Aust. J. Soil Res., 1987, **25**, 21-7

The Use of Electromagnetic Induction to Detect the Spatial Variability of the Salt and Clay Contents of Soils

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Abstract

The apparent electrical conductivity (EC_a) of a 250 ha area of the Riverine Plain in New South Wales was mapped using a Geonics EM 34/3 electromagnetic terrain conductivity meter. The EC_a values obtained were highly correlated with both the total soluble salts and the total <2 μm clay material to a depth of 15 m. The spatial variability of both these properties has a direct bearing on present and future land-use practices.

Introduction

The Murrumbidgee Irrigation Area in New South Wales, Australia, is characterized by riverine plains of low gradient with heavy, and often saline, clay soils (Butler *et al.* 1975). Within the unconsolidated sediments, sand lenses and prior streams (Pels 1964) are common, and their presence is not readily detectable from surface features. The spatial distribution of soluble salts is important with respect to crop production, while the distribution of coarse-textured lenses and channels has a significant role in the groundwater hydrology of the region.

An indirect method for assessing the distribution of soluble salts is to measure the apparent electrical conductivity (EC_a) of the soils by electromagnetic induction (EM) (De Jong *et al.* 1979; Corwin and Rhoades 1982; Williams and Baker 1982). Similarly, McNeill (1980) and Zalasiewicz *et al.* (1985) have used the EM technique to map textural discontinuities within a landscape. Both variables have been shown to affect EC_a values measured by the four-probe electrical resistivity method (Halvorson *et al.* 1977; Read and Cameron 1977), hence it would appear that EM surveys could be used to simultaneously describe salt and textural variations within soil profiles. This study examines the relative contributions of salt and clay content to the EC_a values obtained by electromagnetic induction, and the value of the EM technique to predict the spatial distribution of both these variables.

Method

Approximately 250 ha, located on the 'Carrego' property west of Griffith (Fig. 1), was surveyed using a Geonics EM34/3 terrain conductivity meter, with an intercoil spacing of 20 m and coils in the vertical mode. This corresponded to a theoretical effective depth of penetration of the transmitted EM wave of 15 m. Readings of EC_a were made at 20 m intervals along transects 200 m apart. The relief was approximately 40 cm over the 2 km transects followed.

Holes were drilled to a depth of 15 m along a central transect, the sites being chosen to correspond with a wide range of EC_a values. Samples were taken at 50 cm intervals down the holes for 1:5 electrical

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conductivity ($EC_{1:5}$) determinations and for particle size analysis. No groundwater was encountered during drilling, as the regional groundwater table in that area is generally deeper than 18 m.

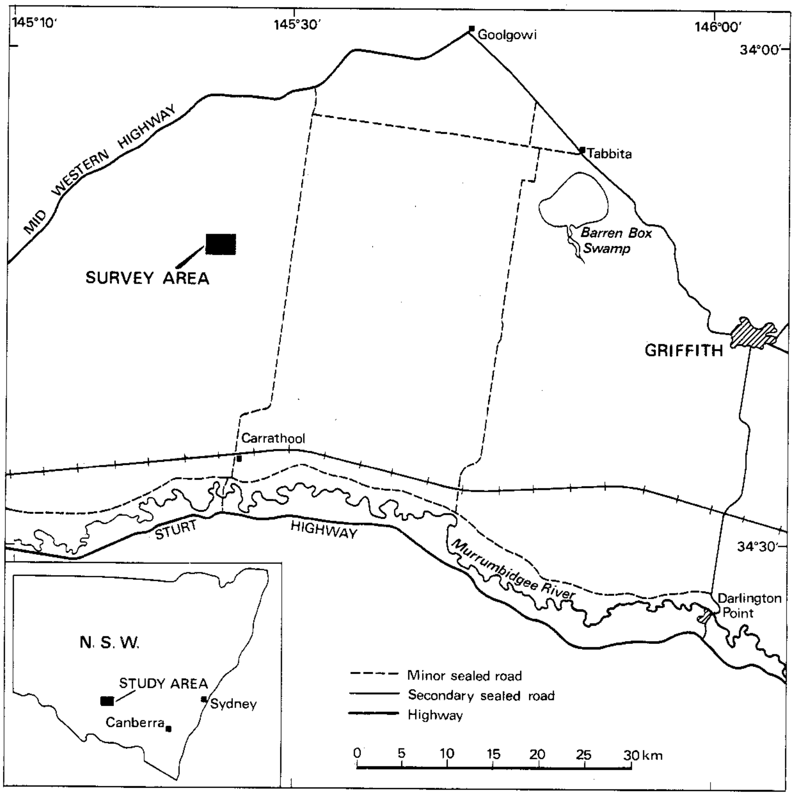

Fig. 1. Location of experimental site.

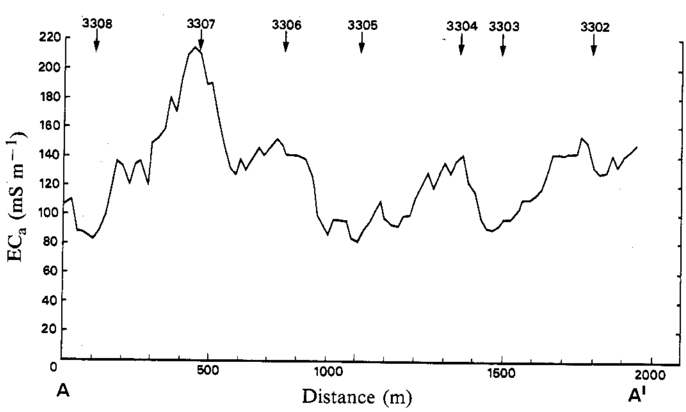

Fig. 2. Apparent electrical conductivity transect. The numbers at the top relate to Fig. 4.

Results and Discussion

Apparent conductivity values, as read directly from the EM instrument, were normally distributed within the range of 60–240 mS m^{-1}. Individual transects showed very marked changes of EC_a over short distances (Fig. 2). As errors in reading the instrument would not have exceeded ± 5 mS m^{-1}, variations observed must be regarded as real and due to one or more of the factors that are known to affect the electrical conductivity of soil material. Combined transect data are shown as an EC_a contour map in Fig. 3, where smoothing options in the program MAPCON (Hutchinson 1984) were used to remove variations of less than 10 mS m^{-1}. The resultant map shows a series of crests and troughs that have been arbitrarily shaded in four classes to emphasize the location of relatively low conductivity zones. Fig. 3 also displays the very abrupt changes in EC_a that were encountered over distances of 20–60 m. The location of the transect shown in Fig. 2 is indicated by A–A′ in Fig. 3.

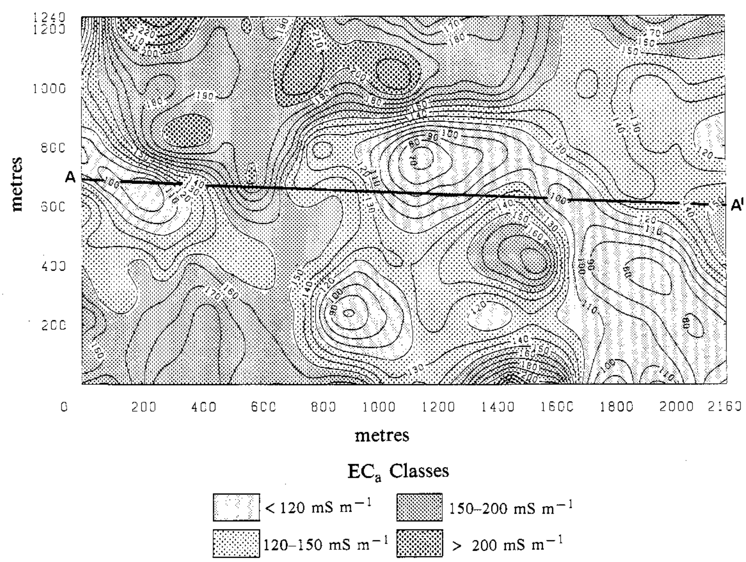

Fig. 3. Apparent electrical conductivity contour map.

The electrical conductivities ($EC_{1:5}$) of seven profiles (Fig. 2) determined on 1:5 soil:water extracts are shown in Fig. 4. The most striking feature is the extremely variable distribution of soluble salts within the profiles. This follows approximately the distribution of <2 μm clay material, also shown in Fig. 4, although a linear regression of these two variables (n = 210, R^2 = 0·174) indicates that there is little predictive value in that relationship. The profile descriptions show beds of sands and clayey sands interspersed with clay deposits, particularly below 2–5 m.

Previous studies (Williams and Baker 1982, Williams and Fidler 1983) used the area under the salinity:depth curve as a measure of the Integrated Salinity (I_{sal}) of the profile. Then, by successive regressions of I_{sal}:EC_a for integration depths of 0–1, 0–2,...0–n layers the effective depth of penetration of the electromagnetic wave was determined as that depth resulting in a maximum correlation coefficient (R). R^2 then gave a measure of the total variation in EC_a explained by salinity alone.

A similar analysis in this investigation indicates that the effective depth of penetration was approximately 12–15 m with an R^2 value (corrected for degrees of freedom) of 78% (Fig. 5). Also shown in Fig. 5 is the result obtained by using the Integrated Clay Content (I_{clay}) as the independent variable in the regression equations. This shows a maximum R^2 value at a depth of integration of 4 m followed by a decline and two more peaks at 9·0 and 14·5 m. Including both I_{sal}

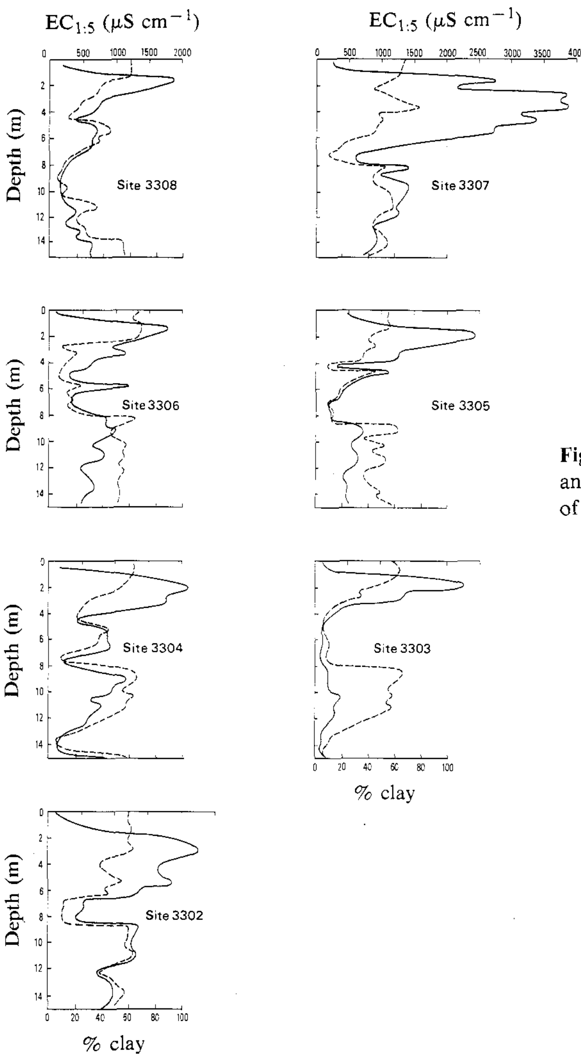

Fig. 4. Electrical conductivity (1:5) (——) and clay content (< 2 μm) (– – –) of soil profiles.

and I_{clay} in the regression equations with EC_a results in little or no improvement in R^2 values (Fig. 5). The multiple regression is most closely allied with I_{clay} to a depth of 5 m, but then becomes increasingly similar to the I_{sal} relationship at greater depths. This is further demonstrated in Fig. 6, where the proportion of the Regression Sums of Squares explained by I_{sal} or I_{clay} is shown for the case where either one is entered into the X-position of the multiple regression:

$$EC_a = a + b\underset{\substack{I_{sal}\\ I_{clay}}}{X} + c\underset{\substack{I_{clay}\\ I_{sal}}}{Y}. \tag{1}$$

Although the $X = I_{clay}$ relationship is somewhat more irregular than when $X = I_{sal}$, both explain a high proportion of the Sums of Squares due to Regression. Clearly, EC_a could be used equally well to predict either the average salt content or the average clay content to a depth of 15 m. The two relationships are:

$$\underset{(\mu S\ cm^{-1})}{\text{Average } EC_{1:5}} = -256 + 8.733 \underset{(mS\ m^{-1})}{EC_a} \quad (R^2 = 0{\cdot}777) \tag{2}$$

$$\underset{(\% < 2\mu m)}{\text{Average clay}} = 22{\cdot}8 + 0{\cdot}133 \underset{(mS\ m^{-1})}{EC_a}. \quad (R^2 = 0{\cdot}727) \tag{3}$$

Although it was stated earlier that there is a poor predictive relationship between percentage clay and $EC_{1:5}$ values ($R^2 = 0{\cdot}174$), this improves markedly ($R^2 = 0{\cdot}693$) if I_{sal} and I_{clay} are used as the variables (Fig. 7). Again, if profile 3307, shown independently in Fig. 7, is analysed separately from the other six profiles, R^2 values obtained are 0·939 and 0·845, respectively. Hence I_{sal} and I_{clay} are strongly interdependent, although site-to-site variations do occur. The source of variation is probably due to both the depositional, as well as the subsequent water and solute transport, histories within the profile.

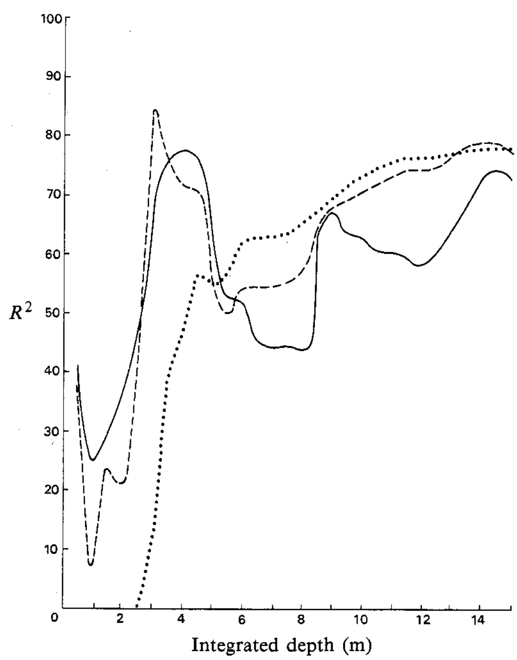

Fig. 5. Variation in coefficient of determination (R^2) with regressions of apparent electrical conductivity as a function of salt and clay content against depth.
···· $EC_a = f(I_{sal})$.
—— $EC_a = f(I_{clay})$.
- - - $EC_a = f(I_{sal}, I_{clay})$.

The range of EC_a values encountered in the survey area correspond to predicted average $EC_{1:5}$ values of 270–1840 μS cm^{-1} and average clay contents of 31–55%, but they do not provide any information of the distributions of salt and clay in the profile. For example sites 3303 and 3308 have the same EC_a value but the salinity and clay profiles are rather different (Fig. 4). However, average profile values can be useful for delineating areas of moderate to high salinity hazard and so provide an early warning of possible secondary salinization if that salt should be mobilized towards the land surface. Similarly, given the stratified nature of these unconsolidated sediments, low average clay contents can be interpreted as indicating the presence of a layer of coarse-textured material in the profile. The lower the average clay content of the profile, the larger the coarse-textured beds

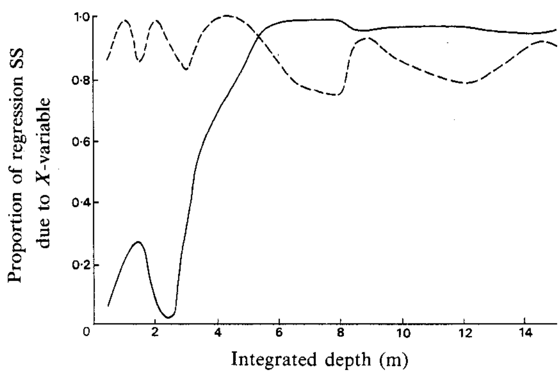

Fig. 6. Proportion of Regression Sums of Squares due to the X-variable.
—— $EC_a = a + b(I_{sal}) + c(I_{clay})$.
--- $EC_a = a + b(I_{clay}) + c(I_{sal})$.

present. For example, site 3307 has an EC_a value of 202 mS m^{-1} and contains a layer of less than 2 m of coarse (>20 μm) material compared with site 3308 (EC_a = 86 mS m^{-1}) that has greater than 5 m of coarse material. Thus, for describing heterogeneity in the extensive Riverine Plains area, Fig. 3 could be interpreted in terms of areal distribution of soluble salts or the distribution of relatively shallow, coarse-textured prior-stream material. Both attributes have considerable implications for land-use planning.

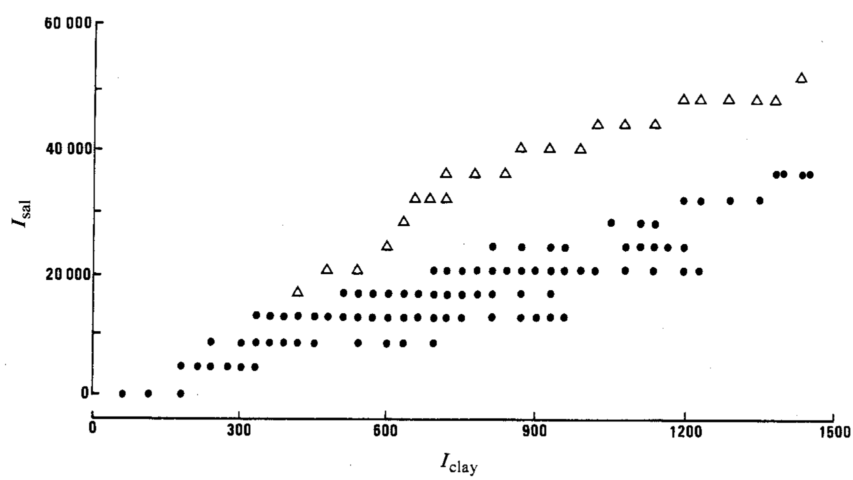

Fig. 7. Scatter plot of I_{sal} versus I_{clay}. (△) represents profile 3307.

Apart from interpreting EC_a values in terms of average salinity and clay content, it is even more useful to examine the rate of change of EC_a within the landscape. Figs 2 and 3 illustrate the very rapid changes that can take place over a distance of a few tens of metres. Zalasiewicz *et al.* (1985) interpreted similar rapid changes of EC_a values in their non-saline experimental sites in terms of boundaries between clay-rich sediments and sandstone/limestone formations. At the 'Carrego' site, and presumably elsewhere on the plain, such rapid changes can also be used to identify major changes in profile characteristics. This can lead to a far more efficient and accurate strategy for detailed site investigations.

Conclusions

In saline, multi-layered soil profiles which are common in the Riverine Plains of south-eastern Australia, EC_a values can be interpreted both in terms of the average salt content or the average clay content over a depth of 15 m. Although there is a poor relationship between the soluble salt content and the clay content of individual soil samples, there is a good correlation between the total amounts of these materials within the profile, at least to a depth of 15 m. Thus the EM technique can be used not only for mapping the potential salinity hazard in these areas but also for locating areas having marked textural discontinuities within the profile. The spatial variability of both these soil properties are important in land-use planning, particularly for irrigation and waste-water disposal systems.

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Manuscript received 24 March 1986, revised manuscript received 24 August 1986, accepted 7 October 1986