

**Attachment 2:** SRDC Project BPS001, Final Report

# **Operations manual for soil electrical conductivity mapping**

*A guide to collecting, analysing, and interpreting soil ECa data in precision sugarcane agriculture*

by

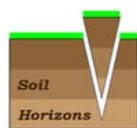
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## Table of Contents

Item	Page
Acknowledgements	4
Aims of the manual	6
Soil ECa mapping and precision agriculture	7
Collecting Veris 3100 soil ECa data	15
Processing Veris 3100 soil ECa data	19
Optimal conditions for Veris 3100 soil ECa mapping	27
Stability of soil ECa mapping over time: shallow soil ECa mapping	31
Stability of soil ECa mapping over time: deep soil ECa mapping	35
Using soil ECa maps: examples from Project BPS001	39
Role of soil ECa mapping in defining management zones within paddocks	47
Further reading	55

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## Acknowledgements

- This manual is an outcome from Project BPS001 entitled, “*Establishing georeferenced management zones within cane paddocks: a foundation for precision agricultural approaches to reliable sugarcane production*”. The project received funding from SRDC for four years: 2007 – 2011.
- Project BPS001 was carried out by staff of:
  - Burdekin Productivity Services Ltd, Ayr (*Project Administration*),
  - Soil Horizons Pty Ltd, Townsville (*Project Leadership*),
  - Queensland Department of Employment, Economic Development, and Innovation (DEEDI), Mackay, Townsville, and South Johnstone,
  - Ag Data Solutions Pty Ltd, Ayr,
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## Acknowledgements

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### **Burdekin Cane District:**

- Ian Haigh, Brandon. Site B1, 7 km west of Ayr on light sandy “Burdekin Delta soils”.
- Steve Lando and farm manager Bruce Graham, Brandon. Site B2, 13 km west of Ayr on heavy clay soils typical of the Burdekin River Irrigation Area.

### **Herbert Cane District:**

- Alan Pace, Mutarnee. Site H1, 35 km southeast of Ingham on younger alluvial soils adjacent to Crystal Creek.
- Geoff and John Morley, Lannercost. Site H2, 15 km northwest of Ingham on older heavy clays of an ancient Herbert River distributary system.

### **Central Cane District:**

- Tony and John Bugeja, Rosella Farm, Homebush. Site M1, 12 km south of Mackay on clayey alluvial sediments.

## Aims of this manual

- Project BPS001 was funded by SRDC in 2007 – 2011 to identify the roles of soil ECa mapping, processed satellite imagery, and crop yield monitoring in providing a foundation for precision agriculture in sugarcane production.
- This manual provides guidelines for the production and interpretation of soil ECa maps for use in the application of precision sugarcane agriculture.
- The material set out in this manual has been derived from experience gained in using *Veris 3100 Soil ECa Mapping Units* from Independent Agricultural Resources, Mackay, and Ag Data Solutions, Ayr, to map five study sites in the Mackay, Burdekin, and Herbert areas, as part of Project BPS001, and from prior commercial experience.
- The methods and procedures provided have been discussed in detail in the Final Report of Project BPS001 which is available at: [www.srdc.gov.au](http://www.srdc.gov.au)

**Soil apparent electrical conductivity mapping  
and  
precision agriculture**

## What is “apparent soil electrical conductivity” ?

- The **Veris 3100 Soil ECa Mapping System** (Veris Technologies, 2000) measures the apparent electrical conductivity (ECa) of soils, as opposed to laboratory-measured soil electrical conductivity. In earlier times the technique was referred to as ‘soil EM mapping’ which also embraces soil electromagnetic induction mapping techniques.
- **‘Soil electrical conductivity’ (EC)** is an indicator of soil salinity and is determined in the laboratory by inserting a glass electrode into a shaken suspension of 1 part of soil to 5 parts of water and measuring the flow of electrical current.
- **‘Apparent soil electrical conductivity’ (ECa)** is measured by direct contact in the field by passing an electric current through the upper part of the soil profile. Changes in voltage of the return signals, recorded at specific locations in the paddock, indicate the concentration of electrically conductive material in the soil.
- The main factors affecting soil ECa signals include soil salinity and a combination of the following soil properties: clay type and percentage, bulk density, moisture, and temperature (Rhoades *et al.*, 1989).
- The factors contributing to the soil ECa signals in many locations are also known to limit crop yields (Johnson *et al.* 2005).

## What is “precision agriculture” ?

- Precision agriculture is a farm management approach that underpins sustainable farm returns by selectively applying inputs and management practices to spatially defined parcels of land (*i.e.* management zones) within paddocks, farms, or catchments.
- Precision agriculture begins with the soil, which is the basic management unit in any paddock, and deals with the responses in crop growth to the complex interactions of soil nutritional status, soil physical properties (especially soil texture), surface and subsurface drainage, seasonal conditions, soil health, pests and diseases, cane variety adaptability to soil type, and paddock management practices.
- In summary, precision agriculture is focused on:
  - identifying within-paddock variability in soils and crops,
  - determining soil- and site-related constraints to crop growth,
  - providing a basis for managing inputs (*e.g. fertiliser, gypsum, lime, herbicides, pesticides, water, tillage, etc*) to selected parts of paddocks in order to manage the constraints to crop production.

# Project BPS001 and precision sugarcane agriculture

Where the industry wants to be →

## 5. Whole catchment management:

- Economically, environmentally, and socially sustainable systems
- BMPs applied to whole catchments

## 4. Zonal management in paddocks and farms:

- Application of BMPs (e.g. 'Six Easy Steps') to separate management zones within paddocks

## 3. Georeferenced zones based on:

- Actual soil data or soil ECa maps
- Paddock topography (drainage)
- Sugarcane yield patterns

Project BPS001 →

## 2. Integrated farming systems:

- Controlled traffic, with or without GPS guided steering
- Reduced tillage, permanent beds
- Legume fallow cropping
- Nutrient inputs as uniform dressings over the whole paddock

← Where many growers currently operate

## 1. Well established, conventional farming practices:

- 1.5 m row spacing
- Bare fallow
- Plough out – re-plant

← Where most growers have come from

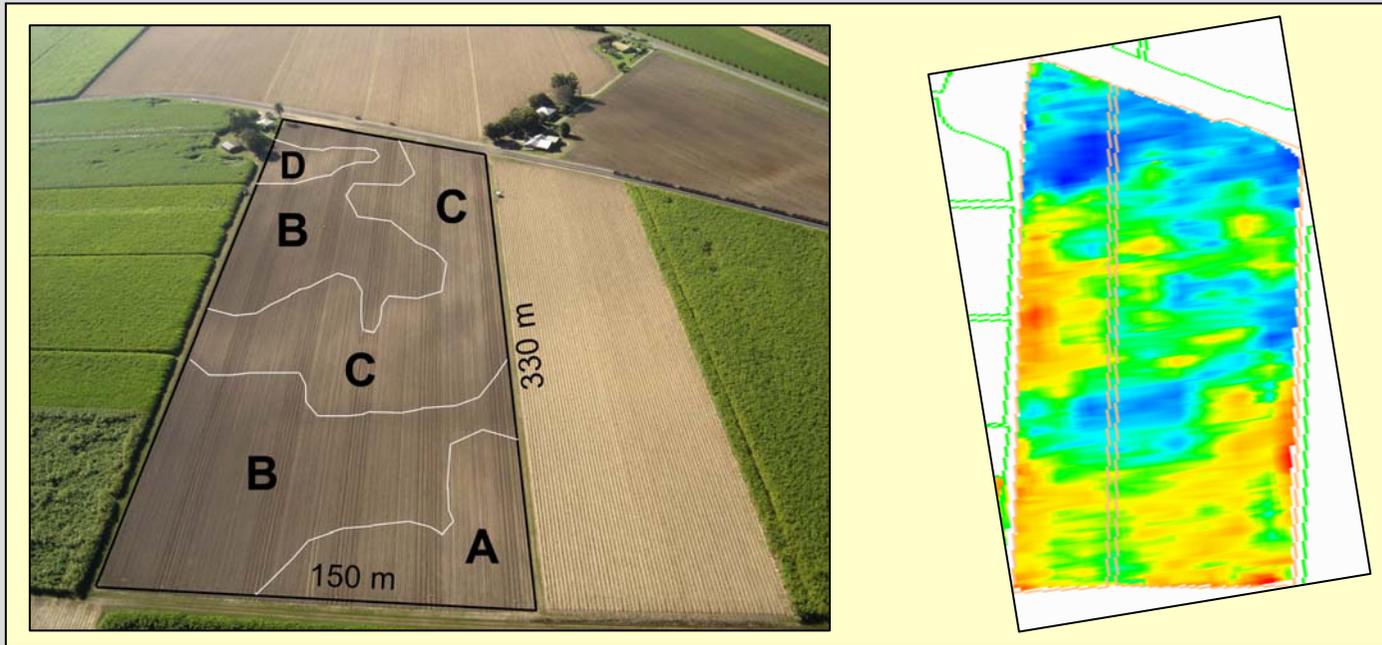
## Tools for precision agriculture in sugarcane production

- Over the last decade, technological advances have provided the sugar industry with precise, georeferenced, spatial location systems, variable rate control of inputs, and yield monitoring and mapping (Bramley, 2007), including:
  - controlled traffic through GPS-guided steering of machinery,
  - crop yield monitors on harvesters,
  - GPS-controlled equipment for site-specific application of inputs such as fertiliser, gypsum, lime, herbicides, and pesticides.
- Increasing use is being made of spatial data such as:
  - georeferenced sites for soil sampling and testing (Di Bella *et al.*, 2009a),
  - apparent soil electrical conductivity (ECa) mapping (Coventry *et al.*, 2009),
  - crop yield mapping (Di Bella *et al.*, 2009b).
- However, the best use of these tools for managing spatial zones in paddocks cannot be made without **detailed maps** that depict the **variability of the soil** and the **variability of crop yield response patterns**.
- Knowledge of variations in soil properties is still poor, especially at a cane paddock or sub-paddock scale where it is appropriate to manage relatively small land units.

## Inadequacy of published soil maps for precision agriculture

- The application of precision agricultural techniques in cropping systems depends on the recognition of georeferenced zones within paddocks.
- The zones provide a framework for growers who wish to make site-specific decisions in applying management practices to individual areas within paddocks. In this way, input levels can be targeted for cost-effective production, minimised waste, and reduced environmental impacts.
- But management decisions must be underpinned by sound knowledge of variations in the underlying soil properties.
- With the exception of much of the Herbert District, however, there are few areas where soil maps are available to cane growers at a scale meeting the requirements of precision agriculture, and with sufficient detail to show soil variations within cane paddocks.
- Coventry *et al.* (2009) estimated the cost for the 53 man-days required to map 100 ha at 1:5,000 scale, using conventional soil mapping methods (*i.e. soil boreholes to 1 m depth on a 40 x 40 m grid*), at \$34,000 for the labour alone + travel + accommodation + base maps and images + GST.

## Mapping soil patterns within sugarcane paddocks



- Collecting reliable soil information using conventional mapping methods, and at a scale useful for precision agriculture, is becoming prohibitively expensive.
- A typical cane paddock (*left*) of 5 ha is likely to include several areas with contrasting soil characteristics.
- A soil ECa map (*right*) of the same paddock shows soil-related variations that can be mapped commercially by operators based in Mackay or Ayr at a rate of 5 ha / hour, and at a current cost of \$30 / ha + travel + map production costs.
- The present manual aims to demonstrate how such maps are constructed and what the patterns mean for precision agricultural practices.



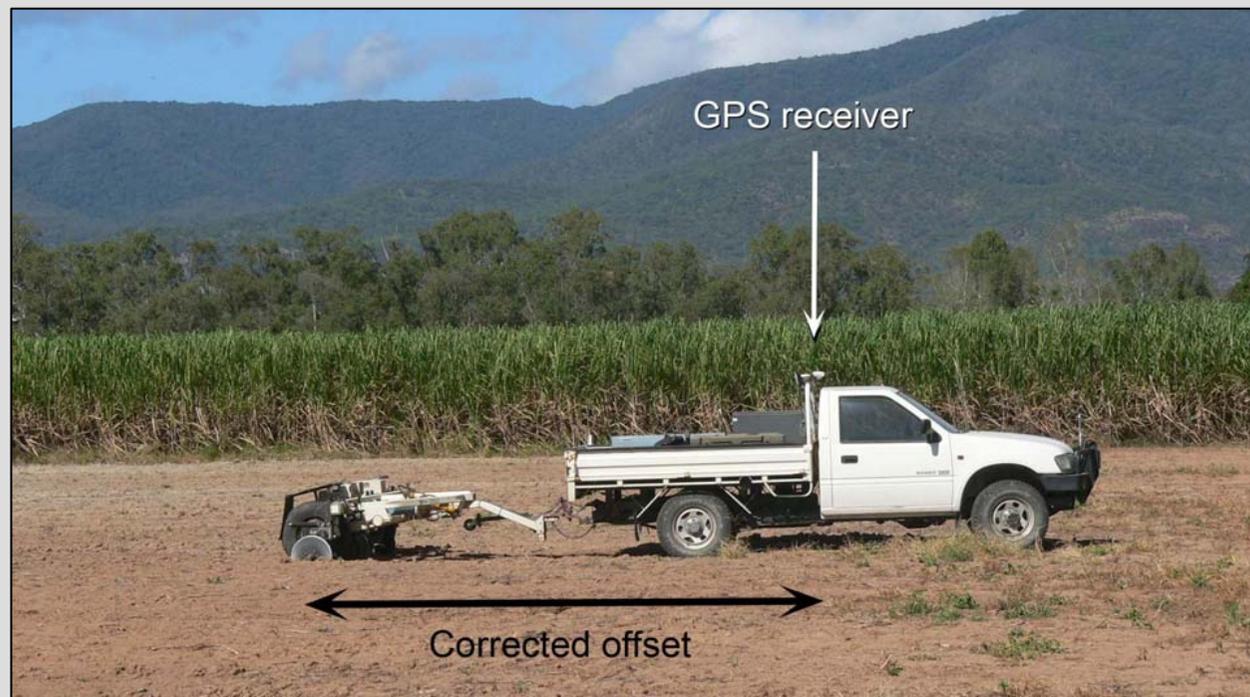
**The Veris 3100 Soil ECa Mapper**

# **Collecting soil ECa information**

*Field operations*

## Apparent soil electrical conductivity mapping using the Veris 3100 Soil ECa Mapper

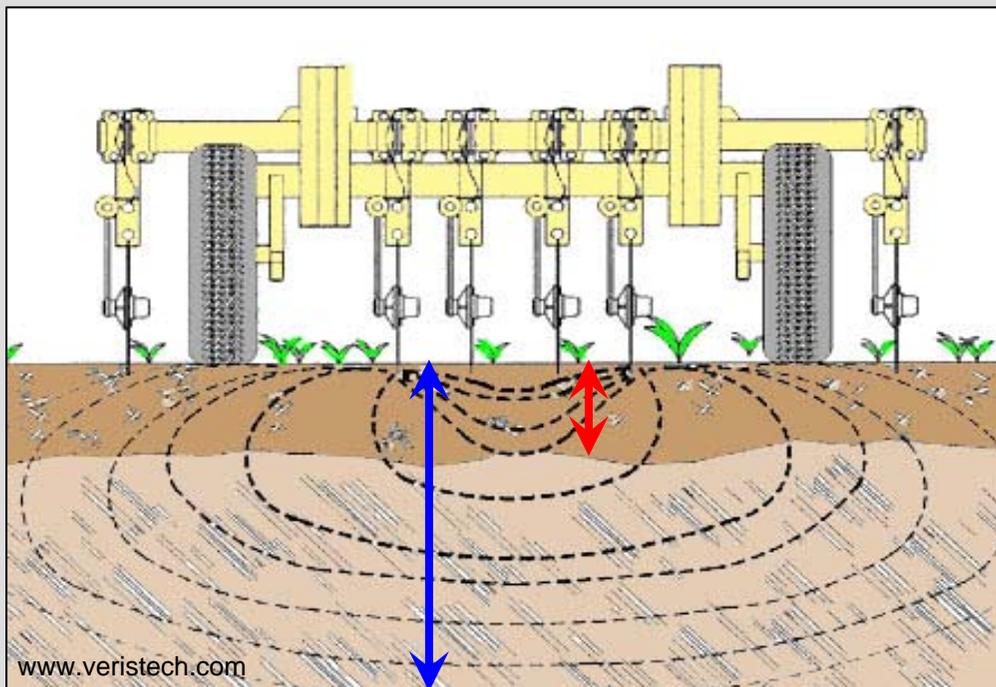
- The Veris 3100 Soil ECa Mapper is manufactured by Geoprobe Systems, Salinas, Kansas, USA. It consists of a trailer with coulters (electrodes) set at different spacings and in contact with the soil, an electrical current emitter and detector, a GPS receiver, and an on-board data logger.
- In project BPS001, apparent soil electrical conductivity mapping was carried out during the fallow phase between cropping cycles, and in cultivated land or prepared seed beds, just prior to planting the sugarcane crops at each study site





## The Veris 3100 Soil ECa Mapper

- The machine injects an electric current into the soil and measures the return voltage changes.
- Data are recorded at 1 second intervals (approximately 5 m spaces) along the run.
- Apparent electrical conductivity readings are collected from the soil over two depth intervals at georeferenced locations in the paddock:



← ● **0 – 300 mm:**  
*cultivated topsoil*

← ● **0 – 900 mm:**  
*disturbed topsoil and  
undisturbed subsoil*



# **Processing Veris 3100 soil ECa data**

*Processing for rapid in-field mapping*

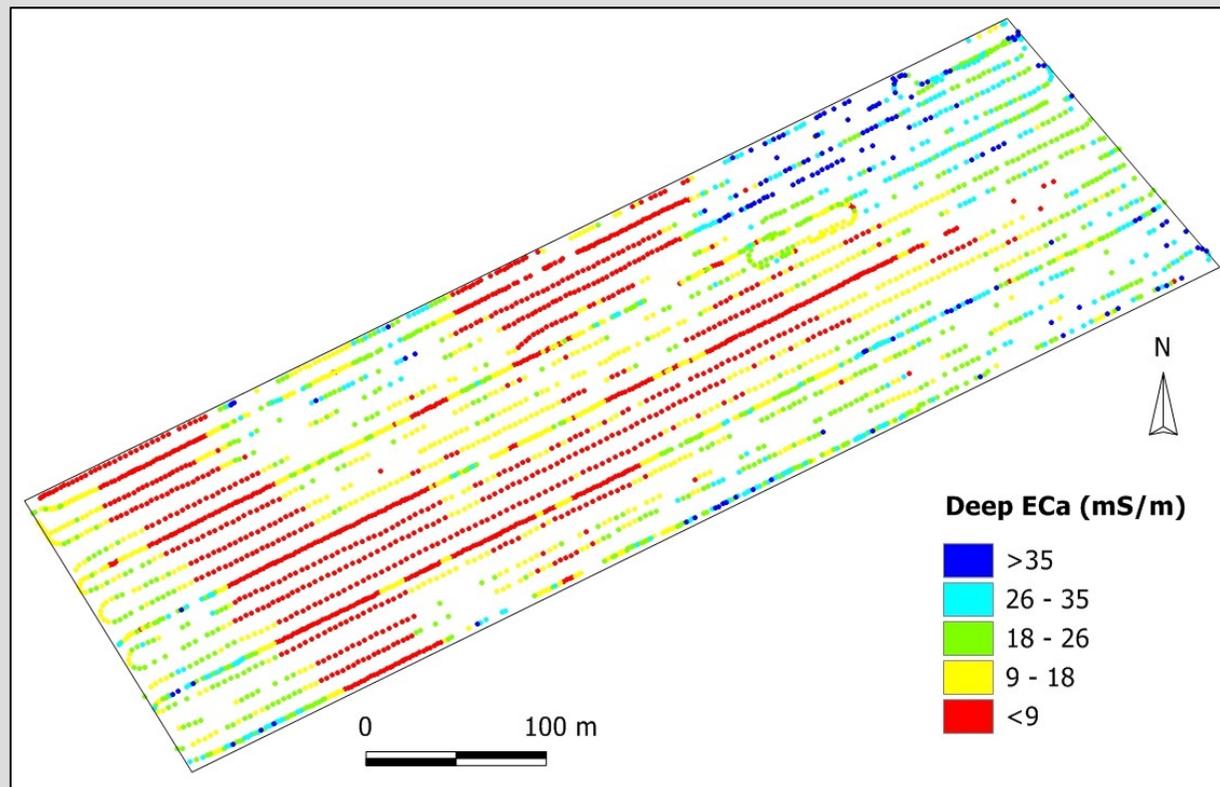
*Processing for spatial and statistical analysis*

*Validating soil ECa maps*

*Normalising ECa maps of different ages*

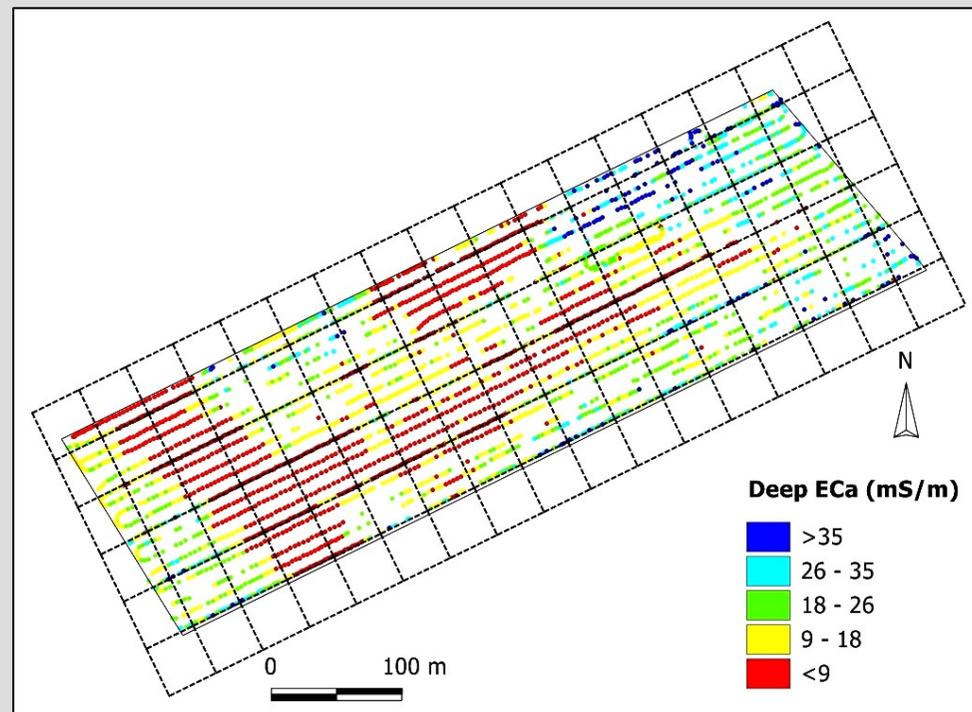
## Processing Veris 3100 data for rapid in-field mapping

- Immediately after completion of the Veris data collection, the raw ECa data were imported into a GIS system (Project BPS001 used the Manifold GIS package) and mapped as a 'Veris track map' in a 5-zone, equal count, point-data layer.
- The soil ECa values were coded, red representing the low ECa values, through yellow, green, and light blue, to dark blue representing the high ECa values.
- Missing values, usually indicating poor soil-coulter contact, were left blank.



## Processing Veris 3100 data for rapid in-field mapping

- A 40 x 40 m grid was created in Manifold and laid over the Veris track map to facilitate the georeferenced collection in Project BPS001 of bulk density and surface moisture samples at regular grid intersection points across the paddock.
- To check the validity of the data, borehole sites (for investigating the nature of the soils included in the soil ECa mapping patterns) were strategically selected according to point-data colour patterns and were spatially located along the Veris 3100 tracks.
- The selected validation borehole locations were then uploaded from the study site map file in Manifold into Garmin hand-held GPS units (accuracy ~ 4 m) for field location of sites.

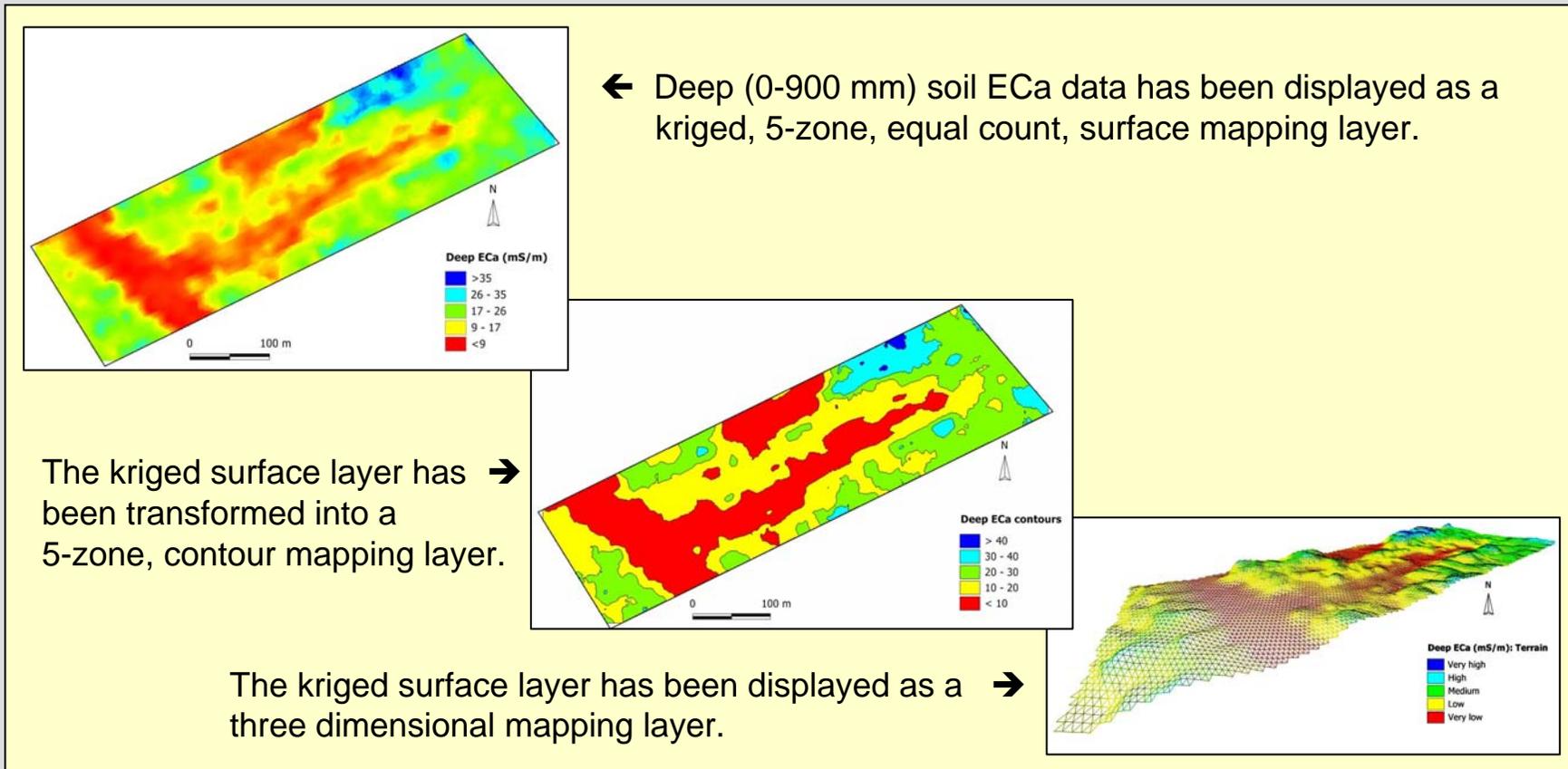


## Processing Veris 3100 data for spatial and statistical analysis

- The raw ECa data from the Veris 3100 track paths were converted from a WGS84 projection to MGA94 (55) in the Manifold package.
- Following the approach of Bramley and Williams (2001), intermediate ECa values were interpolated through a kriging process on a 7 x 7 m grid within defined study site boundaries using an exponential variogram (program VESPER; Minasny *et al.*, 2005) on a site by site basis.
- The area of each grid cell, almost 50 m<sup>2</sup>, offers fine spatial resolution for site maps and is smaller than the minimum area that a sugarcane grower is likely to adopt for site-specific management inputs.
- All the matched spatial data (*e.g.* soil ECa, paddock elevation, crop yield patterns) on the kriged 7 x 7 m grid for each data layer at each study site were subsequently linked in Manifold and the tables exported for interrogation and statistical analysis.
- Similarly, the spatial data were attached to a suite of soil physical and chemical properties from three sample depths at 130 georeferenced soil profile validation locations across the 5 study sites; these tables were also exported for statistical analysis.

## Displaying the processed spatial data

- In Manifold (and other GIS software programs), spatial mapping layers may be digitally displayed as kriged, colour coded surfaces which can be transformed into contoured mapping layers or three dimensional terrain layers.
- The maps may be displayed electronically on a laptop computer in the field, or in hard copy form at an appropriate scale (1:5,000, or more detailed for precision agriculture purposes; Gallant *et al.* 2008).



## Validating the soil ECa map patterns

- The nature of the soils within selected ECa map patterns was validated by drilling a borehole by hand-auger to 1 m and observing the soil profile, recording its characteristics, and collecting samples for analysis from standard depth intervals, at georeferenced locations determined by the soil ECa map patterns:
  - topsoils (0 – 25 cm depth),
  - upper subsoil (40 – 60 cm depth) and deep subsoil (75 – 100 cm depth).



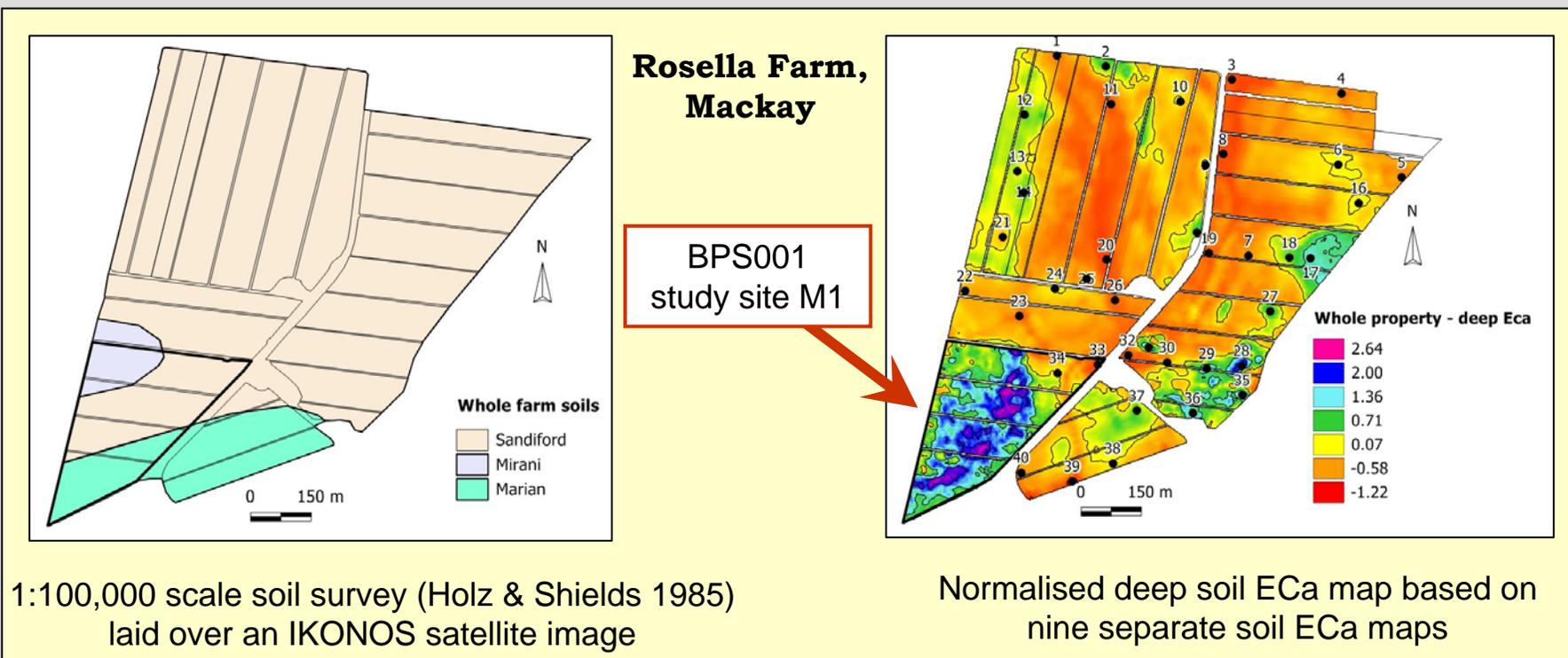
### Recommended soil analyses

● *Topsoil* ◆ *Subsoil*

- ◆ Soil pH
- ◆ Soil electrical conductivity
- ◆ Chloride content
- ◆ Exchangeable cations, CEC
- ◆ % coarse sand, fine sand, silt, clay
- Organic carbon
- Available phosphorus (BSES, Colwell)
- Potassium (nitric acid) reserves
- Sulphate sulphur (MCP)
- Extractable silicon (BSES and  $\text{CaCl}_2$ )

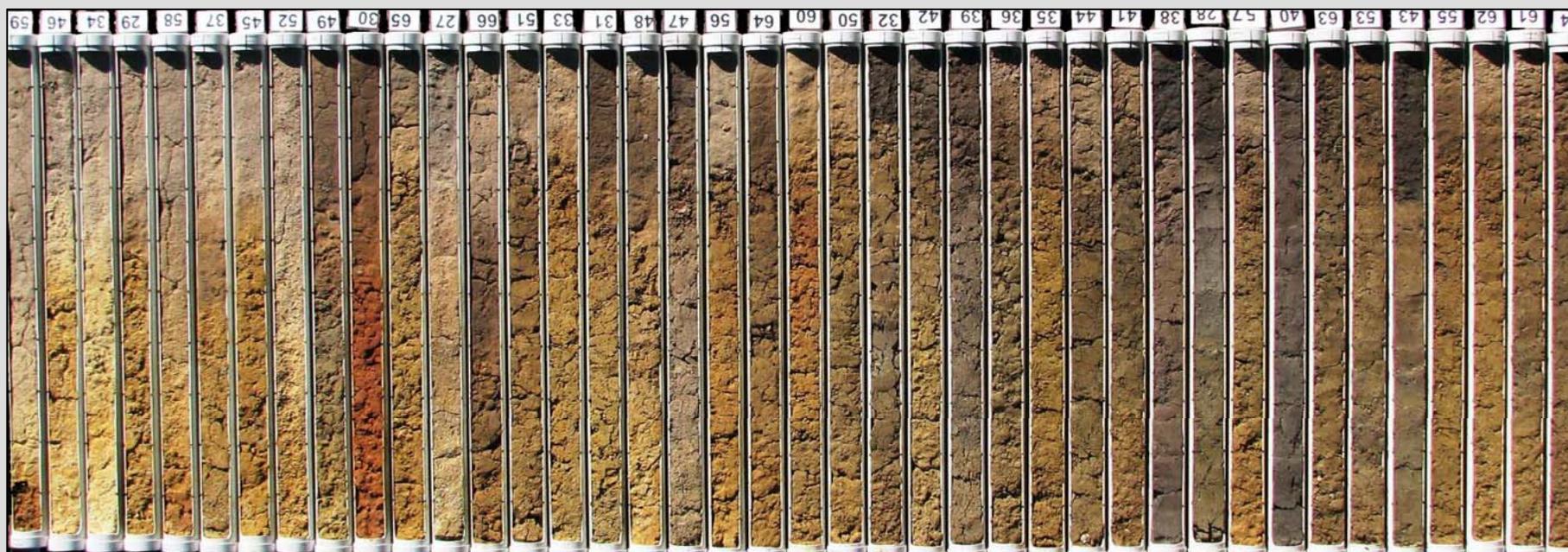
## Comparing soil ECa maps of different vintages

- The data normalising process of Steele and Torrie (1981), based on calculations of  $(\text{point value} - \text{mean}) / \text{standard deviation}$ , was used to unify soil ECa data sets collected by separate Veris 3100 mapping operations at different times on the one property.
- The 15 paddocks of the Rosella sugarcane farm (82 ha, 12 km south of Mackay) of A. and J. Bugeja, includes BPS001 study site M1. The farm was progressively soil ECa mapped between 2001 and 2010.
- The previous 1:100,000 scale soil survey of Holz and Shields (1985) allocated the soils of the farm to the north of site M1 to a single soil mapping unit (the Sandiford Soil).



## Comparing ECa maps of different vintages

- The normalised deep soil ECa map patterns revealed significant contrasts in soil properties across the farm and they were used as the basis for a soil validation exercise over the farm.
- The 40 x 1 m deep, georeferenced soil profiles used in the validation exercise, excluding site M1, are displayed below; their locations are shown as ‘•’ on the previous page.
- The gross differences in horizon thicknesses, colours and mottle patterns, textures, gravel contents, and gravel compositions were consistent with the variability in soil properties indicated by the deep soil ECa patterns across the farm.



Low soil ECa



High soil ECa

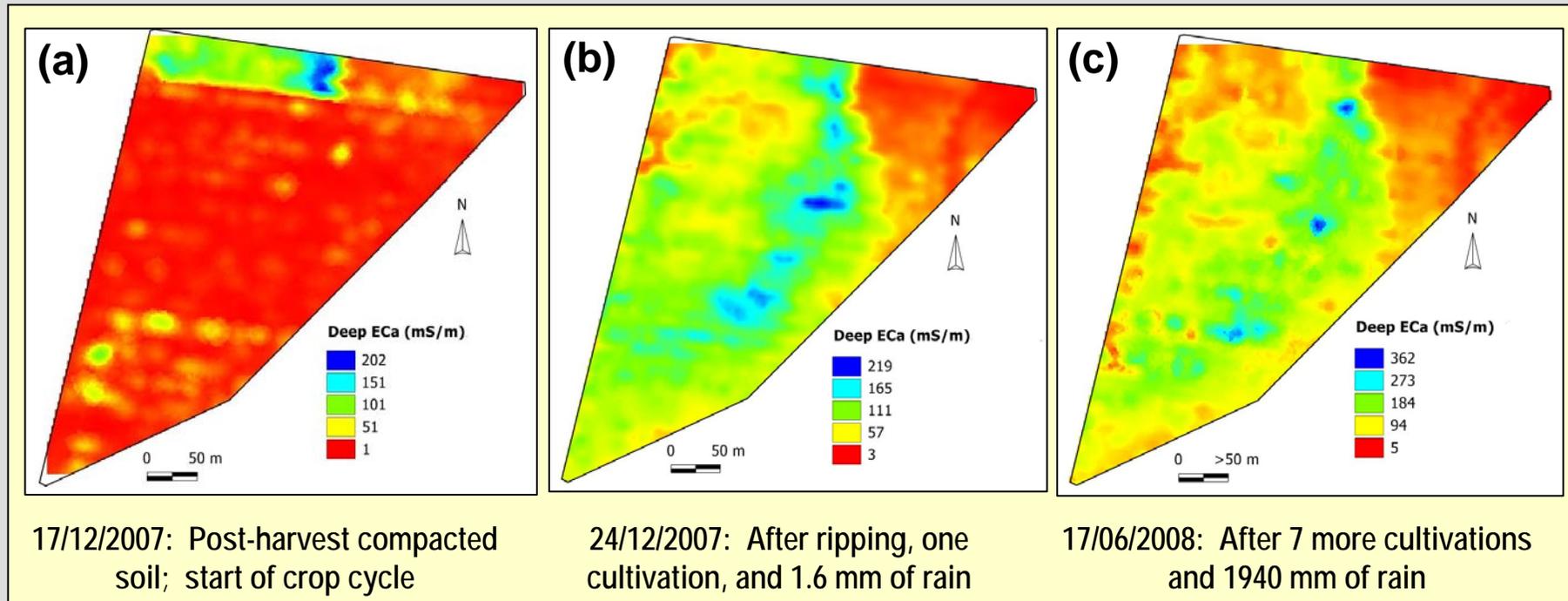
## **Optimal conditions for soil ECa mapping:**

*Uniformly wetted, loose, cultivated, moist soil,  
ready for planting*

## Relieve soil compaction before ECa mapping

- Veris 3100 soil ECa mapping carried out over hard, compacted soils prevents good soil contact with the coulter electrodes and produces 'noisy' data containing missing values in areas of poor soil contact.
- For example, the harvest at Site M1 (Mackay) on 6 December 2007 was carried out less than a week after 45 mm of rain; another 6 mm of rain fell on the day of the harvest. The movement of harvester and haul-out traffic over the moist soil resulted in severe soil compaction of wet topsoils that also set very hard as they dried out after the harvest.
- The soil ECa mapping over dry, compacted soil (*see Map (a), next page*) lacks details that became evident in soil ECa maps made after subsequent ripping and cultivation.
- As part of the cane plough-out process, the paddock was ripped to a depth of 600 mm and cultivated by offset discs to 200 mm depth on 21 December 2007. A second soil ECa mapping on 24 December, at essentially the same soil moisture content as at the time of ECa mapping 12 days earlier, produced a more detailed map (*see Map (b), next page*).
- The site received 1940 mm of rain before a third ECa mapping on 17 June 2008 (*see Map (c), next page*). The paddock had been cultivated after each significant period of rain; planting occurred on 29 August 2008.

## Relieve soil compaction before ECa mapping: site M1



### Effect of cultivation on the quality of deep soil ECa mapping at Site M1, Mackay.

- (a) Deep soil ECa, 17/12/2007:** dry, compacted soil 11 days after harvest. Five rows had been disced at the northern end of site (*top of map*) as a weed control.
- (b) Deep soil ECa, 24/12/2007:** dry soil after ripping to 600 mm depth and offset ploughing to 200 mm depth; 2 mm of rain fell between ECa mappings on 17/12/2007 and 24/12/2007.
- (c) Deep soil ECa, 17/06/2008:** cultivated soil ready for planting. Between 24/12/2007 and 17/06/2008, the site received 1940 mm of rain and had been cultivated another 7 times (disc and spring-tyne implements) for weed control and to alleviate soil crusting.

## Soil conditions for optimal soil ECa mapping

### For best results using the Veris 3100 Mapping System in sugarcane soils:

- It is recommended that soil ECa mapping is performed on **moist, loose, cultivated soil that has been prepared for planting seed cane.**
  - Such soil preparation offers good contact between the soil and the coulters (electrodes) and produces a continuous data set from which the best quality maps may be produced.
  - The soil ECa mapping should be conducted on soils with more than 10% moisture content, preferably after rain has uniformly wet up the soil profile.

### Validation of soil ECa mapping patterns:

- The variability evident in soil ECa patterns at a paddock-scale should always be checked against the actual properties of the soils occurring at specific sites in the paddock.
- Field-validated soil ECa maps may be used as reliable surrogates for detailed soil maps where such are unavailable.

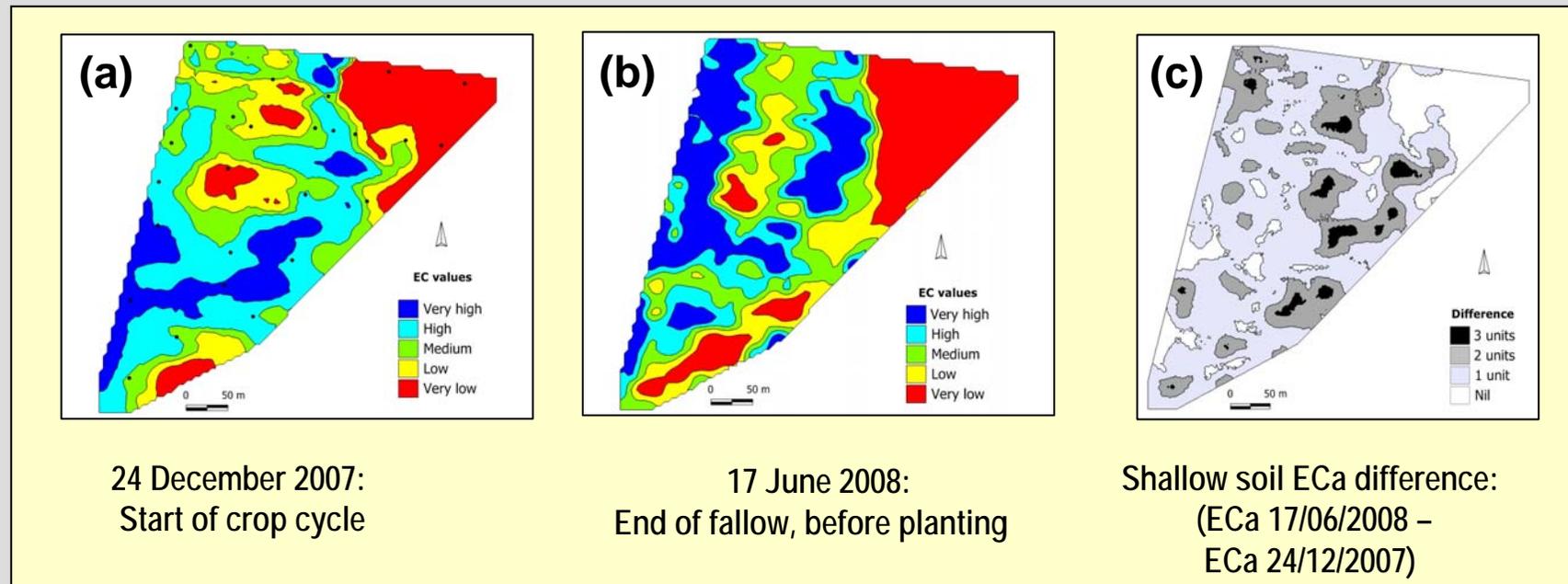
## **Stability of soil ECa mapping over time**

***Shallow (0 – 300 mm) soil ECa maps are  
inherently unstable***

## Stability of soil ECa maps over time: Sites M1 and B1

- In order to evaluate the stability of soil ECa maps over time, and to explore the effects of cultivation and subsequent soil settlement on the stability of ECa map patterns, Project BPS001 carried out multiple ECa mappings on sites M1 (Mackay) and B1 (Burdekin) during the fallow phase of the cropping cycle using the protocols set out above.
- **Site M1:** underlain predominantly by poorly drained yellow duplex soils and grey clays, was ECa mapped (*as discussed above*) on:
  - 17 December 2007 on compacted, dry soils after a wet harvest and before plough-out;
  - 24 December 2007 following deep ripping and offset discing to plough out the previous ratoon crop.
  - 17 June 2008 following 1940 mm and multiple discing and spring-tyne cultivations during the fallow period to control weeds and to disrupt soil crusts.
- **Site B1:** underlain predominantly by well drained dark coloured sandy soils and poorly drained dark clays, was ECa mapped on three separate occasions:
  - 15 December 2007 immediately after harvest of the last ratoon crop before plough-out;
  - 24 March 2008 during the fallow period after double discing, bed forming, and herbicide applications;
  - 19 July 2009 after harvest of the plant cane crop.

## Unstable shallow ECa mapping over 6 months of fallow: site M1



- The **shallow soil ECa** mapping events at site M1, six months apart at the start and end of the fallow period, produced generally similar patterns: low signals from the sandy topsoils of the duplex soils in the northeastern part of the paddock, and more variable responses from the rest of the paddock.
- A linear regression of the **shallow soil ECa** values from corresponding georeferenced 7 x 7 m cells of the 2007 and 2008 mapping events was highly significant ( $p < 0.001$ ), but the adjusted  $R^2$  value was only 0.35 ( $n = 2312$ ), showing that only about one third of the variability in the data could be explained by this regression.

## Unstable shallow ECa mapping over short fallows: sites M1 and B1

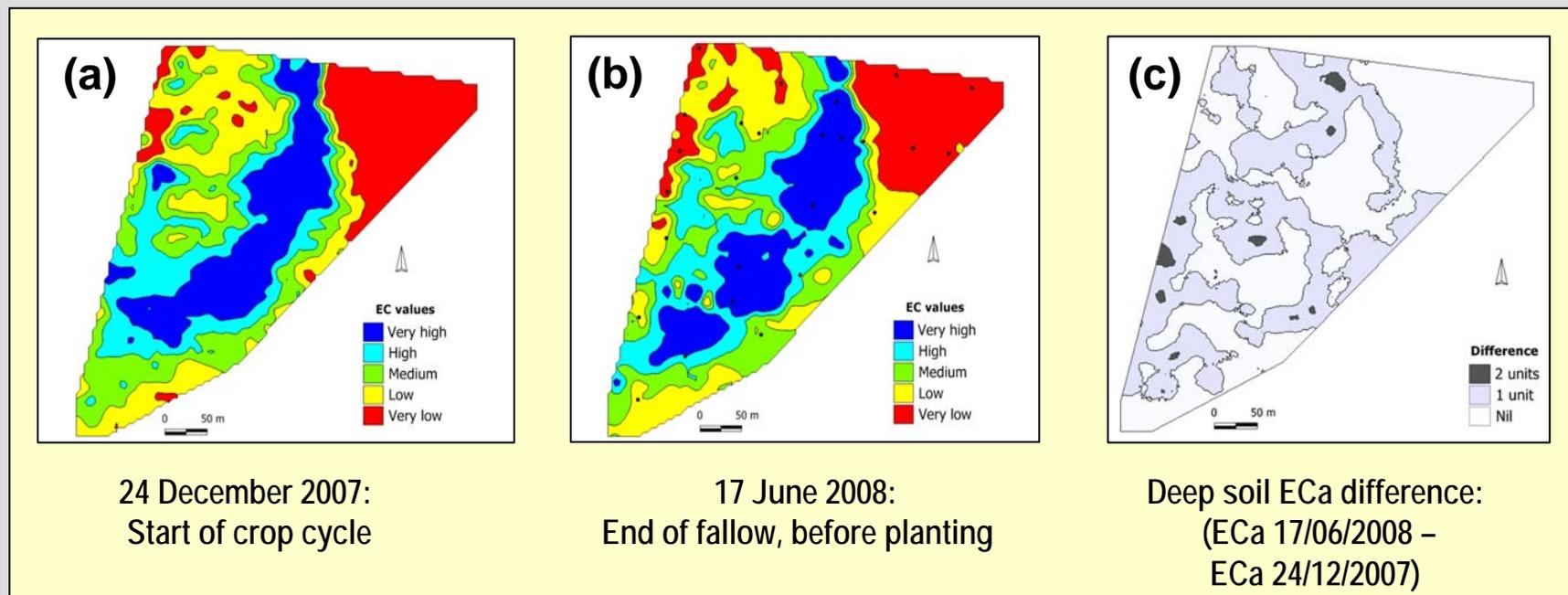
- Analysing the spatial stability of soil ECa patterns over time has been facilitated by the preparation of **soil ECa difference maps**, as follows:
  - All the 7 x 7 m grid cell values enclosed by the lowest contour interval on the soil ECa map, such as those of the red zones of *Maps (a) and (b) on the previous page*, have been allocated the same integer value of 1; values within increasing contour intervals have been allocated increasing integer values from 1 (very low) to 5 (very high).
  - Subtracting the integer values of all points related to the first mapping in 2007 from corresponding, spatially-matched values from the second mapping in 2008 shows where there has been nil, little (1 unit), or much (2 or 3 units) change between the soil ECa maps (*see Map (c) on the previous page*).
- In this manner, the soil ECa difference map technique is capable of illustrating the repeatability of the delineation of zones from soil ECa measurements, and the stability of those patterns over time.
- At site M1, the **shallow soil ECa** values over only 32% of the paddock remained unchanged between the two ECa surveys six months apart (*see Map (c) on the previous page*).
- A similar, poor correlation was evident in **shallow soil ECa** signals from the two mappings just over 3 months apart at the start and end of the fallow period at site B1 in the Burdekin District (data from the Project BPS001 Final Report).

## **Stability of soil ECa mapping over time**

***Deep (0 – 900 mm) soil ECa maps are stable over:***

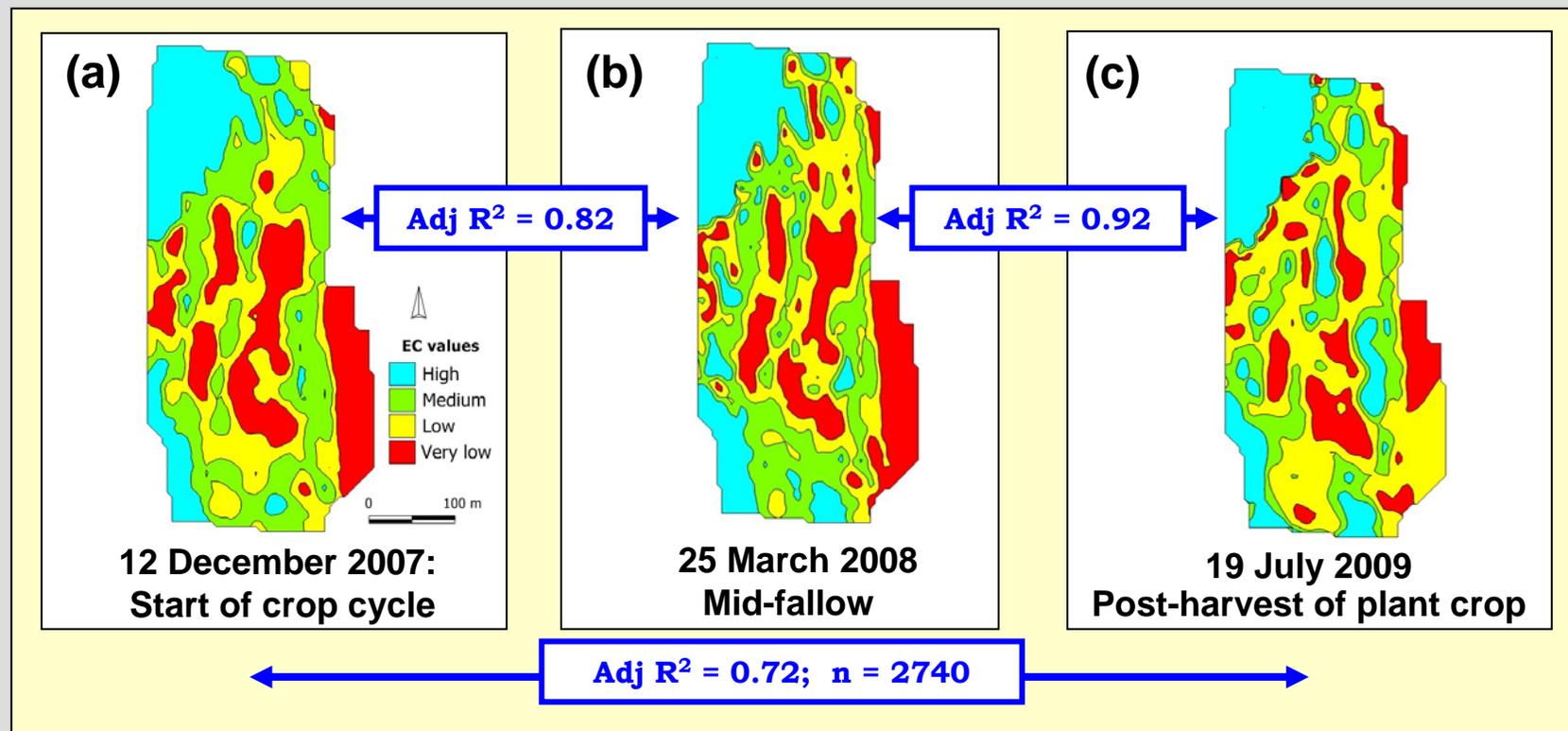
- ***Fallow periods: 6 – 8 months***
- ***Fallow and plant cane crop: 18 + months***
- ***Cropping cycles: 5 + years***

## Stable deep ECa mapping over 6 months of fallow: site M1



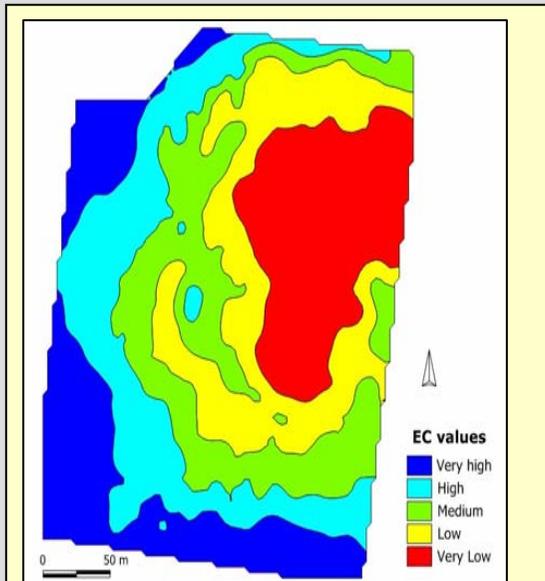
- **Deep soil ECa patterns**, reflecting the nature of the soil properties lying largely below the cultivation layer, varied much less than the shallow soil ECa patterns detected by consecutive mapping events at site M1, Mackay.
- The 2007 and 2008 **deep soil ECa** data for site M1 were much more closely related than were those of the shallow ECa maps. A linear regression for matching, georeferenced deep ECa values was highly significant (adjusted  $R^2 = 0.75$ ,  $p < 0.001$ ,  $n = 2312$ ).
- The **deep soil ECa difference map** (*Map (c) above*) indicates that 59% of the area of the paddock showed no change between ECa mapping events, and only 6% of the area changed by more than one unit.

## Stable deep ECa mapping over 18 months (fallow, plant crop): site B1

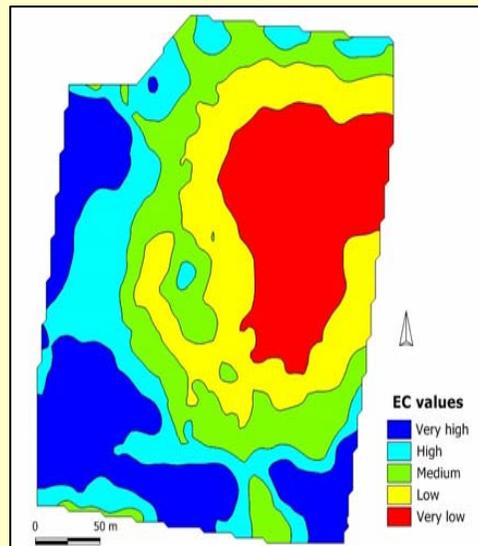


- The similarity of the **deep soil ECa** readings from three successive soil ECa surveys at site B1 revealed strong correlations between 2740 corresponding georeferenced 7 x 7 m cells of each of the pairs of deep ECa maps.
- The strongest correlation in the **deep soil ECa** maps (adjusted  $R^2 = 0.92$ ;  $n = 2740$ ) was between the 2008 and 2009 data sets that related to soils that had been allowed to settle after cultivation and provided good contact between the coulters and non-compacted soil.
- The results from sites M1 and B1 confirmed the stability of deep soil ECa map patterns over fallow periods, and over the year between planting and harvesting the plant-cane crop.

## Stable deep ECa mapping over a 5-year cropping cycle; Mackay



Deep soil ECa, March 2003



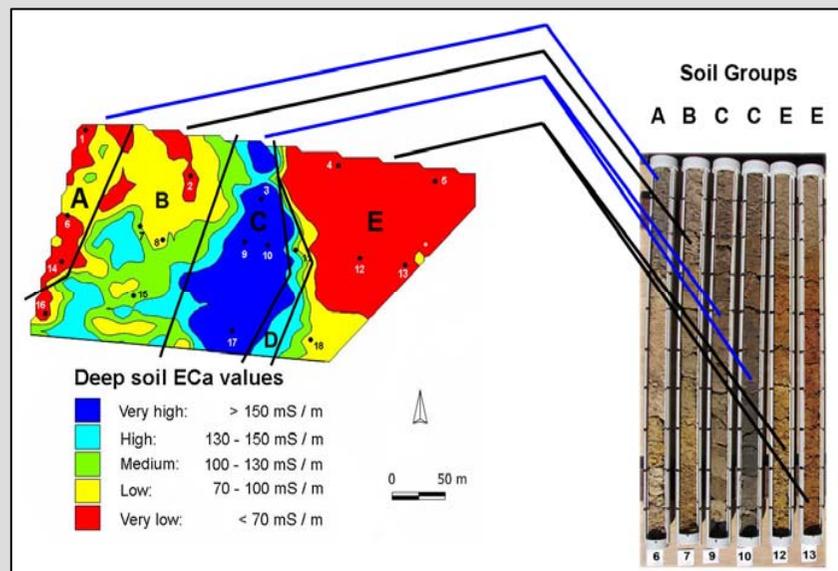
Deep soil ECa, May 2008

- An 8.2 ha paddock (Calen Soil; 5.6 km west of site M1, Mackay) had been soil ECa mapped in March 2003 during the fallow phase of the crop cycle. It was re-mapped five years later as bare fallow in May 2008.
- The **shallow soil ECa map patterns** were found to have varied considerably over the five years between mapping events. Linear regressions for logarithm-transformed data explained only a small proportion of the variability (adjusted  $R^2 = 0.25$ ,  $p < 0.001$ ); the log transformation was required for the data to meet normality assumptions.
- In contrast, however, the **deep soil ECa patterns** were found to be remarkably stable between the two separate surveys five years apart (*compare Maps (a) and (b)*).
- There was a very strong linear relationship between the log transformed values from corresponding georeferenced 7 x 7 m cells of the 2003 and 2008 **deep soil ECa** mapping events (adjusted  $R^2 = 0.86$ ,  $p < 0.001$ ,  $n = 1633$ ).
- The **deep soil ECa patterns** were remarkably stable over five years.

# **Using soil ECa maps**

***Some examples from the Project BPS001  
study sites***

## Soil moisture and texture as drivers of soil ECa responses in non-sodic, non-saline soils: northern part of site M1, Mackay



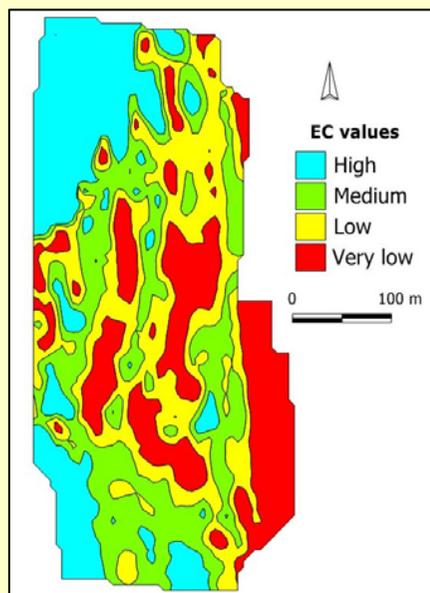
- The soils at site M1 changed systematically down the topographic transect. Strongest **deep ECa values** were in the similar grey clays of Groups C (*neutral – weakly alkaline subsoil*) and D (*strongly alkaline subsoil*) with the highest subsoil clay and moisture contents.
- A potential outcome from the strong relationships between **contrasting moisture patterns and deep soil ECa** patterns is the possibility of estimating sub-surface drainage characteristics through soil ECa mapping.

Soil Group Properties		Group A	Group B	Group C	Group D	Group E
Shallow soil ECa, 0 – 30 cm depth	mS / m	9	8	10	7	4
Deep soil ECa, 0 – 90 cm depth	mS / m	53	84	<b>208</b>	<b>127</b>	44
Surface drainage status		Very poor:	Poor	Imperfect	Imperfect	Good
<b>Topsoil (0 – 25 cm depth):</b>						
Coarse sand	%	46	12	17	10	16
Clay	%	11	12	25	22	6
Gravimetric moisture at sampling	%	11	14	7	16	12
<b>Deep subsoil (75 – 100 cm depth):</b>						
Coarse sand	%	36	17	5	3	10
Clay	%	30	20	<b>51</b>	<b>42</b>	21
Gravimetric moisture at sampling	%	16	12	<b>30</b>	<b>23</b>	13

### Caution:

Soil sodicity and salinity will significantly influence soil ECa readings, and will influence the integrity of a derived sub-surface drainage mapping layer in areas of sodic or saline soils.

## Deep soil ECa mapping of sandy and clayey soils: site B1, Brandon



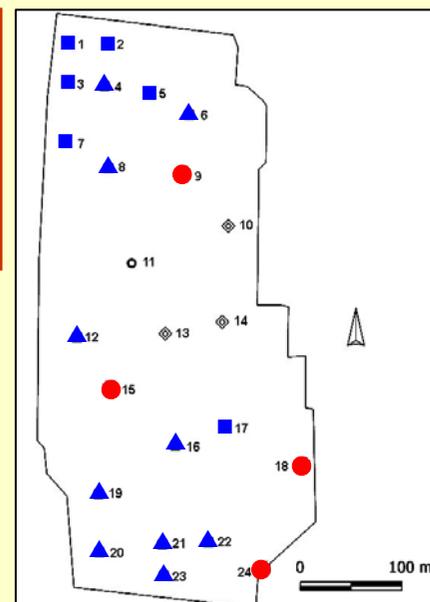
Deep soil ECa  
25/03/2008

Site B1 is underlain by clay soils of the Burdekin River floodplain that have been overlain, in part, by fine aeolian sands that have been blown out of Sheep Station Creek, which lies immediately to the west of the site.

### Generalised soil profile characteristics

(after Northcote 1979):

●	well drained red sand	(Uc 5)	4 profiles
■	cracking clay	(Ug 5)	6 profiles
▲	non-structured clay	(Uf 6)	10 profiles
◊	dark massive earth	(Gn 2)	3 profiles
○	red duplex soil	(Dr 4)	1 profile



Soil profiles

- Strong spatial associations occurred between
  - the **clay soils**, especially those with medium – heavy clay textures in deep subsoils, and **intense deep soil ECa** responses;
  - the **deep sandy soils** with **weak deep soil ECa** responses.
- The bulk of the soils in the paddock had a deep sandy substrate that represents sandy layers in the underlying alluvial sediments. The deep sands were moist to wet at the time of ECa mapping and soil sampling, and their depth and moisture contents appear to have dominated the low to medium signals of the **deep soil ECa** responses.

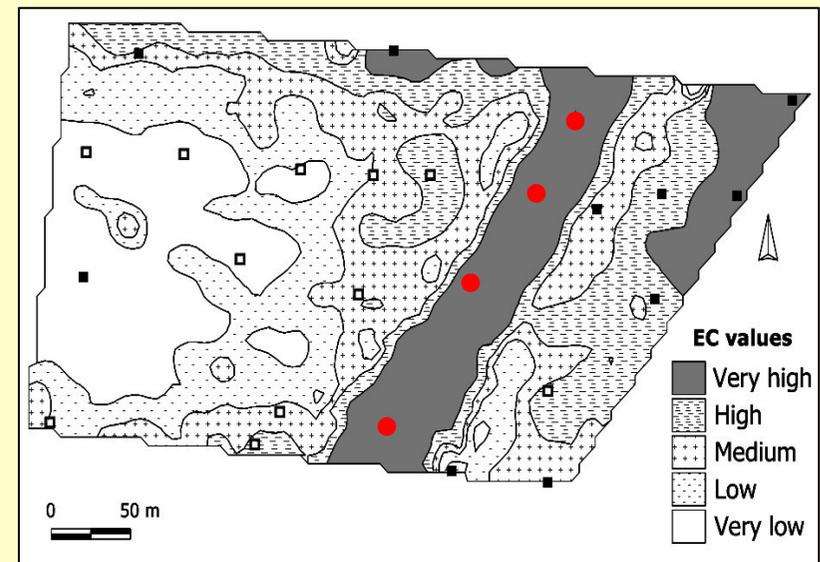
## Self-mulching soils and soil ECa mapping: site B2, Brandon

Site B2 is located in an area dominated by clay soils with different properties. They are typical of the heavy textured soils of the older alluvial sediments that underlie the Burdekin River Irrigation Area.

### Generalised soil profile characteristics

(following Northcote 1979):

□	non-structured clay	(Uf6)	11 profiles
■	cracking clay	(Ug)	9 profiles
●	self-mulching, cracking clay	(Ug5)	4 profiles



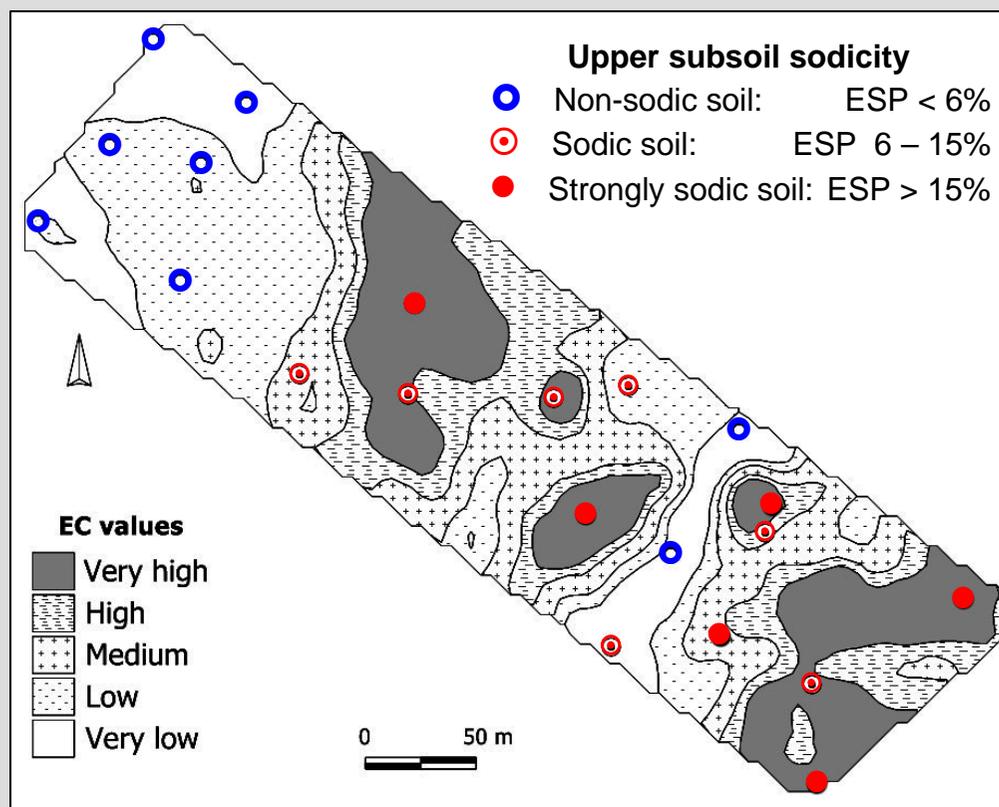
- The topsoils of the clay soils at site B2 are generally hardsetting with coarse blocky structure. The topsoil of the band of self-mulching clay (*in the zone of very high deep soil ECa readings, above*) swells when moistened and forms a soft, loose mass of small polyhedral aggregates up to 4 mm in diameter, like match heads, when the soils dry out.
- Irrigation furrows run east-west, across the band of self-mulching soils. They have to be regularly re-graded (after harvest and cropping cycles) to remove the slightly raised area of the swelling, self-mulching topsoils and the barrier they present to flood irrigation.
- Re-grading the furrows has smeared the self-mulching topsoils and their very high **shallow soil ECa** signals across the paddock. The very strong **deep soil ECa** signals are unaffected by cultivation and define the distribution of the self-mulching soil group.

## Sodic soils and soil ECa mapping: site H1, Mutarnee

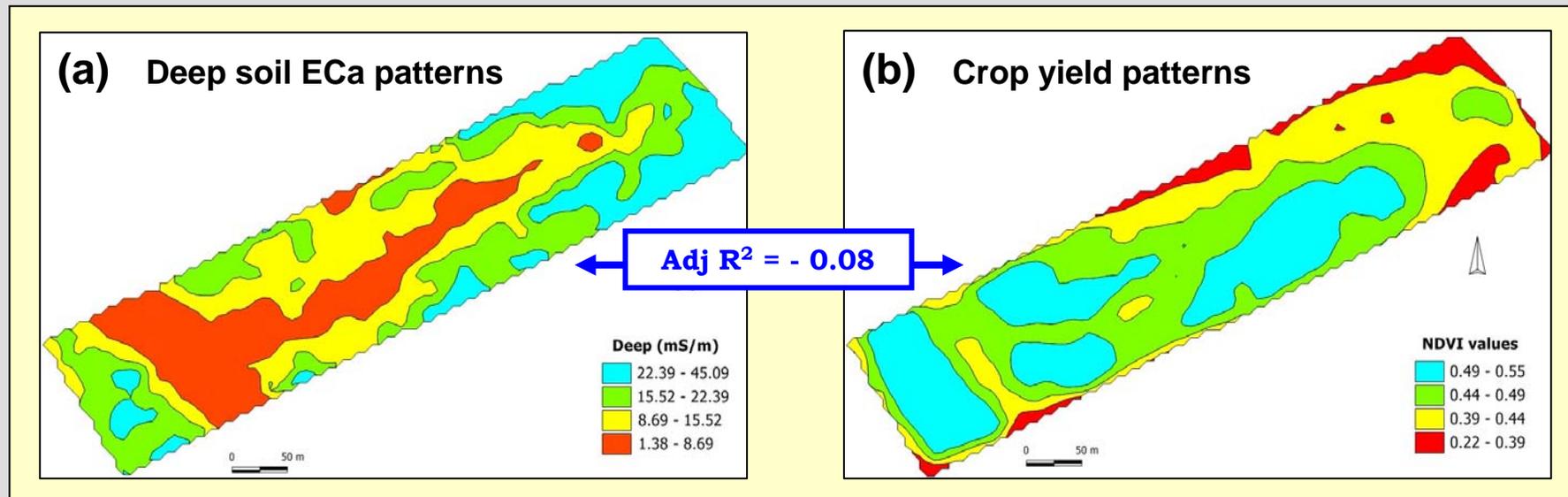
**Sodic soils** have exchangeable sodium percentages of 6 – 15%, and **strongly sodic soils** have exchangeable sodium percentages exceeding 15% (Isbell *et al.* 1983).

**Effect of soil sodicity on sugarcane yield:** Nelson (2001) showed that the sodicity of the 25–50 cm soil layer (corresponding with the upper subsoil sampling interval 40–60 cm of Project BPS001), is crucial to the growth of sugarcane, especially in ratoon crops; crop yields are diminished by 1.5 – 2.1 t/ha for every 1% increase in exchangeable sodium percentage.

- There was a clear association of **sodic soils** with **intense deep soil ECa** signals recorded at site H1 where 5 of the 6 strongly sodic soils were found in the areas that returned the highest soil ECa values.
- All but 1 of the 13 sodic or strongly sodic soils were found in areas of medium to very high **deep soil ECa** responses.
- Only one sodic soil was found in the areas of weak deep soil ECa signals.



## Poor link between deep soil ECa and crop yield: site H2, Lannercost



- Variations were evident in the patterns of **deep soil ECa** responses measured on 12 May 2008 (*left*) and in the growth of the **plant cane crop growth** (*right*) determined by normalised difference vegetation index (NDVI) analysis of satellite imagery captured on 2 August 2009, 22 days before harvest.
- Weak associations were evident visually between low soil ECa values in the generally sandier, lighter textured soils with higher crop yield, and also between higher soil ECa values in the more clayey soils with low crop yield.
- When the values in matching, georeferenced, 7 x 7 m pixels were compared statistically, however, the correlation between **deep soil ECa and crop yield** was found to be very poor with an adjusted  $R^2$  value of  $-0.08$  ( $n = 1820$ ).

## Limitations of deep soil ECa maps

- Project BPS001 results suggest that **field-validated, deep soil ECa maps** may be used confidently as surrogates for detailed soil maps within paddocks.
- The value of soil ECa mapping in sugarcane lands may be compromised by:
  - Extensive paddock earthworks and laser levelling,
  - Altered water movement across the landscape through a network of man-made drains and roads,
  - Grower management strategies.
- Soil ECa information was not closely related to crop yield patterns. Hence, soil ECa data cannot be used as a stand-alone GIS layer for determining the patterns of paddock management zones, as is discussed below.



**Role of soil ECa mapping in defining  
management zones within paddocks**

*Findings from Project BPS001*

## Soil ECa and management zones within paddocks

- **Variability in plant growth** across spatial zones within sugarcane crops arises from the **complex interactions** of soil nutritional status, soil physical properties (especially soil texture), surface and subsurface drainage, seasonal conditions, soil health, pests and diseases, cane variety adaptability to soil type, and paddock management practices imposed by the grower.
- Precision agricultural technology is currently available to allow sugarcane growers to provide the inputs required to cope with most of the factors that control paddock variability on a site-specific basis.
- Managing crop variability within zones in a sugarcane paddock remains an extremely complex issue, requiring an understanding of all of the variables that influence crop growth within spatially defined zones within the paddock.
- Project BPS001 has demonstrated that no single GIS spatial layer is sufficient, by itself, to identify and manage the variability inherent in sugarcane paddocks.
- Soil ECa maps are one component of a set of GIS layers that explain crop variability and provide tools for its management.

## Key GIS layers for simplifying and managing paddock variability

- The variable application of paddock inputs is likely to be most effective if the yield potential of the management zones within each paddock is defined in terms of **three key GIS layers**:
  - **a paddock soil layer** (*stable*): based on actual soil data from the field, if detailed soil maps and descriptions are available. In the absence of detailed soil maps (the case for most Australian sugarcane farms), **field-validated deep soil ECa maps** may be used as surrogate soil maps. Soil ECa map patterns must always be checked against actual soil profile data, especially soil texture and sub-surface drainage characteristics, at strategically located sites.
  - **a paddock drainage layer** (*stable within a crop cycle, but influenced by paddock earthworks*): a surrogate estimator for site drainage and based on detailed topographic data that may be readily accessed during soil ECa surveys, or by machinery equipped with real-time kinematic global positioning systems (RTK-GPS).
  - **a crop yield layer** (*variable responses to seasonal fluctuations in weather regimes, pests and diseases, and paddock management practices and strategies*): reflecting differences in soil and site parameters controlling growing conditions within spatially defined areas (*i.e.* management zones) within paddocks. The crop growth patterns may be detected from processed high resolution satellite imagery captured prior to harvest, or from harvester-mounted crop yield monitors.

## Skills needed to implement precision agriculture practices

- A recurrent theme throughout this manual has been the emphasis on the **complexity of the interactions** among the factors controlling spatial and temporal (seasonal) variability in sugarcane crop growth within a paddock.
- Identifying the spatially defined areas giving rise to this complexity, and developing and implementing strategies to manage those zones, requires **a combination of specialised skills**, including:
  - **data management skills** and **high level computer skills** to set up numerical and spatial data files for interrogation, analysis, display, and storage in a GIS and web-based environment;
  - **spatial analysis skills** to allow the overlaying of various data layers as diverse as soil profile descriptions, soil test results, soil ECa maps, processed satellite imagery, and digital terrain data;
  - **high level agronomic skills to be able to recognise and devise strategies to manage crop growth differences** that may be attributed to:
    - short-term influences such as the impact of irregular watering, temporary flooding, weather patterns, uneven nutrient applications, pests, and diseases,
    - longer-lived influences such as crop nutrient imbalances, waterlogging, plant establishment problems, and cane stool losses;
    - issues that run across whole cropping cycles such as unsuitable soil type, unfavourable paddock topography, irregular paddock drainage, and long-term climatic influences.

## **Need for a farmer-consultant team to implement precision agriculture practices**

- Project BPS001 has identified the need for **sugarcane growers** to work closely with **precision agricultural consultants** to map and manage spatial zones within paddocks.
- The sugarcane grower will bring to the job **sugarcane farming skills and equipment** to be able to implement management recommendations for specific spatial zones within cane paddocks.
- In addition to agronomic and computer skills, the precision agriculture consultant will need to bring:
  - **well developed interpersonal skills** to allow ready interactions with the grower on the one hand, and on the other with even more specialised problem-solvers such as computer programmers, plant physiologists, soil chemists, GPS specialists, etc, who will inevitably be called on from time to time;
  - **astute observational skills** to detect subtle changes in any of the foregoing agronomic issues and devise a management strategy before they become a major issue that impacts on crop yield.
- The sugar industry has to learn that **precision agriculture is a specialised business** and, like any specialised business, requires an investment in the best advice that is available.

## Benefits from understanding and managing paddock variability

- **Sugar industry benefits:**

Knowledge of relationships among key GIS layers (especially soil ECa, paddock topography, and crop yield) will provide pathways for continual on-farm improvements embracing activities as diverse as:

- soil preparation strategies, zonal ripping, applying plant nutrients, breeding adapted cane varieties, managing irrigation water, refining spatially-defined management techniques based on crop yield potential, and adopting relevant precision agricultural technologies.

- **Farm productivity improvements:**

More efficient and cost-effective use of crop inputs (*e.g.* fertiliser, soil amendments, water, pesticides) will result from applying only the input level needed to support crop growth on particular parcels of land defined in terms of key GIS layers (including soil ECa responses), and from minimising off-farm losses.

Techniques for identifying cane varieties adapted to both soil variability and spatial positions in the landscape are likely to develop, and they will require a 'variable variety planter' to fully capitalise on the possibility of on-the-go planting of varieties that match specific soil conditions.

## Benefits from understanding and managing paddock variability

- **Environmental outcomes:**

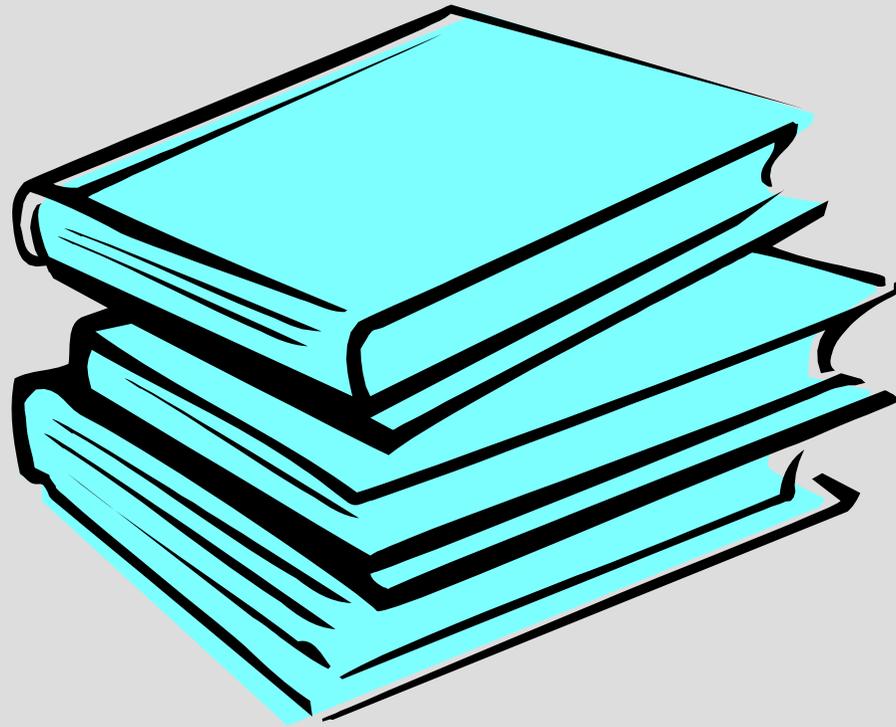
Significant water quality improvements will be generated by paddock inputs based on site-specific management of spatially-defined zones of crop yield potential that are defined in terms of key GIS layers.

It is likely that developments in this area will extend to the revision of State Government regulatory guidelines governing soil nutritional and plant protection inputs in the future.

- **Economic advantages:**

Site-specific application of nutrients (e.g. *'Six Easy Steps'*), pesticides, and herbicides should be based on spatially defined management zones within paddocks including, but not limited to, the yield potential and key soil properties of the zones.

To fully capture this benefit, the definition of the management zones will require a spatial analysis of the impact of seasonal growing conditions on the patterns of crop yield over long sequences of wet, dry, and 'average' years.



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