UNDERSTANDING THE BARRIERS TO THE IMPLEMENTATION OF PRECISION AGRICULTURE IN THE CENTRAL REGION

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Abstract

THERE IS AN INCREASING requirement for more astute land resource management through efficiencies in agricultural inputs in a sugar cane production system. A precision agriculture (PA) approach can provide a pathway for a sustainable sugarcane production system. One of the impediments to the adoption of PA practices is access to paddock-scale mapping layers displaying variability in soil properties, crop growth and surface drainage. Variable rate application (VRA) of nutrients is an important component of PA. However, agronomic expertise within PA systems has fallen well behind significant advances in PA technologies. Generally, advisers in the sugar industry have a poor comprehension of the complex interaction of variables that contribute to within-paddock variations in crop growth. This is regarded as a significant impediment to the progression of PA in sugarcane and is one of the reasons for the poor adoption of VRA of nutrients in a PA approach to improved sugar cane production. This project therefore has established a number of key objectives which will contribute to the adoption of PA and the staged progression of VRA supported by relevant and practical agronomic expertise. These objectives include provision of base soils attribute mapping that can be determined using Veris 3100 Electrical Conductivity (EC) and digital elevation datasets using GPS mapping technology for a large sector of the central cane growing region using analysis of archived satellite imagery to determine the location and stability of yield patterns over time and in varying seasonal conditions on selected project study sites. They also include the stablishment of experiments to determine appropriate VRA nitrogen rates on various soil types subjected to extended anaerobic conditions, and the establishment of trials to determine nitrogen rates applicable to a declining yield potential associated with the aging of ratoons in the crop cycle. Preliminary analysis of archived yield estimation data indicates that yield patterns remain relatively stable over time. Results also indicate the where there is considerable variability in EC values there is also significant variation in yield.

Introduction

The sugar industry is facing increased pressure to adopt improved management practices to mitigate the impact of climate change, fluctuating sugar prices and escalating input costs, and to improve the quality of water leaving farms. This is evident in the Federal Government’s Reef Rescue program which is a major reform package to improve the quality of water entering the Great Barrier Reef from coastal agriculture in Queensland. Bramley (2007) reported that there was and still is a growing interest in precision agriculture (PA) practices in the Australian sugar industry.

An SRDC-funded project, BPS001 (2007–2011), entitled ‘Identifying management zones within cane paddocks’, established that managing within-paddock variability is extremely complex and requires a thorough understanding of the interaction between a number of variables which influence crop growth in defined zones (Coventry *et al.*, 2011). However, it was evident that variability in yield (particularly in wet tropical and subtropical conditions) was fundamentally driven by the hierarchy of soil texture properties through the profile and the soil's position within the topographic landscape.

Ground-truthing of electrical conductivity (EC) mapping patterns confirmed the ability of that technology to accurately define contrasting soil properties within paddocks and highlighted the inadequacy of coarse-scale soil surveys in a PA approach to improved sugarcane production systems. Similarly, regional digital elevation/topographic maps with one metre vertical scale accuracy were of limited value in PA.

The BPS001 project identified three key spatial datasets as being fundamental for the progression of PA in sugarcane, namely:

- A stable soil mapping layer achieved through (EC soil mapping surveys with associated soils data collected through ground-truthing of EC mapping patterns
- A stable elevation/surface drainage layer readily accessed through GPS-equipped tractors or Real-Time Kinematic (RTK) GPS elevation data acquired during EC soil mapping surveys
- A yield mapping layer achieved through processing of strategic satellite imagery captures or yield maps from sugarcane harvester monitors.

Calibration of processed satellite imagery has verified the variability of yield that occurs in many sugarcane paddocks (Noonan, 1999; Markley and Fitzpatrick, 2004; Robson *et al.*, 2012). The integration of variable rate application (VRA) of nutrients based on yield mapping patterns is regarded as an integral component of PA with the potential to enhance water quality and improve the return on investment for nutrient inputs.

However, to maximise the benefits of VRA technology, the determination of the yield potential of defined yield zones is necessary. In addition, determining the stability of yield patterns over time is fundamental to the future delivery of robust VRA nutrient programs.

Yield validation of processed satellite imagery in conjunction with associated borehole data based on EC mapping patterns verified that poor yielding zones within paddocks were generally due to poor subsurface drainage characteristics exacerbated by low-lying areas within the paddock (particularly in the wetter sugarcane growing regions) (Coventry *et al.*, 2011).

The BPS001 project determined that further research was warranted to establish whether more nitrogen was required to offset denitrification losses, or less nitrogen was required due to reduced yield potential in defined waterlogged or low-lying areas of paddocks.

Answers to these questions are pivotal to the provision of robust VRA programs based on the yield potential of defined zones within paddocks. As an extension to the BPS001 project, the following areas of ongoing PA research have been prioritised by the current project:

- Establishing the yield potential of zones using the three key GIS layers from 20 selected study sites in the central region
- Defining the stability of yield patterns over time through the analysis of archived yield estimation data (10 years)
- Establishing experiments in various soil types to determine appropriate nitrogen rates for sugarcane growing under extended anaerobic conditions to determine the effectiveness of root systems compromised by waterlogged conditions to extract nutrients

The project will utilise the information generated through these research activities to develop VRA programs and upgrade the agronomic skill deemed necessary to progress PA in the sugar industry.

Soil mapping and elevation data

Soil mapping layers

Advancements in electromagnetic induction (EM) and electrical resistivity technologies (EC) are being utilised in a number of countries and are a relatively low-cost surrogate for rapid and accurate segregation of soils with contrasting soil properties (Coventry *et al.*, 2011; Bramley *et al.*, 2012). In addition, soil mapping patterns generated through Veris 3100 soil surveys are stable over time and at a scale appropriate for progressing PA programs (Coventry *et al.*, 2011). This project will map 30 000 ha of sugar cane land in the central region during the life of the project (July 2011 to June 2013). Soil survey datasets will be made available to growers and advisers.

Digital elevation layers

Access to elevation data at a scale suitable for PA has also been identified by the BPS001 project as another impediment to the progression of PA in the central region. Elevation data, commonly referred to as Digital Elevation Models (DEM), are captured during aerial surveys that are randomly carried out across the district. The level of accuracy of the DEM obtained from these surveys is variable but, typically, accuracies of 5 m in the vertical axis are quoted. Quite clearly, these data are unsuitable for use in PA where vertical accuracies of < 5 cm are required.

Advancements in GPS technologies through RTK GPS can deliver almost instantaneous point coordinates with centimetre-level accuracy. This project will use the capture of EC mapping data utilising RTK GPS to deliver elevation datasets with vertical accuracies of < 2 cm across the 30 000 ha of mapped sugarcane land.

Study site selection

Twenty study sites were selected representing the diversity of physical soil properties common to sugarcane production in the Central Region (Table 1). Site selection was limited to paddocks where the three key mapping layers were available, namely:

- Processed satellite yield estimation data over a number of crop cycles (2002 – 2010);
- Electrical conductivity (EC) soil mapping data accessed through soil survey operations using a Veris 3100 soil mapping unit;
- Elevation data captured during EC soil mapping surveys with RTK accuracy.

Table 1—Collaborative grower sites and soil descriptions.

Grower name	Location	Number of sites	Area (ha)	*Local mapping units	**Australian Soil Classification
Blackburn N	Eton	1 1 1	5.3 5.5 3.4	Victoria plains Marian Wollingford	Black earth Brown chromosol Grey sodosol
Blackburn P & D	Eton	1 2	4.1 9.3	Victoria plains Brightly	Black vertosol Brown vertosol
Bugeja J	Rosella	1 1	6.0 11.0	Marian Sandiford	Brown chromosol Yellow chromosol
Deguara J	Eton	1 1	21.7 18.3	Nabilla Jumper Victoria plains	Brown dermosol Grey subnatric sodosol Black vertosol
Fox J	Wagoora	1	22.2	Pindi	Grey subnatric sodosol
Pastega J	Eton	1 1	9.5 7.1	Brightly Victoria plains	Brown vertosol Black vertosol
Simpson J	Wagoora	1	8.5	Victoria plains	Brown vertosol
Young N	Walkerston	1	5.2	Marian Pioneer	Brown chromosol Brown chromosol
Young S	Sandy Ck Bakers Ck	2 1 2	11.8 5.3 16.5	Mirani Murray Sandiford	Grey chromosol Stratic rudosol Yellow chromosol
Total	6	20	170.6	10	8

* Holz and Shields, (1985) (1:100,000 soil survey)
** Hardy (2003)

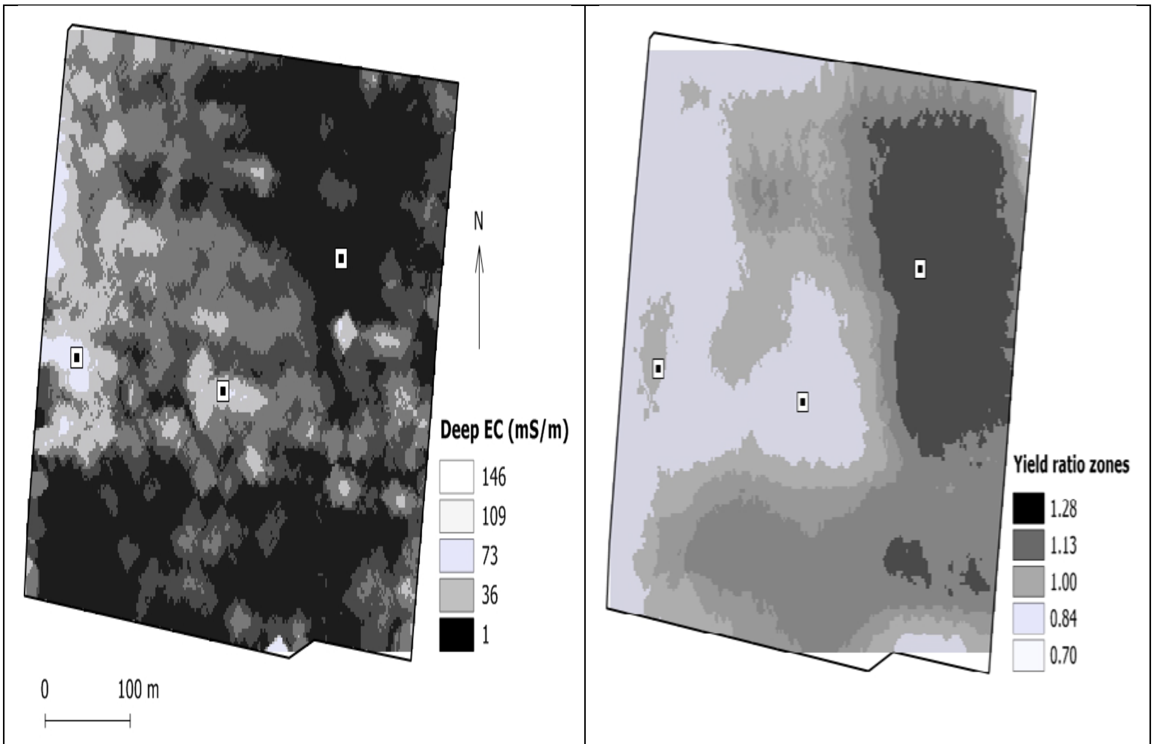
Study site selection was also influenced by the need to incorporate paddocks with a range of soil physical properties based on digitised soil survey data (Holz and Shield. 1985) and growth pattern variability based on analysis of archived satellite yield estimate patterns.

A five-zone thematic surface mapping layer was created for yield, EC and elevation datasets for all study sites using Manifold GIS software. Three geo-referenced borehole sites were selected for each of the study paddocks.

Borehole site locations were determined by overlaying deep EC and yield surface mapping layers in the GIS software package as detailed in Figure 1. In study sites where there was little variation in EC and yield values, the elevation layer was also utilised for the selection of borehole sites.

Samples for full-range chemical and particle size analyses were extracted from the topsoil zones (0–25 cm) for each borehole site and samples for limited-range chemical and particle size analysis were taken from the lower sub surface zone (50–75 cm).

Soil cores were extracted from each referenced borehole site to a depth of 1 m. Soil horizons were colour-coded using Munsell Soil Color Charts. Soil core tubes were photographed and stored for future soil referencing purposes.



(a) Referenced borehole site locations displayed over deep EC mapping patterns.	(b) Borehole locations over a mosaic of yield ratio mapping patterns.

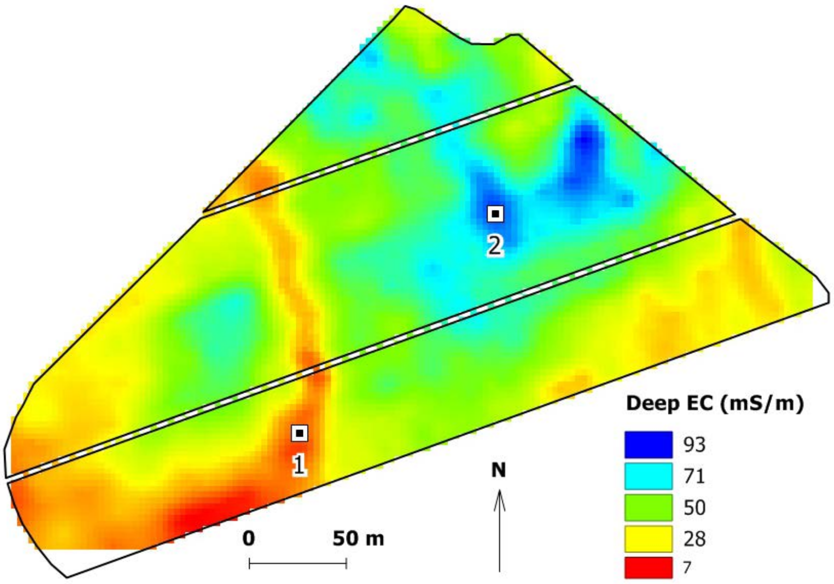
Fig. 1—Deguara study site Farm 3082A Block 13-1: Borehole site location determined by mapping patterns in key soil (a) and yield mapping (b) layers

Ground-truthing of EC mapping patterns across the 20 sites validated the capacity of EC mapping surveys to spatially differentiate areas of contrasting soil properties (Figure 2).

Processing of archived satellite yield estimation data and preliminary analysis

From a PA and VRA perspective access to accurate yield data is fundamental to the progression of an integrated PA farming system. Developing strategies for accommodating practical within-paddock VRA programs is contingent on a number of critical factors:

- Determination of management zones based on processed satellite yield data
- Validation of the stability of yield mapping patterns over a number crop cycles
- Validation and determination the yield potential of management zones defined by yield mapping patterns.



Borehole	Deep EC value (10m grid)	Sample depth (cm)	OC %	CEC	Clay %	CSIRO Texture class	Sample Depth (cm)	CEC	Clay %	CSIRO Texture class
1	14	0–25	0.2	3	14	Sandy loams	50–75	4	9	Sands
2	76		1.0	9	24	Loams		24	49	Clay Loams

Fig. 2—Farm 4074B Block 15-1: The six hectare paddock was mapped as a single unit in a 1:100,000 soil survey; large variability in soil physical properties is evident following borehole validation of EC mapping patterns.

Archived yield estimation data relating to the selected study sites was sourced from Spot IV and Landsat 7 processed satellite imagery. Yield estimation data are based on normalised difference vegetation index (NDVI) adjusted to compensate for the different reflection properties of the various sugarcane varieties.

The digital yield data are projected at either 20 metre or 30 metre pixel resolution depending on the archived imagery. For all the study sites yield estimation data were only sourced for plant cane and 1st and 2nd ratoon crops for the years where satellite yield data were available from 2002 to 2010. The integrity of yield data from older ratoons can be compromised by a number of variables including disease incursions, weed pressure, crop damage from harvesters and soil compaction to name a few. Yield estimation point data for all sites were converted into a yield estimate ratio by dividing the actual value for each point by the site average of yield data for those years where the cane class matched plant, 1st or 2nd ratoons.

The created yield ratio data sets along with EC and RTK elevation digital data for each study site were transformed onto a common 10 m grid enabling accurate analysis across the three key GIS layers.

This was achieved by converting all study site GIS data sets into a common projection, MGA 94 Zone 55 using Manifold® software prior to transforming the data sets onto a 10 m grid through a kriging process in Vesper® software. Further processing enabled the creation of yield zones with defined yield potentials by the grouping and allocation of calculated yield ratio data into defined yield ratio parameters using Mapinfo® software (Table 2).

Yield zone mapping patterns were created for each of the study sites for the years where satellite yield estimation data were available. A stand-alone yield potential mapping layer mosaic was created by incorporating the yield ratio data from all the years into a single spatial data set. Processed yield ratio data were transformed into a three zone yield potential contoured mapping layers for each of the years.

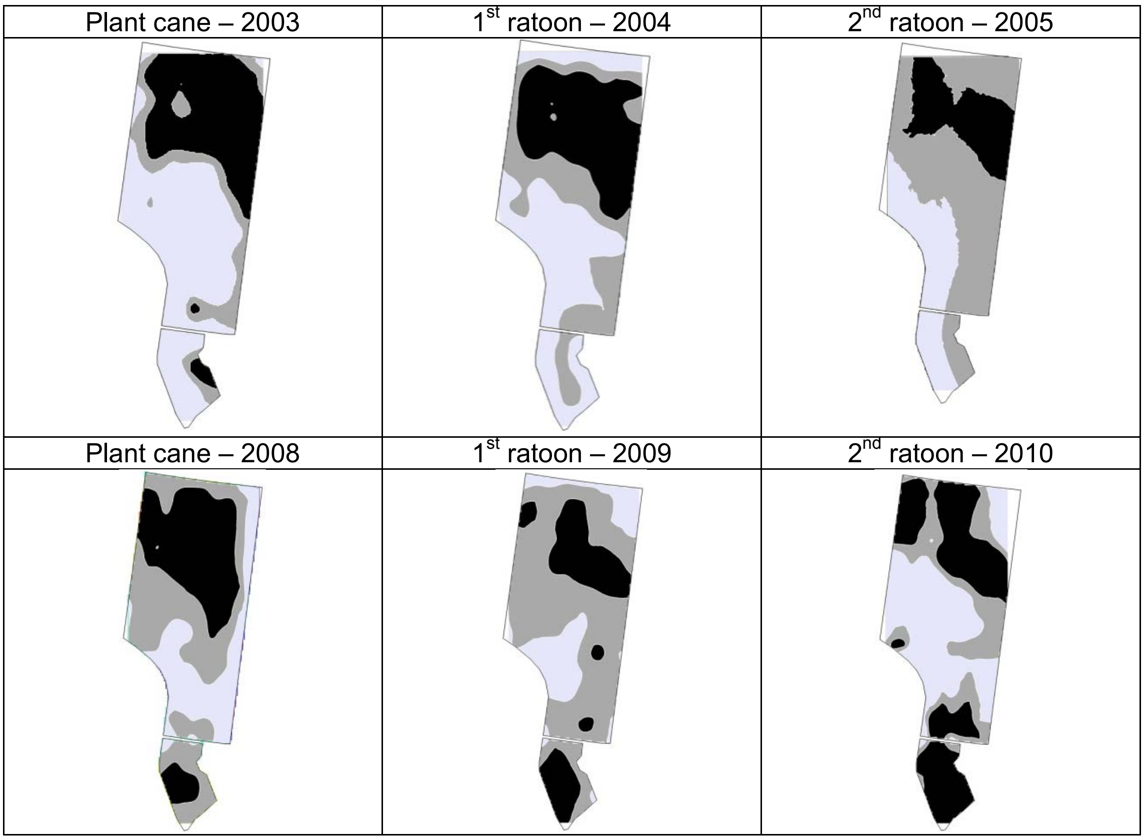
Table 2—Allocation of yield categories through grouping of yield ratio values within specific parameters.

Yield zone	Yield category	Yield ratio parameters
1	Low	< 0.92
2	Medium	0.92–1.08
3	High	>1.08

Determination of spatial yield stability is possible by comparing the three zone yield layers for each of the years by study site. This underpins the integrity of the yield potential mapping layer mosaic as a potential base layer for progressing VRA in the future (Figure 3).

To investigate the stability of the low, medium and high yield zones within the project study sites, yield ratio data were averaged for each yield zone by year and the averages compared to the parameters established for that zone (Table 3). The result for Farm 4202A Block 11-1 indicates that there would be a predicted 34% yield difference between the high yield zone and the low yield zone.

Yield validation of satellite yield mapping patterns conducted during the 2012 season have confirmed these predictions and will be detailed in future publications.



Mosaic of all years

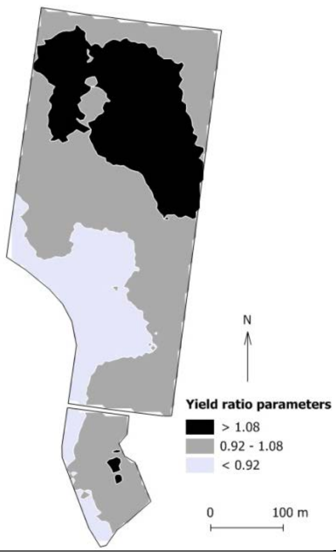


Fig. 3—Young study site Farm 4202A Block 11-1: Relative stability of defined within-paddock yield zones over six years and two crop cycles and a mosaiced yield map incorporating data from all years where data were available.

Table 3—Farm 4202A Block 11-1: Averaged yield ratio by yield zone by year.

Yield zone category	Zone yield ratio parameters	Ave ratio Yr 1	Ave ratio Yr 2	Ave ratio Yr 3	Ave ratio Yr 4	Ave ratio Yr 5	Ave ratio Yr 6	Av ratio all years	Stability by year
Low	<0.92	0.73	0.81	0.84	0.89	0.89	0.78	0.82	6 from 6
Medium	0.92–1.08	0.95	0.96	0.99	1.01	1.01	1.01	0.99	6 from 6
High	>1.08	1.23	1.15	1.13	1.14	1.10	1.22	1.16	6 from 6

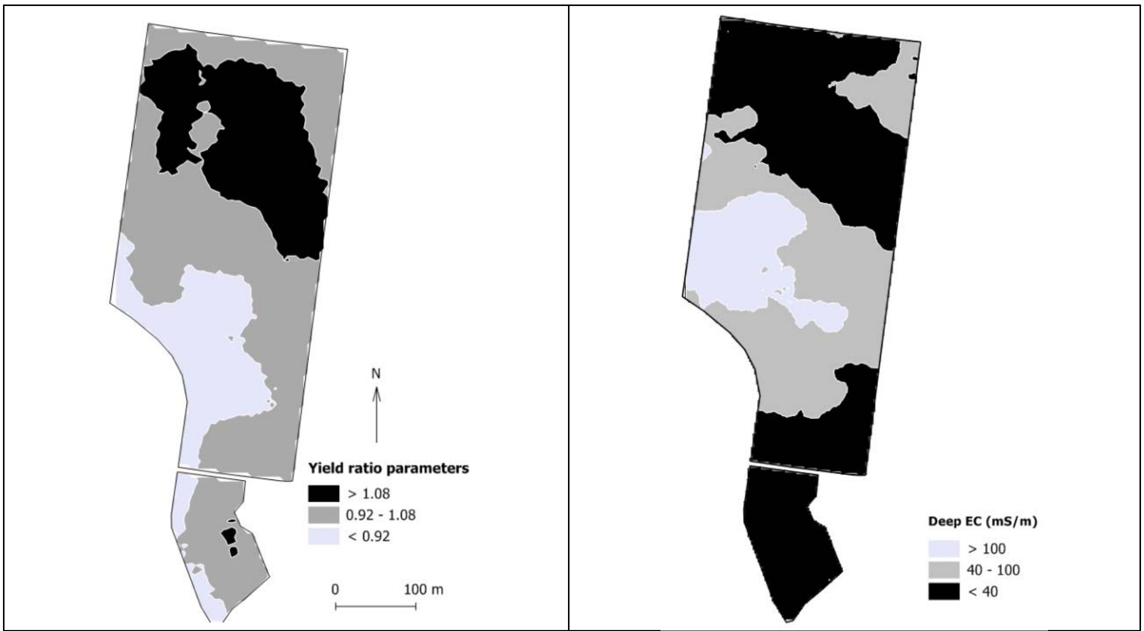
Preliminary results indicate that approximately 30 to 40 % of study site paddocks have yield variability of greater than 15% either side of the average and these paddocks also display significant variability in deep EC values.

Preliminary analysis of the gridded spatial data also indicates that there is a reasonable relationship between yield ratio and EC and mapping patterns where both matched data sets display significant variability and high yielding zones are generally located in areas displaying low deep EC values (Figure 4).

Low EC zones are generally lighter textured soils with good subsurface drainage characteristics, which is a major driver of yield in high rainfall sugarcane production areas. It is proposed that paddocks falling into this category are potential candidates for three zone VRA programs with the base yield layer mosaic providing distinct spatial boundaries for manipulating nutrient input rates. The option exists to increase the number of within-paddock management zones based on increasing levels of agronomic expertise in PA systems over time.

Approximately 30% of the study sites had relatively homogeneous soils with little variability in deep EC and yield ratio values (Figure 5).

It is suggested that paddocks falling into this category do not warrant any VRA in relation to nutrient input and nutrient management would be on a whole-block basis. Preliminary analysis of study site spatial data indicates that where yield variability occurs on blocks with homogeneous soil properties with only marginal variations in EC values, it is likely that surface drainage or other issues are responsible for crop growth variability. This highlights the importance of having access to digital elevation mapping layers.

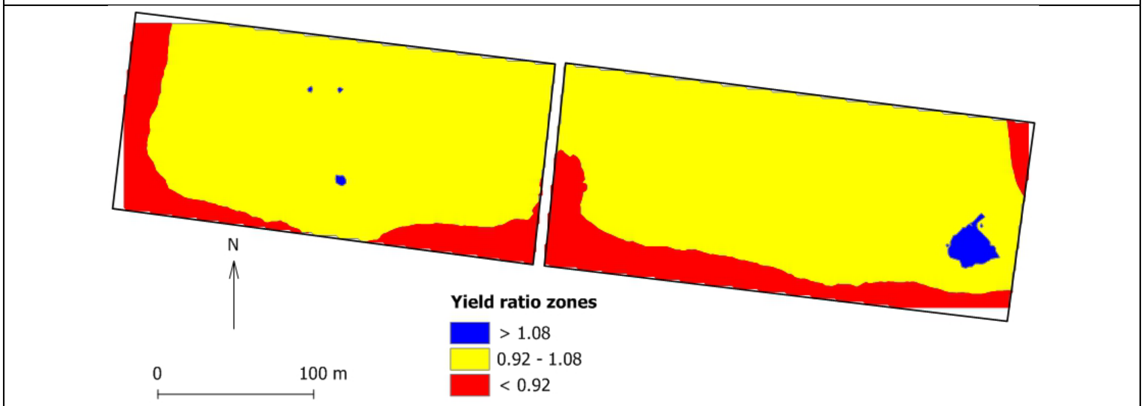


(a) Yield map mosaic incorporating six years of yield estimation data

(b) Deep EC mapping patterns

Fig. 4—Farm 4202A Block 11-1: A strong relationship between the yield mosaic patterns (a) and deep EC mapping patterns (b). The relative poor growth in the potentially high yielding area located at the southern end of the block is attributed to poor coverage of the pivot irrigator.

(a) Yield ratio mosaic mapping layer showing little variability in crop growth



(b) Deep EC mapping layer indicating a homogeneous soil with little variability in deep EC values

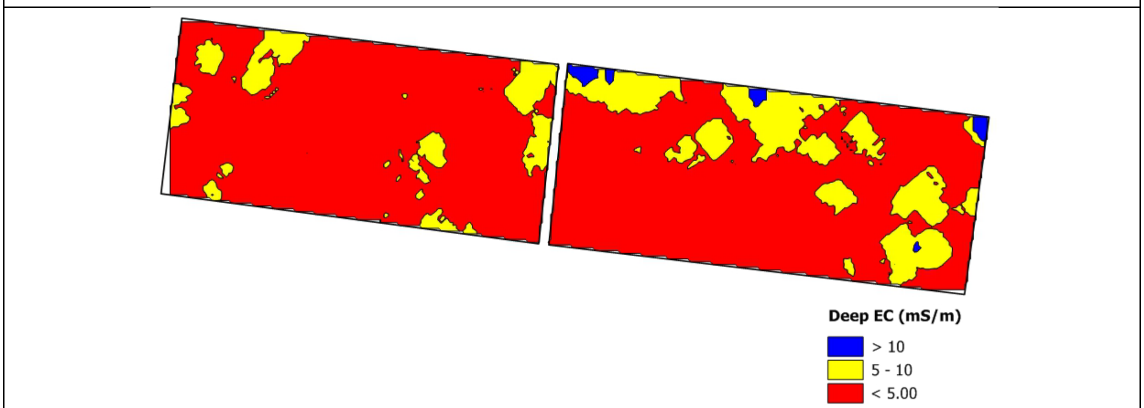


Fig. 5—Farm 3120B Block 14-3: Example of paddocks showing little variability in deep EC (b) and yield value (a) and able to managed on a whole-block basis from a nutrient input perspective.

Experiments to determine nitrogen requirements of sugarcane growing in areas subjected to extended anaerobic conditions

Extensive ground-truthing of EC and satellite mapping patterns during the BPS001 project indicated that poor yielding areas within paddocks were largely driven by poor sub-surface drainage characteristics, which are exacerbated by low-lying areas within paddocks. Variable-rate technology is well advanced; however, lack of agronomic expertise within PA systems is a serious impediment to progressing VRA of nutrients. Some of these critical agronomic knowledge gaps within a PA system include:

- Managing within-paddock variability in crop growth through manipulation of nutrient rates is problematic where the yield potential of defined zones is not known;
- Under wet tropical conditions, there is little information on the ability of sugarcane roots compromised by extended waterlogged conditions to extract nutrients;
- Does an increase in nitrogen rates offset nitrogen loss through denitrification and help maintain yield or can nitrogen rates be reduced without compromising yields in extended waterlogged conditions?

To better understand these factors curtailing the adoption of variable rate application of nutrients, two trial sites were carefully selected from the 20 study sites. A site was selected at Walkerston with light-textured, free-draining soils. A second site was selected at Eton with poorly drained black vertosol soils to contrast the well-drained soils at Walkerston.

The trial design for both sites incorporated the application of three rates of nitrogen, 90 kg/ha, 160 kg/ha and 230 kg/ha. At each trial site, the nitrogen treatments were applied to two designated anaerobic zones and two conventional supplementary irrigated zones (Figure 6). Anaerobic conditions were maintained in designated zones through flood irrigation regimes for the traditional wet season period– January to March 2012.

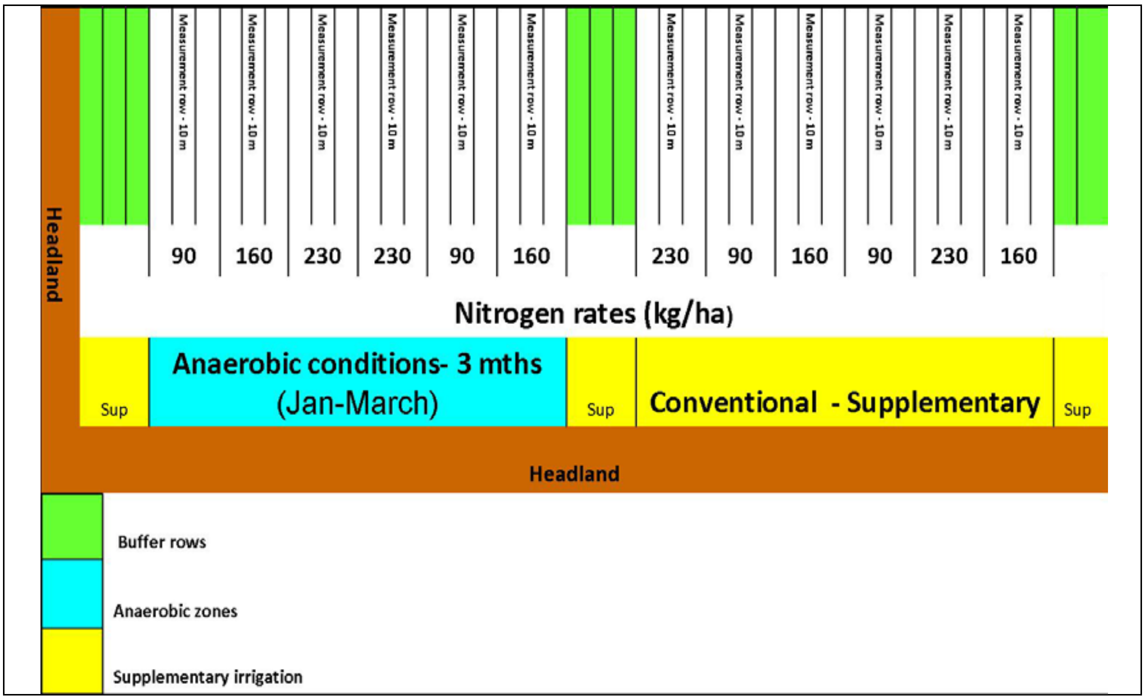


Fig. 6—Experimental design to determine appropriate nitrogen rates for yield zones with low yield potential due to extended waterlogged conditions across various soil types.

The design featured in Figure 6 is duplicated to achieve four replications of nitrogen treatments for each watering regime.

Strategic leaf sampling and yield data from the anaerobic and rain-fed zones at both sites will assist in determining whether more or less nitrogen should be applied to poorly drained low-lying areas with inherent low yield potentials. This information will significantly contribute to the delivery of VRA programs where nitrogen inputs are based on stable yield zones and supported by enhanced agronomic expertise. The results of these experiments will be detailed in future publications

Discussion

VRA of nutrients is an important component of a PA approach to achieve a sustainable sugarcane production system. Advancement in VRA technology has generally not been supported with the agronomic expertise required to progress this technology within a PA framework.

Poor subsurface drainage and low-lying areas within paddocks were identified as major drivers of poor growth zones in the central region. Experiments have been established to determine appropriate nitrogen rates for sugarcane subjected to extended anaerobic conditions. Results from these experiments will underpin the integrity of VRA nitrogen rates in the future.

This project is on track to deliver key EC soil and digital elevation data for 30 000 ha which will contribute to the progression of PA in the central region. A critical impediment to progressing VRA of nutrients is determining the stability of defined yield zones over time.

Preliminary analysis of ten years of archived satellite yield estimation data has confirmed that yield zones are relatively stable over time and varying seasonal conditions within the project's twenty study sites. The conversion of yield estimation point data into a relatively stable mosaic of yield potential in a mapping layer is an important step in the delivery of robust VRA programs.

Ground validation of EC mapping patterns and yield ratio maps indicate that approximately 30% of paddocks have significant variability in soil properties and yield and may warrant the introduction of a three-zone VRA nutrient program with nitrogen rates being determined by zonal yield potential. In contrast, 30% of paddocks display little variability in EC values or crop growth, and nutrients can be managed on a whole of block basis.

The range of interactive activities and experiments being conducted in this project will address a number of the impediments to PA in the central region. Preliminary analysis will be further defined during the course of the project

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