DEFINING APPROPRIATE NITROGEN RATES IN LOW YIELDING LOCATIONS WITH INHERENT WATERLOGGING ISSUES IN THE CENTRAL CANE GROWING 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. Precision agriculture (PA) provides a pathway and a framework for enhanced economic and environmental sustainability in the sugar growing sector with variable rate application (VRA) of nutrients regarded as an integral component of PA. Trials have been conducted in the Mackay region to determine the potential to reduce nitrogen (N) rates in defined zones with low yield potentials due to poor sub-surface drainage characteristics with inherent waterlogging issues. Results from these trials will assist in developing intra-paddock variable rate nitrogen guidelines for defined low yielding waterlogged areas. The two-year trial was established on a Victoria Plains series soil (black clay) with nitrogen application rates of 90, 160 and 230 kg N/ha respectively. The trial incorporated two water regimes, namely: a predominantly rain-fed system; and a waterlogged system maintained in an anaerobic condition through flood irrigation for the traditional three month wet season (January to March) Rainfall events over the traditional 'wet season' period resulted in both anaerobic and rain-fed zones being maintained in a relatively waterlogged state in consecutive trial years. Results from the February 2012 leaf analysis program showed increased leaf N concentrations with increasing N rates in the anaerobic zones. However, leaf N concentrations were below critical levels across N treatments and water regimes. In contrast, there was no statistical difference in leaf N concentrations in the rain-fed plots. In the 2012 and 2013 trial periods, results from April leaf analysis programs showed leaf N concentrations were well below critical levels across treatments and water regimes. In the 2012 trial period where sub-optimal moisture conditions post application of nitrogen treatments impeded the uptake of applied nitrogen, the 160 N treatment had a 27% higher yield than the 90 N treatment in the anaerobic zones. However, in the 2013 trial, two irrigations post application of N and prior to imposed waterlogged conditions resulted in no significant yield differences across N treatments in the anaerobic zones. The dry season irrigations in the imposed waterlogged plots resulted in a yield increases of 69% in the 90 N treatments, 34% in the 160 N and 23% in the 230 N treatments compared to the previous year's yield data. In the rain-fed zones there were no statistical differences in yield between N treatments in consecutive trial years although rainfall over the traditional 'wet season' period had maintained the rain fed plots in a virtual anaerobic state for the three-month 'wet season' period (January to March). These results indicate that there is the potential to reduce N inputs in an intra- paddock VRA program in

defined zones with low yield potential caused by inherent waterlogging issues. It is recognised that under extreme and sustained anaerobic conditions yield penalties may occur with reduction in N rates at or below 90 kg N/ha. However the 2013 trial results showed that yield can be maintained with low N inputs when strategic irrigations are implemented prior to the onset of waterlogged conditions.

Introduction

Nitrogen (N) constitutes a significant input cost in sugarcane production and has been identified as a major pollutant contributing to the quality of water entering the Great Barrier Reef lagoon (Thorburn *et al.,* 2013). Variable rate programs in a PA system offers the potential to refine N rates based on variations in yield zones within paddocks (Bramley, 2009).

Yield validation of satellite imagery in conjunction with borehole data based on electrical conductivity (EC) mapping patterns verified that poor yielding zones within paddocks were often due to poor subsurface drainage characteristics and exacerbated by low lying areas within the paddock (particularly in the wetter sugarcane growing regions) (Coventry *et al*, 2011). In addition, analysis of archived satellite yield data verified that within-paddock yield patterns were relatively stable over a number of crop cycles (Markley and Hughes, 2013).

It is apparent that agronomic expertise within precision agriculture (PA) systems has fallen well behind the significant technological advances made in variable rate application (VRA) of nutrients. From a nitrogen input perspective, progress in VRA in the sugar industry has not been prominent due to knowledge gaps in key agronomic areas, namely:

- Manipulation of N rates is difficult where the yield potential of defined zones is not known;
- There is little information available on the functionality of root systems compromised by extended waterlogged conditions to extract nutrients;
- It is not known if an increase in nitrogen rates can offset nitrogen losses through denitrification and help maintain yield or whether a reduction in nitrogen rates would further compromise yields in areas subjected to extended waterlogged conditions.

Weather patterns in the Central cane growing region are defined by a dry spring period which coincides with the harvesting and fertilising of the crop followed by a three to four month ‘wet season’ where heavy rainfall events can cause significant waterlogging issues and poor crop growth, particularly within specific soil types.

The refinement of N rates linked to the yield potential of soil groups with known characteristics provides an opportunity to:

- Manipulate N inputs without compromising yield;
- Optimise a growers return on investment in nitrogen inputs;
- Improve the quality of water leaving farms by not exceeding a crop’s capacity to utilise N inputs in defined zones.

Methodology

The two-year trial was conducted in a commercial 7.4 ha block in the Eton irrigation area of Mackay. The 2nd ratoon block selected for the trial was planted to cane variety KQ228 in September 2009. The trial design established allowed for split block design with two water regimes (waterlogged for an approximate three month period and a rain-fed system) as the main plots and N rates as the sub-plots. Three nitrogen treatments were incorporated in the trial design (90, 160 and 230 kg N/ha) with four replications for each treatment. Each treatment replicate consisted of three × 1.8 m rows by a 15 m row length which incorporated a 5 m buffer on the headland end of the replicates. A 10 m length of the centre row was pegged as a measurement row for each treatment replicate across the water regime beds (Figure 1).

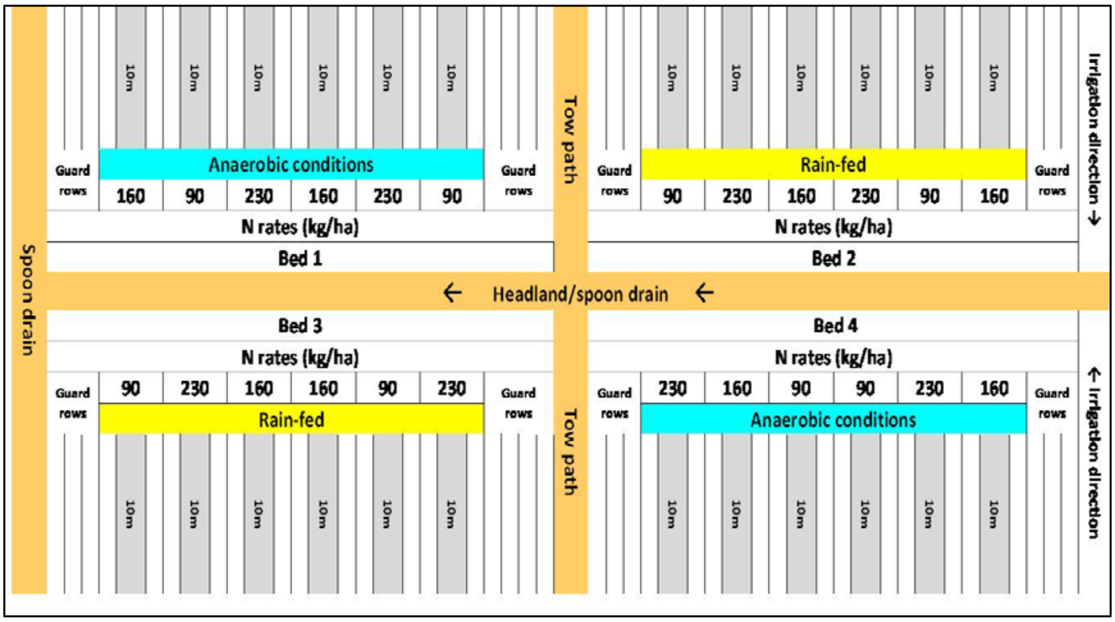

Fig. 1—Split block trial design showing locations of anaerobic and rain-fed plots with associated nitrogen treatments.

The waterlogged plots (Beds 1 and 4) were maintained in a sustained waterlogged state for the duration of the traditional ‘wet season’ period (January to end of March) using background rainfall events supplemented by flood irrigation (Allen *et al.*, 2010). Inter-row levy banks were constructed 25 m down-slope of the irrigation fluming in the designated anaerobic beds to contain water from irrigation and rainfall events over the three month wet season period (Figure 2).

Fig. 2—Constructed inter-row levy banks to impede the surface drainage of water and maintain the anaerobic plots at field capacity over the wet season period.

The trial block was mapped using a Veris 3100 soil electrical conductivity (EC) mapping unit post-harvest of the 1st ratoon crop in 2011. An interpolated surface map using EC deep values validated the overall homogeneity of the block (Figure 3).

The deep EC surface mapping layer was used to direct the selection of a borehole site for the characterisation of the trial site. The trial site was determined to be on a black clay soil of the Victoria Plains series (Holtz and Shields, 1985).

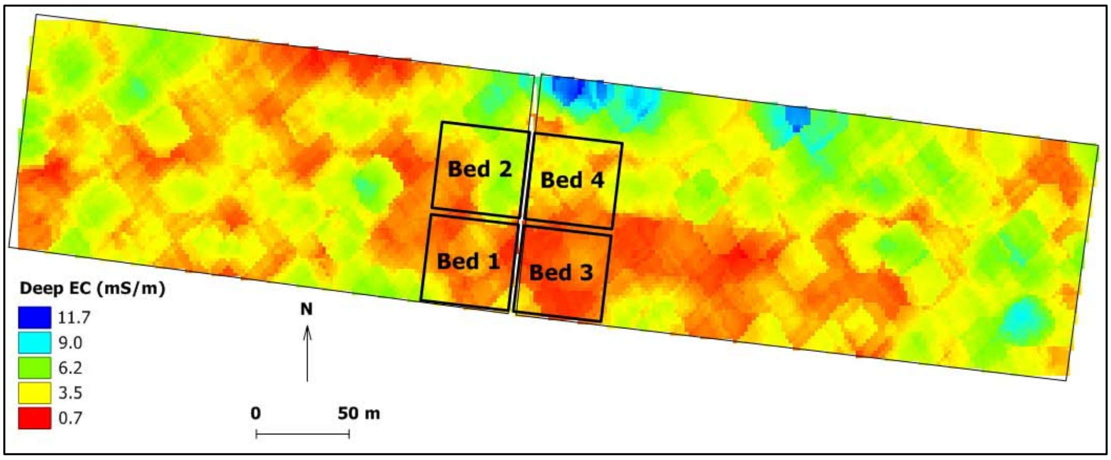

Fig. 3—Distribution of EC mapping values on the trial plots and (b) EC mapping patterns showing relatively homogeneous soil across the trial plots.

Samples for chemical soil tests and particle size analysis were extracted from the topsoil zone (0–25 cm) and from the 50–75 cm zone of the profile to determine the physical and chemical attributes of the trial area (Table 1). Soil texture data confirmed the relatively high clay content in the 0–25 cm zone (41%) increasing to 49% in the 50–75 cm zone of the profile.

Table 1—Chemical and physical site characterisation data.

Attribute	0–25 cm	50–75 cm
Clay %	41	49
pH (1:5 water)	6.6	6.0
Organic carbon (%)	1.3	Not tested
Phosphorus (BSES) mg/kg	15	Not tested
Potassium (amm-acet) (meq/100 g)	0.2	0.18
Potassium (nitric K) (meq/100 g	0.93	Not tested
Sulphate sulphur (MCP) (mg/kg)	12	Not tested
CEC (meq/100 g)	18	20.9
Calcium (amm-acet) (meq/100 g)	11	12
Exchangeable sodium percent (%)	2	4.4

In both trial years, chemical analyses were taken prior to the harvest of the crop to determine macro-nutrient requirements for the basal applications of phosphorus, potassium and sulphur using the Six Easy Steps (6ES) nutrient guidelines. The balance of the nitrogen for the three treatments (90, 160 and 230 kg N/ha) was applied as urea using a three-row stool splitter and applied in mid-October for both years.

In the 2011/2012 trial period, no irrigation was applied prior to the onset of the wet season. Three irrigations averaging 43 mm were applied to the anaerobic zones to supplement the rainfall (1 970 mm) and maintain the water-logged beds at field capacity for the duration of the wet season period. Irrigation management was modified in the second trial year (2012/2013) to improve the uptake of applied N prior to the onset of the wet season:

- The trial block was irrigated 24 days following the harvesting of the first year trial with an application of 45 mm of water;

- A second flood irrigation of 70 mm was applied 50 days post harvest but restricted to the anaerobic beds of the trial;
- Six additional irrigations totalling 280 mm were applied to the anaerobic plots to supplement the 1 580 mm of rain over the three month wet season period.

In both trial years there was sufficient rainfall in the wet season period to maintain the rain-fed beds of the trial in a relatively waterlogged state. However, in the rain-fed beds, surface water was able to drain from the inter-row area in contrast to the anaerobic plots which had constructed inter-row levy banks to impede the drainage of surface water

Shoot counts from the 10 m measurement rows were recorded at regular intervals over the two year trial period. Leaf tissue sampling was conducted in early February and repeated in early April for both trial years. Sampling regimes were conducted according to BSES sampling protocols with 30 leaves extracted from each 10 m measurement row. Leaf samples were oven dried at 60 °C and forwarded to BSES laboratories for analysis of total nitrogen and phosphorus concentrations.

Yield was determined by hand harvesting and recording the total biomass weight from the 18 m² measurements rows. CCS was determined from the juice extracted from six randomly selected stalks in the measurement rows. The 2nd ratoon trial was harvested mid-September 2012 and the 3rd ratoon trial on the 13th August 2013.

To determine root functionality, root systems were excavated from the 5 m buffer zone of a 160 kg N/ ha measurement row in the anaerobic zone (Bed 1) in mid-February 2013. A comparative root system was extracted from the same row outside of the trial site anaerobic zone but located approximately 400 mm higher in the landscape and subjected to intermittent anaerobic conditions.

Stalk counts, leaf analysis, yield (tc/ha) and tons of sugar/ha (ts/ha) data from the two trial years were statistically analysed using analysis of variance techniques in statistical software.

Results

Rainfall

Rainfall patterns over the two year trial period were fairly uniform although rainfall was slightly below average in the period from July to the start of the wet season in December/January. In contrast, the wet season periods late December to end of March were slightly above average (Figure 4).

Stalk counts

There was no significant difference in stalk counts across N treatments and water regimes at the last count prior to the harvesting of the first year trial in mid September 2012. Similarly, there was no statistical difference in stalk numbers between N treatments and water regimes prior to harvest in the second year of the trial.

Leaf analysis

Leaf N concentrations in the 230 kg N/ha treatments were significantly higher than the 90 kg N/ha in both the anaerobic and rain-fed zones for the early February 2012 leaf analysis program. However, leaf N concentrations were below critical levels (1.9%) for all treatments and across water regimes. In contrast, there was no significant difference in leaf phosphorous (P) concentrations in N treatments or water regimes and P levels were all well above the critical value of 0.19% (Table 2). The below critical N level results are attributed to denitrification losses and potentially the inability of root systems compromised by waterlogged conditions to extract nitrogen.

The satisfactory uptake of P in the trial indicates that the root system was effectively able to utilise applied P despite the extended waterlogged conditions that existed in both the anaerobic and rain-fed zones. Subsequent root system extractions from the anaerobic plots showed that the sugarcane root system had adapted to the extended waterlogged environment by prolific production of superficial roots (Figure 5).

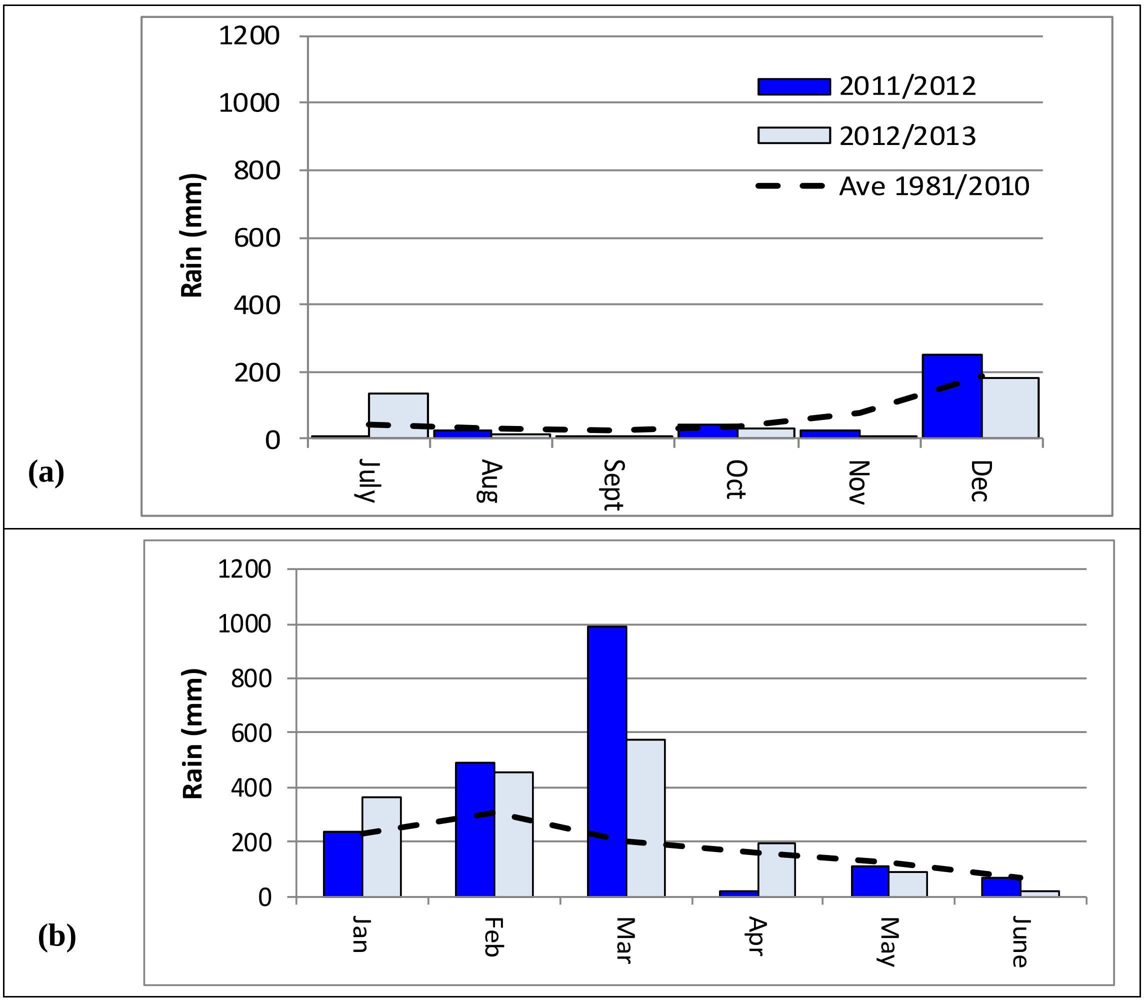

Fig. 4—(a) Rainfall patterns for period July to December for the trial years 2012 and 2013 against average rainfall data for the years 1981 to 2010 and (b) Rainfall patterns for period January to June for the trial years 2012 and 2013.

Table 1—Leaf nitrogen and phosphorus concentrations across N treatments and water regimes from the mid February 2012 sampling period (values with the same letters are not significantly different p = 0.05).

N treatment (kg/ha)	Leaf N % *Critical value 1.9%*		Leaf P% *Critical value 0.19%*	
	Anaerobic	Rain-fed	Anaerobic	Rain-fed
90	1.52 (c)	1.60 (bc)	0.26 (a)	0.28 (a)
160	1.60 (bc)	1.61 (b)	0.27 (a)	0.27 (a)
230	1.67 (ab)	1.76 (a)	0.30 (a)	0.29 (a)

The satisfactory uptake of P is most likely as a consequence of this root adaptation. The P was surface, band applied in the dunder basal application. The relatively immobile P (in comparison to N) was able to be utilised in contrast to the N which may have moved below the compromised root system, denitrified due to the extended anaerobic conditions or lost from the site in water run-off.

In the February 2013 leaf analysis there was no significant difference in leaf N concentrations across N treatments and water regimes and levels were only marginally below the critical values. The general improvement in leaf N concentrations over the previous year's results for the same analysis period is attributed, in part, to the additional irrigation applied prior to the onset of waterlogged conditions. Similar to 2012 results, there was no significant difference in P levels across N treatments and water regimes (Table 3).

The early April leaf analysis programs in both trial years showed no statistical differences in N leaf concentrations and levels had fallen well below critical values (average of 1.2 % in 2012 and 1.4% in 2013).

Table 3—Leaf N and P concentrations for the February 2013 analysis period (values with the same letters are not significantly different p = 0.05).

N treatment (kg/ha)	Leaf N %		Leaf P%	
	Critical value 1.9%		Critical value 0.19%	
	Anaerobic	Rain-fed	Anaerobic	Rain-fed
90	1.74 (a)	1.77 (a)	0.36 (a)	0.35 (a)
160	1.70 (a)	1.67 (a)	0.35 (a)	0.33 (a)
230	1.67 (a)	1.80 (a)	0.34 (a)	0.35 (a)

(a) **(b)**

Fig. 5—(a) Superficial root development adaptation with a compromised buttress root system in the sustained anaerobic zone and (b) Root system in the same row subjected to intermittent waterlogging (0.4 m higher in the landscape).

Yield data

Seasonal conditions over the two year trial period were fairly similar and defined by the traditional dry spring period followed by heavy rainfall inundation in the wet season period (late December to the March). The management of irrigation was modified in the second trial year in order to enhance the uptake of N prior to initiating the imposed waterlogging of the anaerobic beds and a 'one off' irrigation of the entire trial block which also facilitated the improved uptake of applied N in the rain-fed beds.

This slight modification in the irrigation practice was reflected in improved leaf N concentrations and yield (tc/ha) results in the anaerobic component of the second year trial despite the sustained and uninterrupted anaerobic status over the three month wet season period. Yield improvements in the second trial year for the anaerobic plots were in the order of 69% for the 90 kg N treatment, 34% for the 160 kg N and 23% for the 230 kg N/ha treatments (there was no statistical difference across N treatments in the anaerobic zones in the second year trial). This is in contrast to the first trial year where the yield of 160 N treatments was significantly higher than the 90 N treatments (28%) in the anaerobic zones although there was no statistical difference between the 90 N and 230 N treatments. The improved uptake of N attributed to the dry season irrigations in the anaerobic beds was also reflected in improved in the yield of tons of sugar/ha (ts/ha) in the three N treatments (Table 4).

Table 4—Two year's yield data for three nitrogen treatments for the anaerobic component of the trial (values with the same letters are not significantly different p = 0.05)

N treat (kg/ha)	Anaerobic 2012			
	Yield (tc/ha)		Yield (ts/ha)	
90	40.2 (c)		7.16 (b)	
160	51.4 (ab)		8.59 (b)	
230	49.4 (bc)		8.66 (b)	
	Anaerobic 2013			
	Yield (tc/ha)	Difference from 2012 (%)	Yield (ts/ha)	Difference from 2012 (%)
90	67.9 (a)	+69	12.35 (a)	+72
160	68.8 (a)	+34	12.53 (a)	+46
230	61.0 (a)	+23	11.05 (ab)	+28

There was no significant difference in yield across N treatments in the rain-fed component of the trial for both trial years despite these zones being maintained in a relatively waterlogged state due to high rainfall inundation over the wet season period in both years (Table 5).

The tc/ha and ts/ha achieved in the rain-fed plots were similar between trial years although there was significantly higher ts/ha in the 230 kg N/ha treatment in the 2012 trial period (this is attributed to an abnormally high CCS result (19%) from one of the treatment replicates).

Table 5—Two year yield data for three nitrogen treatments for the rain-fed component of the trial (values with the same letters are not significantly different p = 0.05).

N treat (kg/ha)	Rain-fed 2012	
	Yield (tc/ha)	Yield (ts/ha)
90	50.5 (ab)	8.8 (b)
160	52.2 (ab)	9.0 (b)
230	59.3 (a)	*11.0 (a)
	Rain-fed 2013	
90	44.3 (b)	8.1 (bc)
160	50.5 (ab)	9.3 (abc)
230	43.8 (b)	7.7 (c)

* The significantly high value is attributed to an abnormally high CCS result from one replicate of 230 kg N/ha.

Discussion

The results from this trial validate the existence of zones of low yield potential and the potential role of intra-paddock VRA programs to apply cost effective N rates without impacting on productivity. The highest mean yield achieved across N treatments and water regimes over the two year trial period was only 69 tc/ha.

The low yields across N treatments and water regimes achieved in the two consecutive trial years is indicative of the low yield potential of the trial area which is defined by soils with poor subsurface drainage characteristics and low lying location in the landscape. The trial results indicate the limited capacity of the crop to access N under extended waterlogged conditions. This may be attributed to a number of factors including N loss through denitrification and poor root functionality due to extended anaerobic conditions. The trial results indicate that the yield potential of poorly drained soils with inherent waterlogging issues in the Central region is influenced by the soil moisture status post-application of N and prior to the onset of anaerobic conditions over the traditional wet season period.

The trial results show that there is an opportunity to reduce N rates within a VRA program on low yield potential, seasonally anaerobic zones within paddocks. This is underpinned by the trial results which showed no significant difference in yield across N treatments in the rain-fed zones which remained in a waterlogged state from rainfall over the wet season period for consecutive trial years. At N rates equal to or less than 90 kg/ha there is the potential for a reduction in yield under extreme and sustained waterlogged conditions following a relatively dry spring period. However, this can be managed with strategic irrigations post application of N and prior to the onset of the wet season period.

It is suggested that the 1.4 kg N/ton of cane multiplier incorporated in the 6ES nutrient program may be a mechanism for allocating base N rates for low yield potential anaerobic zones within a VRA program. Further manipulation of base N rates using the 6ES mineralisation index may not be warranted for these defined anaerobic zones. A base yield platform of 75 tc/ha for low yield potential zones provides a minimum start N rate of 105 to 110 kg N/ha.

Within the current project, variable rate trials on sodic soils using the same N treatments as reported in this paper showed no yield response to the higher N rates (data not published). There may the potential to use the same 1.4 multiplier to allocate appropriate VRA nitrogen rates for sodic soils with reduced yield potentials. Within the project, significant advances have been made to progress variable rate programs in the Central region and include:

- Validation of the stability of intra-paddock management zones over number of crop cycles;
- Utilising satellite yield maps, digital elevation data and EC soil mapping patterns to understand and ground-truth the casual effects of yield variability;
- Development of a yield ratio mapping layer incorporating management zone polygons for VRA fertiliser applicators;
- Trials to define appropriate N rates for low yielding sodic and waterlogged zones within paddocks;
- Trials to define appropriate N rates for well drained soils with high yield potentials.

Additional trials are required to validate N rates for specific soil properties and management practices.

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