

High EC1:5 tends to occur at depth and the depth-weighting of the different EM38 dipoles (vertical = peak at 0.4m, horizontal = peak at surface) might be used to advantage to avoid its confounding effect in some paddocks where only deeper soil has high EC1:5; in these paddocks better calibrations may be obtained with the horizontal dipole. That the EM38 measures a weighted combination of soil electrical conductivity at different depths may itself lead to poor or irregularly shaped calibrations with some variates, due to the non-linear combination of sodium- and chloride-related soil electrical conductivity at different depths.

Importance of salt-texture relationships

The importance of salt as a source of variation in the EM signal in Mallee soils highlights the importance of consistent salt – texture relationships within paddocks for consistent interpretation of EM surveys (Corwin and Lesch 2003). In other work we have identified some causes of inconsistencies. In some paddocks runoff and ponding of water leads to greater leaching of low areas, which then are measured as low-EM38 despite usually heavy clay texture. Salt sourced from other-than-rainfall (eg. erosion from a salt lake) may also cause a different salt-texture relationship within a paddock.

Conclusion

Consistent salt-texture relationships demonstrate the potential of EM surveys in the south east Australian Mallee as a stable 'base' layer of soil properties likely to be useful for farmers developing site specific management and choosing appropriate paddocks for crops sensitive to salt, boron and other soil limitations. Understanding the dynamic of relationships between the constituent ions of salt and EC1:5 assists with the agronomic interpretation of surveys on particular paddocks.

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