2.6 Soil imaging

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Key points

- Soil electrical conductivity and resistivity can be used to spatially represent soil properties such as moisture, clay content and salinity.
- A number of different instruments are available and are suited to different tasks.
- Some techniques offer detailed information such as multi-depth imaging.
- It is important to ground truth data to known physical properties within the sampling area.
- EM surveys can be used to ensure soil moisture probes are located in representative areas of a field.

This chapter gives a basic introduction into some of the techniques that can be used to provide an understanding of the spatial variability of soil properties. Some of these techniques, such as electromagnetic (EM) devices, are reasonably commonly used across the cotton and grains industries, whilst others such as geolectric (or 'DC resistivity') techniques have had some limited use in specific situations.

For those interested in more detail, the publication Geophysics for the Irrigation Industry provides an excellent background to the various techniques and specific pieces of equipment available and covers a range of issues that users of these methods should consider.

Electrical Conductivity

Most of the techniques available for soil imaging measure the electrical properties of the soil which are influenced by the soil texture, moisture and salinity. The most common soil imaging techniques measure either electrical conductivity or resistivity. Electrical conductivity is the ability of the soil to conduct an electric current, whilst resistivity is the inverse of conductivity; in other words, the ability of the soil to impede an electric current.

Electrical conductivity is measured by soil imaging instruments as an average over a bulk sample of the ground. However, the averaging is never uniform within the sampled volume and the values reported by the instrument are termed apparent electrical conductivity (EC_a). It should be noted that that different instruments may report different apparent electrical conductivity depending upon the way they are designed to operate and the heterogeneity of the particular soil.

General Considerations

There are over one hundred different instruments that can be used to measure soil spatial properties, using different techniques and with different characteristics. It is important to understand what information you hope to obtain for your particular circumstance, what technique is best suited and what other issues should be considered.

For example, what specific soil properties are you interested in? Do you want to understand differences in soil type, salinity or soil moisture, and how will you isolate the specific information that you require?

This is usually done by calibrating the measurements against soil samples at a number of locations, but it may also be possible to remove some variables in other ways. For example if a water storage is measured whilst it is full of water, it may be possible to eliminate moisture content as a variable (as all the soil is saturated).

Horizontal resolution is also important, particularly in locations where narrow features such as paleochannels may be likely. In such cases, the footprint of the device and the survey spacing used should have a horizontal resolution small enough to be able to resolve such features in cases where this is important.

Survey depth is a very important consideration. Different devices are designed to measure different soil depths, with some devices also able to measure at multiple depths. The purpose of the measurements will largely determine the depth to be measured and the vertical resolution required, although site conditions may also need to be considered.

One final consideration of particular importance is the impact of metal objects on readings, because instruments measuring electrical conductivity are often strongly influenced by metal objects in their vicinity. However different types of devices may respond to different types of metal objects in different ways, so that an object that creates a significant artefact when using one method may not show up at all when using a different method. It is important to note the location of objects that may cause an issue. Such objects might include fences, pipelines, power lines or machinery.

Most EC measuring devices are very strongly affected by metallic objects in their proximity. Shape and grounding of such objects may be very significant. For instance, an ungrounded fence, around a rectangular paddock, with a closed gate may not affect geoelectric devices but may cause problems for electromagnetic devices. Simply by opening the gate, the circuit through the fence may be broken resulting in negligible effect on electromagnetic devices. Similarly, a buried copper pipe may cause problems for a geoelectric device but have less effect on an electromagnetic device.

From: Geophysics for the Irrigation Industry

Some existing surveys have been conducted poorly, although the quality of surveys in general has increased considerably over time as operators have greater experience with the equipment and techniques. It is important for landholders to understand the capabilities of individual contractors and their own requirements for different soil imaging purposes. For example, a contractor who routinely and adequately conducts EM surveys for precision agriculture purposes may or may not have the equipment or experience to conduct detailed investigative imaging to identify preferential seepage paths in a water storage. It may be worthwhile discussing your requirements with a number of providers to find one who best suits your needs for each task.

Imaging techniques

Electromagnetic (EM) surveys are the most commonly utilised technique for imaging in agricultural soils and are most frequently conducted using Geonics EM31 and EM38 equipment, although other devices such as those manufactured by DUALEM are also in use. In typical use, this equipment provides an interpretation of the average bulk soil parameters which provides adequate data for most precision agriculture applications. The commonly used EM equipment provides information to depths of around 1 to 2 metres (EM38) and 6 metres (EM31), although a range of alternative EM meters exist with various characteristics and operating depths.

More sophisticated techniques and equipment are capable of providing additional information such as multi depth imaging. In this case, the nature and thickness of different soil layers can be identified, rather than an average of the characteristics over the total depth of measurement. Such techniques have not been widely used for agricultural purposes but might be particularly relevant for some purposes, for example identifying storage seepage issues. In particular, the presence of seepage pathways (such as sandy paleochannels) which are otherwise surrounded by clay material can sometimes be difficult to identify using EM surveys alone.

Geoelectric devices (often referred to as DC Resistivity techniques) have been used within the cotton industry more recently, although their use is still confined to a small number of cases at this stage. These devices are capable of providing information on soil at specific depths within the soil profile, and operate across a wide range of depths from less than 2 metres to greater than 40 metres. Some devices can also be adjusted so that the total depth of measurement can be varied. These devices require good electrical contact with the ground or water and have been typically employed in research projects with electrodes hammered into the ground to provide a single transect of information. However it is also possible to tow some devices, which is particularly practical on water surfaces and is therefore particularly relevant for identifying soil characteristics in storages.

Other techniques have also been used for specific purposes. For example, Central Downs Irrigators Limited used ground penetrating radar in 2005/06 to investigate possible wall weaknesses on 50 water storages in the Darling Downs region. Around the same time, researchers at the National Centre for Engineering in Agriculture used standard capacitance soil moisture probes to produce two dimensional images of soil moisture under centre pivot and lateral move (CPLM) irrigation (see WATERpak Chapter 5.5). More recently, Anna Greve at the University of NSW has developed a system to investigate three dimensional soil moisture movement using electrical resistivity techniques. Further information on this technique is available on the Connected Waters website and in the Australian Cotton Water Story (p. 53).

Examples of EM and geoelectric surveys for identifying storage seepage are included in WATERpak Chapter 1.6 whilst Chapter 1.5 also contains an example of a geoelectric survey being used to investigate soil moisture changes under cropping and native vegetation as part of a deep drainage study. Further examples are included below. Many additional examples and further information on the various techniques are contained in Geophysics for the Irrigation Industry.

Practical applications of EM surveys

The two case studies of EM application described below are from the irrigated cotton-growing areas of northern New South Wales.

The first is a field in the Namoi Valley experiencing minor cyclical salinity.

The second field, which is located in the Gwydir Valley, has perennial problems with a shallow watertable.

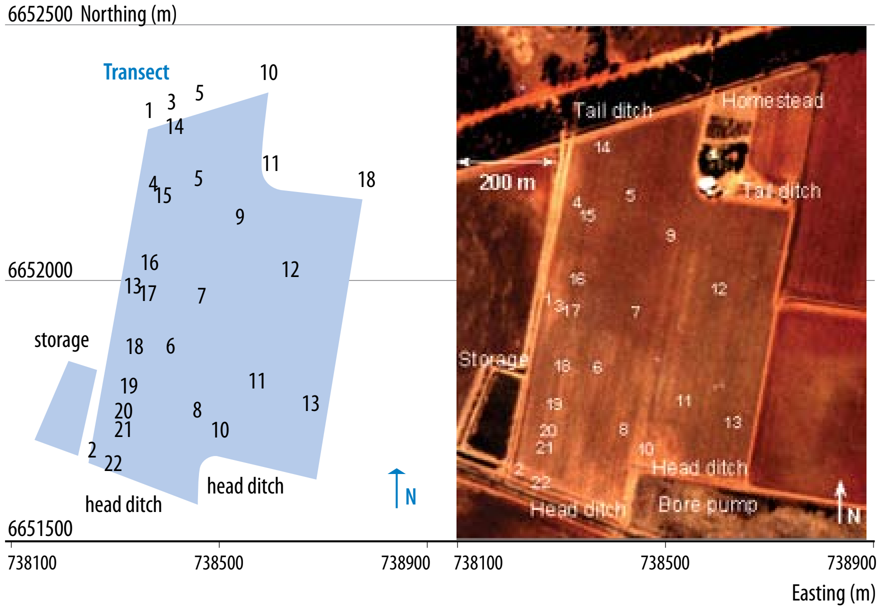
The EM survey helps identify likely causes of soil salinity and clay content in each cotton field studied, and adds value to limited soil information, helping identify where soil samples could be taken to enhance interpretation.

Case study 1, EM application

The first case study is located in the lower Namoi valley near Wee Waa. Figure 5.6.1 shows an aerial photo of a field that is experiencing problems with a shallow watertable and minor soil salinity. The head ditch is located at the southern end of the field next to the water storage.

An EM survey was undertaken to ascertain the extent of waterlogging and soil salinity and the likely causes. Eighteen transects were traversed in a north-south direction in this 29 ha field, recording 20,000 EC_a measurements with the EM38 and EM31 instruments. Twenty-two soil profiles were sampled to a depth of 2.0 m for calibration. Samples were obtained at 0.3 m increments.

Figure 2.6.1. Aerial photograph, location of transects and sampling sites, Case study 1

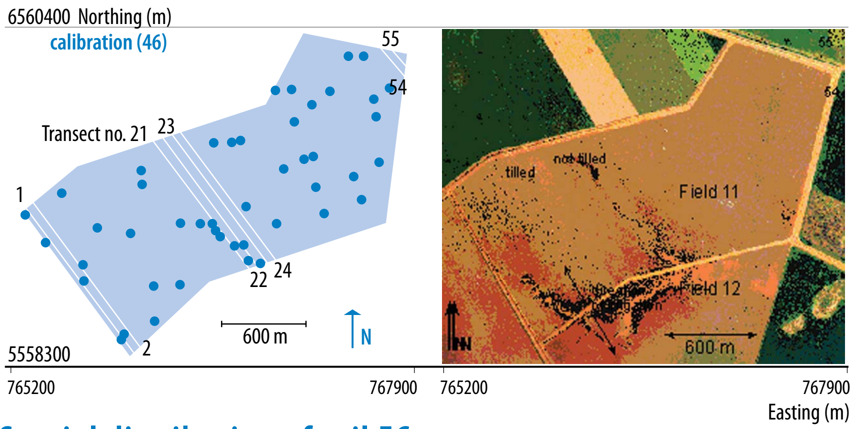


Case study 2, EM application

The second case study is located in the lower Gwydir Valley north-west of Moree. The problem experienced in this field is the presence of a shallow watertable which is causing waterlogged conditions in the middle sections and near the head ditch. Figure 2.6.2 shows the irrigation layout. Again, the head ditch is located at the southern end of the field. A large supply channel and the head ditch of the southern field run parallel to the head ditch of the field.

Fifty-five transects were travelled at a spacing of 48 m. In this field of 240 ha, 27,000 EC_a measurements were made with the EM instruments. The EM survey took two days to complete. A total of 46 soil profile sites were chosen at low, intermediate and high values of soil EC_a for calibration. These were sampled to a depth of 1.5 m.

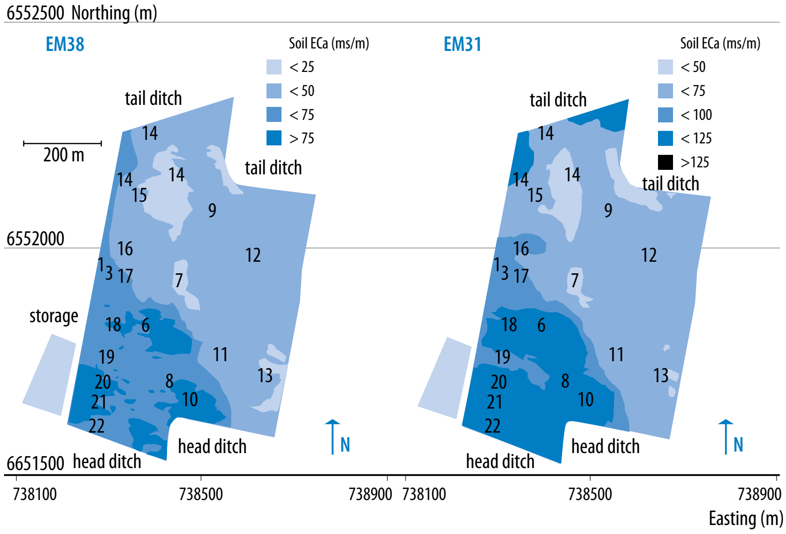
Figure 2.6.2. Aerial photograph, location of transects and sampling sites, Case study 2.



Spatial distribution of soil EC_a

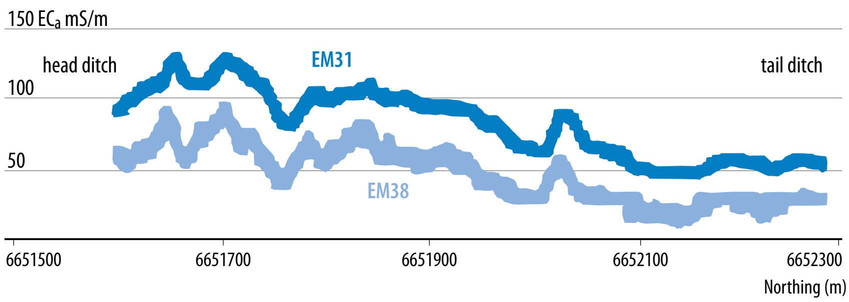
Figure 2.6.3 shows the spatial distribution of EC_a as generated by EM38 and EM31 in Case Study 1. Both instruments show that in the south-west corner, near the head ditch and eastern storage wall, EC_a is higher (for example, EM31 > 125 mS/m) than at the northern or tail ditch end (EM31 < 75 mS/m). This is consistent with where waterlogging is apparent.

Figure 2.6.3. Spatial distribution of EC_a, Case study 1: a) EM38; and, b) EM31



It is also evident that a sharp drop in EC_a occurs approximately halfway between the head and tail ditch. This drop in soil EC_a is shown more clearly in Figure 2.6.4, along transect 3.

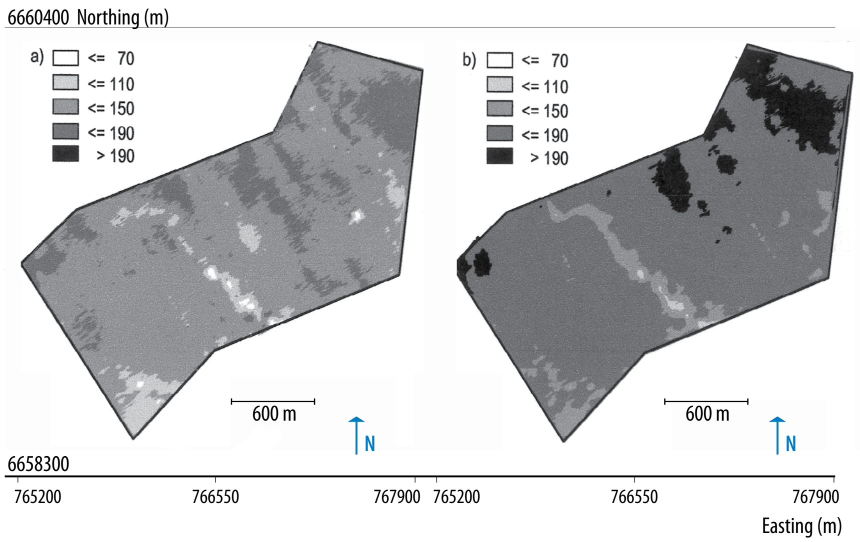
Figure2.6.4. Spatial distributions of soil EC_a along transect 3, Case Study 1.



What is also apparent in Figure 2.6.3b is a small band of low EC_a (that is, <100 mS/m) which lies perpendicular to the eastern storage wall at an approximate Northing of 6651750 (sample site 19). This lower band of soil EC_a is more evident in Figure 2.6.4 for both EM instruments (that is, Northing 6651750).

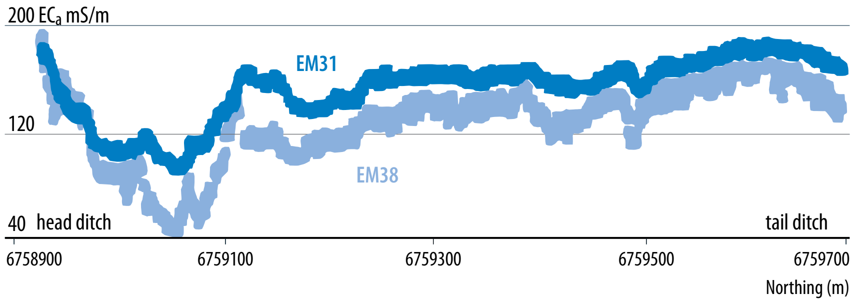
The spatial distribution of soil EC_a generated at Case study 2 is shown in Figure 2.6.5 for the EM38 and EM31. In the north-eastern part of the field, larger values of EC_a (>185 mS/m) were generally obtained with the EM38 and reflect areas where heavy clay profiles exist. Similar, EC_a patterns were obtained with the EM31.

Figure 2.6.5. Spatial distribution of ECa across Case Study 2 for: a) EM38; and, b) EM31 in vertical mode of operation



The lighter shaded areas in Figure 2.6.5 (EC_a < 110 mS/m) indicate parts of the field where a prior stream travelled and where sandier soil types are apparent. This suggests both instruments are primarily responding to clay content and soil mineralogy and hence strongly reflect geology and geomorphology. This is more clearly illustrated in Figure 2.6.6, which shows the spatial distribution of soil EC_a recorded along transect 22 at Case Study 2. The location of the sandier prior stream material is evident between the Northings of 6758900 and 6759100. Further away soil EC_a generally increases and reflects the more clayey soil of the alluvial plain.

Figure 2.6.6. Spatial distributions of soil ECa along transect 22, Case Study 2.



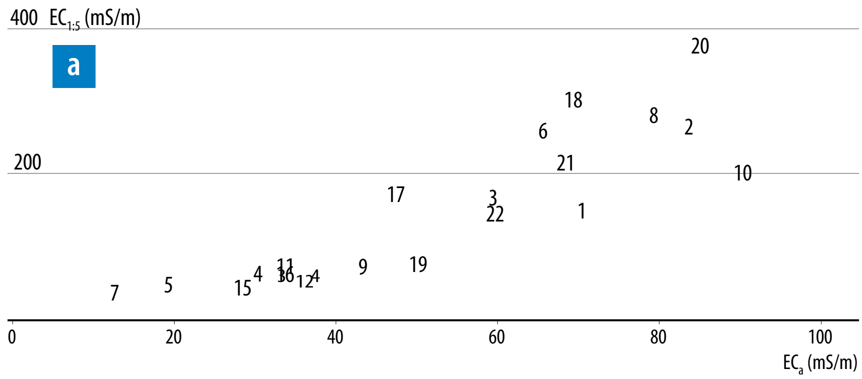
Interpreting soil EC_a

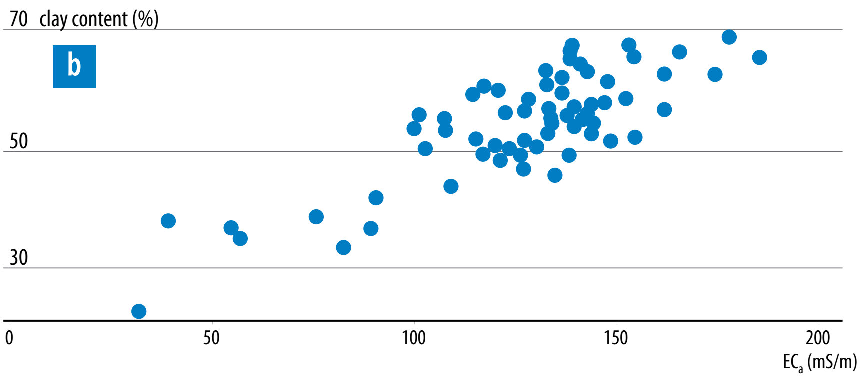
In order to confirm these field observations and determine which soil attributes influence EC_a, average profile values for clay content (%), soil moisture (field moisture %), effective cation exchange capacity (cmol(+)/kg) and soil salinity ($EC_{1:5}$ – dS/m) were determined from the samples collected in each case study. These average profile values were compared with soil EC_a using simple linear regressions.

At Case Study 1, soil EC_a was generally not correlated with average field moisture or clay content. Figure 2.6.7 (a) shows that a reasonable relationship exists between EC_a and $EC_{1:5}$. The low salinity profiles are generally located in the northern half of the field, near the tail ditch. The more saline profiles characterise the southern half near the water storage and where soil EC_a was also much larger. Significantly site 19, which is located in the southern half of the field and lies adjacent to the northeast corner of the storage, does not belong to this group of more saline/high soil EC_a profiles. It is apparent from Figure 2.6.3 that this site does lie within the lower band of soil EC_a as measured by the EM31 and EM38, however.

By comparison, soil EC_a at Case Study 2 was most strongly correlated with average soil clay content and to a lesser extent cation exchange capacity (cmol(+)/kg) and field moisture content (%) to a depth of 1.5 m. The relationship between EC_a and clay content is shown in Figure 2.6.7.

Figure 2.6.7. Relationship between soil EC_a as measured by the EM38 and average a) soil $EC_{1:5}$ at Case Study 1, and b) clay content at Case Study 2.





In summary, the EM system that was developed and deployed provided preliminary soil EC_a information which could be used to determine suitable soil sampling sites. Once analysed for the various soil properties that affect EM instrument response, interpretations could be made as to the likely cause of soil salinity and irrigation inefficiencies in these two irrigated cotton-growing field in northern New South Wales.

At the first case study site, the field is experiencing perched watertables and modest saline soil conditions. This is affecting irrigated cotton production. The probable cause of the problem originates from the storage dam, which has either been constructed poorly or includes soil types which are unsuitable. Further investigation is required and should be targeted at the north-west corner of the storage dam. This coincides with the lower band of soil EC_a apparent in Figures 2.6.3 (b) and 2.6.4. The reason for this is that lower soil EC_a coincides with lower soil salinity ($EC_{1:5}$) as evidenced at site 19. This suggests that the salts have been leached. It is most likely that the movement is lateral through this band of lower soil EC_a because in the adjoining areas soil salinity is quite high at some depths ($EC_{1:5}$ of 6 dS/m). Once the area of leakage has been determined, the dam wall can be reconstructed or lined with impermeable clay membranes.

At the second case study site, the field is similarly experiencing a perched watertable. The problem appears to be due to the location of the supply channel and head-ditch of this field on top of a prior stream channel. Because of the sandy nature of the soil, the supply channel and head ditch are extremely permeable. At the time the EM survey was undertaken, the field was in fallow. However, a shallow watertable was evident when soil samples were taken near the head ditch. The likely management required in this area includes lining the channel with impermeable membranes or re-routing the location of the supply channel to a more suitable area on the farm.

Case Study 3 - Using EM surveys to locate soil moisture probes

Soil moisture monitoring tools are commonly used in the irrigation industry to assist growers like Andrew Parkes of Keytah, Moree and Von Warner, the manager of Bullamon Plains, Thallon with their scheduling decisions. They provide soil moisture information at a specific location within a field. To have confidence in any soil moisture monitoring tool you need to ensure it is located in the most representative part of the field in which it is used to schedule irrigations.

A moisture probe placed in the wrong spot can result in over or under irrigation of the majority soil type in that field. For example, a probe sited in a section of field where the soil is lighter (hence lower water holding capacity) may result in more frequent irrigations than is required for the majority of the field, costing you valuable resources.

EM surveying, used in conjunction with soil sampling, can be used to map soil variations across fields and farms. After ground truthing the instrument by comparing soil samples and EM readings at a number of locations, an EM survey can give an indication of texture changes over the field. Further analysis of this data provides maps of similar soil types and consequently can be used to locate the "majority" soil type within a field.

Andrew and Von are convinced about the benefits of EM soil surveys on their farms. Both growers have used calibrated EM maps to examine soil variability across their fields in order to position moisture probes in sites that are representative of the field, ensuring that their probes are located within the majority soil type, year in and year out.

"Using EM surveys to assist siting moisture probes has given me more confidence with my scheduling decisions" Von said. "It gives me the ability to draw down water and stretch irrigations if necessary". Von did point out that moisture probes are just one tool he uses to schedule irrigations. "Keeping a close eye on weather forecasts and visual inspection of the crop is still vital"

For Andrew, the change in practice for siting moisture probes occurred when capacitance probes first came to the fore. The use of telemetry meant these probes could be placed anywhere in the field. Previously he would position the probe tubes in a section of paddock that looked representative, but was also easily accessed. Back in 2001-02 he was sitting down with Andrew Smart from Precision Cropping Technologies, Narrabri, looking at yield maps.

"I asked him how he knew the probe was placed in the right area in terms of soil water holding capacity." Andrew (Smart) said. "An initial EM survey using an EM38 showed that the EM data on Keytah was heavily influenced by clay content and therefore data from the EM survey could be used to provide a detailed map of potential water holding capacity to around 1.2 to 1.5 metres."

As luck should have it, the probe had been placed in a site that was close to the fields "majority" soil type (and hence "majority" water holding capacity), but the EM survey pointed out the variability of soil in this field. In fact, close to the probe site was a section of field that was much lighter in texture, and the probe could just as easily have been placed in this area.

Because yield maps were also being produced, it was possible to determine that scheduling based on the majority soil type had a positive impact in terms of production. "Yield maps were compared with the data collected from the EM survey and a close correlation between yield and EM readings was found." Andrew (Smart) said.

Figure 2.6.8 shows the relationship between EM and yield, which shows that the majority soil type (with an EM reading of between 120 and 140), matched the areas of the field with the highest yield. This illustrates that they are managing the field and its water based on the majority soil type, as the highest yields are occurring in the majority soil area.

Figure 2.6.8: Relationship between EM reading and Yield (Bales/ha)

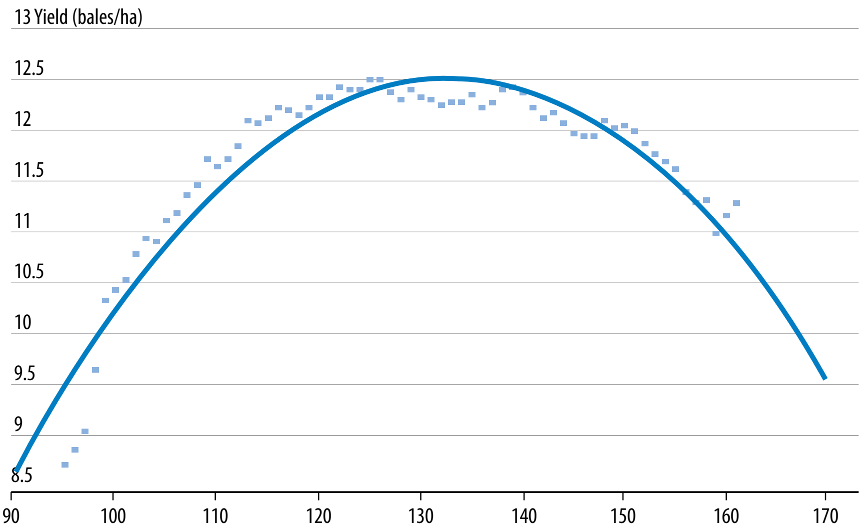


Figure 2.6.9. EM soil variability map

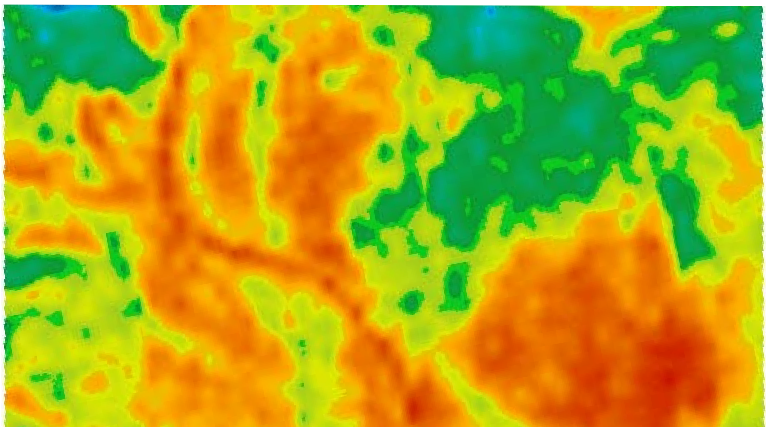


Figure 2.6.10. Slope map to identify possible hollows or ridges

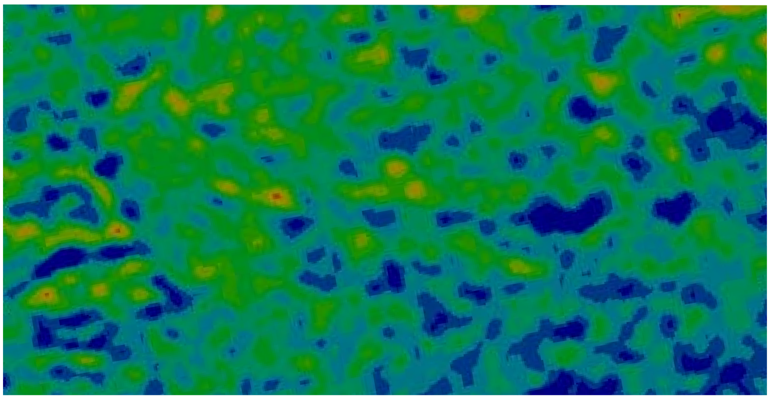


Figure 2.6.11. Combined map showing majority soil type and majority slope

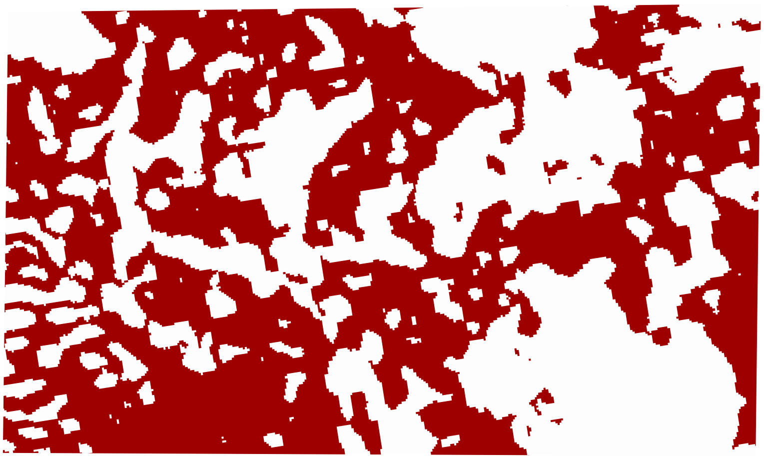


Figure 2.6.8 also shows the lighter soils yielding less because they would have been more stressed from lack of timely water. The higher clay areas or higher EM readings (EC_a>140) were more than likely water logged, but both these soil types only make up a small area of the field.

To refine probe placement, an EM soil variability map (Figure 2.6.9) was overlayed with a slope map (Figure 2.6.10) to analyse variations from perfect plane (to make sure the probe is not placed in a hollow or a ridge) and also a cut and fill map if the field was laser levelled in the last 2-3 years.

These layers of data can then be combined to produce a map (Figure 2.6.11) which best represents majority soil type, closest to majority slope and in some cases removal of areas of high previous cuts and is then used to site the location of the probe in the field. In conjunction with this type of map, Andrew (Parkes) reminds us that ground truthing is still critical, "You need to check your probe is placed in an average plant stand which is also representative to the rest of the field