Use of a Mobile EM Sensing System for improved natural resource management at the fieldscale

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Introduction

In the irrigated cotton-growing areas of southeastern Australia, there is an increasing awareness for the need for land resource information and its importance for environmental management. This is particularly the case at the field scale where soil management is highly desirable. Acquisition of soil information at this level is labor intensive and time consuming, however. A major problem is determining where samples should be taken.

What is required is a relatively cheap and efficient technique, based on remotely sensed data, which can be used as a surrogate for soil survey and therefore assist with the selection of suitable sampling sites to account for the various soil types and spatial variability of soil properties. Previous attempts at providing this preliminary information are wide and varied. They include the use of electromagnetic (EM) induction instrumentation, (Williams and Baker, 1982; and Lesch *et al.,* 1995), direct electrical methods (Halvorsen and Rhoades, 1974; and Cameron *et al.,* 1981), ground penetrating radar (Boll *et al.,* 1996; and Doolittle *et al.,* 1998) and soil spectral reflectance data (Zhang *et al.,* 1992).

Of these, EM methods have been used in several countries with some success. In the Netherlands an EM38 instrument (i.e. Geonics Ltd.) was used to determine the depth to boulder clay (Brus *et al.,* 1992) and depth to a soft layer in the western marine districts (Knotters *et al*., 1995). In the US, an EM38 was similarly used to determine its application for determining productivity on clay pan soil (Suddeth *et al.,* 1995), estimating depth to clay pan (Doolittle *et al.,* 1994) and delineation of soil based on textural properties in Kansas (Doolittle *et al.,* 1996). In Australia, clay content and salinity have been mapped with an EM34 (Williams and Hoey, 1982). Various other applications have included their use in determining soil nutrient status (Suddeth *et al*., 1995), moisture content (Kachanoski, *et al*., 1988) salinity status (Lesch *et al.,* 1995; and Triantafilis *et al*., 2000) and the estimation of deep drainage at the field scale (Triantafilis *et al*., 1998). In order to improve the efficiency in collecting this information, at the field level, various groups have developed Mobile Electromagnetic Sensing Systems (Rhoades 1992, Cannon *et al.,* 1994).

In this article, an example of how a Mobile EM Sensing System (i.e. MESS) (Triantafilis and McBratney, 1998) can be used to understand the hydrological processes causing isolated problems with water logged and saline/sodic soil conditions in an irrigated cotton field in the Namoi valley is demonstrated. Some future work and management strategies to overcome the problems are also suggested.

Mobile Electromagnetic Sensing System

A Mobile Electromagnetic Sensing System (i.e. MESS) has been developed at the University of Sydney and is stationed at the Australian Cotton Research Institute (Triantafilis and McBratney, 1998). The system includes various electronic and mechanical components (figure 1). All components have been mounted on a 4WD hydrostatic and articulated tractor, powered by a 20 HP Kohler Petrol Engine. The central processing system is a 486 computer, which acts as a data logger and controller for an EM38. The EM38 is enclosed in a non-conductive vinyl-ester tube and located at the rear of the tractor. An EM31 has also been mounted and is located in front of the system and is suspended 1.0 m above the ground. This is achieved using a PVC cradle. A Trimble® FieldGuide provides positioning and guidance, while a Trimble® AgGPS132 provides wide-area differential correction to ensure sub-meter accuracy.

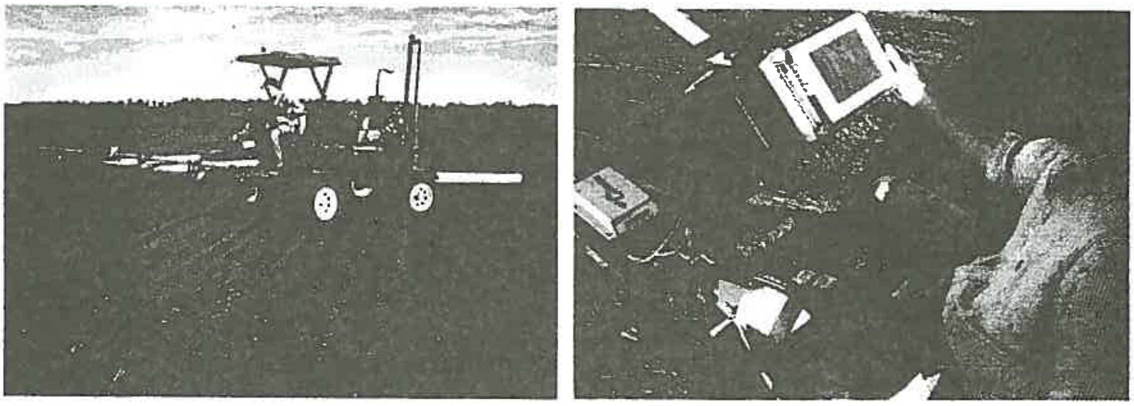

Figure 1. View of MESS with EM31 at front and EM38 inside polyvinyl tube at rear; and, close up of 486 logger and Trimble™ Fieldguide and Ag132.

Study area

The study area is situated at *"Cumberdeen,"* which is an irrigated cotton-growing farm located approximately 2 km south-east of the township of Wee Waa. The farm is associated with the Pilliga Scrub Complex (Stannard and Kelly, 1977). They found that in this area the soil showed considerable variation and includes; a) contorted gilgai soil, b) red-brown earths and transitional red-brown earths, c) solodized solonetz and d) deep sandy profiles.

The transitional red-brown earths show a sharp texture contrast between the surface horizons and subsoil with usually a high coarse sand content in the former. The B-horizon of these profiles is lower in clay content than any horizon of the self-mulching clays, upon which most irrigated cotton production is primarily based on in the lower Namoi valley. The fine sand and silt fractions also increase with depth but essentially the profiles are relatively fine textured. Where the texture is sandy, the subsoil horizon is generally weakly developed, however.

The red-brown earths also exhibit strong texture contrasts, but the surface horizon varies considerably in depth and texture. The subsoil possesses similar clay contents to the transitional red-brown earths, but usually clay content decreases significantly with depth. The deep sandy soil profiles, by comparison, were generally obtained in the channels of the more prominent prior stream formations. These profiles are dominated by the sand fraction throughout.

MESS Survey

It is apparent that a shallow water table and saline/sodic soil conditions affect cotton production in an isolated area in the southwest corner of field 4. The field covers approximately 26 ha. Fig. 2a shows an aerial photograph and the location of a water storage adjacent to the southwest corner. The western part contains irrigation runs that are between 600 m (transect 1) and 800 m in length (transect 10), whilst the eastern area contains runs that are about 540 m in length (figure 2b). The width of the field is approximately 408 m.

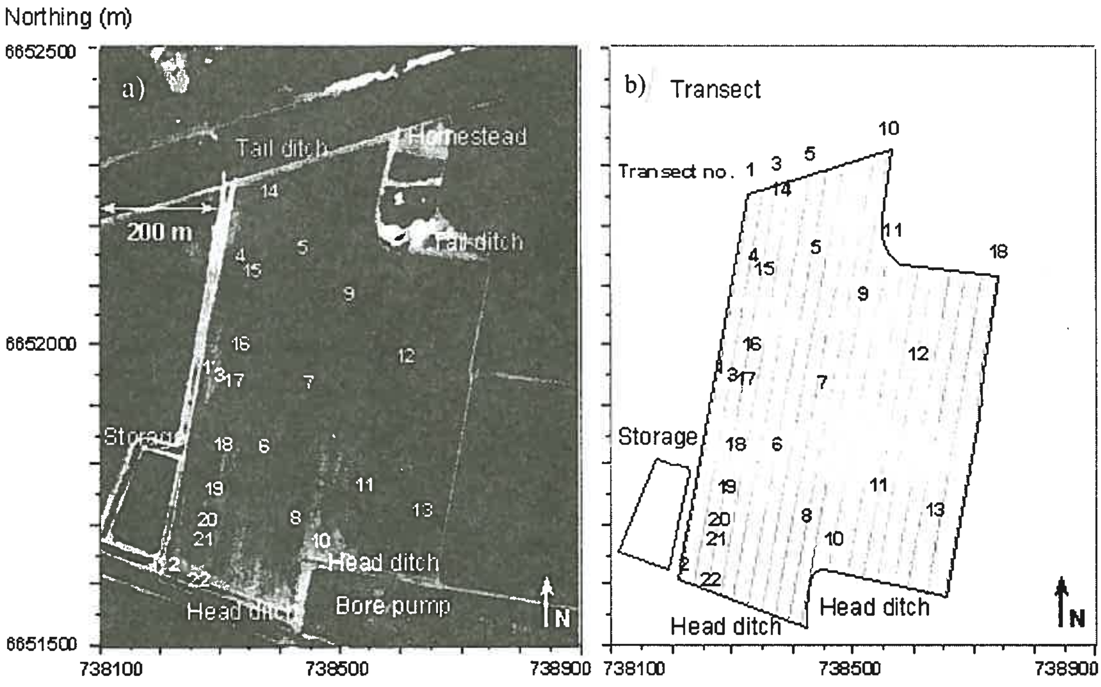

Figure 2. a) Aerial photograph and sampling sites and b) location of MESS survey transects and sampling sites.

In order to characterise the soil in field 4 a MESS survey was undertaken. The survey consisted of generating EC_a measurements from the EM31 (EC_{31}) and EM38 (EC_{38}) in the vertical mode of operation across the field. The EM38 was positioned 0.2 m above the ground surface. A total of 18 transects were traversed and situated approximately 24 m apart, (figure 2b). Approximately 10,000 measurements were made along the 11,000 m of travel during the one day the survey took to complete.

Figures 3a and 3b show the spatial distribution of soil EC_a as recorded with the EM38 and EM31, respectively. In the southwest corner of the field, near the head ditch and the eastern storage wall, soil EC_a is consistently much higher (e.g. EM31 > 125 mS/m) than at the northern or tail-ditch end (EM31 < 75 mS/m). A sharp drop in soil EC_a is also apparent halfway between the head and tail ditch. This is most evident in figure 3b, where at sites 18 and 16 soil EC_a generally ranged between 100-125 mS/m. Approximately 125 m to the north of these sites, soil EC_a was less than 75 mS/m. What is also evident in figure 3b, is a small band of lower EC_a, which lies perpendicular to the eastern storage wall at a Northing of 6651750. In figure 3a, soil EC_a is similarly low in this area (i.e. 50 < EM38 < 75 mS/m).

Soil sampling and laboratory analysis

In order to explain the variations in soil EC_a a small number of sampling sites were selected by plotting soil EC_a as recorded with the EM38 against that obtained with the EM31. From this plot, 13 sites ranging from low, medium and high values were chosen. Consideration was also given to ensure representation across the field.

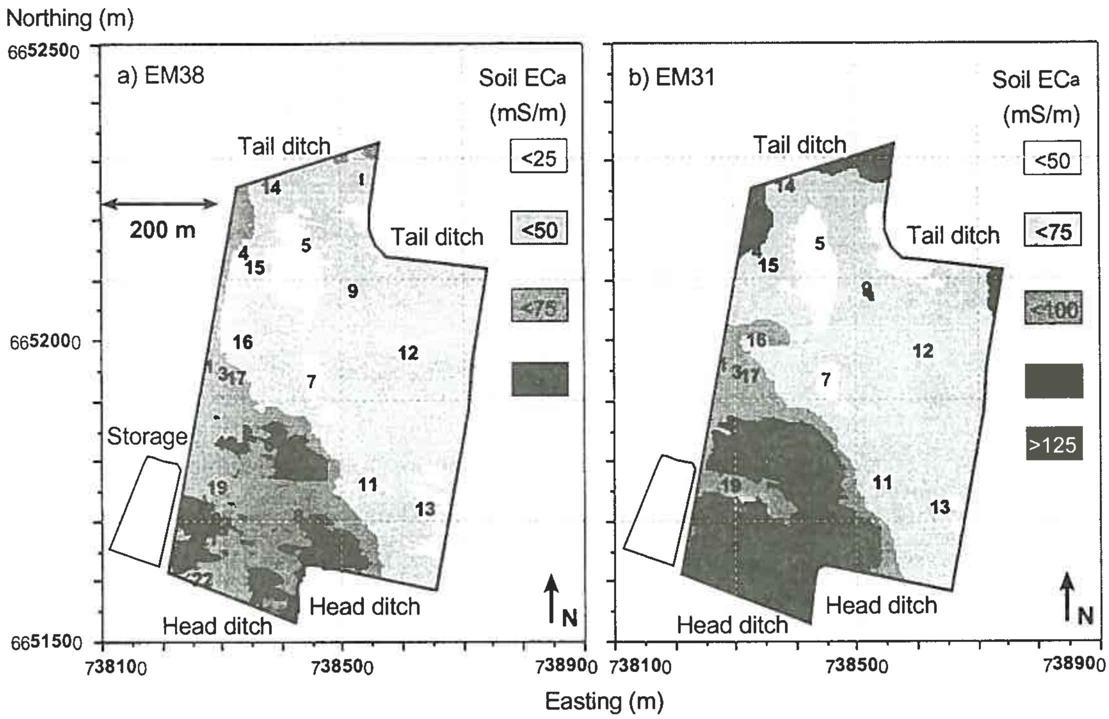

Figure 3. Spatial distribution of soil EC_a a) EM38 and b) EM31.

A further 9 sites were selected along a single north-south transect (i.e. transect 3). At all sites an intact soil core to a depth of 2 m was collected and bulked into 0.30-m increments. Soil EC_a measurements were taken directly above each site.

The 22 soil profiles collected were analysed for: field moisture content (%); electrical conductivity (mS/m) of a 1 part soil to five parts water solution ($EC_{1:5}$); clay content (%) using hydrometer method; and, effective cation exchange capacity (ECEC, mmol(+)/kg) (Tucker 1974) using a mechanical leaching device (Holmgren *et* *al.*, 1977). These analyses were carried out at depth increments of 0.30 m and to a depth of 2.0.

Correlations between measured soil properties and soil EC_a

The correlation achieved between EC_a and each of the measured soil properties is shown for the EM38 only, since the EM31 results were similar. Figures 4a and b show that EC_a is generally not correlated with average field moisture or clay content, respectively. With respect to field moisture content the lack of correlation is consistent with the field being managed in the same way (i.e. furrow irrigated) and heavy rain fell prior to the survey being carried out. Figure 4c, on the other hand, shows a good relationship exists between EC_a and $EC_{1:5}$ and, secondly that two distinct salinity populations are apparent. The lower salinity profiles are located in the northern half of the field near the tail ditch. More saline profiles characterise the southern half near the storage. This suggests differences in drainage between the southern and northern ends. Significantly site 19, which is located at the northern end and adjacent to the northeast corner of the storage, does not belong to this group of more saline profiles.

ECEC is also strongly correlated with EC_a (figure 4d). Interestingly, the relationship between clay content and exchangeable cations is often strong and similarly that EC_a is well correlated with each of these soil properties. The reason for the poor relationship between EC_a and clay content and the good relationship with ECEC is attributable to mineralogical differences, however.

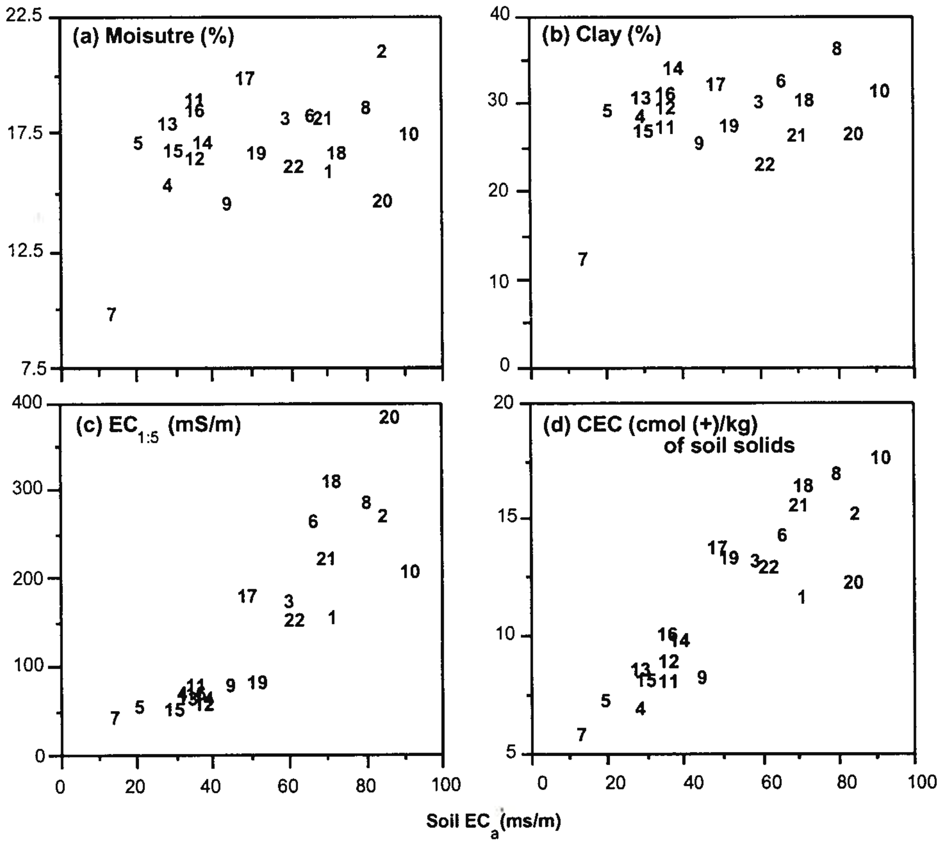

Figure 4. Soil EC_a (EM38) versus average a) moisture, b) clay, c) $EC_{1:5}$ and d) ECEC.

Spatial distribution of soil properties along transect 3

In order to elucidate where the storage dam may be leaking and why free water was found at depth, plots of each of the average soil variables measured along transect 3 were generated. Along this transect site 22 is located approximately 10 m north of the head ditch. Sites 21, 20 19 and 18 lie approximately 80, 100, 160 and 230 m, respectively from 22. Sites 17, to 14 lie in the northern, half of the field.

Figure 5a shows average moisture content is similar at each of the nine sites. Similarly, figure 5b indicates average clay content at the northern end is generally greater than at the southern end. In addition, and between sites 22 and 19, clay content is similar. The lack of clay is compensated somewhat by the larger ECEC and clay ratio (figure 5d) at this site as compared to sites 20 and 19. This is significant as the soil in this profile is more likely to shrink and swell during wetting and drying cycles.

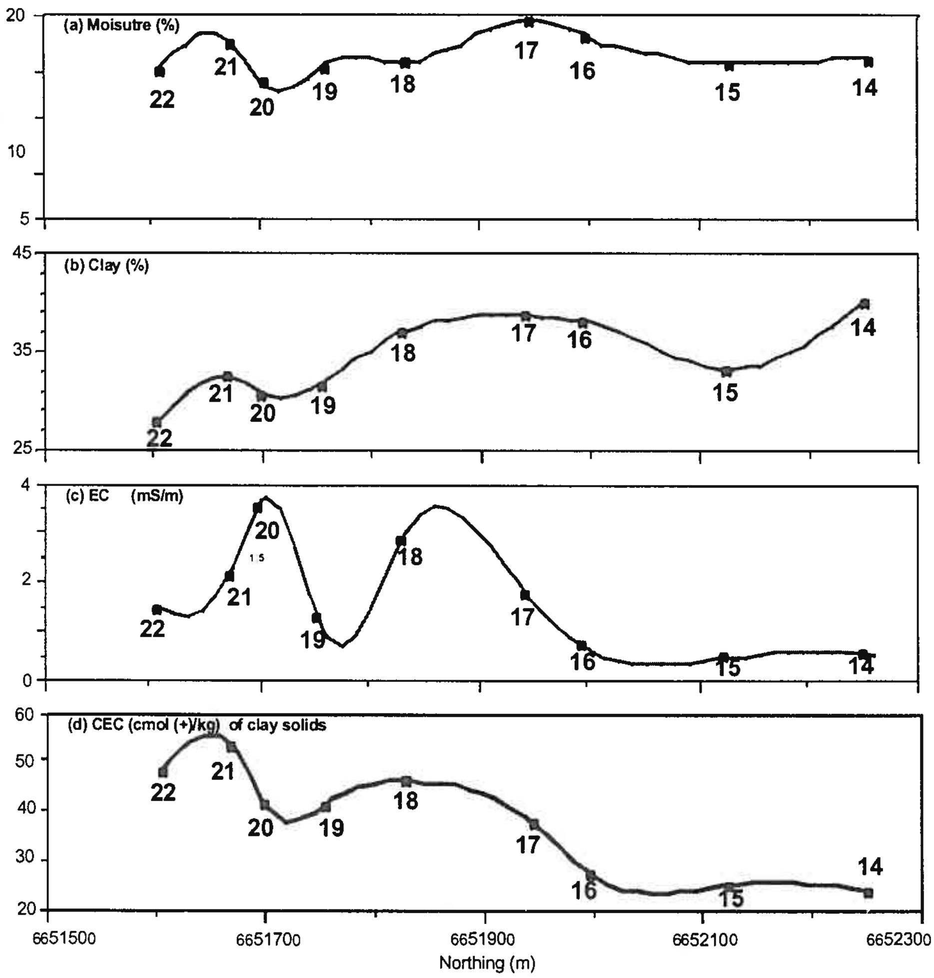

Figure 5. Spatial distribution along transect 3 of average profile a) field moisture content, b) clay content, c) $EC_{1.5}$, d) CCR (cmol(+)/kg of clay solids).

The best indicator of where the water is most likely to be leaking is provided by average soil $EC_{1:5}$ shown in figure 5c. At sites 19 and 22 average soil profile $EC_{1.5}$ is low and respectively 77 and 150 mS/m. By comparison sites 18 and 20, (located either side of and within 70 m of site 19, have levels of soil salinity around four times that at site 19. This suggests that site 19, as compared to 18 and 20, is located in a recharge area where soluable salts are leached. Conversely, and as suggested by the larger amounts of soluable salts associated with sites 18 and 20, these profiles are located in the discharge area where salts are accumulating.

The larger values of average soil $EC_{1:5}$ evident at sites 22 and 21, although not as low as 19, suggests that these sites may also be located in an area where salts are leached. However, these sites are both located within 80 m of the head ditch. Because this field was irrigated during the summer of 1998-1999, any soluable salts discharged into this area from site 19 would most probably have been leached via deep drainage. The rational for this is that a large amount of water is applied at this end of the field to enable a sufficient amount of water to irrigate the crop at the northern end of the field.

Conclusions

The MESS developed by the University of Sydney and based at the Australian Cotton Cooperative Research Centre (Australian Cotton Research Institute) provides rapid measurements of EC_a at the field scale. The data generated at *"Cumberdeen"* assisted in a) describing the spatial distribution of EC_a, b) design of a suitable soil sampling strategy to calibrate EM instruments, and c) elucidating the likely area of leakage from the storage dam and hence probable cause of soil salinity in an irrigated cotton field.

With respect to the calibration of the instrument a simple linear regression analysis of average soil profile moisture, clay, salt concentration (i.e. $EC_{1:5}$) and ECEC against EC_a allowed for the determination that $EC_{1:5}$ and ECEC had the largest influence on the response of the instruments in this field. As a result interpretations about the likely causes of leakage and effects of soil salinity on the field-scale could be determined and a hydrological model developed.

Further work may involve corroborating the results obtained here by carrying out a MESS survey within the dam and taking more detailed soil samples at the base of the eastern storage wall. Once the area of leakage is pinpointed along the base, appropriate management options can be determined and may include the use of an impermeable membrane or use of clay in the reconstruction of the wall. This strategy should result in improved water holding capacity of the storage and improved crop production in the small area of the field affected by water logging and soil salinity.

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