

Progress with soil salinity assessment in the lower Namoi valley

Cotton Research & Development Corporation Project US05C

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INTRODUCTION

Soil salinisation is the steady process of soluble salt accumulation in the rootzone, that ultimately affects agricultural productivity. There are basically two types of soil salinisation: primary salinisation which is a naturally occurring process and; secondary salinisation which is a consequence of man's interaction with the landscape. The latter is caused by alteration of the hydrological balance in the landscape, usually as a consequence of irrigation particularly in semi-arid and arid environments similar to where cotton is currently grown in Australia.

Irrigation is used to negate the climatic irregularities of rainfall. The long term sustainability of such irrigation is dependant on maintaining the quality of irrigation water (*i.e.*, low salt concentrations) and minimising excessive deep drainage, without which regional rises in water tables cause accretion of soluble salts in the rootzone. To prevent occurrences of secondary salinisation, baseline information should be collected and monitoring procedures need to be developed and implemented to continually assess the effects of irrigation. This project is aimed at developing soil salinity assessment techniques (primarily electromagnetic induction (EM) and geostatistical) for rapid, reliable and repeatable broadscale salinity assessment and monitoring purposes, specifically on a previously identified salt rich subsoil layer, (Triantafilis and McBratney, 1993).

STUDY AREA

The lower Namoi valley, characterised by fertile cracking grey clay soil profiles (*i.e.*, vertisols)

was recognised as having great potential for irrigated agricultural production in the early 1960's. Consequently extensive areas of the valley have been converted from sheep/cattle grazing and wheat cropping to irrigated cotton production. With such developments the potential for secondary salinisation would appear to be quite large. The study area is about 20 km west of Narrabri (approximately 450 km north-north-west of Sydney, NSW), on the Auscott (Namoi valley) farm. In all, 8 fields covering an area of 649 ha have been selected to assess the suitability of field, laboratory and geostatistical methods for broadscale salinity assessment.

SOIL SALINITY ASSESSMENT

Soil salinity assessment has been based on a field sampling/laboratory analysis methodology. Traditionally, soil samples were obtained from the field and prepared for laboratory analysis. The electrical conductivity of either a one part soil to five parts water ($EC_{1.5}$) or a saturated soil paste (EC_e) is then normally determined. Conversion between the two is based on textural properties of the soil, (*e.g.*, for a heavy clay $EC_e = 6 \times EC_{1.5}$). Despite the accuracy of this methodology it is time consuming. Further, it only provides information at the site of sampling.

In the last ten years, technological advances have led to field instruments that are easy to use and portable and can provide reliable and rapid estimates of the apparent electrical conductivity (EC_a , *in situ*). Electromagnetic (EM) induction is one such technology that is capable of delineating saline areas that require either immediate remedial attention or long-term monitoring.



Figure 1. EM38 in vertical mode of operation provides 2.0 m EC_a .



Figure 2. EM31 in vertical mode of operation provides 7.0 m EC_a .

ELECTROMAGNETIC INDUCTION

Electromagnetic induction involves the use of alternating electric fields, produced in a transmitter coil, that induces a primary magnetic field directly beneath the instrument. This magnetic field produces eddy currents in the soil conductive material (usually the salts) that induce a secondary magnetic field in the receiver coil. The ratio of the primary and secondary magnetic fields is an indication of the amount of salt in the soil. The resultant electrical conductivity, termed EC_a , provides the apparent bulk or average electrical conductivity of the soil directly beneath the instrument.

EM38, EM31, EM34-3 and EM39

A number of EM instruments are commercially available and provide EC_a measurements to varying depths. The EM38 is a rootzone salinity meter (Figure 1) that measures EC_a to a depth of approximately 2.0 m (vertical mode). The EM31 is capable of providing complimentary data on the medium-deep subsoil salt status (Figure 2) capable of measuring EC_a to a depth of up to 7.0

m (vertical mode). In the horizontal modes of operation the above instruments have effective depths of penetration of 1.0 m and 3.5 m, respectively. A deeper penetrating instrument known as the EM34-3 has an effective depth of EC_a measurement (horizontal mode) of 30, 15 and 7.5 m when coil separation is respectively 40, 20 and 10 m. Finally, a down-the-hole EM39 probe can be used, as the name suggests, in bore holes and wells to provide information on the vertical distribution of salts. It can also be used to assist with the interpretation of the EM34-3 and EM31 EC_a measurements. The device is also useful for water table monitoring.

EC_a CALIBRATION

EM instruments were designed specifically for simplicity of operation, provide readily reproduceable results and to rapidly assess the salinity status of soil profiles *in situ*. For a specific soil profile type, calibration is required that relates laboratory analysed $EC_{1.5}$ or EC_e to field EC_a . This requires that soil samples be obtained at a number of sites where the EM instrument has been used to obtain EC_a .

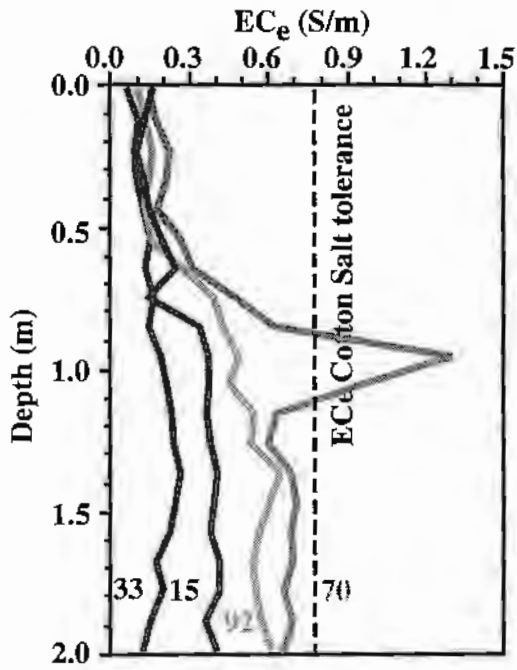


Figure 3. EC_e distribution of four profiles used in average 2.0 m EC_e calibration.

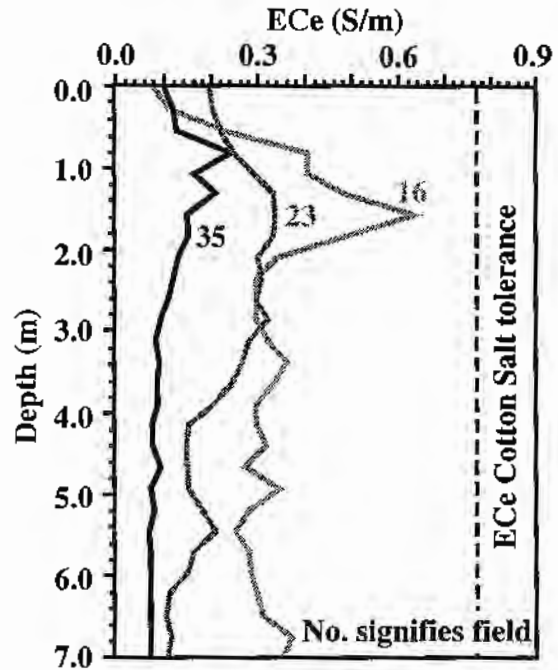


Figure 4. EC_e distribution of three profiles used in average 7.0 m EC_e calibration.

In the lower Namoi valley, 23 soil profiles were sampled at 0.10 m increments to a depth of 2.0 m for $EC_{1.5}$ analysis, for EM38 calibration. Converted EC_e profile data to 2.0 m is shown in Figure 3 for four of the profiles. There is a bulge of salt accumulation at approximately 1.0 m depth. This is indicative of the Boolcarrol salt-rich subsoil layer. Similarly, the EM31 was sampled at 11 sites to a depth of 7.0 m at 0.25 m intervals for $EC_{1.5}$ analysis within the Auscott farm. Figure 4 shows the EC_e increases to a depth of 2.0 m, illustrating again the presence of the

Boolcarrol subsoil layer. Figures 3 and 4 also indicate the EC_e (0.77 S/m) at which cotton may be affected by excessive soil salts.

Calibration simply involves direct comparison of EC_a to average EC_e of each soil profile since EC_a is the apparent bulk or average electrical conductivity of the profile. Figures 5 and 6 illustrate strong linear correlation between 2.0 m EC_a and average 2.0 m EC_e and 7.0 m EC_a and average 7.0 m EC_e . These calibrations allow the estimation of the average EC_e from EC_a (EM)

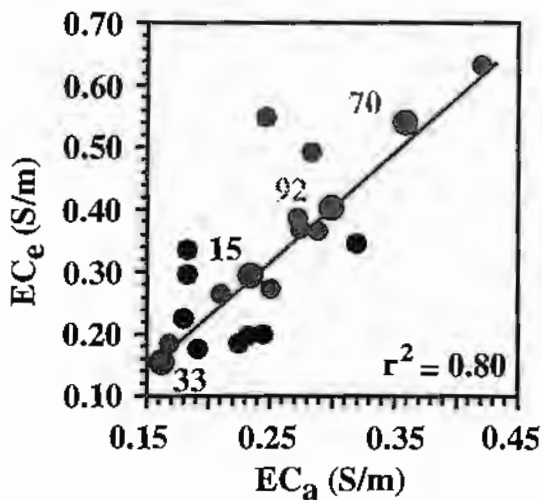


Figure 5. Calibration of 2.0 m EC_a to average 2.0 m EC_e .

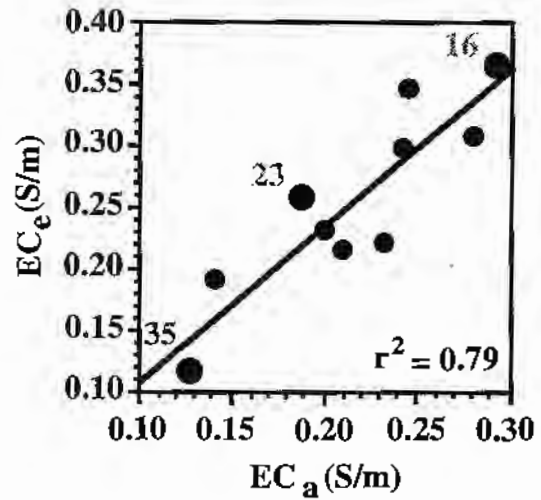


Figure 6. Calibration of 7.0 m EC_a to average 7.0 m EC_e .

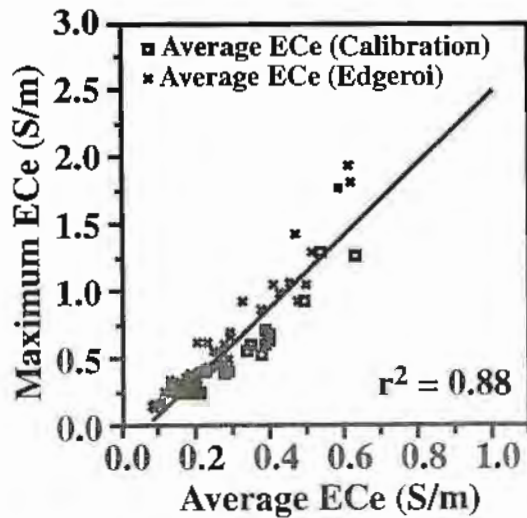


Figure 7. Linear relationship between Average Profile EC_e and Maximum EC_e .

measurement sites. Further, as illustrated in Figure 7, the EC_a calibration data along with the Edgeroi data (McGarry *et al.*, 1989) highlighted the potential of the EM38 instrument to determine the maximum EC_e within each profile (*i.e.*, to a depth of 2.0 m) due the strong correlation between average EC_e and maximum EC_e . Such knowledge can allow the production of maps that can delineate areas of potential salinity concern (*i.e.*, where monitoring sites can be established). The EM34-3 has yet to be calibrated as soil samples are required to a depth of up to 15 m.

GLOBAL POSITIONING SYSTEM

A Global Positioning System (GPS) was used to accurately locate EC_a measurement sites. The system operates by utilising a network of satellites. At any point in time as many as 7 to 8 satellites will be visible to the five channel GPS receivers. Out of these satellites an optimal set of four will be selected to trigonometrically calculate the location of the EC_a measurement site to within a few metres. The accuracy of the system can be greatly improved by using two receivers in tandem, with one located at a known position and used to correct errors caused by the atmosphere or poor satellite constellations. Further, using Carrier Phase antennae that can gather information on the velocity and direction of each satellite allowing the system to obtain

accuracies to within 1 m. Such a system is currently available to the researchers (Figure 8) with a base station located at the Australian Cotton Research Institute. The data generated will place each EC_a measurement site into the Australian Map Grid coordinate system to allow mapping. To date the system has been used to generate location data for the sixteen transects used to survey the three EM instruments of Auscott Field 19.

EC_a SURVEYING

Following calibration, EC_a measurements of the EM 31, EM38 and EM34-3 were used on a 50 m sampling grid (Triantafilis and McBratney 1992). Additional EC_a readings were taken where EC_a suggested larger EC_e values. For the EM31 and EM38 this occurred when the EC_a suggested average 7.0 m and 2.0 m $EC_e \geq 0.30$ and 0.40 S/m, respectively. In these areas data was generated at 25 and 12.5 m intervals. Data was also col-

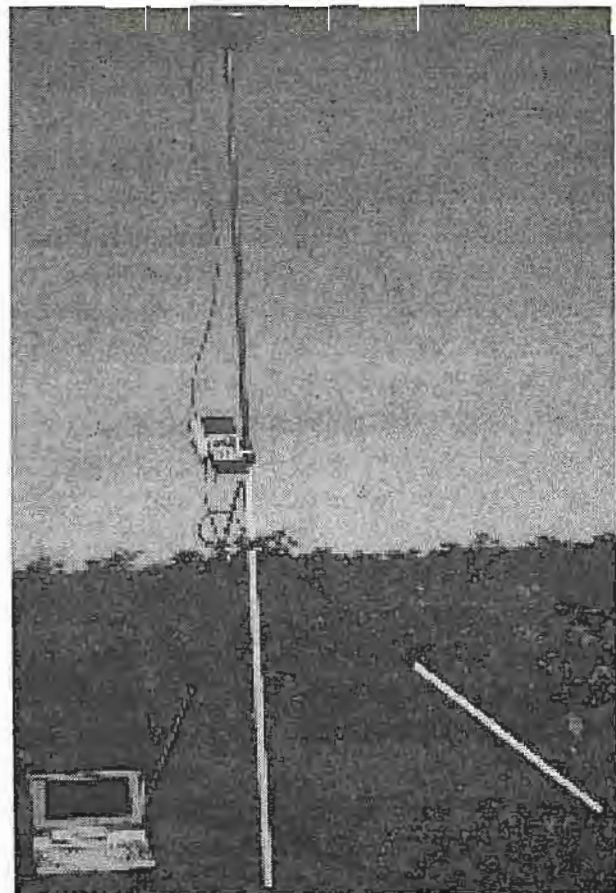


Figure 8. GPS 5-channel receiver with Carrier Phase Antennae and data logger.

lected randomly throughout the field at 1 m spacings to determine the short range spatial variability for continuous EC_e maps produced using geostatistical techniques.

GEOSTATISTICAL TECHNIQUES

Geostatistical techniques are used to estimate the value of a soil variable, such as average 2.0 m EC_e , at unsampled locations based on the values of the nearest spatially correlated neighbours. Techniques such as ordinary kriging can produce smoothly contoured maps that highlight those areas where further investigation is required. Another geostatistical technique called indicator kriging, can as the name suggests, indicate whether an unsampled site will exceed a critical EC_e value such as 0.77 S/m and 0.60 S/m. EC_e values that may effect cotton and wheat production, respectively.

Kriging involves two steps. Production of a variogram is the first. It simply indicates the distance the soil is spatially related and therefore the distance a particular point is eligible for predicting an unsampled point. The two components of the variogram are the variance and the lag. When the variance (*i.e.*, sill) is constant after a particular distance or lag, the soil within that distance is said to be spacially related. A variogram model, such as the spherical model fitted to figures 9 and 10, is then used describe the spatial correlation of the data and used for

prediction.

The variograms illustrate that the short range spatial variation (1 m) is very small, (*i.e.*, that those sites closest together are most similar) and that the data is spatially correlated to a distance of 85 and 82 m for the average 2.0 m EC_e and average 7.0 m EC_e , respectively. Therefore any data point where an EC_e value was obtained with and EM38 or EM31 reading within approximately 80 m of a unsampled location we wish to estimate can be used with confidence to determine an average profile EC_e value. The variograms also indicate the variance of the average 2.0 m EC_e throughout the field is slightly larger than the variance of the average 7.0 m EC_e . We can deduce that more of the variability with respect to EC_e is located in the surface 2.0 m of soil. This is attributable to the subsoil salt-rich Boolcarrol layer lies within this depth.

ORDINARY KRIGING

As mentioned previously, EC_e data was generated on a 50 m grid. Ordinary kriging was used for interpolation to a 5 m grid for Auscott Field 19 using the estimated average 2.0 m EC_e and average 7.0 m EC_e values (Figures 11 and 12, respectively). The 2.0 m maximum profile EC_e was also interpolated in this way (Figure 13). The resultant maps clearly identify a trend of larger average and maximum 2.0 m EC_e from the mid-eastern side of the field through an arc

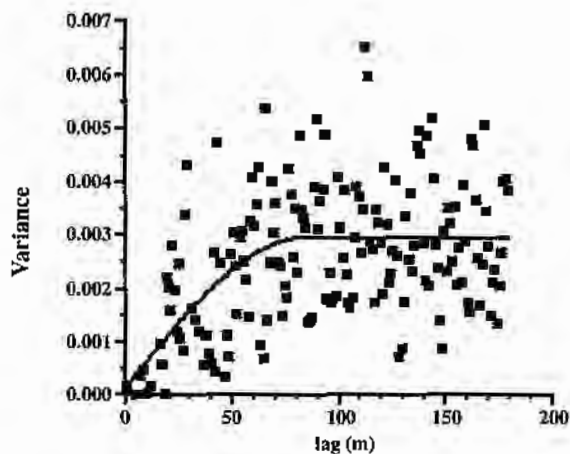


Figure 9. Variogram for calibrated 2.0 m averaged EC_e data..

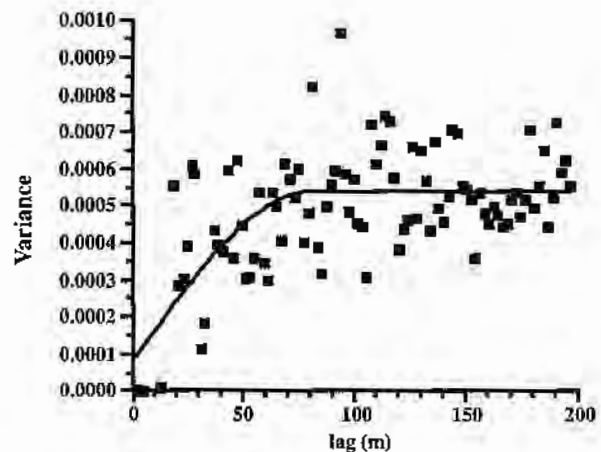


Figure 10. Variogram for calibrated 7.0 m averaged EC_e data..

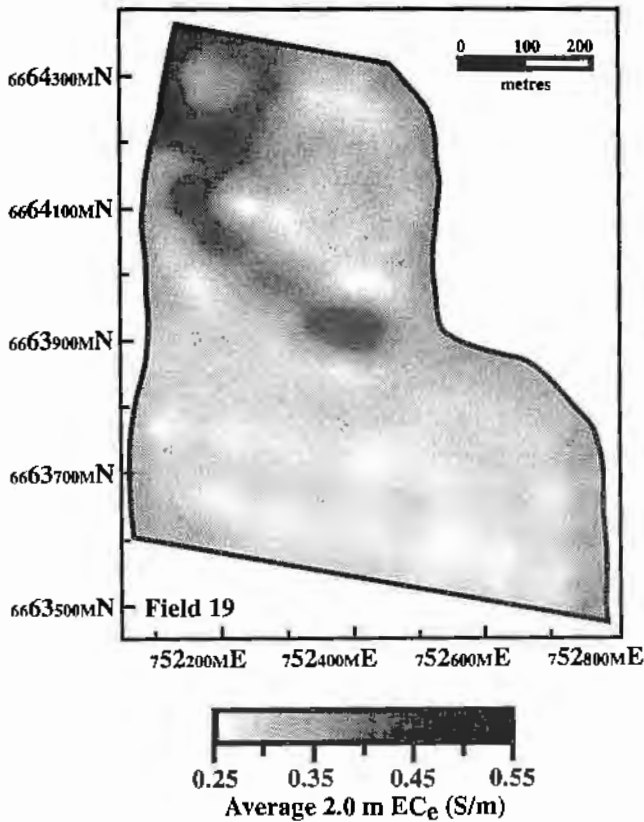


Figure 11. Kriged averaged 2.0 m EC_e calibrated survey data, Field 19

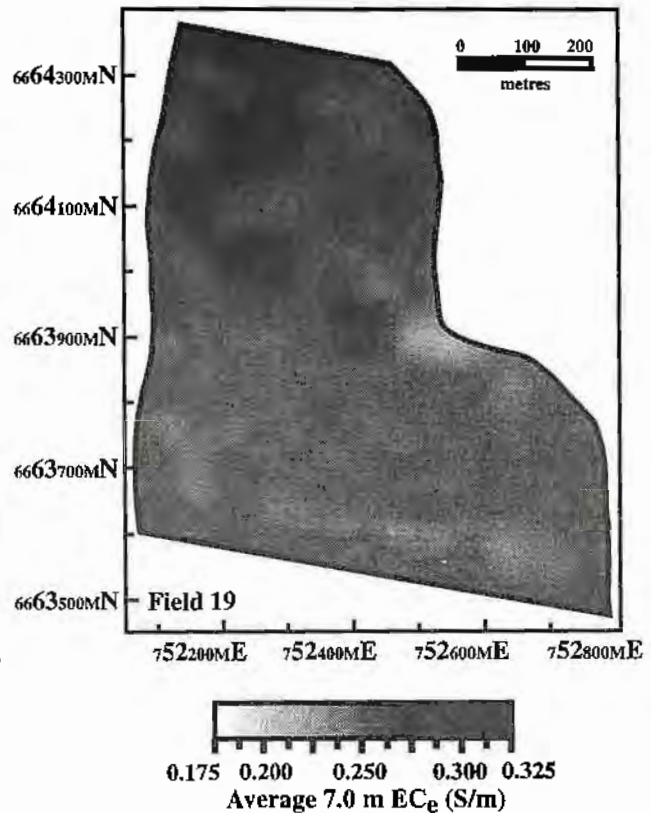


Figure 12. Kriged 7.0 m EC_e calibrated survey data, Field 19

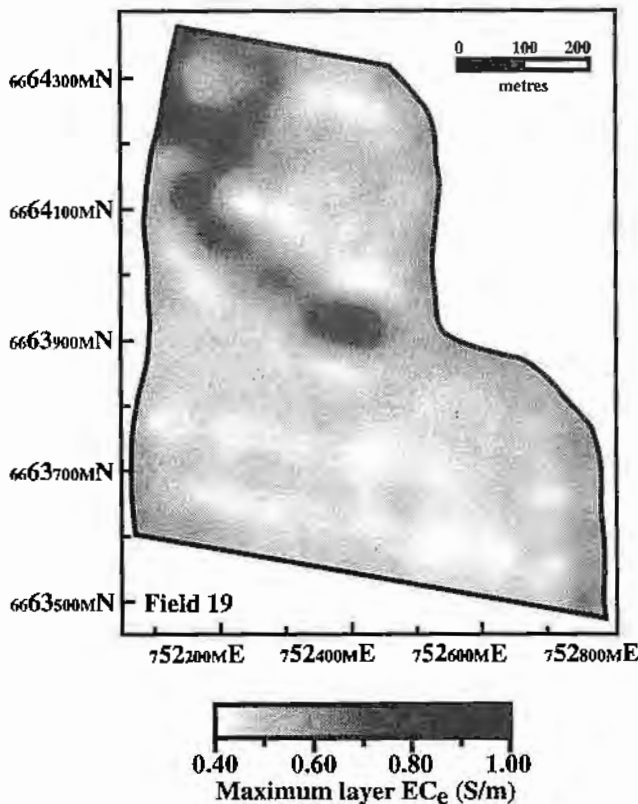


Figure 13. Kriged predicted maximum EC_e , Field 19.

to the north-west corner. These results tend to indicate the presence of the salt-rich Boolcarrol subsoil layer.

INDICATOR KRIGING

If we assume that a monitoring site should be established where maximum 2.0 m EC_e exceeds the critical value at which cotton becomes stressed, that is 0.77 S/m, then we can map with indicator kriging those sites where this value would be obtained. Such a map is presented in Figure 14. It was generated by allocating a value of 1 for each site that had a maximum EC_e greater than 0.77 S/m and a value of 0 for those sites less than 0.77 S/m. The map again highlights the north-east facing arc of larger EC_e .

Critical values of other crops grown in rotations with cotton can similarly be mapped, particularly as they not as tolerant. This is the case for wheat. Figure 15 was produced by using the critical EC_e value of 0.60 S/m as the cut off value for maximum 2.0 m EC_e . The map, again indicates

the characteristic arc but indicates that a larger area of the field exceeds the critical value. This reinforces the need for monitoring site location in the north-west part of the field and suggests the location of additional complimentary sites in other parts of the field. It is important that such sites be established and be investigated further since the cumulative EC_e values of some of the profiles presented in Figures 3 and 4 exceeded the EC_e at which yields and emergence of cotton are reduced by 50%, respectively 1.7 S/m and 1.5 S/m (Mass, 1986). Similarly with wheat, respectively 1.3 and 1.4-1.6 S/m.

DISCUSSION

Soil sampling and mapping were conducted in this area to provide monitoring data and assess the effects of a large earthen dam located adjacent to Field 19 (*i.e.*, dam wall runs parallel to south eastern portion of the field). Many cases of dam leakage had been reported in other valleys causing local rises in water tables and redistribution of deep salt stores into the rootzone

(Hall *et al.*, 1991). This led to 100 % reduction of crop yield in some areas. If leaks or permeable layers in the infrastructure caused such water seepage, a localised water table would be apparent near the dam walls and reflected by large EC_a readings. This was not the case here.

The noticeable trend or arc of higher EC_a (and hence EC_e), identified within Field 19 is not a consequence of dam leakage. Instead the explanation for the spatial distribution of EC_e appears to be due to the a lower lying position it once held in the landscape prior to development. Further, its proximity to the ephemeral Galathera Creek rendered it susceptible to periodic flooding. Therefore the trend is the result of natural accumulations of salts in the profile due to inundative events and poor deep drainage plus atmospheric accumulations of salts. It should also be noted that the trend in higher EC_e values is similar to that of the 'Galathera Syndrome' where poorer cotton growth is evident particularly during years where the crop is stressed. Further work needs to be done to verify the higher EC_e

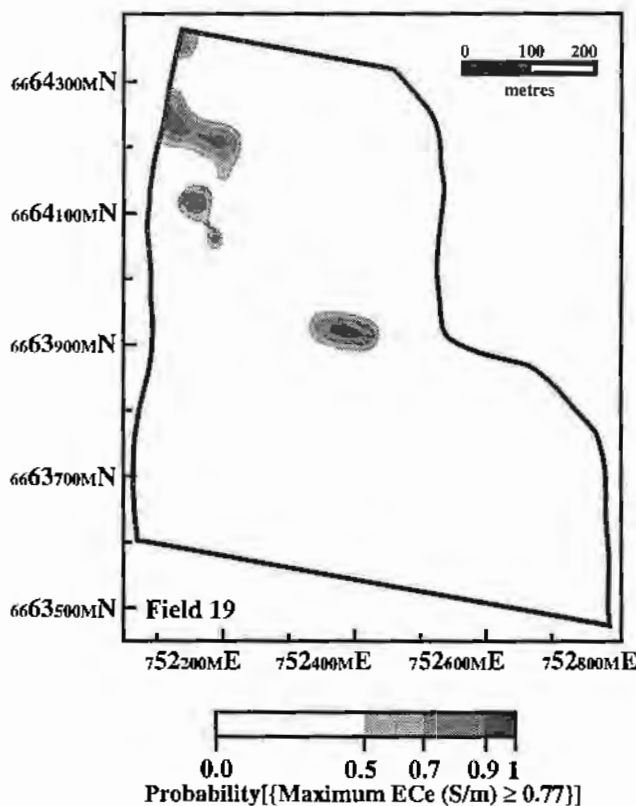


Figure 14. Indicator kriged map of maximum $EC_e \geq 0.77$ S/m, Field 19.

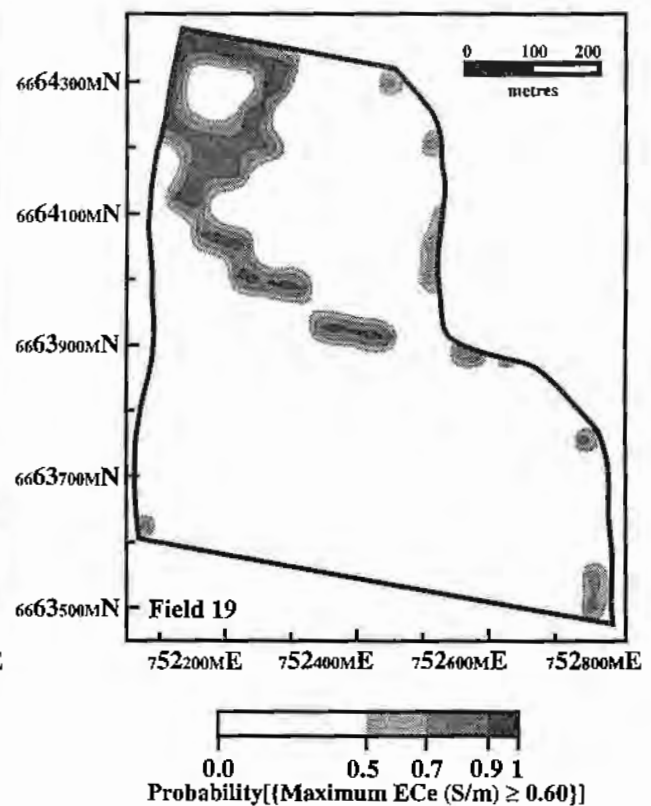


Figure 15. Indicator kriged map of maximum $EC_e \geq 0.60$ S/m, Field 19.

values obtained in this area since no calibration holes have been sampled and analysed, and to determine any link with the Galathera Syndrome.

CONCLUSIONS

The EM equipment and geostatistical techniques implemented here are providing baseline information on the spatial distribution of the subsoil salt-rich Boolcarrol soil layer. The instruments are proving to be reliable and rapid with the geostatistical techniques applied so far indicating areas of potential salinity concern and the location of monitoring sites.

IMPLICATIONS FOR THE COTTON INDUSTRY

The research and development of salinity assessment methodology will provide the cotton industry with techniques for rapid soil salinity assessment and baseline data collection for long term salinity monitoring purposes. The data generated and the laboratory and field methodology developed in the Namoi valley will provide future users of the information to assess the effect of irrigation in the valley and the methodology to assess the impacts of irrigation in other cotton growing areas.

FUTURE RESEARCH

To date up to 3 000 sites have been visited on a 50 m sampling grid with each of the three EM instruments within 8 fields (649 ha) on the Auscott, lower Namoi valley farm. However, data generation could be significantly accelerated by the development of an integrated EM-salinity module capable of transporting each of the three EM instruments. Coupled with a real time differential GPS for site location, the module would facilitate much more rapid data generation, mapping and field interpretation.

Broadscale salinity reconnaissance data that could act as baseline monitoring information could also be collected with the use of airborne EM instrumentation. Such instrumentation is

currently being assessed for its suitability for similar purposes. Data generated in this way could be stored in a GIS and compared with existing data stored in the system, including hydrology, soil, geomorphology, geology, *etc.*, to assess areas of potential salinity threat. Further, models could be developed to provide predictions as to where salinity monitoring sites should be located and where the integrated EM-salinity module is required for more detailed salinity mapping and monitoring.

Research work, is also required to produce salt-water balance models to assist with predictions of deep drainage and salt loading in the irrigated soil profiles. This will assist in determining the dynamics of the salt-rich subsoil layer.

EXTENSION

Extension of the field techniques established by the currently funded **Cotton Research and Development Corporation** project will be facilitated during field days and workshops with laboratory methods incorporated into the SOILPak manual, a soil management package for cotton production on cracking clays. During November of 1993 a small workshop entitled 'Silt, salt and Stuffed Soils' organised by the North-west Regional Committee of the Irrigation Association of Australia was used to introduce to the assembled growers, consultants and other researchers the usefulness and applicability of the EM34-3, EM38 and EM31 for salinity monitoring purposes.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of the **Cotton Research and Development Corporation** who provide the senior author with a generous **CRDC** studentship and for project US05C. We should like to thank Dr. I.O.A. Odeh of the CRC for Sustainable Cotton Production, who provided constructive comments and criticisms on earlier drafts of this article.

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