Final Report: SRDC Project BPS001

*Identifying management zones within
cane paddocks:
an essential foundation for precision sugarcane
agriculture*

Attachment 4:

Substantive publications arising from the project

A ROLE FOR SOIL EM MAPPING IN PRECISION AGRICULTURAL PRACTICES FOR SUGARCANE PRODUCTION

by

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Abstract

The application of precision agricultural techniques in cropping systems depends on the recognition of geo-referenced zones within paddocks. The zones provide a framework for growers who wish to make site-specific decisions in applying appropriate 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. The management decisions must be underpinned by sound knowledge of variations in the underlying soil properties. In the northern Australian sugar industry, however, there are few areas where detailed soil maps are available at a scale meeting the requirements of precision agriculture.

Given the cost and time involved in making conventional soil surveys, surrogate methods are gaining popularity for detecting variations in soil properties at a cane paddock and sub-paddock scale. The methods include the use of electromagnetic induction mapping (commonly known as EM mapping and based on the electrical conductivity of the soil), processed satellite imagery, and geo-referenced sugarcane yield monitoring. EM mapping has been used extensively in the past for identifying soil salinity hazards. With the development of accurate geo-positioning and computerised spatial data management technologies, the method is evolving into a tool for defining variations in soils on a sub-paddock scale.

This paper reviews some of the advantages and potential of applying EM mapping methods to precision agricultural practices, utilising the wealth of spatial data that is relatively cheaply and readily available. It is concluded that EM mapping techniques provide a useful tool that may be used to help underpin new strategies for best management practice for improved sugarcane production and enhanced stewardship of natural resources.

Introduction

Variation in the vigour and yields of broad-acre crops is controlled by many factors including weather patterns and the incidence of pests and diseases during the cropping cycle, but more fundamentally by variations in the nature and properties of the soil. The soil controls the characteristics of the seed bed, the availability of nutrient and water supplies to the growing plants, and the health of the plant root-zone. In many sugarcane farms, the extent and significance of soil variability remains poorly understood.

Soil spatial data interpretation and variable rate application technology are recognised as vital tools in precision agriculture (Bramley *et al.*, 1997), yet their adoption by the North Queensland sugar industry lags behind adoption rates of the technology in other Australian rural industries. The lag may be due, in part, to the sugar industry not taking up one or more of the three basic technologies that precision agricultural systems must have access to, at a price acceptable to growers (Roth and Bramley 1997):
- accurate spatial referencing using a global positioning system,
- variable rate control for application of inputs (*e.g.* fertiliser, soil ameliorants, agrochemicals, water),
- management based on the nature and variation of soil properties (*e.g.* moisture, nutrients) and in crop yield (product tonnage and quality).

Over the last decade, technological advances have provided the sugar industry with precise geo-referenced spatial location systems, variable rate control of inputs, and yield monitoring and mapping. However, knowledge of variation in soil properties is still poor, especially at a cane paddock or part-paddock scale where it is appropriate to manage relatively small land units.

Electromagnetic induction mapping, commonly known as 'EM mapping', is based on responses to the electrical conductivity of the soil. EM mapping identifies and highlights zones in farm soils that reflect potentially different soil physical and chemical properties. The technique has been used in a variety of Australian production systems (wine grapes: Bramley and Williams 2001; cotton: Stewart *et al.*, 2005; grains: O'Leary and Peters 2005; rice: Beecher *et al.*, 2007) where the influences of soil depth, salinity, clay mineralogy, clay content, and water properties on EM readings have been explored.

Electromagnetic approaches to soil mapping

We are researching the extent and pattern of responses evident in EM maps of cane paddocks. Some growers are using EM map zones to identify sites of principal interest for surface soil sampling for chemical analysis as a precursor to the application of soil amendments. There is wide potential for EM mapping to provide a base layer for site-specific application of nutrients and soil amendments.

Paddock maps of soils, topography, crop yield, EM signals, and other variables can be superimposed using GIS software to compare and combine common trends between values. Management zones can then be determined on the basis of variations in the combined variables that can be categorised into levels (*e.g.* low, medium, high). The resultant map may provide a foundation for the implementation of site-specific precision agricultural techniques within the paddock.

Previous Australian studies identified the potential for EM methods to recognise soil salinity hazards (Williams and Baker, 1982; McKenzie *et al.*, 1997), and to assess the spatial distribution of soil salinity in rice cropping (Beecher, 2001) and in cotton production (Triantafilis *et al.*, 2001a).

EM techniques recognise that soil conductivity is influenced by three primary factors: the concentration of soluble salts in the soil solution; the abundance, mineralogy, and cation exchange capacity of the clay fraction; and the soil moisture content. The relative contribution from each of the salinity, clay, and moisture variables, as sources and influences of soil conductivity, is unclear under field conditions, and cannot be quantified, except perhaps in a detailed study in a small area or volume of soil (Auerswald *et al.*, 2001). However, in situations where soil salinity is low and there is little likelihood of a salinity hazard for crop growth, soil conductivity assessment provides a useful insight into other soil properties, notably soil moisture, soil water holding capacity, and soil mineralogy (Triantafilis *et al.*, 2001b).

In sugar cane cropping, uptake of the technology has been slow. Initial studies focused on the use of the EM38 instrument for mapping soil depth and salinity (Kingston *et al.*, 2005). Nelson and Ham (2000) and Nelson *et al.* (2002) observed strong correlations between EM38 data and the degree of soil sodicity in north Queensland sugar cane soils. Soil conductivity technology usage has been increasing in the Burdekin and Sarina-Mackay-Proserpine regions since 2002, and more recently in the Bundaberg and Herbert regions, with the availability of Veris 3100 mapping units through a commercial provider.

Conventional soil maps

The distributions of soil mapping units are displayed on soil maps that are prepared at scales determined by the factors discussed by Reid (1988) and Gallant *et al.* (2008). Firstly, the amount of time and funds available for the soil survey determine the resources available to the soil surveyor to make an adequate number of observations in the field; these underpin reliable descriptions of each of the soil mapping units shown on the map. Secondly, the map scale should allow for the unravelling and depicting of the complexity of the soil pattern to an extent that is consistent with the purpose of the soil mapping exercise. Thirdly, the scale of detailed soil maps should be chosen such that the map permits the separation of soil bodies that may behave differently and require different management approaches.

The density of ground observations should be directly related to the scale of publication of the soil map and the complexity of the soil patterns encountered (Soil Survey Staff, 1952). Table 1 relates the Australian soil mapping guidelines to the most detailed soil maps that are available for the central and northern sugarcane districts. At a 1:50,000 scale, accurate soil mapping relies on 1 ground observation per 20-100 ha, and the smallest area of soil that can be shown on such maps is 10 ha, or about the area of a typical sugarcane paddock. The 1:100,000 scale maps are even less detailed (Table 1). On the few "high-intensity" soil maps (scale 1:25,000) that are available to assist in evaluating the cropping potential of the soils of the Burdekin region, the minimum area that can be displayed is 2.5 ha (Table 1).

Table 1: The influence of the scale of the most detailed published soil maps for the central and northern sugarcane districts on the minimum area that can be portrayed on the map, and on the number of field observations required for reliable and accurate soil mapping. Sources: Grundy *et al.* (2003) and Gallant *et al.* (2008).

Sugarcane region	Scale of the most detailed published maps available *(A thin pencil line will be 0.5 mm wide on the map)*		Minimum area that can be depicted on the map	Number of observations required for accurate soil mapping
Mackay–Proserpine; Atherton Tableland	1 : 100,000	1 mm on map = 100 m	40 ha	1 per 100 to 400 ha
Cardwell-Tully-Innisfail-Cairns-Mossman	1 : 50,000	1 mm on map = 50 m	10 ha	1 per 20 to 100 ha
Burdekin	1 : 25,000	1 mm on map = 25 m	2.5 ha	1 per 5 to 25 ha
Herbert	1 : 5,000	1 mm on map = 5 m	0.1 ha (~ 32 x 32 m)	4 to 20 per ha

Hence, the mapping units displayed on the most detailed published soil maps provide only generalised information about soil distribution patterns and, as a result, soil variations within paddocks cannot be represented on the existing soil maps of any of the regions. Important small occurrences of certain soils are lost at the scale of most of the current soil maps, and complex patterns of different soil types cannot be delineated. Such soil units are either omitted from the map, or are incorporated into other soil mapping units which become, of necessity, even more variable in their soil composition and less useful in precise land management practices (Beckett and Webster, 1971; Kingston and Hyde, 1995).

Wood (1988) and Wood *et al.*(2003) mapped much of the canelands of the Herbert District at 1:5,000 scale, showing soil mapping units down to about 1,000 sq m (Table 1). While such a map scale can depict the variability of soils within paddocks, it requires 4–20 soil observations per hectare, or 400–2,000 boreholes / 100 ha farm to support reliable and accurate soil mapping at this scale (Table 1). Even then, the level of detail is still inadequate for precision agricultural management where soil maps at 1:2,500 scale are more appropriate (Gallant *et al.*, 2008).

If a minimum of only 400 soil boreholes were required to map a cane farm of 100 ha at the required level of accuracy, the cost of the mapping job can be conservatively estimated as follows. In our experience, two operators can dig, describe, and sample 15 x 1 m soil boreholes per day; 400 boreholes would take at least 53 man-days (427 hours). Allowing $130 / hour salary + on-costs for a professional soil surveyor and $30 / hour for a labourer, results in a minimum of $34,000 for the labour component, plus GST, travel, accommodation, base maps

and aerial photos, soil analysis, and other ancillary costs. Making a soil map of an "average cane farm" of 100 ha at a scale depicting the variability of the soil at a scale that is appropriate for precision agricultural applications is, therefore, a time-consuming, expensive, and impractical task when using conventional soil mapping techniques.

Soil-related information from surrogate data sources

Bramley (2007) and Davis *et al.* (2007) have identified recent advances in spatial data collection techniques that may underpin precision agricultural practices and improved property planning. To capitalise on the wealth of spatial data that is relatively cheaply and readily available from EM surveys, satellite imagery, and yield mapping of cane paddocks, data patterns must be related to similarly detailed information on patterns of variation in soil properties within paddocks. Such data may be combined for site-specific inputs with actual soil profile information, and the patterns of variability in land management zones defined at sub-paddock scales, thus avoiding the prohibitive costs currently involved in detailed soil surveys.

The Veris 3100 soil EC mapping system

The Veris 3100 soil EC mapping system (Veris Technologies, 2000) measures the electrical conductivity of soils and is capable of detecting responses related to changes in soil properties. The machine consists of a trailer with coulters set at different spacings and in contact with the soil. An electrical current is transmitted between matching coulters and the unit is calibrated to record the conductivity of the soil over the uppermost 300 mm of the soil profile (effectively the cultivated topsoil), and the uppermost 900 mm of the soil profile (the bulk of the root zone of sugarcane plants). The position of the machine on 10–15 m run spacings in the field is logged at one second intervals (approximately 5 m intervals along the run) through an on-board GPS. The soil conductivity data are converted to a continuous map by triangulation or kriging processes to interpolate map values between the data points. The resultant map can be displayed electronically or in hard copy form at an appropriate scale (1:5,000, or more detailed, as required).

Maps of shallow and deep EM signals of a 10 ha paddock can be produced in an hour or two of the arrival of the Veris unit and operator in the paddock. The cost of Veris mapping is currently of the order of $30 / hectare, which compares very favourably with the high cost and time required for conventional soil survey methods at a similar map scale.

Using the Veris 3100 mapping system: a case study

The use of soil EM mapping to identify soil variability and define management zones in sugarcane paddocks is being addressed by the SRDC-funded project BPS001 at six study sites in the Mackay, Burdekin, and Herbert regions. EM mapping and ground truth evaluations of the soils at each site are backed up by extensive topsoil and subsoil sample analysis.

The project is addressing two important research questions:

- How should the patterns produced by emerging geo-referenced technologies be interpreted in terms of actual soil characteristics and sugarcane land management practices?
- How can the new technologies be used at an individual cane block scale, and at a whole farm scale, to enhance both economic productivity and environmental management?

One of our study sites is located in the Lannercost area, Ingham, on an ancestral floodplain of the Herbert River. A low, red, sandy ridge, which is probably a remnant of an old channel sand deposited by a stream traversing the clayey soils of the floodplain, lies close to the southwestern side of the sugarcane paddock (Fig. 1a). Medium–heavy clay soils lie to the northeast of the ridge, in an area that had been a shallow, poorly drained depression under cattle grazing, prior to tree clearing and development of the land for sugar cane production within the last 20 years. The topography has been significantly modified by laser-levelling. The surface soil of a substantial part of the topsoil of the sandy ridge has been removed and spread nearby in the paddock, and the former depression has been infilled, mainly by using heavy clay soils from an adjoining paddock. The pattern of the shallow EM responses (0 – 300 mm) in the topsoils was variable, but there was an identifiable spatial matching with the northern margin of the infilled depression evident on the satellite image (Figs 1a and 1c).

The pattern of the deep EM signals (0 – 900 mm) was more strongly related to both the distribution of the sandy and clay soils, as detected by 1:5,000 scale conventional mapping (Figs 1b and 1d), and to the shape of the infilled depression evident on a high resolution satellite image (Figs 1a and 1d). The match in soil patterns has been confirmed by detailed description and analysis of 26 soil profiles in the paddock (Fig. 1d).

The EM mapping has drawn out details of the fundamental nature of the soils that appear to relate to land characteristics that predate the conversion of the study site from cattle grazing to sugarcane production. Some of the soils have undergone significant modification in the ensuing land use changes, yet the broad features of their profile characteristics, probably reflecting their pedogenetic processes, were still evident in the patterns of the deep Veris 3100 signals.
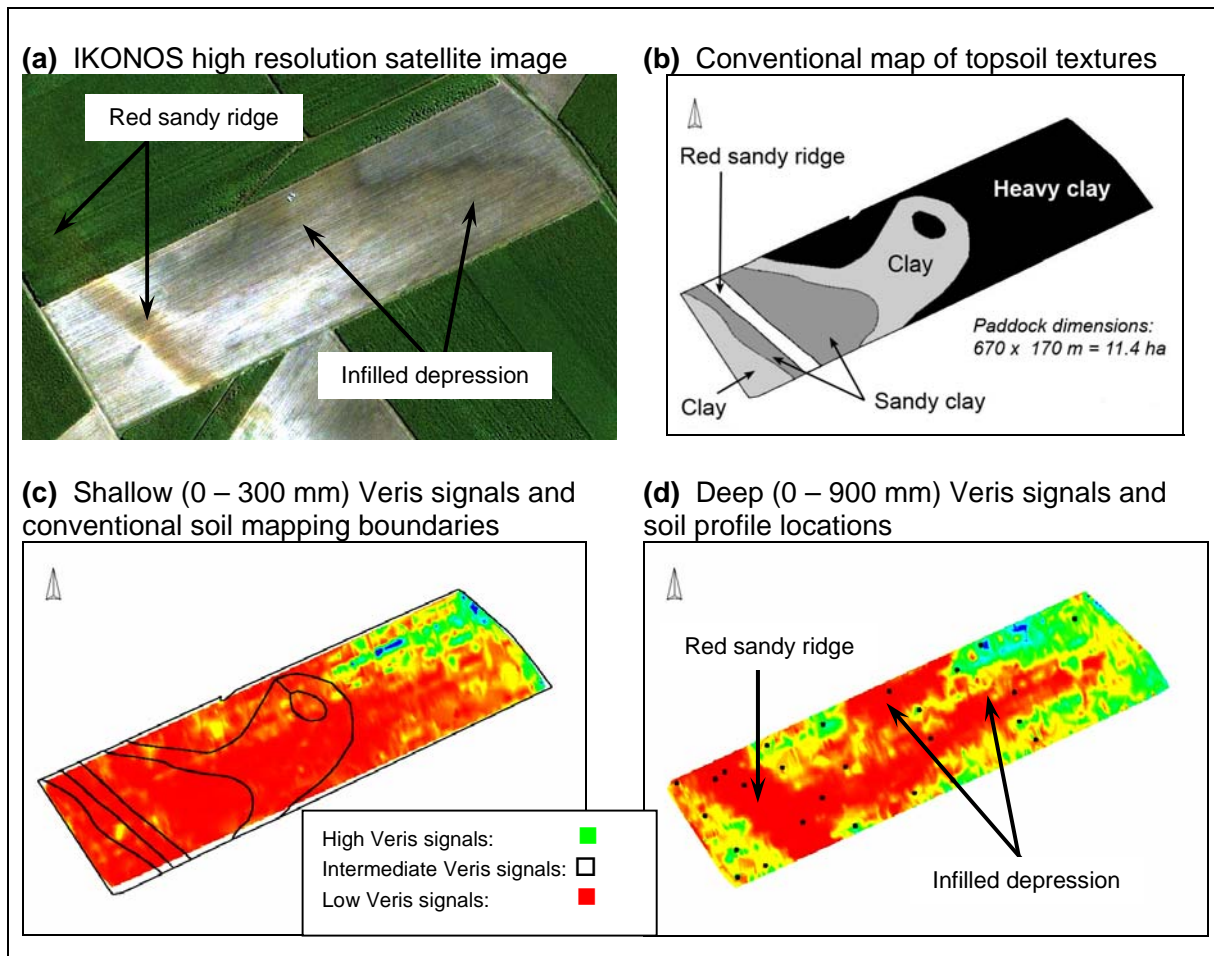
Figure 1: Application of modern mapping technologies to a study site on the farm of G. and J. Morley, at Lannercost on the floodplain of the Herbert River, Ingham:
(a) High resolution IKONOS satellite imagery (1 m resolution; captured 13 June 2008 after cultivation and before planting) showing the red sandy ridge and infilled drainage depression;
(b) Extract from a conventional soil map at 1:5,000 scale showing the distribution of topsoil textures (source: A.W. Wood, CSR Ltd, Macknade);
(c) Kriged map of shallow (0 – 300 mm) EM responses to Veris 3100 mapping;
(d) Kriged map of deep (0 – 900 mm) EM responses to Veris 3100 mapping showing the locations of soil profile verification sites (•).

Coventry, R.J., Pollock, D.C., Hughes, J.R., and Di Bella, L.P. (2009). A role for soil EM mapping in precision agricultural practices for sugarcane production. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31,** 265- 273.

As more Veris 3100 maps are made of closely located sugarcane blocks within a region, the information will have the potential to generate farm maps incorporating aspects of landscape history relevant to current land management decision making. For example, the distribution of well drained channel sands in otherwise poorly drained, fine textured sediments is considered to be a major driver of sugarcane yield variability, as has been found by EM mapping and crop yield monitoring at several sites in the Herbert District (Di Bella *et al.*, 2009).

Conclusions

In the absence of detailed soils information at a paddock and sub-paddock scale in sugarcane lands, EM mapping, satellite image analysis, and yield monitoring are being used increasingly as surrogate data for implementing site-specific management practices. But the linkages among the different datasets are not well understood. Our project is developing scientific foundations for the interpretation of EM responses, and other relatively low cost and readily available data, in relation to actual soil conditions in the field, and to strategies to ameliorate the soil properties for enhanced farm productivity.

The use of EM mapping techniques is providing a tool, for use with soil spatial data and variable rate application technology, to help underpin new strategies for best management practice for improved sugarcane production and enhanced stewardship of natural resources.

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SUGARCANE YIELD MONITORING IN THE HERBERT DISTRICT

By

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KEYWORDS: Yield mapping, Yield monitors, Precision agriculture, Geo-spatial data, GPS, Herbert River District.

Abstract

Sugarcane yield mapping began in the Herbert District in the 1998 crushing season on the Quabba-Russo farms. A prototype cane yield monitor was developed and field tested, and produced yield maps of the harvested areas. At that time, cane yield monitoring and precision agriculture were regarded as ahead of their time.

Interest in cane yield monitoring systems was regenerated in the region when the Cuban Techagro company field tested one their yield monitors during the 2005 harvest. In 2006, staff of the Herbert Cane Productivity Services Limited and others travelled to Brazil and Cuba to review yield monitoring systems, and were also successful in obtaining a Federal Government Regional Communities Project grant to assess and install yield monitoring equipment to the Herbert harvesting fleet for the 2007 and 2008 harvests. Twenty Techagro yield monitors were in operation in the region in 2008.

Techagro and Techagro Pacific have undertaken research to assess the effectiveness of its yield monitoring system and to develop calibration methods, and has delivered a user-friendly computer interface to process and generate yield maps. Development of this system is ongoing and is being modified to meet client requirements.

Geo-spatial data such as yield maps, block boundaries, and soils maps have allowed the industry identify and gain a better understanding of why yield variation occurs within a cane block. Yield variations may differ between blocks and seasons, and can usually be attributed to single factors such as cane grub invasion, or to multiple factors such as a combination of poor soil profile drainage and wet weather. Understanding the reasons for yield variation is still a major challenge for the industry to consider when implementing precision agricultural techniques.

INTRODUCTION

Harris and Cox (1997) reported that BSES and the University of South Queensland (USQ) were engaged in 1994 in the development of a sugarcane yield monitor based on the mass flow rate of cane through the harvester and GPS positioning systems. David and Graeme Cox, created the first world's sugarcane yield map in October 1996 using a mass flow sensor in a cane harvester (Cox *et al.* 1996).

Bramley and Quabba (2001, 2002) confirmed the opportunities to change sugarcane management strategies through the adoption of yield monitoring and other precision agricultural technologies. Growers from both the Herbert (Quabba, 1997) and the Burdekin (Cox, 1997) considered the development of a reliable sugarcane monitor as a priority for the further adoption of precision agriculture in sugarcane (Di Bella *et al*., 2008).

Sugarcane yield monitoring systems evolved globally over the next few years with various companies (AgGuide, MT Data, and Trimble) and the Cuban company (Techagro) developing different yield monitoring systems in Australia.

AgGuide and Techagro field tested their yield monitors in the Herbert District in the 2005 harvest (Esquivel *et al.* 2007). In the following year the Herbert Cane Productivity Services Limited was successful in obtaining a Federal Government Regional Communities Project grant to install AgGuide and Techagro yield monitoring equipment on 50. harvesters (72 % of the fleet in the Herbert District). At the end of the 2008 harvest there were 20 harvesters operating on the Techagro system.

The Herbert region is well positioned as a test area for yield monitors, compared to other cane growing regions in Australia because it has a wealth of geo-coded, site specific cane block information, excellent data management systems and protocols structures in place in co-operating agencies (Herbert Cane Productivity Services Limited, the Herbert River Information Centre, CSR Limited, and BSES, and a large group of co-operating sugarcane growers (Di Bella, *et al.* (2008).

THE TECHAGRO YIELD MONITORING SYSTEM

Operation of the yield monitoring sensors

The Techagro yield monitor measures the mass flow of sugarcane through the harvester through sensors installed on the feed rollers before the cane gets to the choppers and elevator (Fig. 1). The mass flow can be calculated by simply multiplying the density of the sugarcane by the cross sectional area through which the cane is flowing, and by its velocity relative to the harvester roller chamber (Fernandez *et al.* 2007).
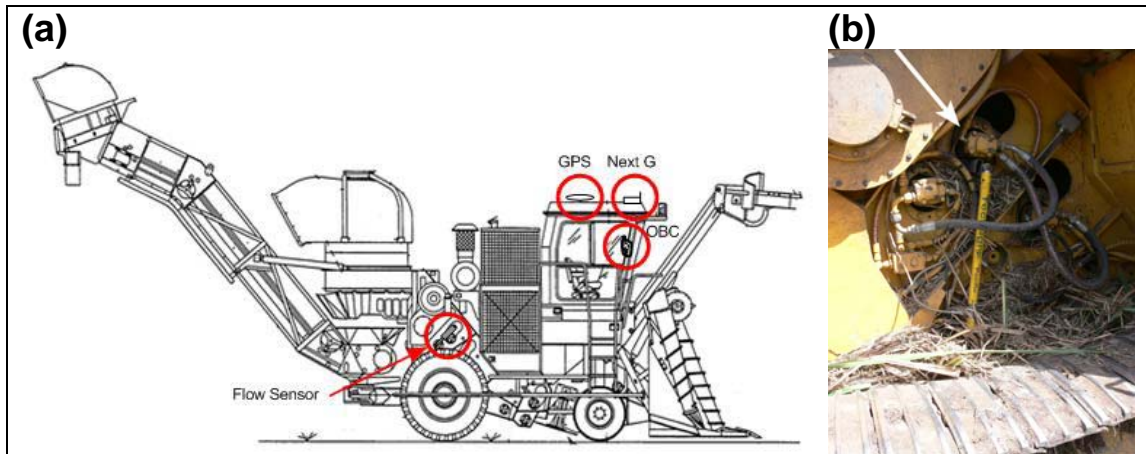
Figure 1: Elements of the Techagro sugarcane yield monitoring system:

(a) Harvester components: the flow sensor, GPS antenna, mobile phone antenna (Next G), and on-board computer (OBC). Source: Fernandez *et al.* (2007)

(b) The Techagro mass flow sensor (arrowed) installed on a cane harvester.

The Techagro researchers found that monitoring the flow of sugarcane through a harvester on the basis of hydraulic oil pressures in various parts of the machine is inaccurate because of significant variations in oil pressure, temperature, and density during the operation of a harvester (S. Marrero, pers. comm. 2008).

Harris and Cox (1997) stressed that, yield measurements on the elevator do not consider losses through the cane harvester extractor systems. Therefore, yield estimations of the mass flow rate in the roller train to the chopper are closely related to yield as grown, which has strong agronomic significance.

In trial work undertaken by Techagro using weighing platforms within the harvester elevator proved to be not sufficiently robust and posed considerable problems for maintenance and up-keep. Soil accumulation under load cells caused false readings during operation, and posed a considerable challenge. It was decided that this method was impractical to operate and expensive to maintain; hence the decision was made to discontinue the development of this sensing method (S. Marrero, pers. comm. 2008).

The Techagro yield monitoring system

An onboard computer reads and logs the cane mass flow signal once a second and combines it with GPS positioning data (Fernandez *et al.* 2007). Information is stored on a memory data card in an on-board computer. The logged data consists of: GPS latitude position, GPS longitude position, cane mass flow measurement (i.e. a surrogate yield measurement), harvester speed, and harvester status (including elevator on, elevator off, harvester stopped, and harvester manoeuvring.

Di Bella, L.P., Sefton, M., Marrero, S., Ponce, E., Fernandez, F., Esquivel, M., and Coventry, R. (2009). Sugarcane yield monitoring in the Herbert District. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31,** 274-281.

In the Herbert District, the Techagro yield monitoring system is interfaced with the CSR Mill Data Systems and is integrated into the software program developed by Techagro. Yields are generated by reconciling the cane block yield from the sugar mill with the data measurements recorded by the yield monitor sensor.

The yield mapping software was developed and first tested in Brazil by Techagro and a new version was released for Australia in late 2007 with a user-friendly interface (Esquivel, 2007; Fig. 2).

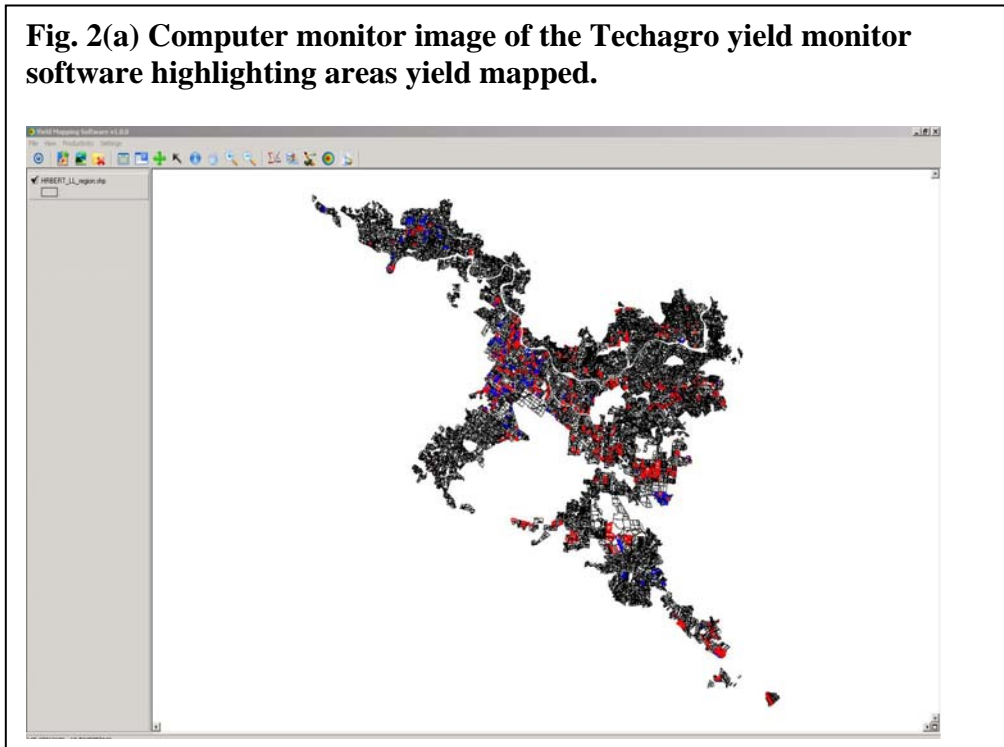**Fig. 2(a) Computer monitor image of the Techagro yield monitor software highlighting areas yield mapped.**

Di Bella, L.P., Sefton, M., Marrero, S., Ponce, E., Fernandez, F., Esquivel, M., and Coventry, R. (2009). Sugarcane yield monitoring in the Herbert District. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31,** 274-281.
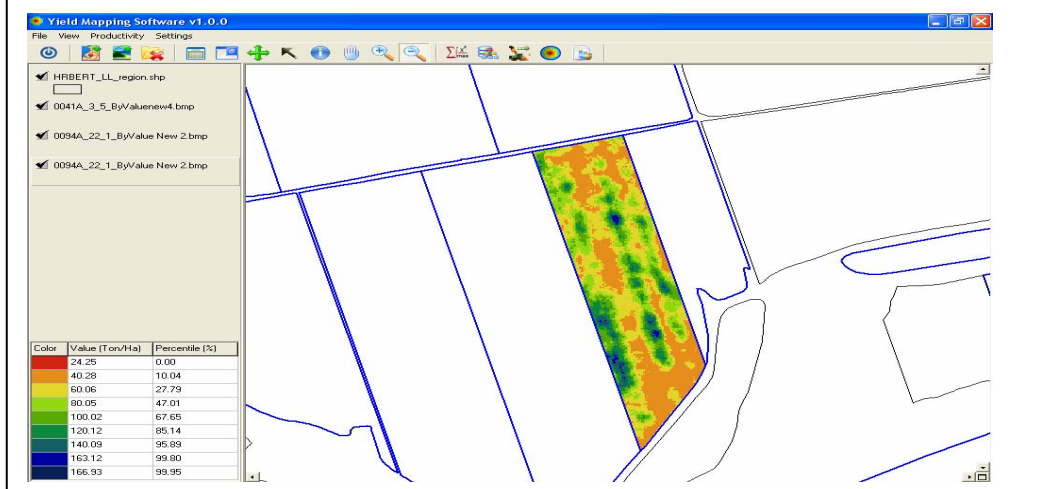
Fig. 2(b) Computer monitor image of a Techagro yield map for a specific block.

Fig. 2(c) Computer monitor image of the Techagro yield monitor report for specific fields

HCPSL
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BSES

Harvested Areas by Yield Intervals Report

Date:10/10/2007 3:21:01 PM

Farm_No	Block_No	Subblock_N	AREA_HA	Cut_Ha	0<Ha<40	40<Ha<60	60<Ha<80	80<Ha<100	100<Ha<120
0719A	1	4	2.61	2.36	0.04	0.13	0.28	0.4	0.53
0774A	2	3	7.65	3.96	0.19	0.22	0.41	0.52	0.71
0774A	2	4	3.88	2.84	0.14	0.35	0.39	0.47	0.76
0774A	4	2	0.41	0.41	0.04	0.03	0.03	0.08	0.09
0774A	4	3	2.68	2.68	0.28	0.37	0.35	1.04	0.61
0774A	4	4	1.05	1.05	0.35	0.26	0.35	0.09	0
0774A	6	1	7.84	7.84	0.76	1.31	1.78	1.92	1.25
0774A	6	5	3.44	3.44	0.19	0.5	0.84	1.31	0.54
0719A	1	1	9.57	9.57	2.8	2.18	1.89	1.42	0.8
0719A	1	3	6.53	6.53	3.32	1.46	0.83	0.54	0.24
			45.66	40.68	8.11	6.81	7.15	7.79	5.53

Figure 2: Computer monitor images of parts of the outputs from Techagro Yield Mapping Software. The images show: (a) yield mapping for the whole district, (b), yield mapping for specific paddocks, and (c) yield reporting for specific paddocks.

RESULTS

Accuracy of the Techagro yield monitoring system

Trials were conducted in Brazil, and in the Herbert, Burdekin, and Mackay areas during the 2006 harvest. The yield monitor data from the Herbert District were

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calibrated against bin weights, and a regression analysis performed between estimated and real weights (Fig. 3). The high coefficient of determination ($R^2 = 0.91$) demonstrated the tight relationship between the calculated and real weights of the cane harvested (Fernandez, *et al.*, 2007).

Bin weights (t)

$y = 9E-05x + 2.7755$
$R^2 = 0.9156$

Estimated cane flow
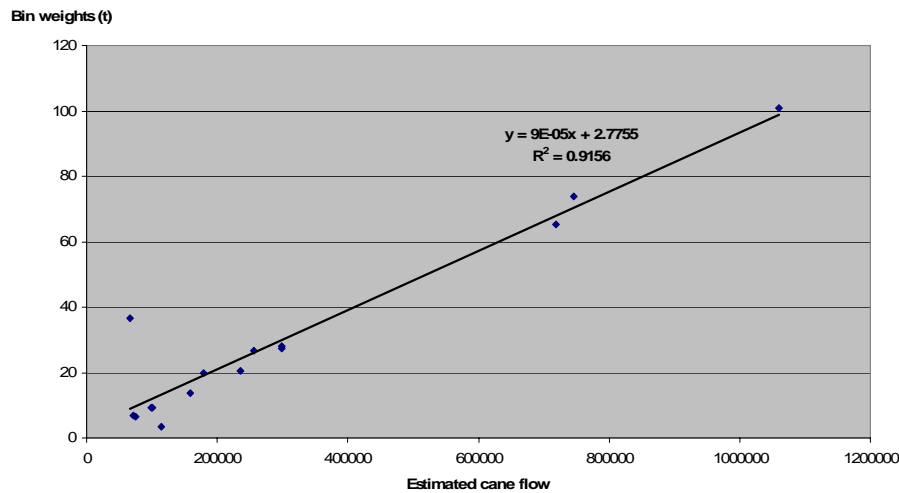
Figure 3: Regression analyses between bin weights estimated by the Techagro system and actual bin weights. Source: Fernandez *et al*. (2007).

The influence of data logging interval for yield mapping was also studied by Techagro. Yield maps were produced with data being logged at 1, 3 and 5 seconds, as well as 1 second logging averaged for every 3 and 5 seconds, and the resultant yield maps compared; a 6 x 6m grid was also created to compare the mean and standard deviation for each grid in the maps. (Fernandez *et al*. 2007).

Fernandez *et al.* (2007) reported that the best yield maps were obtained by using one second data averaged over 3 seconds ($R^2 = 0.92$), although current Techagro yield maps are generated using 1 second logging data that are not averaged.

Yield maps and the field variability of sites and soils

The usefulness of the Techagro yield monitoring system has been monitored over the past two years to identify the site and soil properties that underpin variability in yields from different parts of cane blocks. Field observations are closely related to trends evident in the Techagro yield maps, and are illustrated below in three case studies.

1. . Reproducibility of yield monitor data (the Mc Kell site)

The McKell site is located in the Lannercost area on clay-rich soils of an ancestral floodplain of the Herbert River; yield maps are available for the 2007 and 2008 harvests. The yield maps show areas of similar yields in successive years (Fig. 4). Areas of relatively high yields in 2008 overlap and are slightly expanded from the areas of high yield in 2007; similarly, areas of low yield overlap and are reduced on the 2008 yield map (Fig. 4a, 4b).

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These results are consistent with the overall yields from the block in the two harvests: 2008 was a better year than 2007 and the mill data shows the yield for the block in 2008 was greater than its yield in 2007 (Fig. 4). The overall difference in yields from the block in the two years may be attributed to differences in seasonal factors such as rainfall. Nevertheless, the spatial distribution of patterns of variability in yield are similar from one year to the next.
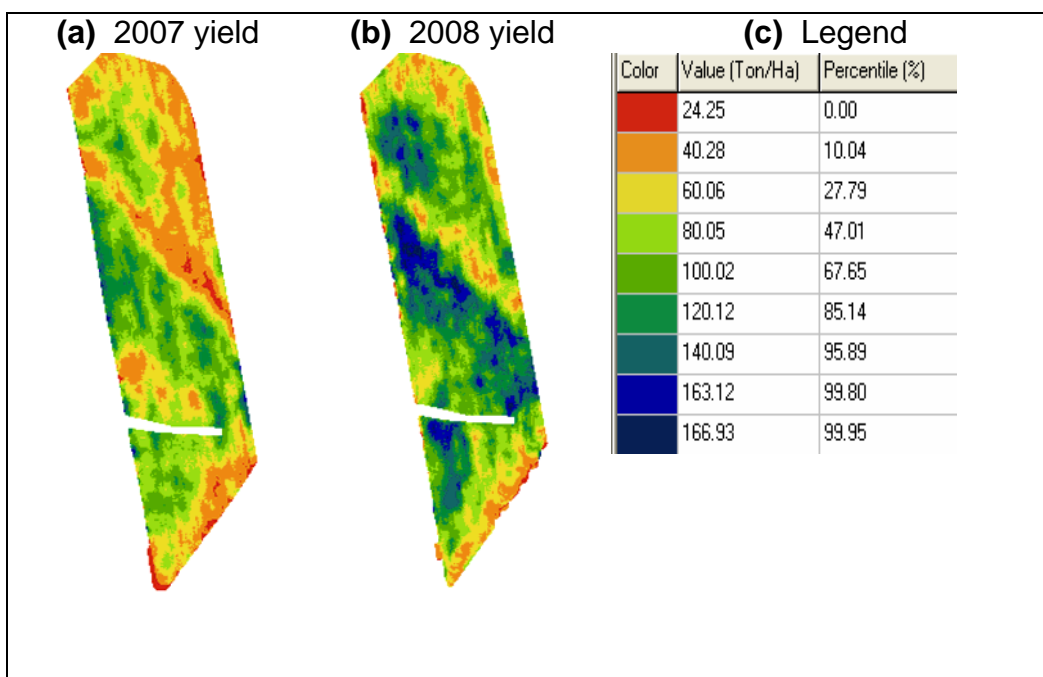
Figure 4: Yield maps produced by the Techagro yield monitoring system for the McKell site, Lannercost:
(a) 2007 harvest – cane block yield
(b) 2008 harvest – cane block yield
(c) Yield classes (tonnes of sugarcane / ha, and percentages of the total yield within each class)

2. *The influence of soil profile drainage (the Trotter site)*

The Trotter site is located in a low-lying, almost flat paddock in sodic duplex soils on alluvial sediments that stand only a few metres above sea level and a few kilometres to the north of Mutarnee. A Techagro yield map was made from the 2008 harvest data from the site which had been carried out under dry conditions (Fig. 5a). In the two weeks after harvest, approximately 150mm of rain fell and the clay-rich subsoils impeded soil profile drainage so badly that surface water ponded for at least 2 weeks in drains and in the slightly lower parts of the paddock (Fig. 5b). The areas of poor drainage corresponded directly with the areas of low yields that were identified on the Techagro yield map (Fig. 5a, b); similarly, the areas of better drained soils on slight

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rises (relief is less than 2 m over 2 km) were associated with the areas of higher yield on the yield maps (Fig. 5c).

Periods of intermittent waterlogging in the lower areas of poor yield have produced hydromorphic features in the soils such as ferromanganiferous gravel, grey mottles, and manganese stains on cracks in the soil. They indicate that the poor soil drainage conditions have persisted for a long time and that they have most likely caused the areas of poor yields that were detected by the Techagro yield monitor.

(a) Area of poor drainage and low sugarcane yield

(b) Area of good drainage and high sugarcane yield

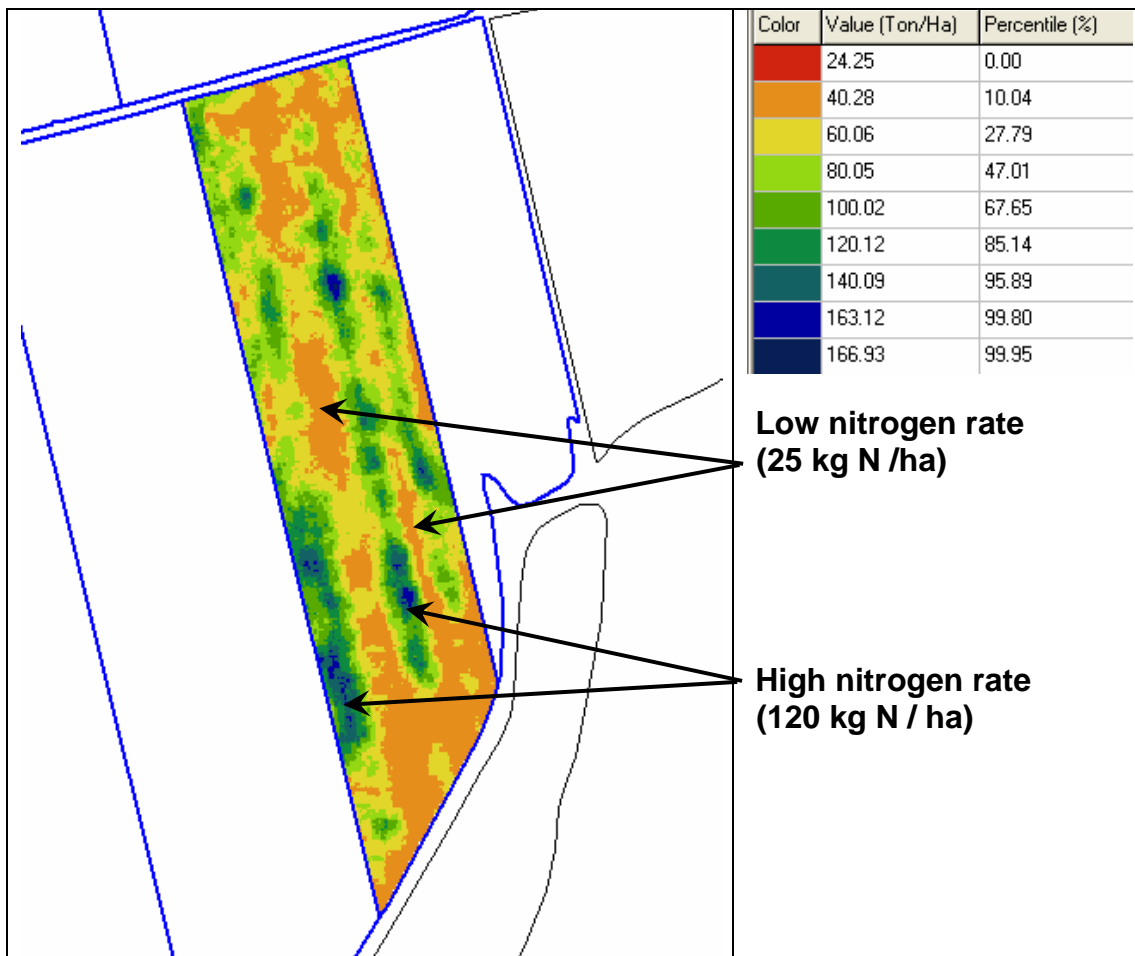**Figure 5:** Sugarcane yield controlled by soil profile drainage, Trotter site, Crystal Creek.
(a) Low-lying areas of poor drainage are evident in low yields on the Techagro yield map and waterlogged soils that received 150mm of rain since harvest.
(b) Slightly higher, better drained areas produced the higher yields that are evident on the Techagro yield map.

3. The influence of nitrogen application rate (the Waring site)

A nitrogen trial (24 and 140 kg of nitrogen / ha) was established in 2006 at the Waring site that is located in the Trebonne area, north-west of Ingham. The site was harvested using a Techagro yield monitor in 2007 and the yield differences on the map correspond accurately with the applied nitrogen treatments (Fig. 6).

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Color	Value (Ton/Ha)	Percentile (%)
	24.25	0.00
	40.28	10.04
	60.06	27.79
	80.05	47.01
	100.02	67.65
	120.12	85.14
	140.09	95.89
	163.12	99.80
	166.93	99.95

Low nitrogen rate (25 kg N /ha)

High nitrogen rate (120 kg N / ha)

Figure 6: Techagro yield map made from 2007 harvest data for a nitrogen rate trial**,** Waring site, in the Trebonne area.

DISCUSSION

Techagro yield maps have been generated in the Herbert District over the last two years, and over 10, 000 hectares have been mapped. Such information acquires value when it enables farmers to make better informed decisions (Cook, 1997), so the yield monitoring data should not be used in isolation, but with complementary information such as soil and plant tissue analysis data, soil and topographic maps, and other geo-spatially referenced data. This information will assist with decision making processes. To date, growers and local agronomists have used the spatial data to target problem areas and to identify yield limiting factors such as waterlogging, fertiliser application rates, soil sodicity, acidity, or salinity, and varietal selection issues.

An important issue that needs to be considered when interpreting a yield map is the stability of yield over time. Yield stability factors can be grouped into three categories:

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- *Short term yield variability:*

Short term yield variability is controlled by factors that impact on cane yield in a single year. They include flooding, rainfall distribution, nitrogen application, pests, and foliar leaf diseases.

- *Medium term yield variability:*

Medium term yield variability is controlled by factors that impact on cane yield during or over one cropping cycle. They include variety selection, plant establishment problems, stool loss, or stool death.

- *Long term or permanent yield variability:*

Long term yield variability factors is controlled by factors that impact on over several cropping cycles. They include soil type, topography, climate, and land tenure issues.

The short and medium term factors can be manipulated or managed in most cases. The long term or permanent factors generally cannot be readily modified or easily managed. In most cases, the long term or permanent factors determine the viability of farming operations on a particular parcel of land.

CONCLUSIONS

Further research and development is planned to occur in 2009 to assess the effectiveness of the Techagro cane yield monitoring system in the Herbert District. There is still considerable debate among researchers over how yield monitoring should be assessed, and what parameters yield maps should reflect (i.e. the yield of sugarcane in the field, or the cane harvester's output and performance).

Further refinement and development of sugarcane yield monitoring protocols are still being undertaken by Techagro Pacific and are being investigated by an SRDC funded project.

To date there has been no development of a sensor for on-the-go monitoring of commercial cane sugar (CCS) or sucrose levels, even though the current industry payment systems are based upon cane yield and CCS (Bramley, 1997). If the industry is to move forward in the area of site specific land management, the spatial significance of the interactions between cane yield and CCS must be understood.

The main challenges facing the sugar industry is how to manage site and soil variability, and how to build cost-effective, precision agricultural tools to assist management of that variability, particularly in areas where detailed soils maps are not available to support site specific management decisions.

ACKNOWLEDGEMENTS

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THE USE OF GEO-REFERENCED SOIL TEST DATA IN THE HERBERT DISTRICT

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ABSTRACT

Topsoil samples have been collected for many years to develop on-farm nutrient management guidelines but their precise locations were largely unknown because geo-referencing technology was previously unavailable. Consequently, spatial analysis of the data was not possible. Over the past four years, the Herbert Cane Productivity Services Limited has provided a service to growers to co-ordinate soil sample collection, sample analysis, and reporting of soil test information; a geo-referenced position is recorded for every sample. This information is collated in a spatial database and forms a layer in the GIS systems managed jointly by the Herbert Cane Productivity Services and the Herbert River Information Centre.

The interpretation of the data has provided spatial patterns of soil properties across the district. This paper presents examples of the spatial distribution of different nutrients and soil chemical characteristics such as soil pH, extractable phosphorus, cation exchange capacity, and exchangeable calcium and aluminium. It shows how geo-referenced soil test data can be used to develop nutrient management strategies within the region, and to address specific issues associated with nutrient deficiencies and excesses.

INTRODUCTION

A wide variety of soils is found in the Herbert district. An understanding of the soil differences, at both district and farm levels, provides a basis for nutrient management strategies that reflect the soil diversity, while enabling profitable and sustainable sugarcane production on the coastal lowlands part of the Herbert River catchment (Wood *et al*., 2003).

In the past, growers and agricultural service providers have tested soil samples from cane blocks, but the samples had not been precisely located or spatially referenced. In many cases it may be difficult to locate even the field from which the soil samples had been collected because of unclear identification of the sample, a change in block

details or property ownership, or simply because the sample collector did not record or cannot remember the soil sample location. To monitor soil nutrient trends over time, it is essential that precise and accurate soil sample records are kept and maintained.

The sugar industry has been ineffective in utilising geo-referenced soil samples and in managing soil analytical data, largely because the appropriate technologies may have been unavailable or not fully understood. The introduction of relatively cheap global positioning systems and user-friendly geographic information systems has created new opportunities for agricultural industries to better utilise spatial data.

Since 1996, the Herbert Cane Productivity Services Limited (HCPSL) has been applying the guidelines of Webster *et al.* (1996) in collecting farm data on fertiliser application and pest and disease control measures adopted by growers (Wood *et al.,* 2008).

In 2003, HCPSL commenced a soil sampling service in the district, to encourage growers to use soil tests in farm planning and decision making, to monitor soil nutrient levels, and to underpin nutrient management programs. Since the program began, over 700 samples have been collected, analysed by commercial laboratories, and the results entered into a regional database that includes cane block-specific data (such as crop yield maps, topographic maps, soil maps, and remotely sensed imagery) and is managed by the Herbert Resources Information Centre (HRIC), Ingham.

The farm-focused nutrient management programs of HCPSL are designed to assist growers make informed decisions, and to support the adoption of site-specific land management. They are based upon soil specific guidelines developed for the region (Wood *et al.,* 2003) and the "Six Easy Steps" approach to sustainable nutrient management (Schroeder *et al.,* 2005).

The soil test samples are geo-referenced to a specific cane block through the use of the ArcMap GIS system that is upgraded annually. Latitude and longitude coordinates for the centre of a block are generated and recorded in the attributes table of the district cane blocks layer of the GIS. From these coordinates a point file is created for all of the site attributes recorded.

The present paper presents an overview of aspects of the data extracted from the Herbert District soils database that has been developed during the period 2003-2008. In particular, the paper identifies and discusses regional soil chemical trends in cation exchange capacity, exchangeable calcium, extractable aluminium and soil pH, and weak acid extractable phosphorus.

RESULTS

Cation exchange capacity

Wood *et al.* (2003) assigned the soils of the Herbert District to three categories:
- Low: less than 3 cmol(+)/kg
- Medium: 3 - 6 cmol(+)/kg

- High: greater than 6 cmol(+)/kg

Of the 700 soil test results entered into the HCPSL soil database, 25% of the cation exchange capacity determinations lay in the low group, 44% were in the medium group, and 31% were in the high group. The soils with low cation exchange capacities are typically located on lighter textured, sandy soils with low organic matter levels (Fig. 1). What appear to be unusually large numbers of soil tests with high cation exchange capacities are located close to the Victoria and Macknade sugar mills, and on the Herbert River floodplain in the vicinity of Abergowrie where the upper Herbert River leaves the confines of its rocky gorge and discharges over the coastal lowland part of its catchment.

Regional CEC levels for Herbert sub-districts

Di Bella, L.P., Coventry, R.J., Sefton, M., Moody, P.W., Hanks, M., Stringer, J.K., and Kerkwyk, R.E. (2009). The use of geo-referenced soil test data in the Herbert District.
Proceedings of the Australian Society of Sugar Cane Technologists, **31,** 296-306.

Figure 1: The regional pattern of cation exchange capacities in the soils of the Herbert sub-districts.

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Phosphorus

Phosphorus is routinely applied as DAP fertiliser or in mill mud products to cane fields in the Herbert district as a part of the crop fertilising program. During the past 24 months application rates have decreased in response to dramatic increases in fertiliser and fuel prices. Even though application rates have decreased, there is evidence of excessively high residual levels of extractable P in the soils.

Table 1 and Fig. 2 highlight the soil test results within sub-districts of the Herbert region for soil phosphorus contents that have been extracted by the BSES (0.005 M H_2SO_4) method. The lowest content of extractable P recorded was 4 mg/kg and the highest was 340 mg/kg, indicating a very wide range in plant-available phosphorus in the soils of the district (Fig. 5). Sixty percent of soil tests in the HCPSL soil database had BSES extractable P levels greater than the critical value for sugarcane growth of 50 mg/kg, indicating that supplementary P applications to such soils are not required.

Table 1: Analysis of soil test results (2003-08) for BSES extractable soil P for sub-districts within the Herbert region.

Sub-district	No. of samples	Min P (mg/kg)	Max P (mg/kg)	Average P (mg/kg)
MACKNADE	22	25	250	117
VICTORIA ESTATE	9	21	300	94
TOOBANNA	28	16	150	86
GARRAWALT	55	10	330	85
FORESTHOME	13	25	340	82
HALIFAX FOUR MILE	26	23	260	80
SUNNYBANK	25	10	300	79
CORDELIA	41	8	290	73
BAMBAROO WEST	21	22	150	66
RIPPLE CREEK	10	11	110	59
LOWER STONE	20	18	190	59
HELENS HILL	13	18	270	58
HAWKINS CREEK	11	15	140	56
LONG POCKET ELPHINSTONE	10	30	97	54
LANNERCOST	18	7	110	53
LEACH	25	11	140	52
TARA SEYMOUR	23	15	170	47
LANNERCOST EXTENSION	8	4	120	41
YURUGA	17	8	140	36
MID STONE	9	7	120	36
FAIRFORD TREBONNE	17	10	100	36
BAMBAROO EAST	38	9	130	36
BLACKROCK	12	4	110	35
HAMLEIGH	20	7	67	27
UPPER STONE	20	12	45	23
COOLBIE ROLLINGSTONE	20	6	38	20

Di Bella, L.P., Coventry, R.J., Sefton, M., Moody, P.W., Hanks, M., Stringer, J.K., and Kerkwyk, R.E. (2009). The use of geo-referenced soil test data in the Herbert District. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31,** 296-306.
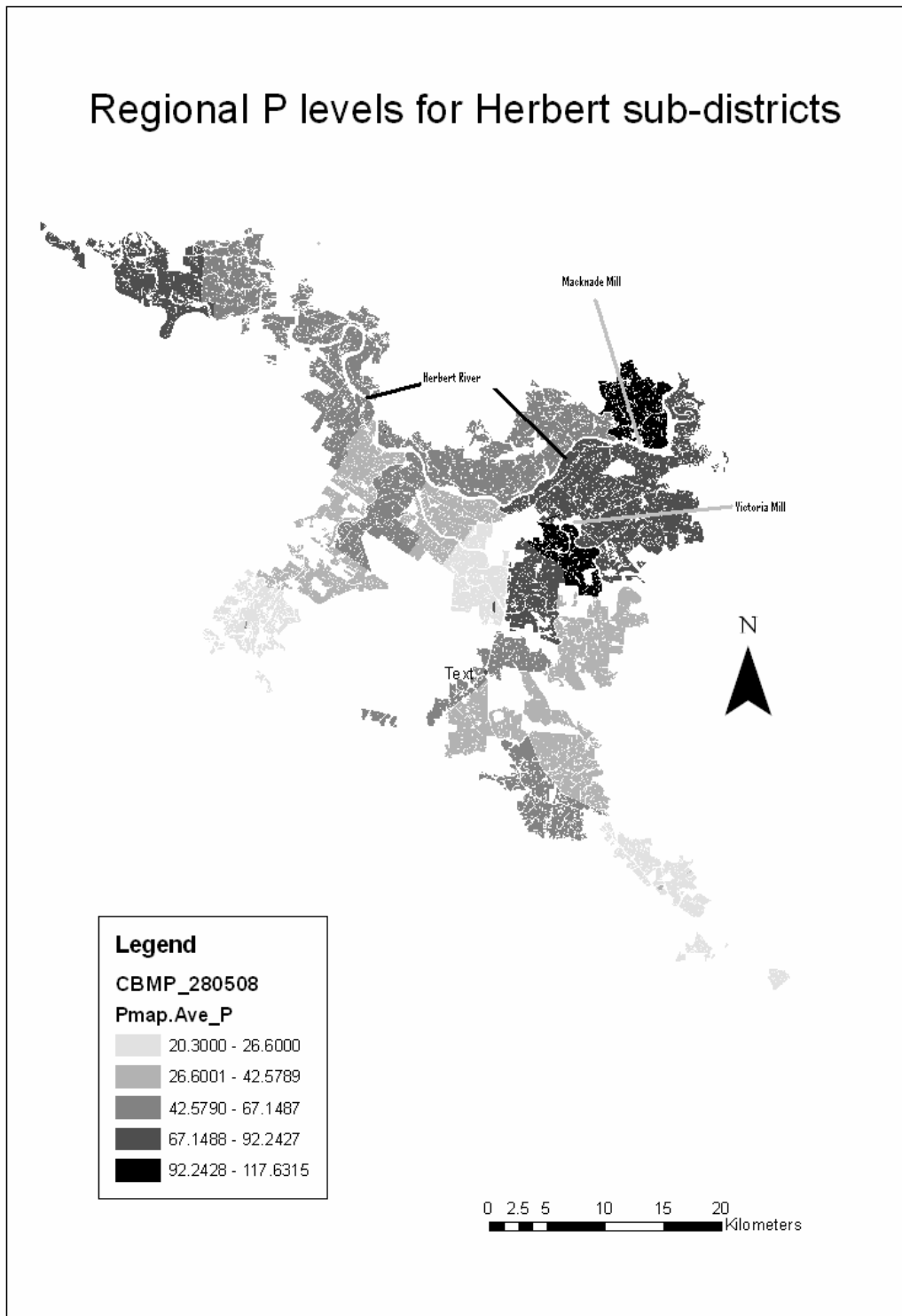
Figure 2. Average BSES extractable soil phosphorus contents (mg/kg) in the soils of the Herbert sub-districts.

Figure 2 clearly indicates that there is a strong relationship between soil phosphorus contents and paddock locations close to the local sugarcane mills. In the past, application rates of 200-250 wet tonnes /ha of mill mud (from Victoria Mill) and mill

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mud/ash mixtures (from Macknade Mill) have been applied to cane fields in the region. The cost of transport has generally limited the distribution of mill products to areas close to the mills.

The application rates have decreased slightly too approximately 100 wet tonnes /ha in the past two years due to modification of truck application equipment developed by commercial spreading companies in the region; but the lower rates are only applied when requested by the grower purchasing the product. Even at 100 wet tonnes /ha, excessive rates of phosphorus are being applied to some soils, and repeat applications are common.
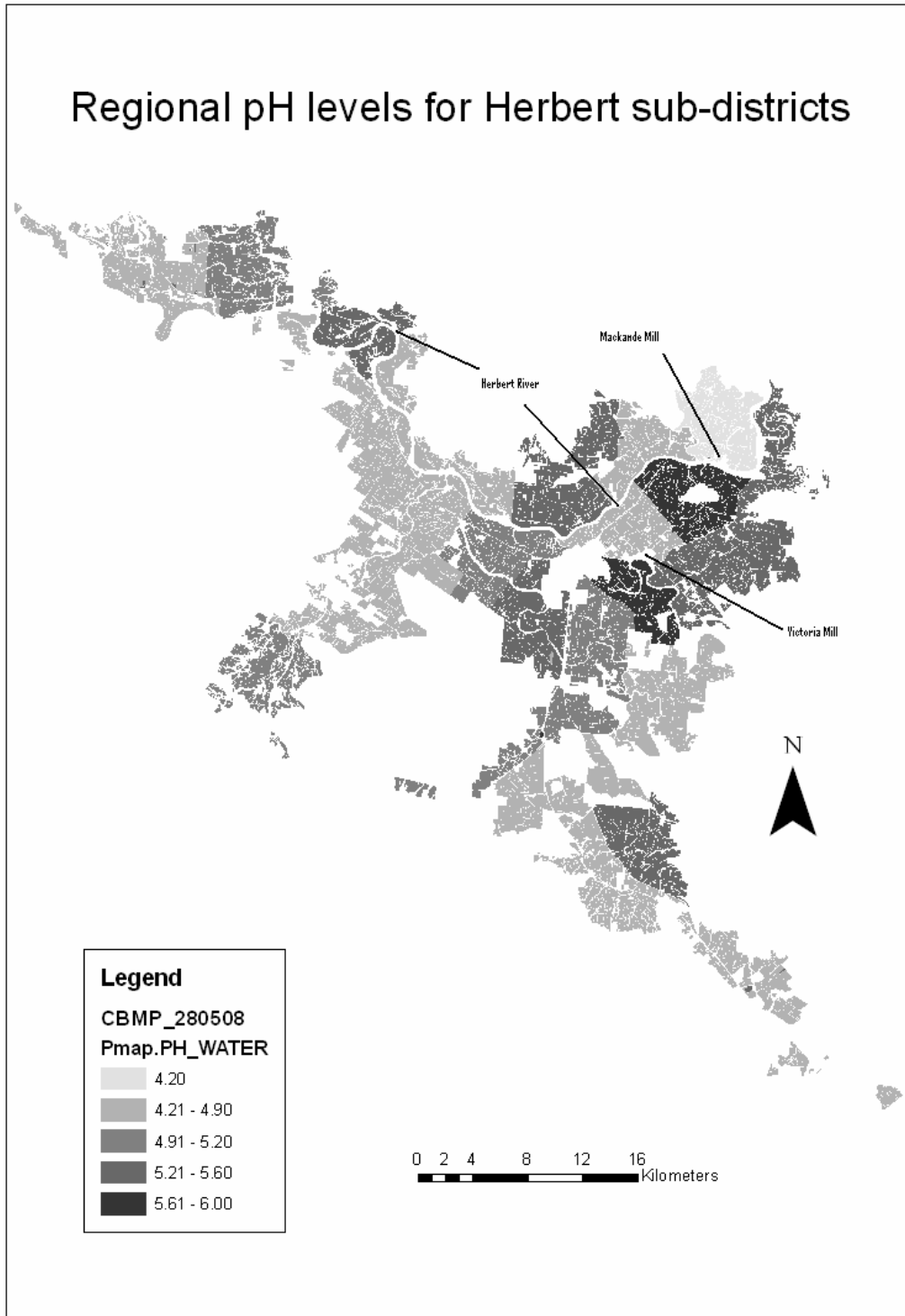
The reasons for the high phosphorus levels found in Herbert soils may be driven by several factors, including:
- High or prolonged applications of phosphorus from fertiliser or mill products as a component of the farm's nutrient management program (Wood *et al*., 2008).

- Unfounded grower perceptions that plant cane will not effectively germinate and establish without the application of phosphorus, regardless of the phosphorus status of the soil.

- Naturally high levels of soil phosphorus are found in some of the alluvial soils of the Herbert cane growing area (Wood *et al*., 2003). A large proportion of the region is regularly flooded and phosphorus-rich sediment is deposited on the flooded farms, especially those in the Lower Herbert floodplain areas downstream of Ingham, and those upstream in the vicinity of the Abergowrie flats below the Herbert River gorge (Fig, 5). Nevertheless, Bartley (2003) suggested that detailed patterns of erosion and sediment movement were difficult to define over the Herbert floodplain.

- Regular applications of mill mud to cane land in close proximity to the two sugarcane mills in the district is the most likely controlling factor. This may explain the high contents of extractable P and the high cation exchange capacities of the soils which are found close to the mills in the Macknade and Victoria Estate sub-district areas and adjacent sub-districts (Figs 4 and 5).

Soil pH

The optimal soil pH_{water} for the growth of most plants is between 6.0 and 7.0 (Glendinning, 2000), however sugarcane is very tolerant of more acidic, low pH soils. It is recommended that topsoil pH levels be maintained at levels above pH_{water} 5.5 (where possible) to ensure adequate cane and legume break-crop growth, and to prevent subsurface acidification (Webster and Wilcox, 1999).

Figure 3 shows average soil pH_{water} values for each sub-district region and the Herbert district average of soil pH_{water} is 5.0. Soil pH values as low as 3.2 have been determined after continued farming of sugarcane in non-acid sulphate soils, but these are isolated instances.

Figure 3: Average soil pH$_{water}$ values for the soils in each sub-district region.

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Soil pH_{water} levels vary across the district and between farms as a result of:
- Soil parent material and soil type.
- The removal of large amounts of biomass at harvest produces a high net acid addition rate to the sugarcane system (Moody and Aitken, 1997). Soils with a low pH buffer capacity (such as light textured soils) will therefore acidify quickly in comparison to heavier textured, clay and / or organic matter-enriched soils.
- Farming practices such as the use of heavy applications of sulfate of ammonia and other forms of acidifying, nitrogenous fertilisers (Glendinning, 2000).
- Spoil from acid sulphate soils that was spread over cane blocks. This practice occurred in the past and has now been addressed as a part of the district's acid sulphate soil management practices. Such soils account for less than 1% of the total number of samples in the soil database.
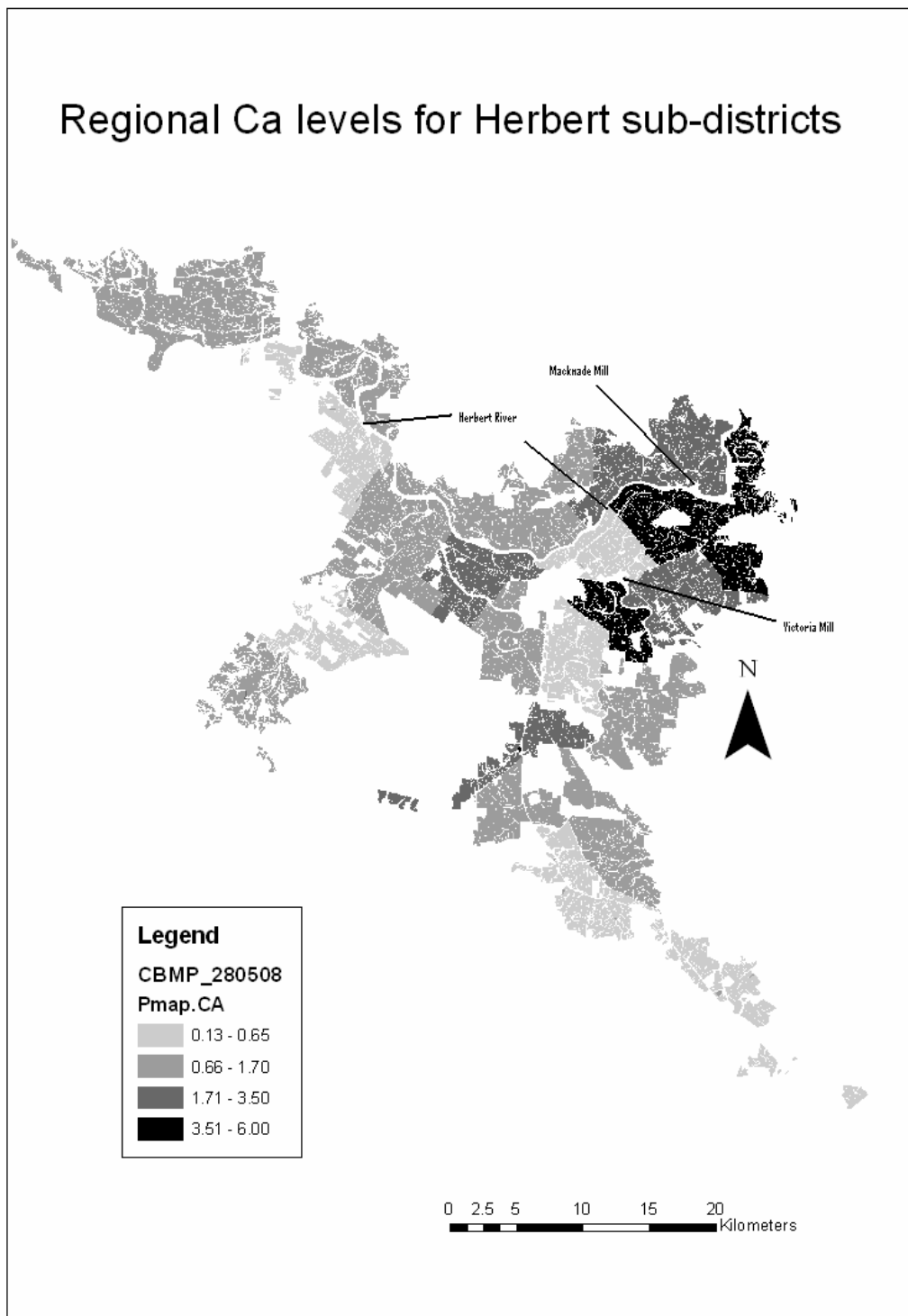
Soil calcium

Exchangeable calcium (Ca) contents of the soils vary considerably throughout the district depending on:
- Soil parent material;
- Soil type;
- Calcium applications in the form of agricultural lime, gypsum, dolomite, or calcium found in mill mud.

Low exchangeable Ca levels are common in the district, especially in soils located in the western and southern areas (Fig. 4). Exchangeable Ca levels below 0.6 cmol(+)/kg were found in 11 % of the soil samples in the database and one third of the samples had levels below 1.5 cmol(+)/kg, which is is considered to be the optimal level for growing cane within the region. The lowest recorded exchangeable Ca level in the database was 0.04 cmol(+)/kg.

A Least Squares Linear Regression analysis revealed that there was no statistical relationship between exchangeable Ca and pH_{water} ($R^2 = 0.33$).

Figure 4: Average exchangeable calcium contents in the soils of each sub-district region.

Di Bella, L.P., Coventry, R.J., Sefton, M., Moody, P.W., Hanks, M., Stringer, J.K., and Kerkwyk, R.E. (2009). The use of geo-referenced soil test data in the Herbert District. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31,** 296-306.

Soil aluminium

Extractable aluminium and aluminium saturation levels vary considerably throughout the district due to:
- Soil pH;
- Soil parent material;
- Soil type;
- Soil CEC.
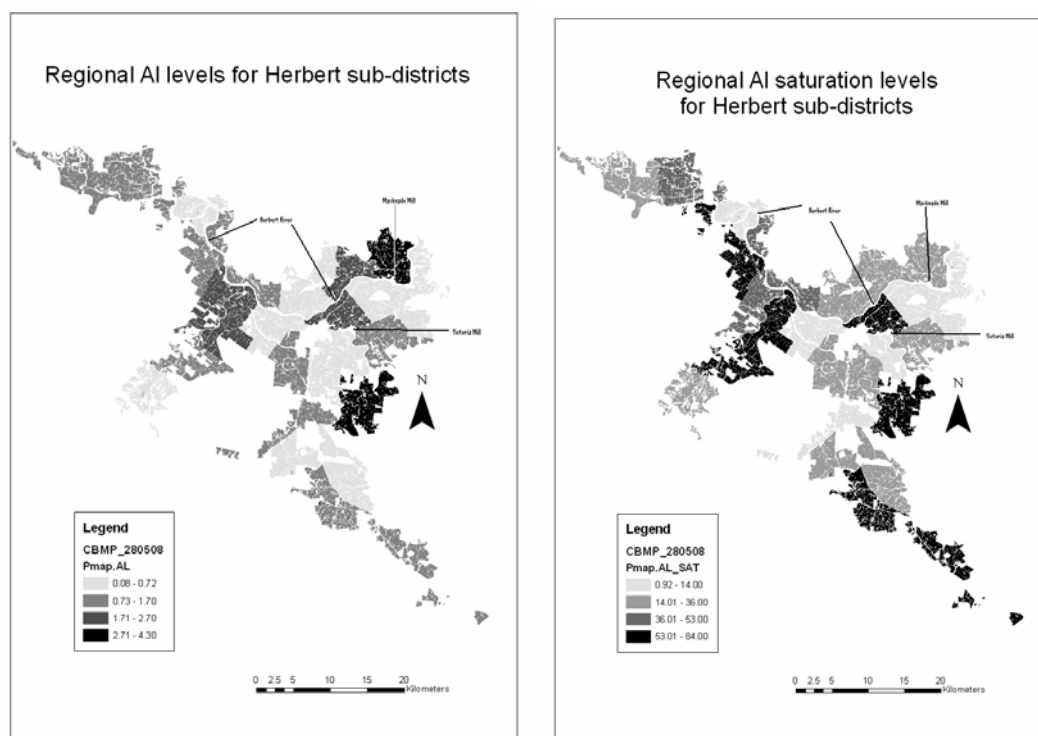
Figure 5: Average soil aluminium contents of the soils of the Herbert sub-districts:
  (a) average extractable aluminium contents;
  (b) Average aluminium saturation values.

While the absolute contents of extractable aluminium in the soils are relatively low (Fig. 5a), the degree of aluminium saturation in the soils is high to very high (Fig. 5b). The relationship between extractable aluminium and soil acidity was shown by a Least Squares Linear Regression analysis in which there was a significant ($P < 0.01$) relationship between extractable aluminium and pH_{water} ($R^2 = 0.81$), similar to that reported by Mengel and Kirkby (1982).

Excess aluminium cations in the soil solution inhibit plant root development and Hazelton and Murphy (2007) suggested that 5% aluminium saturation is the threshold for desirable plant growth. Slattery *et al.* (1999) have shown sugarcane to be one of the few crops that can tolerate soils with high extractable aluminium contents and can achieve its maximum potential yield in moderately aluminium-toxic soils without significant effects on plant growth from aluminium toxicity. Nevertheless, Slattery *et al.* (1999) suggested that, as the soil acidifies and its extractable aluminium contents increase, the growth of even the most aluminium-tolerant plants will be affected.

DISCUSSION

Sugarcane production in the Herbert region is facing some significant challenges in order to maintain soil fertility levels and to address specific nutrient management issues. The use of geo-referenced soil test data will assist growers and industry make informed decisions about nutrient and soil fertility management.

CEC, soil pH, calcium, and aluminium

Our results have shown that large areas of the Herbert region have soils with a combination of low cation exchange capacity, low soil pH, low exchangeable calcium, high extractable aluminium and high aluminium saturation levels.

Low calcium and pH levels will cause significant problems when growers are considering growing pH sensitive crops such as soybeans and other legumes, melons, pumpkins, and maize. Figure 6 shows the poor growth response, decreased crop vigour, and chlorosis of Meringa cowpea as a consequence of low soil pH, low soil calcium levels, and high soil aluminium levels on a legume cover crop grown in the Herbert in 2001.

Figure 6: Effects of low soil pH, low calcium, and high aluminium contents on the growth responses of a Meringa cowpea crop in the Herbert district in 2001.

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It has been noted by local agronomy and extension staff in the Herbert district that particular sugarcane varieties, like Q200, produce higher yields and a longer ratoon cycle on soils with higher levels of soil calcium.

Wood *et al.* (2003) reported that soils with pH_{water} levels greater than 5.5 are desirable for plant growth in the Herbert as concentrations of aluminium, both in the soil solution and on exchange sites, are minimised above pH 5.5.

Mengel and Kirkby (1982) reported that soil acidity and high aluminium levels in the root zone restrict a plant's ability to access water and nutrients. More recent studies such as that of Slattery *et al.* (1999) have also reported that the root system of plants are damaged in soils where excessive contents of extractable aluminium compromise plant growth. Wood *et al.* (2003) also showed that the availability of nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur all decrease in the Herbert district as the soil pH levels decrease, and indicated that soil pH and calcium levels should be monitored to ensure adequate cane growth.

The extent of soils with a combination of low cation exchange capacity, low soil pH, low exchangeable calcium, high extractable aluminium and high aluminium saturation levels in the Herbert catchment indicates a major soil constraint to plant growth in the region; these issues can be addressed by the following practices:

- Base farm nutrient management plans on soil and leaf tissue testing data, in conjunction with other data such as yield maps, soils maps, topographic maps, and remotely sensed imagery.
- Develop farming systems to conserve organic matter and to maintain soil structure using practices such as reduced tillage, controlled traffic, and rotational cropping.
- Strategic applications of calcium sources such as agricultural lime, mill mud, or finely ground rock dust to address soil pH issues.
- Strategic applications of calcium-based products such as agricultural lime, gypsum, mill mud, dolomite, or rock dust to address low calcium levels in soil. The use of these products, with the exception of gypsum, will also induce a beneficial increase in soil cation exchange capacity, and a reduction in aluminium saturation, as a consequence of increasing the soil pH (Webster and Wilcox, 1999).
- Routine monitoring of the soil condition through the use of a geo-referenced soil testing database system.
- Adopt the strategies highlighted in the "Six Easy Steps" program to ensure sustainable nutrient management.

Phosphorus

The high incidence of soils in the Herbert district with adequate or excessive contents of weak acid extractable phosphorus (values greater than 50 mg/kg) highlights the need to review current farming nutrient management practices and mill by-product application practices associated with phosphorus usage.

Mill mud application methods and the distribution of the mill products should be reviewed. Methods to distribute mill mud further from the sugar mill and onto blocks of low phosphorus status should be considered as a regional strategy for managing the best use of the product. Other nutrients present in mill mud such as calcium, magnesium, trace elements, and organic carbon could be of significant benefit to many of the low cation exchange capacity soils to the south and west of Ingham (Fig. 1).

The Six Easy Steps approach to best practice nutrient management recommends that applications of phosphorus should be based on soil test results to avoid over-applications of the nutrient on soils with already high levels of the nutrient present.

Grower demonstration plots should be established on soils with high extractable phosphorus levels to demonstrate to growers that cane can be established and grow well without the application of the nutrient.

CONCLUSIONS

The use of geo-referenced soil test data has proven to be worthwhile for the on-going monitoring of nutrient levels within cane blocks, within farms, within sub-districts, and across the region. It is recommended that this activity continue into the future and that the data are regularly reviewed.

The case studies presented in this paper highlight the benefits of a geo-reference soil test data base and possible uses of such a system. The analysis of other soil chemical properties is an on-going task.

Growers should be encouraged to continue to take soil tests to monitor soil nutrient levels. Soil test data should not be used in isolation but linked to other sources of spatial data such as soil maps, crop yield maps, topographic maps, and remotely sensed images to assist in making informed decisions on farm management practices.

The use of geo-referenced soil test data will assist growers to become more profitable and sustainable and will provide a mechanism to monitor productivity and environmental impacts associated with nutrient management issues in the future.

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STABILITY OF SPATIAL PATTERNS DEFINED BY ELECTRICAL CONDUCTIVITY MAPPING OF SOILS WITHIN SUGARCANE PADDOCKS

by

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KEYWORDS: Soil Variability, Spatial Patterns, ECa Mapping, Geo-referenced Zones, Site-specific Management

Abstract

Information that describes variations in the soil within paddocks can be used for the application of precision agriculture techniques through site-specific management to improve crop production. This paper outlines some of the possibilities for the enhanced recognition of soil-related patterns using maps of apparent soil electrical conductivity (ECa) responses recorded by a Veris 3100 machine at study sites in the Herbert, Burdekin, and Mackay sugarcane districts. The paper demonstrates the stability of deep (0 – 90 cm) soil ECa patterns over a six month fallow period and a five year crop cycle. The map patterns, supplemented by strategic soil description and analysis, are shown to be capable of providing a stable GIS layer that may serve as a surrogate for the soil condition, and as a base for assessing soil-related changes within paddocks, especially in paddocks for which detailed soil maps are not available.

Introduction

Recent technological developments have provided tools to support precision agricultural approaches to agronomy and crop production in the sugar industry (Bramley 2008), including: controlled traffic through GPS-guided steering of machinery; yield monitors on harvesters; 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 geo-referenced sites for soil sampling and testing (Di Bella *et al.* 2009b), apparent soil electrical conductivity (ECa) mapping (Coventry *et al.* 2009), and crop yield mapping (Di Bella *et al.* 2009a) to better understand and manage variability in sugarcane paddocks in North Queensland.

While recognising that a number of spatial mapping layers may be required to interpret paddock-scale variability in soils and crops, this paper aims to demonstrate the potential for soil ECa maps to provide relatively stable, soil-related patterns for use in precision agricultural approaches to rainfed and irrigated sugarcane production systems. Such spatial

information also has potential for use at a scale that is relevant to site-specific land and crop management in paddocks where detailed soil maps are not available.

Study sites and methods

Field sites

The data presented in this paper have been derived from three of the five study sites of the SRDC-funded Project BPS001 that represent a range of soil types and farming conditions in the Mackay, Burdekin, and Herbert districts:

- *Mackay site, M1, 11.24 ha:* sodic duplex and acidic-neutral clay soils; T. Bugeja's farm, Rosella; mean annual rainfall approximately 1690 mm; variety Q208 planted on 29 August 2008; plant-cane harvested on 3 August 2009.
- *Burdekin site, B1, 13.32 ha:* light-textured, sandy loam and neutral-alkaline clay soils typical of the Burdekin delta; I. Haigh's farm, Brandon; mean annual rainfall approximately 980 mm; variety Q208 planted on 31 March 2008; plant-cane harvested on 9-11 July 2009.
- *Herbert site, H2, 11.4 ha:* predominantly heavy textured, older alluvial sediments of the Herbert River floodplain; G. and J. Morley's farm, Lannercost; mean annual rainfall approximately 2400 mm; variety Q200 planted over 8.25 ha on 7 July 2008; plant-cane harvested on 25 August 2009; 3.1 ha was deep ripped on 11 July 2008 followed by 120 mm of rain immediately afterwards and was too wet to plant in 2008.

Soil sampling and analyses

Shallow and deep soil ECa mappings over depths of 0–30 cm and 0–90 cm, respectively, were carried out during the fallow phase of farming operations at each site using a Veris 3100 machine (Fig. 1); commercial operators in the Mackay and Burdekin districts can map 5 – 20 ha of fallow land per hour depending on paddock conditions. Field descriptions of the soil properties to a depth of 1 m were made from 84 soil profiles that had been located within specific soil EC spatial patterns across the study sites. Soil chemical and particle-size analyses were carried out by Incitec Pivot Ltd, Werribee, Victoria, on samples from the topsoil (0 – 25 cm), upper subsoil (45 – 60 cm), and deep subsoil (75 – 100 cm) layers of each described soil profile.
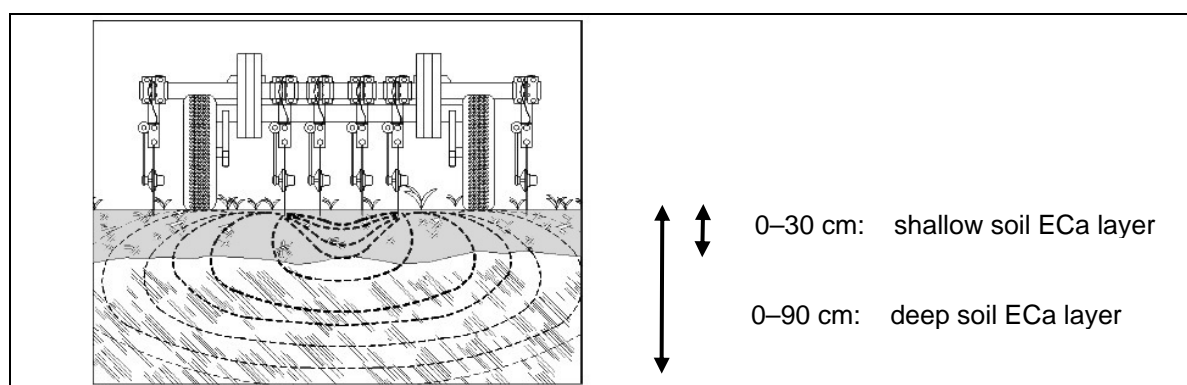

Figure. 1–The Veris 3100 soil electrical conductivity mapping unit extracts geo-referenced data from two soil depths: 0–30 cm *(topsoil and shallow cultivation layer)* and 0–90 cm (*bulk of plant root zone including the undisturbed subsoil)* respectively. Source: Veris Technologies (2000).

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Processing of soil electrical conductivity data

The data from the Veris 3100 unit were used to generate maps of spatially defined areas of soil ECa responses at each of the study sites, using the following GIS and data management protocols to ensure the spatial and statistical compatibility of subsequent analyses. Soil ECa values were interpolated between field observation points (approximately 10 m spacings between Veris runs along sugarcane rows; soil ECa and GPS location data collected at 3 second intervals, or approximately 5 m spacings, along each run) from each site by 10 m block kriging using an exponential variogram (program VESPER; Minasny *et al*., 2005). Soil ECa values were interpolated onto a regular 7 x 7 m grid following the approach of Bramley and Williams (2001). The area of each grid cell, almost 50 m^2, offers fine spatial resolution for site maps and is smaller than the minimum area that a canegrower is likely to adopt for site-specific management inputs. Data were converted by GIS methods (program MANIFOLD; Manifold Net Ltd 2010) to an MGA Zone 55 map projection and displayed as surfaces (program SMS; Ag Leader Technology, 2009). Given the importance in this instance of knowing where any areas of extreme ECa values lay within the field, the data were not de-spiked.

The comparison of soil ECa patterns over time has been facilitated by the preparation of difference maps, using an approach akin to but different from that of Diker *et al.* (2003), where all the grid cell values within a specific contour interval, such as those of Figs 2a and 2b, have been allocated the same integer value; values within increasing contour intervals have been allocated increasing values from 1 (very low) to 5 (very high). Subtracting the integer values 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 greater (2 or 3 units) change between the soil ECa maps (Fig. 2c). In this manner, the differencing technique is capable of illustrating the repeatability of the delineation of zones from soil ECa measurements, and the stability of those zones over time.

Stability of soil ECa mapping patterns over a fallow period

Soil ECa stability at site M1, Mackay

Site M1, underlain predominantly by poorly drained yellow duplex soils and grey clays, was ECa mapped on 24 December 2007 following deep ripping and offset discing to plough out the previous crop. During the fallow period, 1940 mm of rain fell in 17 significant rainfall sequences including 720 mm in a single event. Multiple discing and spring-tyne cultivations were carried out prior to a second ECa mapping on 18 June 2008.

Both shallow soil ECa mapping events produced low signals from the sandy topsoils of the duplex soils in the eastern parts of the paddock, and more variable responses from the rest of the paddock (compare Figs. 2a and 2b). A linear regression of the shallow 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 (adj) R^2 value was only 0.35 (Fig. 4a), thus showing that approximately one third of the variability in the observations could be explained by this regression. The ECa difference map (Fig. 2c) shows that the shallow soil ECa values over only 32% of the paddock remained unchanged between the two ECa surveys six months apart.
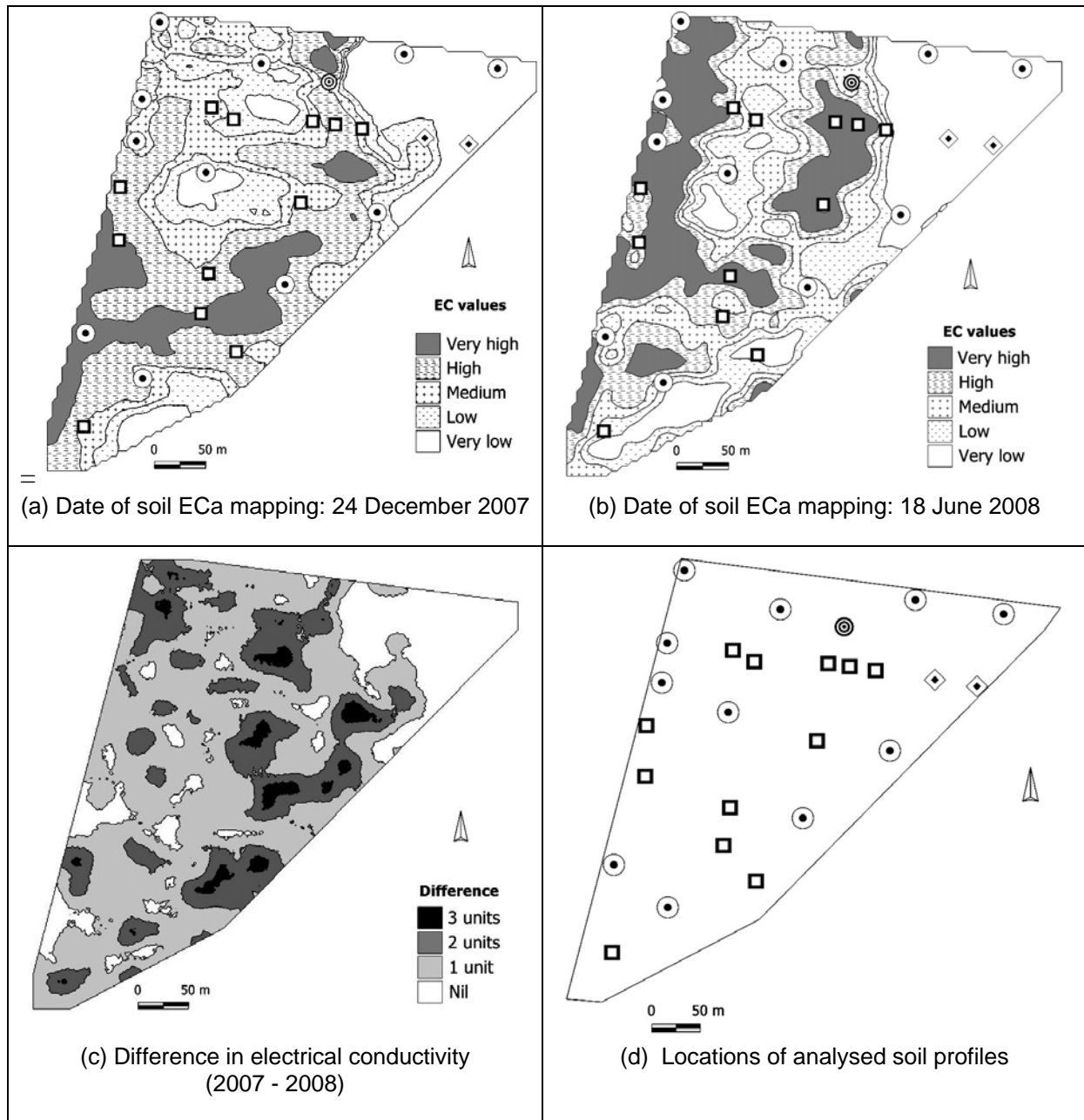
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Figure. 2–Site M1, Mackay: shallow (0-300 mm) soil ECa patterns and soil profile types: (a) patterns produced by shallow ECa mapping carried out after harvest on 24 December 2007; (b) patterns produced by shallow ECa mapping carried out 6 months later on 18 June 2008, before planting; (c) areas of difference in spatial patterns of mapping units between the two shallow ECa mapping events; (d) locations of analysed soil profiles: generalised soil profile characteristics (after Northcote 1979) are shown as: ☐ non-structured clay (Uf 6), ◈ yellow earth (Gn 2.4), ⊙ yellow duplex soil (Dy 5), ◎ dark coloured duplex soil (Dd 4).

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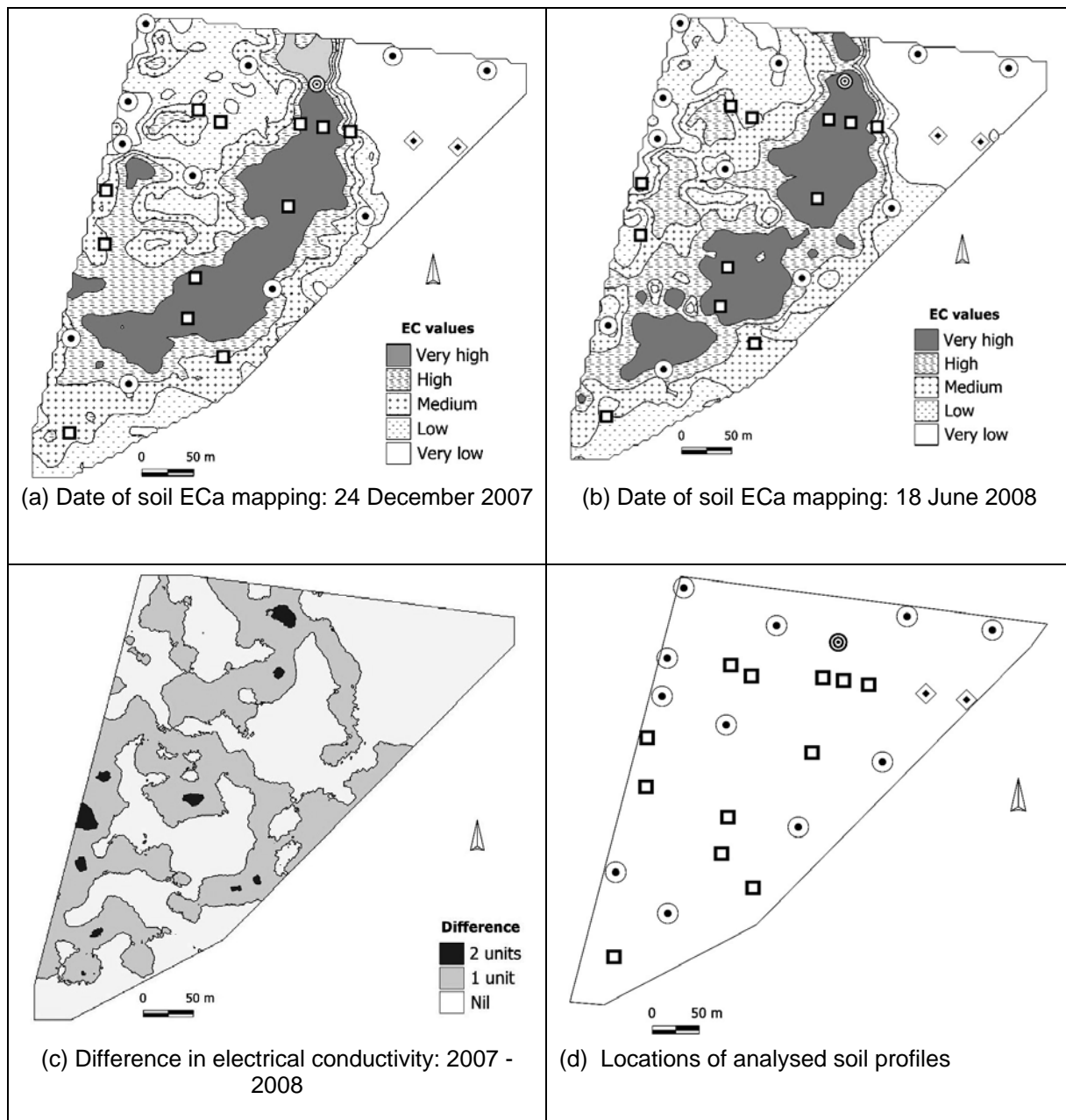
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Figure. 3– Site M1, Mackay: deep (0-900 mm) soil ECa patterns and soil profile types: (a) patterns produced by ECa mapping carried out after harvest on 24 December 2007; (b) patterns produced by ECa mapping carried out 6 months later on 18 June 2008 before planting; (c) areas of difference in spatial patterns of mapping units between the two deep ECa mapping events; (d) locations of analysed soil profiles: generalised soil profile characteristics (after Northcote 1979) are shown as: ☐ non-structured clay (Uf 6), ◈ yellow earth (Gn 2.4), ⊙ yellow duplex soil (Dy 5), ◎ dark coloured duplex soil (Dd 4).

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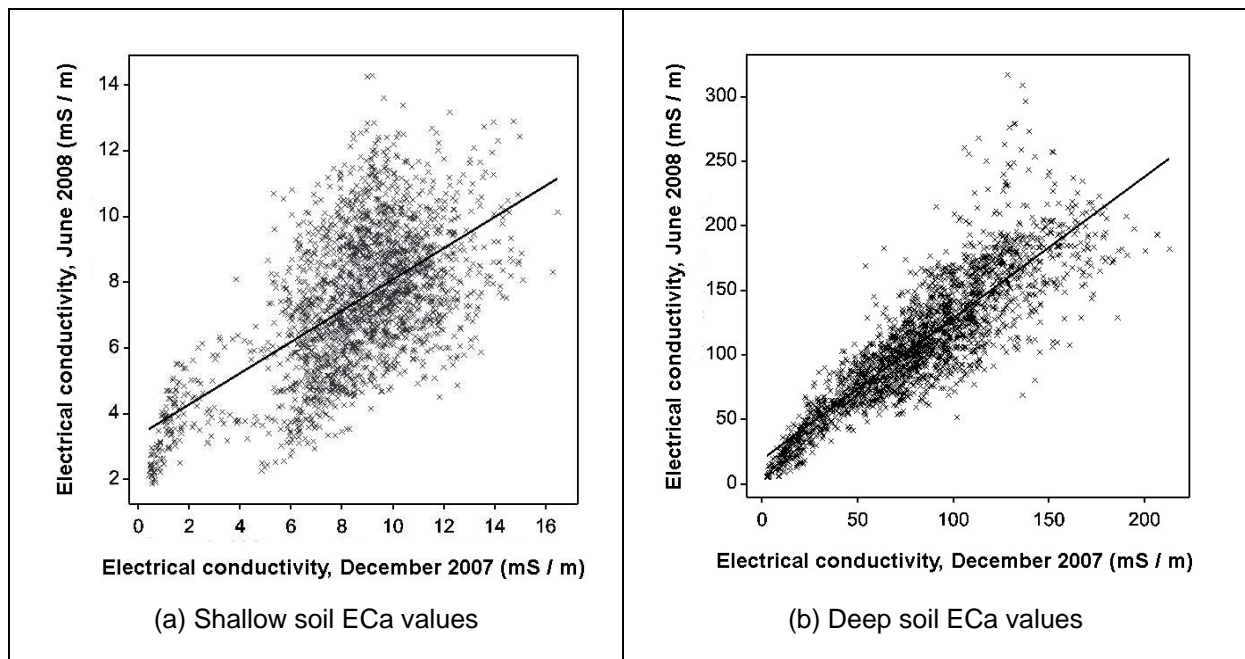
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Figure. 4–Relationships of shallow and deep soil ECa signals from corresponding georeferenced 7 x 7 m cells from two Veris 3100 mapping events (24 December 2007, 18 June 2008) within a fallow period at the Mackay study site (n = 2312).

The deep soil ECa patterns, reflecting the nature of the soil properties that lie largely below the cultivation layer in the paddock, varied between the mapping events much less than the shallow patterns did. Both deep ECa maps have delineated the yellow earth and yellow duplex soils of the northern parts of the paddock, and highlight the distribution of the grey clay soils defined by the pattern of high soil ECa readings through the middle of the paddock (Figs 3a, b). The deep soil ECa difference map (Fig. 3c) indicates that 59% of the area of the paddock showed no change between ECa mapping events, and that 94% of the area changed by 1 unit or less.

The general similarity of the deep soil ECa readings is also reflected in successive soil ECa surveys, reinforcing the stability of the map patterns with time. The relationship between the 2007 and 2008 deep ECa data was much stronger than that of the shallow ECa data (Figs 4a, 4b). A linear regression for deep ECa values was highly significant (adj R^2 0.75, p < 0.001; Fig. 4b). There was minimal improvement in the adjusted R^2 value when the data were log transformed to stabilise the variance of the data across the data range (Fig. 4b), or when a curvilinear relationship was fitted.

Soil ECa stability at site B1, Burdekin

Site B1, underlain predominantly by well drained red 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; and 19 July 2009 after harvest of the plant cane crop (Fig. 5). The stability of the soil ECa map patterns at site B1 was similar to that at site M1. The shallow ECa patterns varied between mapping events, but the deep soil ECa patterns (Figs 5a, 5b, and 5c) were more stable and produced much stronger

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relationships between mapping events (adj R^2: 0.82, 0.92, 0.72 for 2008 vs 2007, 2009 vs 2007, and 2009 vs 2008, respectively).
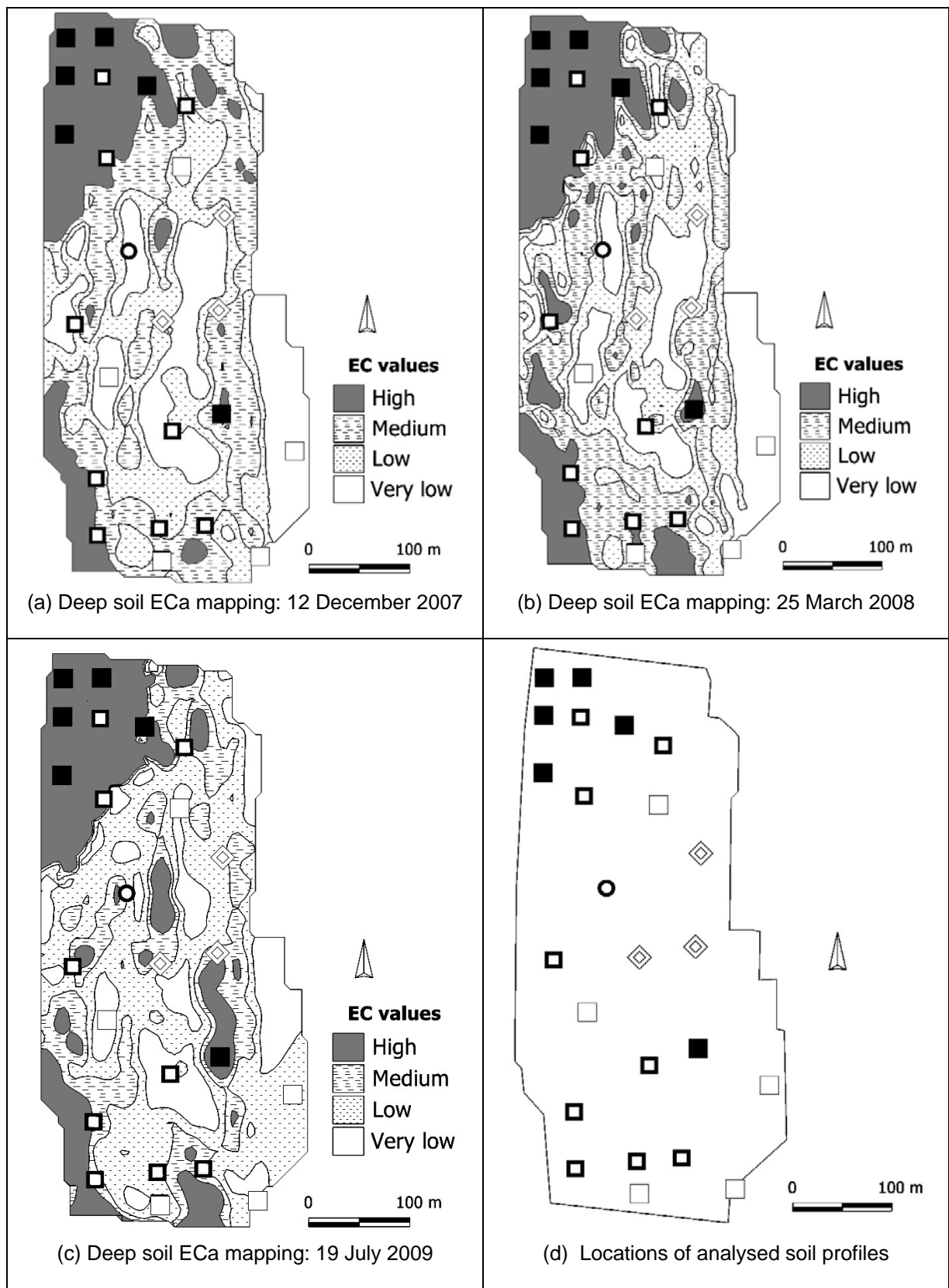
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Figure 5–Site B1, Burdekin (13.33 ha): stable, deep soil ECa patterns (0 – 900 mm) from three mapping events, and locations of analysed soil profiles. (a) soil ECa mapping on 12 December 2007 after harvest of fifth ratoon crop before plough out; (b) soil ECa mapping on 25 March 2008 towards the end of the fallow stage; (c) soil ECa mapping on 19 July 2009 after harvest of plant

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crop (d) locations of analysed soil profiles: generalised soil profile characteristics (after Northcote 1979) are shown as: □ well drained red sand (Uc 5), ◻ non-structured clay (Uf 6), ■ cracking clay (Ug 5), ◈ dark coloured massive earth (Gn 2.0), O red duplex soil (Dr 4).

The strong correlations for the deep soil ECa data from site B1 accord with the findings from site M1 that the soil properties influencing the ECa values had changed little between the surveys during the fallow period. As with site M1, however, variability occurred in the shallow ECa patterns between repeat mapping events, possibly in response to tillage activity, significant rainfall occurrences, and their influence on Veris 3100 readings through variable coulter penetration.

Stability of soil ECa mapping patterns over a crop cycle

Commercial soil ECa mapping by Veris 3100 machines began in the Australian sugar industry in 2001, but no repeat ECa mappings of the same paddock have been attempted (A. Crowley, pers. comm.). Therefore, we specifically re-mapped a sugarcane block at Mackay that had been soil ECa mapped 5 years previously during the fallow phase of the preceding crop cycle.
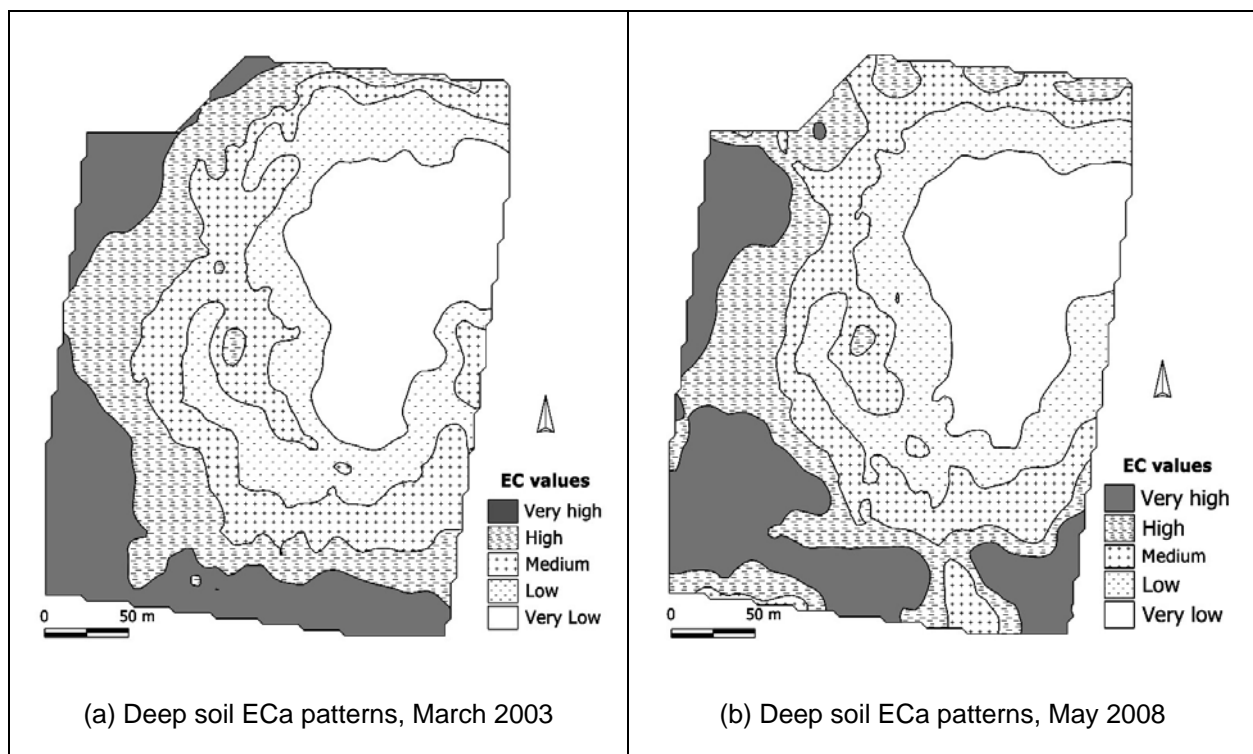

(a) Deep soil ECa patterns, March 2003   (b) Deep soil ECa patterns, May 2008

Figure 6–Deep soil ECa patterns collected from the same sugarcane paddock that lies 5.4 km southwest of site M1, Mackay: (a) Deep soil ECa patterns at the start of a cropping cycle (March 2003); (b) Deep soil ECa patterns five years later at the start of the next cropping cycle (May 2008).

The shallow soil ECa map patterns were found to have varied considerably between the 2003 and 2008 mapping events. Linear regressions for log transformed data explained only a small proportion of the variability (adj R^2 0.25, p < 0.001); the log transformation was required for the data to meet normality assumptions. However, the deep soil ECa patterns

were found to be remarkably stable between the two separate surveys five years apart (compare Figs 6a, 6b). There was a strong linear relationship between the log transformed values from corresponding georeferenced 7 x 7 m cells of the 2003 and 2008 mapping events (adj R^2 0.86, $p < 0.001$, $n = 1633$). Again, the trend was for repeatable patterns of zones derived from the deep soil ECa data that are linked to soil conditions.

Soils and ECa mapping patterns

Non-saline, heavy textured duplex and clay soils with fairly similar soil ECa responses occurred over much of site H2 (Herbert). A low ridge towards the south-western margin of the site represents a remnant of a channel sand deposited by a past stream which traversed the heavier soils of the Herbert River floodplain (Coventry *et al.* 2009). The low relief of the site has been significantly modified by levelling operations over the last 20 years to aid site drainage under sugarcane. The surface soil of a substantial part of the sandy ridge has been removed and spread nearby in the paddock as a fill, producing or enhancing the duplex soil profile trends (Fig. 7).
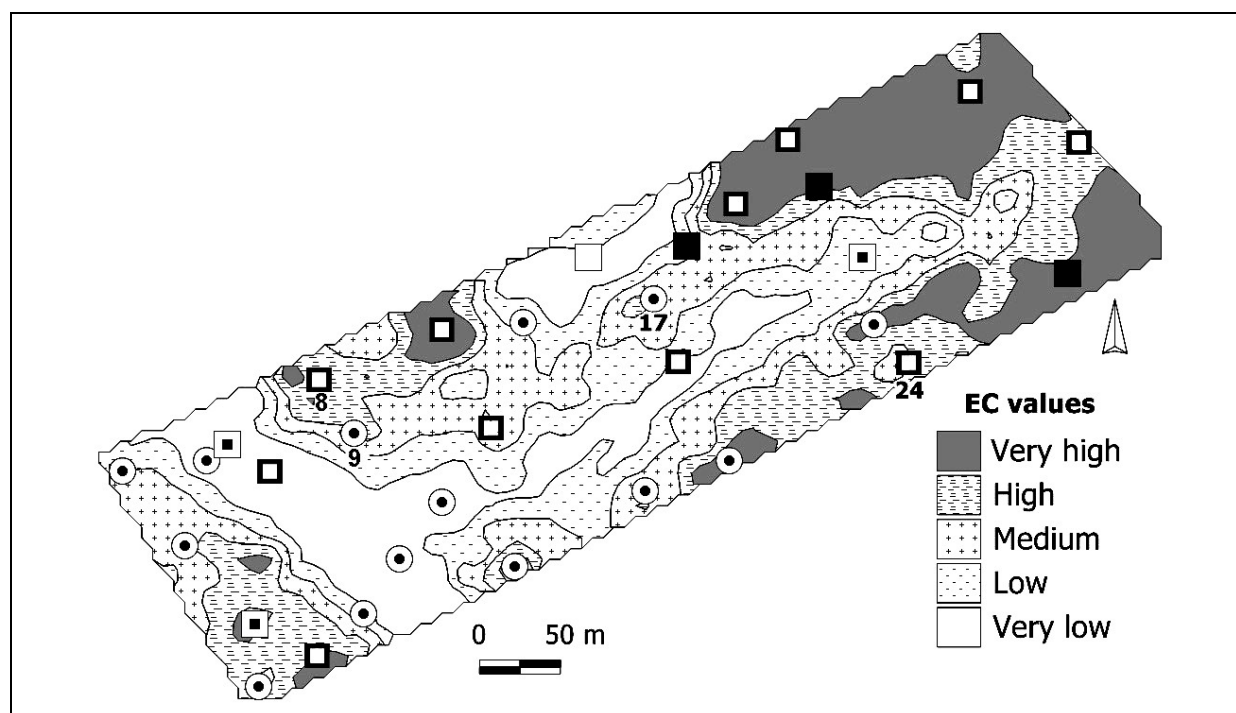

Figure 7–Deep soil ECa patterns at site H2, Lannercost, showing locations of analysed soil profiles. Generalised soil profile characteristics (after Northcote 1979) are shown as: ☐ uniform sand (Uc 5), ⊡ uniform loam (Um 5), ☐ non-structured clay (Uf 6), ■ cracking clay (Ug 5), ⊙ yellow duplex soil (Dy 3 or Dy 5). Data for profiles 8, 9, 17, and 24 are given in Tables 1 and 2.

The main morphological and chemical characteristics of the topsoils and subsoils of four soils (two duplex soils and two non-structured clays) from the same soil ECa mapping unit are summarised in Tables 1 and 2. The contrasting topsoil properties have been shaped largely by the thickness and texture of the fill over the undisturbed clayey subsoils. All of the subsoils are remarkably similar, and the soil profiles differ mainly in the thickness of the lighter textured topsoil (or fill) that overlies the clayey subsoils (Table 2). The uniformity of the heavy subsoils is reflected in the similarity of their deep soil ECa signals (Table 2).

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Table 1– Properties of selected topsoils (0–25 cm depth) from site H2, Lannercost. The profiles are located on Fig. 7.

Profile number (Fig. 7)	Profile type (Northcote (1979)	Veris Deep ECa (mS / m)	Thickness of fill over undisturbed soil (cm)	Field texture *	pH (1:5 water)	CEC (meq/100g)	Organic carbon (%)	P (BSES) (mg/kg)	Exch Ca (meq/100g)	Exch Mg (meq/100g)	Exch K (meq/100g)	Exch Na (%)	Clay (%)
Yellow duplex soils													
9	Dy	18	25	SL	5.1	2.6	1.0	11	1.0	0.5	0.15	2	14
17	Dy	18	28	SL	4.9	4.6	1.1	5	1.4	0.8	0.22	1	28
Uniform, non-structured clays													
8	Uf 6	23	0	LC	5.3	4.2	0.8	7	1.9	1.0	0.14	2	24
24	Uf 6	19	0	LMC	5.1	6.8	1.9	11	3.1	1.3	0.35	1	36

* SL: sandy loam, LC: light clay, LMC: light medium clay.

Table 2– Properties of selected upper subsoils and deep subsoils (40–60 cm and 75–100 cm depths, respectively) from site H2, Lannercost. The profiles are located on Fig. 7.

Profile number (Fig. 7)	Profile type (Northcote (1979)	Veris Deep ECa (mS / m)	Depth to clay textured subsoil (cm)	Upper subsoil (40 – 60 cm)					Deep subsoil (75 – 100 cm)				
				pH (1:5 water)	CEC (meq/100g)	Exch Na (%)	Clay (%)	Field texture *	pH (1:5 water)	CEC (meq/100g)	Exch Na (%)	Clay (%)	Field texture *
Yellow duplex soils													
9	Dy	18	45	5.8	5.9	5	3	LMC	6.8	10.7	9	39	MHC
17	Dy	18	45	5.7	10.0	7	12	s LC	6.4	11.7	9	41	HC
Uniform, non-structured clays													
8	Uf 6	23	0	6.2	9.8	1	45	MHC	7.1	13.0	12	46	HC
24	Uf 6	19	0	6.8	4.3	3	29	g LMC	6.8	9.3	7	41	g LMC

* LC: light clay, LMC: light medium clay, MHC: medium heavy clay, HC: heavy clay,
  s: sandy, g: gritty.

Discussion

Coventry, R.J., Hughes, J.R., Reid, A.E., McDonnell, P. (2010). Stability of spatial patterns defined by electrical conductivity mapping of soils within sugarcane paddocks. *Proceedings of the Australian Society of Sugar Cane Technologists,* **32**, 397-409.

Soil electromagnetic mapping methods have been used to identify patterns of soils in a variety of Australian primary production systems (grapes, Bramley & Williams 2001; grains, O'Leary & Peters 2005; cotton, Stewart *et al.* 2005) where the influences of soil depth, salinity, clay mineralogy, clay content, and soil water properties have been demonstrated. Similarly, the ECa signals of the present study were found to have been moderated by elevated soil moisture contents and cation exchange capacity, both of which are tied to soil texture. At each of the study sites, none of which had high contents of soluble salts in any of the soils, the lighter textured, sandier soils produced low ECa signals and were readily delineated by the deep soil responses recorded by the Veris 3100 machine (Figs 3 and 5). On the other hand, the heavier clay soils were easily identified from the high values of their deep ECa signals, especially where those clays were found to have relatively high cation exchange capacities or high exchangeable sodium percentages.

While soils with similar deep ECa readings generally had similar soil profile morphologies and properties (as within the sandy or clayey soils at sites M1 and B1), it is possible for soils with different profile morphologies to produce similar deep soil ECa signals, as at site H2 (Fig. 7). In our experience, this is a common occurrence in soils modified for agriculture through earthworks, and strongly reinforces the point that the interpretation of a soil ECa map requires verification of the field characteristics of the soils at strategically chosen locations within soil ECa mapping units. Project BPS001 is currently investigating the role of spatial patterns derived from other site data such as topography, soil profile drainage, and crop yield estimates in improving the processes involved in the selection of strategic sites for the verification of soil characteristics.

The soil verification field work may be carried out at relatively few sites and the choice of their locations will be aided by the patterns derived from a soil ECa survey. If the soil verification work incorporates a stable, deep ECa map layer, it should be quicker and require much less effort and expense to obtain soils information at a spatial resolution comparable to that produced by conventional soil mapping on a closely spaced grid of boreholes across the paddock.

Conclusions

Repeated soil ECa mapping of study sites within a single fallow period, and over a 5-year cropping cycle, have shown that the patterns of deep soil ECa values are relatively stable and repeatable, provided that earthworks have not modified the landscape significantly between ECa mapping events.

Soil ECa mapping is a tool that allows the delineation of variations in soils with different morphological properties. The relative stability of deep soil ECa signals over time allows their use, in conjunction with strategically-located soil profile assessments, as surrogates for soil properties that are much more time-consuming and costly to measure directly. The soil verification field work may be carried out at relatively few sites and the choice of their locations will be aided by the patterns derived from a soil ECa survey; site selection is likely to be improved with access to additional spatial layers such as those related to crop growth and other site variables. The supplementary mapping layers may also be used to help to determine where to apply site-specific inputs within paddocks, and are likely to be of greatest value in areas where detailed soil maps are not available.

Deep soil ECa mapping offers a rapidly-acquired, low cost source of soil-related data whose full significance is not yet recognised. The technique has potential to guide grower

decisions on land management strategies by defining basic changes in soil-related zones within sugarcane paddocks at a scale appropriate to the management of site-specific inputs. The relative stability of deep soil ECa patterns, and their strong relationships with actual soil types, provide a base mapping layer for use in geographic information systems supporting the development of precision agricultural practices in sugarcane production systems.

Acknowledgements

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Using spatial mapping layers to understand variability in precision agriculture systems for sugarcane production

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Crop reflectance: NDVI

Crop reflectance was measured from a high resolution IKONOS satellite image, enhanced through the calculation of a normalised difference vegetation index (NDVI) for each pixel, classified, and mapped (right).

$$NDVI = (NIR - Red) / (NIR + Red)$$

where 'NIR' indicates the reflectance measured within the near infrared region of the electromagnetic spectrum (757 – 853 nm) and 'Red' within the visible region (632 – 698 nm).

A high NDVI value generally indicates healthy, vigorous plants while a low value indicates reduced vigour.
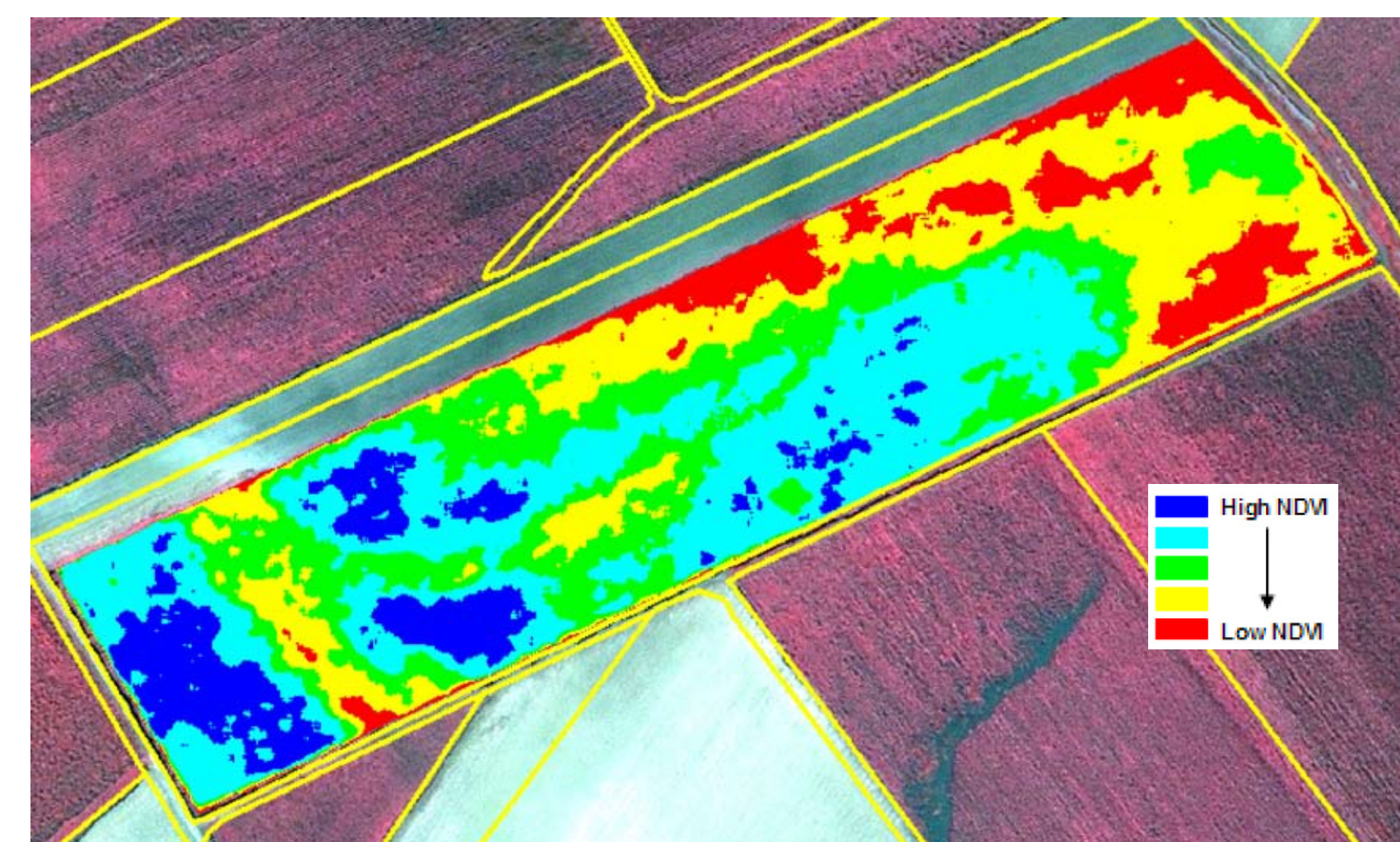

Classified NDVI based on an IKONOS image captured 2 August 2009

Yield validation samples

To assess the correlation between NDVI and yield variability, ten 5 metre rows of cane were manually sampled from areas with a range of NDVI values and weighed via a portable weigh trailer. These samples were collected on the 21 August 2009, 19 days after image capture and three days before the commercial harvest of the crop on 24 August 2009.
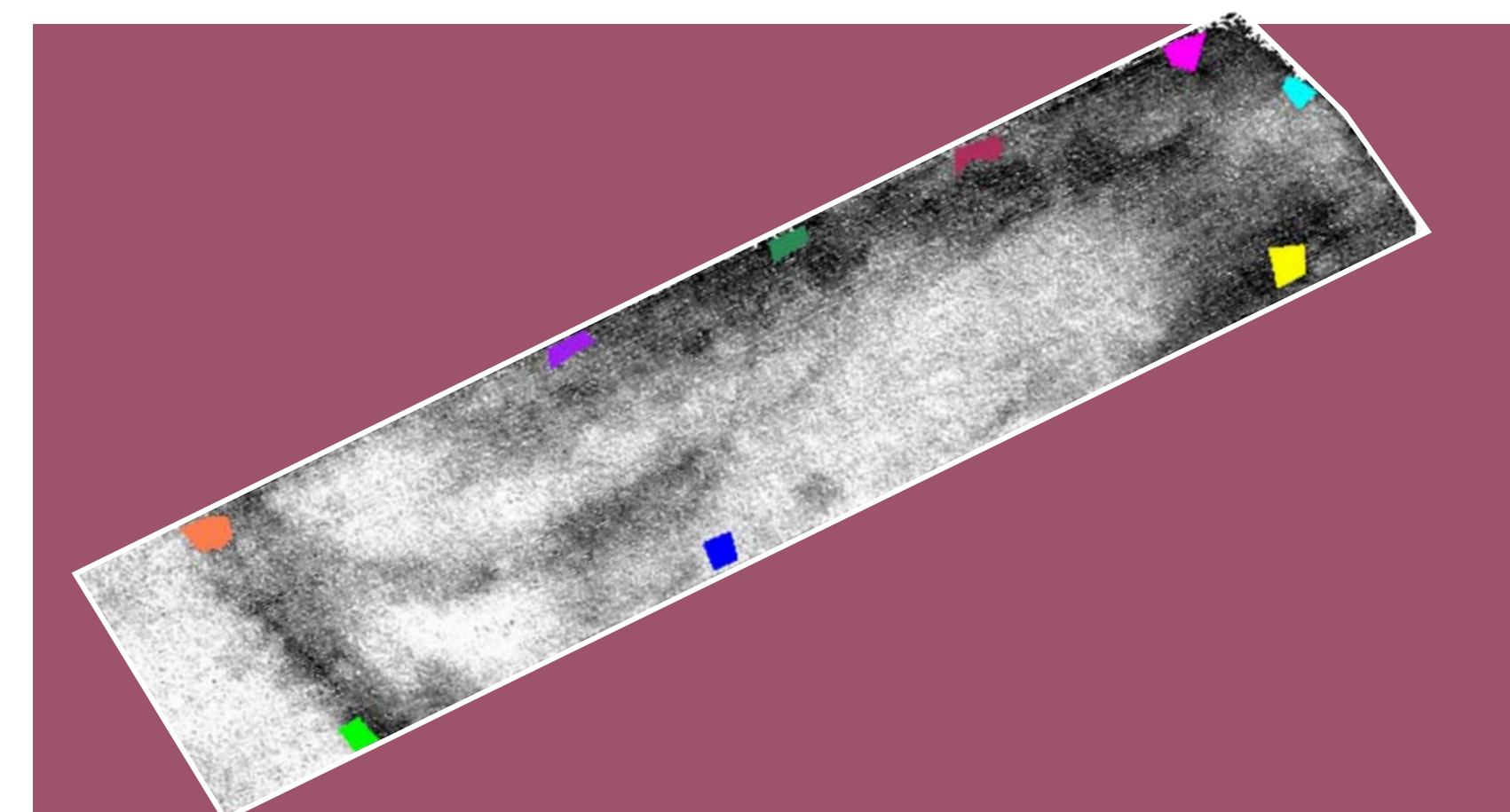

Field sampling locations manually harvested 21 August 2009

Harvester yield monitor

TechAgro yield monitor data and NDVI map data were geo-referenced and set to the same 7x7 metre grid.

A significant correlation was identified between Techagro yield monitor data with NDVI ($R2=0.60$, n=1807; blues points).

The removal of yield monitor values (black ellipse, right) suspected to be spurious (yellow points; n= 226) improved the correlation to ($R2=0.66$, n=1581).
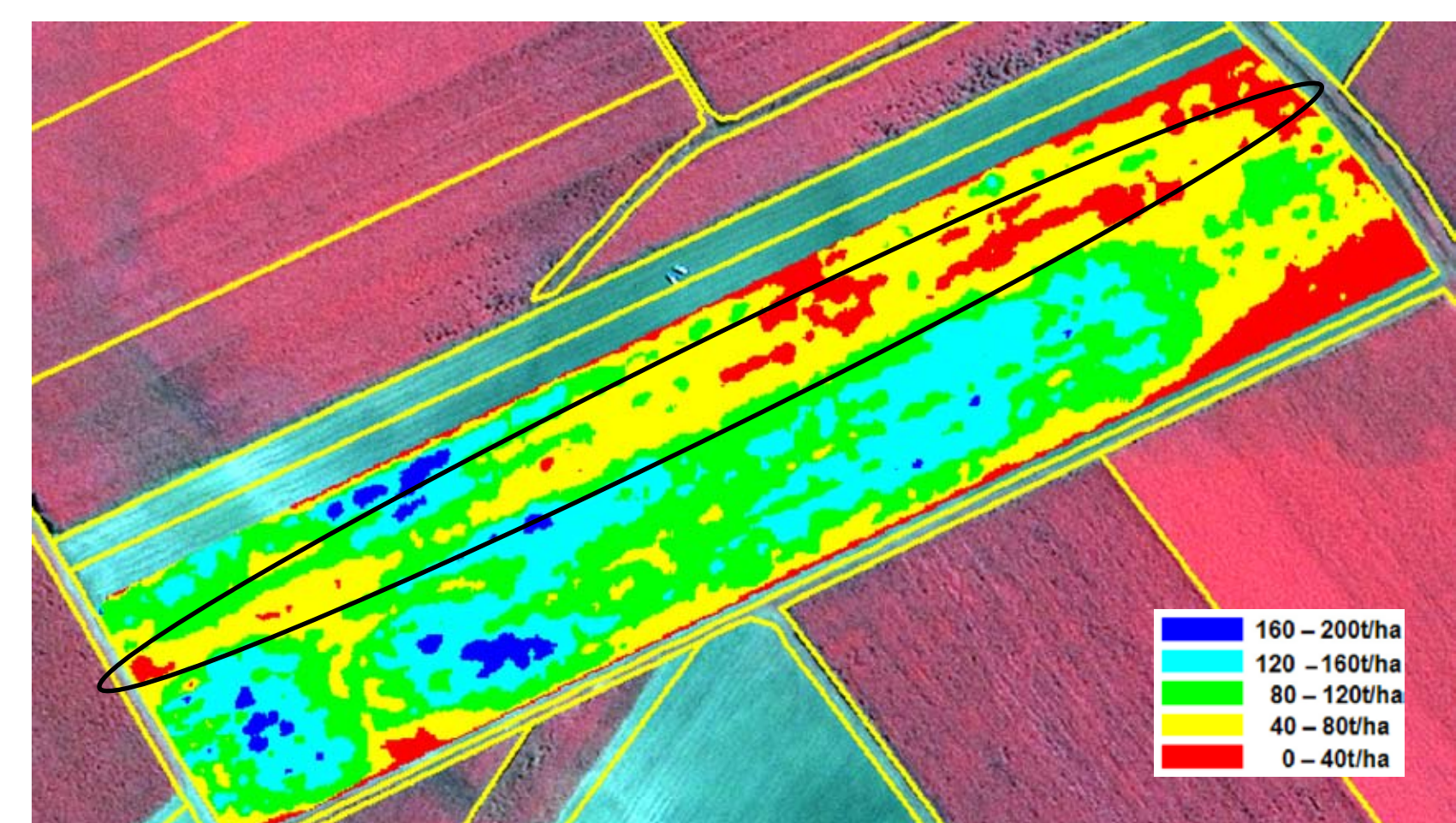
Classified yield map (Techagro): harvested 24 August 2009

Yield prediction

The manually sampled data (pink dots and curve, right) show a close fit to the exponential linear algorithm developed between the Techagro and NDVI correlation (black curve). Total yield prediction using both the Techagro/ NDVI algorithm (714 t) and manually harvested samples/ NDVI algorithm (684 t) were comparable, with the later being more accurate to the actual final yield (594 t). The over prediction of 13% may be explained by harvest losses.

Average NDVI over the whole of the crop = 0.465747

Manual yield   Mean yield = (8.8721*EXP(4.8123*0.465747)) = 83.448 t/ha.
83.448 t/ha * 8.2 ha = **684 tonnes from paddock** (over estimate: 13.3%)

Yield monitor   Mean yield = (4.3911*EXP(6.4136*0.465747)) = 87.068 t/ha
87.068 t/ha * 8.2 ha = **714 tonnes from paddock** (over estimate: 16.7%)

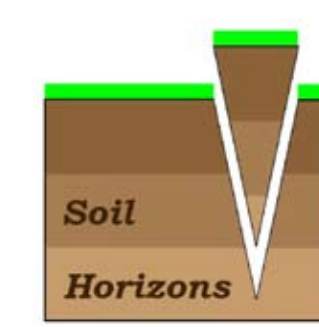**Actual paddock yield** (cane delivered over mill weighbridge) = **594 t**
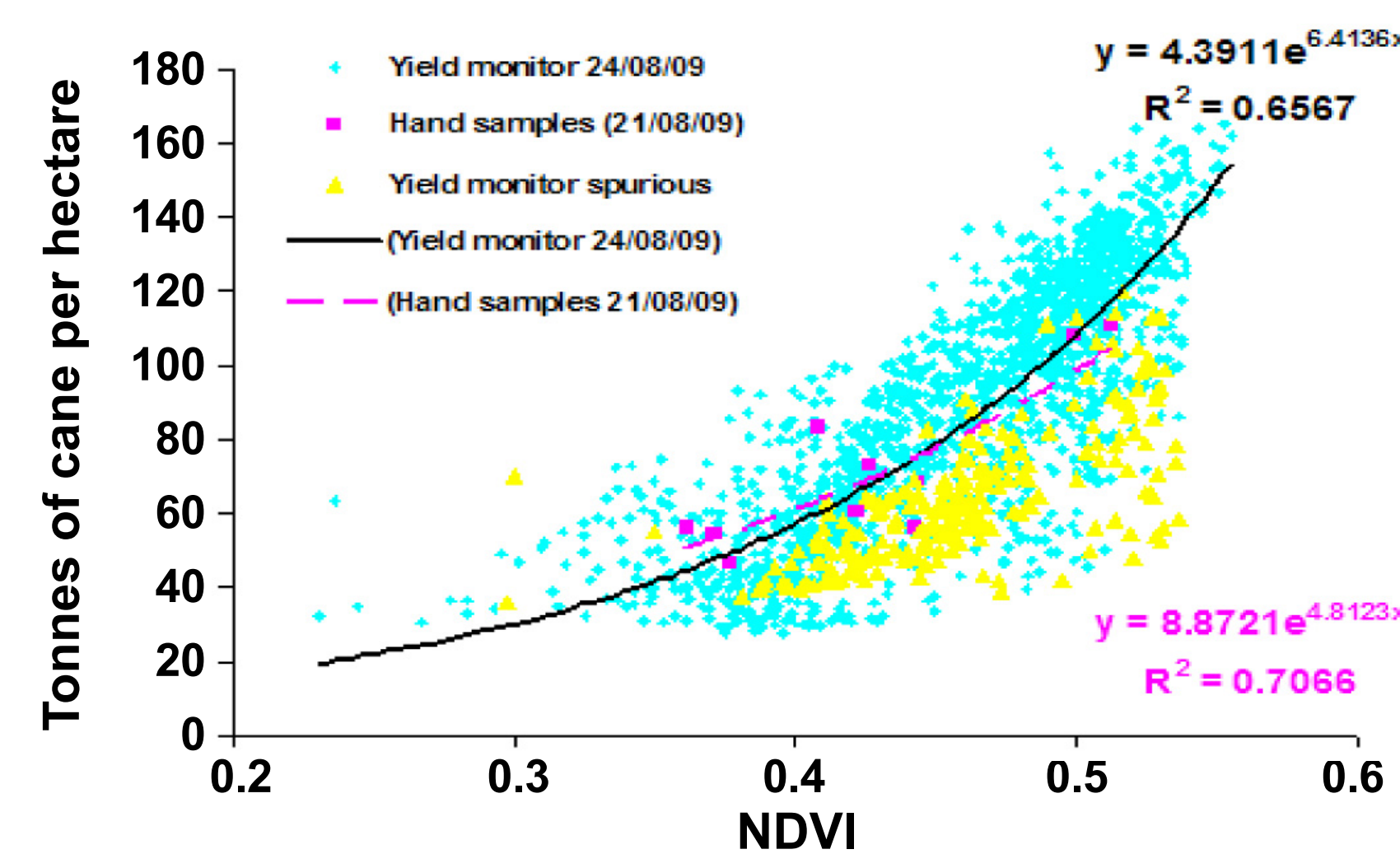
Correlation between Techagro yield data and corresponding NDVI values (blue points); suspected spurious points (above right) shown as yellow points. Pink points and trend line indicate manually sampled data.

These results indicate that the spatial variability of cane yield can be predicted using satellite imagery, if validated with either accurate yield monitor data or strategically located manually harvested samples. Further research is required, however, to identify if accurate algorithms can be developed to predict yield without the need for intensive field sampling, as well as optimal timing for image capture.

HCPSL
Herbert Cane Productivity Services Ltd.

Techagro

REEF CATCHMENTS
Mackay Whitsunday Inc

Australian Government
Sugar Research and Development Corporation

terrain
NATURAL RESOURCE MANAGEMENT

Soil Horizons

Queensland Government

Managing spatial variability in sugarcane paddocks

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Introduction

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.
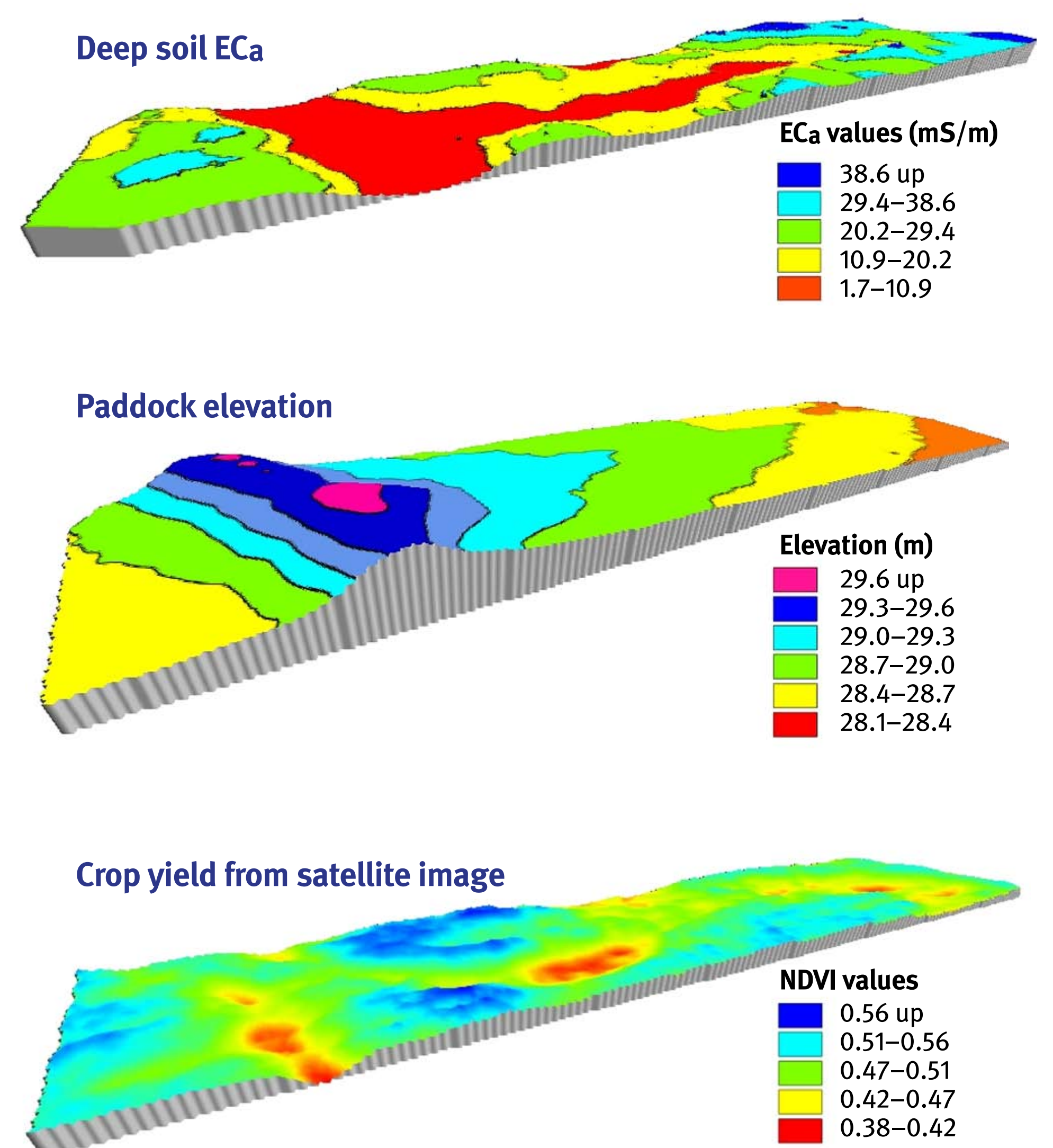
Precision agricultural technology is currently available to allow cane growers to provide the inputs required to cope with most of the site-specific factors that control paddock variability.

Three GIS layers underpin zonal management

A soil layer (stable): based on technologies such as deep soil electrical conductivity (EC_a) responses where detailed soil maps are unavailable; checked against actual soil profile data, especially soil texture and sub-surface drainage characteristics, at strategically located sites.

A digital elevation layer (stable but influenced by earthworks): based on detailed topographic data; defines water movement pathways in paddocks; identifies the drainage status of contiguous segments of the crop along each row within the paddock.

A crop yield layer (variable spatial responses to weather, pests and diseases, and paddock management strategies): reflects differences in soil and site parameters controlling growing conditions within paddock yield zones. Data may be from high resolution satellite imagery captured before harvest or from harvester-mounted yield monitors.

Deep soil EC_a

EC_a values (mS/m)
- 38.6 up
- 29.4–38.6
- 20.2–29.4
- 10.9–20.2
- 1.7–10.9

Paddock elevation

Elevation (m)
- 29.6 up
- 29.3–29.6
- 29.0–29.3
- 28.7–29.0
- 28.4–28.7
- 28.1–28.4

Crop yield from satellite image

NDVI values
- 0.56 up
- 0.51–0.56
- 0.47–0.51
- 0.42–0.47
- 0.38–0.42

Potential benefits

Industry: Knowledge of relationships among these and other GIS layers provide pathways for continual improvements in soil preparation, applying plant nutrients, breeding adapted varieties, adopting relevant technologies, and refining spatially-defined management techniques based on crop yield potential.

Farm productivity: Identifying and planting cane varieties adapted to soil variability and spatial positions in the landscape. Development of a 'variable variety planter' is needed to capitalise on this outcome.

Economic: Site specific application of nutrients (e.g. 'Six Easy Steps'), pesticides, and herbicides based on the yield potential of paddock management zones and their key soil properties.

Environmental: Significant water quality improvements from paddock inputs based on spatially-defined zones of yield potential. This should provide information for a re-assessment of farm management regulations.

More information

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