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Nitrogen availability from legume and past fertiliser history

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Abstract It is likely that land-based activities within the Australian sugar industry have a negative effect on the quality of water in the Great Barrier Reef lagoon. Improvements to nitrogen use-efficiency (NUE) are likely to require a greater understanding of processes affecting N availability, crop-N demand and uptake in sugarcane farming systems. Two issues associated with improving N management were investigated. Firstly, should fertiliser-N recommendations for ratoon crops be altered following a good legume fallow? Secondly, what contribution do past fertiliser-N management practices have on N uptake? Field experiments were established at Mackay. The first- and second-ratoon crops were fertilised at either 0 or 150 kg N/ha (0N; 150N). This followed a fallow period where a bare or soybean fallow were established and a plant crop that received 138 kg N/ha (bare fallow) or 18 kg N/ha (legume fallow). In the third- and fourth-ratoon crops, due to a lack of any significant response to fallow management, the trial was altered to investigate the influence of previous N management on crop-N response. Plots either received 0N or 150N following a history of 0N or received 0N or 150N following a history of 150N. Crop-N uptake, leaf-N, soil mineral-N, crop yield and NUE data were collected. Results showed that the soybean fallow had no lasting N contribution through the crop cycle when N rates in the plant-cane crop were reduced as recommended in the SIX EASY STEPS. Based on this, fertilising ratoons at ‘normal’ N rates following legume fallows should be maintained. In the third-ratoon crop, where there was a history of 150N application, crop-N uptake was greater than where there was a history of 0N application. Cane yield at 0N was higher where there was history of 150N than 0N. These effects were not present in the fourth-ratoon crop. The results either showed a small fertiliser-history effect or were associated with greater N uptake by a crop in better condition.

Key words Sugarcane, crop, physiology, nutrient, efficiency

INTRODUCTION

The Australian sugar industry is under pressure to improve nitrogen use-efficiency (NUE), as it is likely that land-based activities within the Australian sugar industry have a negative effect on the quality of water in the Great Barrier Reef (GBR) lagoon (Brodie and Waterhouse 2012; Thorburn *et al.* 2013). Poor water quality, and in particular high levels of dissolved inorganic nitrogen (DIN), have been linked with outbreaks of crown-of-thorns starfish (Brodie *et al.* 2005; Fabricius *et al.* 2010) and algal blooms, which impact coral cover and condition. Due to this, the Australian and Queensland Governments’ Reef 2050 Water Quality Improvement Plan 2017-2022 sets out a target of a 60% reduction in anthropogenic end-of-catchment DIN loads by 2025 (Anon. 2018). Industry programs such as SmartCane BMP have been developed, in part, to improve nitrogen (N) management, and are based on validated practices such as the SIX EASY STEPS nutrient-management program (Schroeder *et al.* 2005). However, adoption of these guidelines may not meet the proposed water-quality targets (Kroon *et al.* 2016). Further refinement of N management, without negative consequences on crop profitability, is required. These improvements are likely to require a greater understanding of processes affecting N availability, crop-N demand and uptake in sugarcane-farming systems.

The inclusion of a legume fallow crop in the farming system alters N-fertiliser recommendations (Schroeder *et al.* 2005). Plant-crop yields can be maintained without fertiliser N following 'good' legume crops (Garside *et al.* 1996, 1997; Bell *et al.* 2003). Management of the legume biomass and rainfall events affects the amount and timing of N availability to the plant crop. Incorporation of green-legume residue can result in rapid mineralisation and potential N losses through leaching when compared with residue that is managed on the soil surface (Garside and Berthelson 2004). Similarly, tillage of legume residue increased nitrous oxide (N_2O) emissions compared to a bare fallow system in an unusually wet year (Wang *et al.* 2012). Therefore, it is recommended that legume residues should be maintained on the soil surface. Fertiliser-N recommendations for ratoon crops following legume fallows are not reduced. This is due to significant crop responses to fertiliser-N in ratoon crops following a legume fallow (Bell *et al.* 2010) and any N contribution from the legume fallow being unreliable given the significant time between the fallow and a ratoon crop. However, Park *et al.* (2010) suggested that a good legume fallow could contribute N throughout the sugarcane crop cycle and potentially large reductions to N-fertiliser application could be made to ratoon crops.

A further issue that affects N management is the fate of fertiliser-N that is not taken up by the crop in the season of application. While some of this N is potentially lost to the environment, background N from past fertiliser-management practices may also contribute to crop-N uptake in following seasons. This is supported by observations in current N-rate trials where low N-rate treatments are sometimes able to maintain yields in the first season of low application but yield losses occur thereafter. Past studies using ^{15}N (Chapman *et al.* 1992; Meier *et al.* 2006) suggest that this N 'carryover' is small. Furthermore, Chapman *et al.* (1983) concluded that residual effects of N fertiliser applied to the previous crop had negligible effects on following sugar yields.

Our experiments investigated two issues associated with improving N management. Firstly, should fertiliser-N recommendations for ratoon crops be altered following a good legume fallow? Secondly, what contribution do past fertiliser-N management practices have on N uptake?

MATERIAL AND METHODS

The experiments were established at the Sugar Research Australia experiment station near Mackay, Queensland.

Legume fallow history

This experiment followed a farming-systems trial that included fallow (bare; soybean), tillage (zonal tillage; no tillage) and N-fertiliser treatments. The effect of these farming systems practices on soil-N, nitrous oxide emissions, crop-N and yield of the plant-cane crop were reported by Salter *et al.* (2015). Soybean crop size was 6.1 t/ha dry biomass with an estimated total N contribution of 169 kg/ha. The plant crop received 138 kg N/ha as urea following the bare fallow and 18 kg N/ha following the soybean fallow (Salter *et al.* 2015). In the first-ratoon crop, plots were split (25 m x 6 rows) to include two fertiliser N rates, 0N (0 kg N/ha) and 150N (150 kg N/ha). These treatments were maintained in the second-ratoon crop.

Past fertiliser N history

As there did not appear to be any influence of fallow management on crop-N response in the first- and second-ratoon crops, the trial was altered to investigate the influence of previous N management on crop-N response. In the third-ratoon crop plots received either 0N or 150N (as urea) following a history of 0N, or received 0N or 150N following a history of 150N. These nitrogen treatments were maintained in the fourth-ratoon crop.

Rainfall

Rainfall data for the trial period was sourced from the Bureau of Meteorology station located at Dumbleton Rocks (Station 033300) approximately 4.5 km from the trial site.

Crop-N uptake

Crop-N uptake was assessed at 12 months (final harvest) in the first-ratoon crop; 3, 6, 9 and 12 months after harvest (MAH) in the second- and third-ratoon crops; and 3 and 9 MAH in the fourth-ratoon crop. At 3 MAH, shoots in a 5 m section of row (9 m^2) were cut at the base, counted and weighed. A sub-sample of these shoots was weighed, placed in an oven at 60°C and reweighed after drying. This sub-sample was then ground in a Glen Creston Cross Beater Mill with a 2 mm sieve and N content determined (Dumas). At 6, 9 and 12 MAH, stalks in a 10 m section of row (18 m^2) were counted. Twenty consecutive stalks in a section of row were selected, weighed, and partitioned into two components: (i) millable stalk; (ii) green leaf and 'cabbage'. This was achieved by cutting the stalk between the fifth and sixth visible dewlap from the apex of the stalk. Each component was weighed to calculate percent millable stalk and percent green leaf and cabbage. The combination of stalk number, stalk weight and the percentage of each crop component allowed the calculation of total fresh biomass of the crop and each crop component. Material from each component, from five randomly selected stalks, was shredded with a garden mulcher (Bosch AXT 2200) and a sub-sample of the shredded material was processed as above to determine moisture and N content.

Leaf analysis

Leaf samples were collected from the second-, third- and fourth-ratoon crops when the crops were approximately 6 months of age. Samples were dried at 60°C, ground in a Glen Creston Cross Beater Mill with a 1 mm sieve, and analysed for N content (Dumas).

Soil mineral-N

We conducted soil sampling after the previous crop was harvested, and at 3, 6 and 9 MAH. This schedule commenced after the harvest of the first-ratoon crop. For the fourth-ratoon crop, sampling was conducted following the harvest of the third-ratoon crop and after the harvest of the fourth-ratoon crop. Within each plot, two soil cores to 80 cm were collected from each side of the cane row; cores were positioned on the shoulder of the bed. Cores were partitioned into four depth increments (0-10, 10-30, 30-50 and 50-80 cm) and soil from the two cores were pooled. Samples were dried in cabinets where a fan-forced air at ambient temperature over the sample. After drying, samples were ground to 2 mm, and analysed for nitrate-N (mg/kg) and ammonium-N (mg/kg).

Crop harvesting and yield

Ratoon crop yield was determined during the mechanical harvest of the crop. Stalks from the middle two rows of each plot were harvested and weighed. Sugar content was assessed immediately prior to mechanical harvesting. Six stalks were collected from each plot and processed using near-infrared spectroscopy (Berding *et al*. 2003).

Statistical analyses

Data were analysed with analysis of variance procedures (GenStat 16.1). The first- and second-ratoon crops were a split-plot (fallow by N rate) design. The tillage treatments were not included in the model as they had no effect on the growth of the plant crop (Salter *et al.* 2015) and in preliminary analyses of ratoon-crop data. The third- and fourth-ratoon crops were a split-plot design (N-rate history by N rate). Where $P < 0.05$, we used Fischer's least significant difference to compare the treatment means.

RESULTS AND DISCUSSION

Rainfall

Total rainfall was calculated for each crop's duration, which varied among crops. Average total rainfall also took this difference in crop duration and timing into account. Rainfall for the first-ratoon crop was slightly below average (1494 mm) at 1280 mm, well below average (1528 mm) for the second-ratoon crop at 795 mm, slightly above average (1562 mm) for the third-ratoon crop at 1681 mm, and above average (1494 mm) for the fourth-ratoon crop at 2115 mm (Figure 1). Significant rainfall events were experienced in March 2016 during the third-ratoon crop, and in January 2017 and March 2017 during the fourth-ratoon crop. The fourth-ratoon crop was also impacted by Cyclone Debbie (March 2017), which resulted in crop lodging and some damage. Crop condition affected sampling activities in the fourth-ratoon crop and potentially increased variability. No irrigation was applied to the ratoon crops.

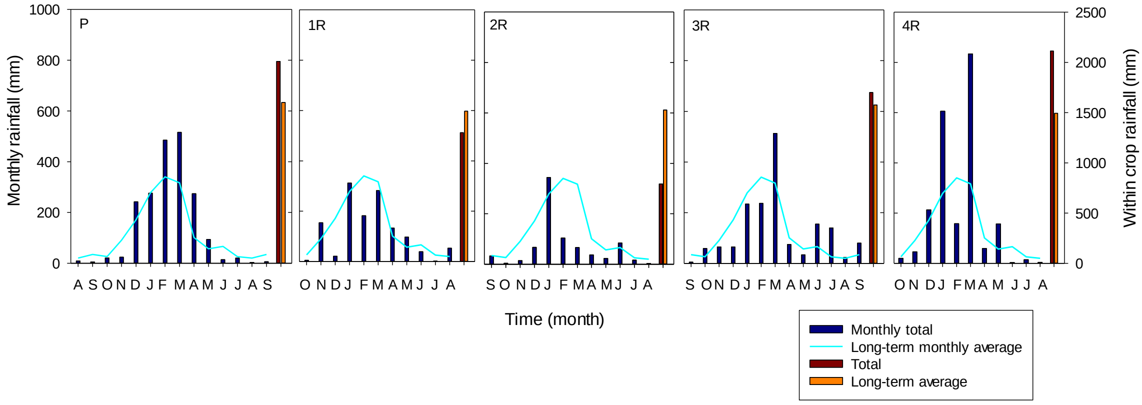

Figure 1. Monthly and annual rainfall from the Dumbleton Rocks BOM site relevant to the experiments at the Mackay SRA station (August 2012 to September 2017).

Legume fallow history

Dry biomass at final harvest of the first-ratoon crop was affected by N rate and the interaction between N rate and farming system (Table 1). Dry biomass was greater at 150N than 0N. At 0N, dry biomass was significantly lower in the soybean fallow than the bare-fallow system. This difference was not present at 150N.

Table 1. Effect of N rates and farming systems on dry biomass (t/ha) and crop N (kg/ha) at 3, 6, 9 and 12 months after harvest of the first-ratoon (1R) and second-ratoon (2R) crops.

Crop	Farming system (FS)	Age (months)	Dry biomass (t/ha) N applied (kg/ha) 0	150	Mean	Crop-N (kg/ha) N applied (kg/ha) 0	150	Mean
1R	Bare	12	21.7	33.6	27.7	37.0	61.1	49.0
	Soybean	12	18.6	35.4	27.0	32.1	78.8	55.5
	Mean		20.2	34.5		34.5	69.9	
	$LSD^{0.05}$		*FS ns (P=0.55); N 1.6 (P<0.01); FS x N 3.0 (P<0.01)*			*FS ns (P=0.06); N 10.4 (P<0.01); FS x N 14.8 (P=0.04)*		
2R	Bare	3	0.9	1.2	1.1	6.5	12.7	9.6
		6	6.1	13.5	9.8	21.7	50.8	36.3
		9	10.1	22.3	16.2	27.3	59.0	43.2
		12	13.9	28.7	21.3	29.9	55.3	42.6
		Mean	7.7	16.4	12.1	21.3	44.5	32.9
	Soybean	3	0.9	1.2	1.0	6.0	13.5	9.8
		6	6.2	13.7	10.0	24.2	54.9	39.5
		9	10.9	20.2	15.6	27.8	51.0	39.4
		12	18.0	23.9	21.0	34.4	40.3	37.4
		Mean	9.0	14.8	11.9	23.1	39.9	31.5
	Mean		8.4	15.6		22.2	42.2	
	$LSD^{0.05}$		*FS ns (P=0.79); N 3.0 (P<0.01); FS x N ns (P=0.17); A x FS ns (P=0.99); A x FS x N ns (P=0.57)*			*FS ns (P=0.56); N 1.3 (P<0.01); FS x N ns (P=0.13); A x FS ns (P=0.57); A x FS x N ns (P=0.36)*		

Crop-N content of the first-ratoon crop was higher at 150N. There was no overall difference in N content between the soybean and bare fallow systems, but where 150N was applied to the crop, crop-N content was higher following soybean than the bare fallow. As there was no difference in crop-N between the bare and legume history where 0N was applied, it is unlikely that the legume history contributed additional N into the system. The additional N taken up where 150N was applied following a legume history may, therefore, be due to other benefits of the legume system that allowed greater N uptake. As an example, a healthier root system would potentially improve N uptake despite similar N availability.

As was the case in the first-ratoon crop, dry biomass and crop-N content in the second ratoon were significantly higher at 150N than 0N. Significant crop-age by N-rate interactions were found for both dry biomass and crop-N content in the second ratoon (Table 1). For dry biomass, this was because there was no difference in dry biomass between N rates at 3 months, but dry biomass was significantly higher at 150N thereafter. For crop-N content, there was no difference between N rates at 3 months, but crop-N content was significantly higher at 150N thereafter. There was no increase in crop-N content at 150N after 6 months. No significant effects due to farming system were evident in the second-ratoon crop, which suggests similar N availability in the two systems.

In the second-ratoon crop, sugarcane that received 150N had significantly higher third-leaf N concentration than where 0N was applied (Table 2). There was no difference in third-leaf N concentration between soybean and bare fallow farming systems and no significant interaction. Third-leaf N values were below the critical value (1.8-1.9 %) in the 0N treatment.

Table 2. Third-leaf N concentration (%DM) as influenced by N rates and farming systems for the second-ratoon crop.

Farming system (FS)	Third-leaf N values (%DM)		
	N applied (kg/ha)		Mean
	0	150	
Bare	1.57	2.04	1.80
Soybean	1.62	2.05	1.83
Mean	1.59	2.04	
$LSD^{(0.05)}$: FS ns (P=0.68); N 0.05 (P<0.01); FS x N ns (P=0.19)			

Soil mineral N in the second-ratoon crop is shown in Figure 2. There was a significant decline in mineral-N with depth. Farming system (bare or soybean fallow) had no effect on soil mineral-N in the second-ratoon crop. Despite the application of 150N prior to sampling at 3 months, there was no statistically significant difference in soil mineral-N due to N treatment at any sampling time. Despite the lack of statistical significance, there was some indication of increased soil mineral-N at 6 months in the 150N treatment. Specifically avoiding sampling in the fertiliser band may have influenced this outcome. However, sampling within the fertiliser band can also result in significant variability if fertiliser granules are included in a sample. Soil mineral-N at 9 and 12 months was low.

Sugarcane yield in the first-ratoon crop was affected by the interaction of N rate and farming systems (Table 3). Where the crop received 0N, sugarcane yield was significantly higher in the bare fallow than in the soybean fallow. There was no difference between farming systems where 150N was applied. This result, and crop-N data, suggest that there was limited N contribution to the first-ratoon crop from the soybean fallow. Only 18 kg N/ha was applied to the plant-cane crop following the soybean fallow whereas the bare fallow received 138 kg N /ha. Lower yield at 0N in the soybean system suggests that this plant-cane rate was low and could have resulted in lower residual N in the soil pool following soybean fallow than the bare fallow system going into the first-ratoon crop. Salter *et al.* (2015) reported lower crop-N uptake in the soybean system during the plant-cane crop.

Sugar yield in the first-ratoon crop showed that where 150N was applied, yield was higher following the soybean than the bare fallow. Given that the response was the opposite at the 0N rate, this yield response may be due to factors other than N availability. In the second-ratoon crop, sugarcane yield was significantly higher following 150N than 0N. No difference between farming systems or interaction between N rate and farming system was evident.

CCS was higher in the 0N treatment than the 150N treatment in the first-ratoon crop, but lower than the 150N treatment in the second-ratoon crop. There was no effect of farming system on CCS and no significant interaction between N rate and farming system in the first- and second-ratoon crops.

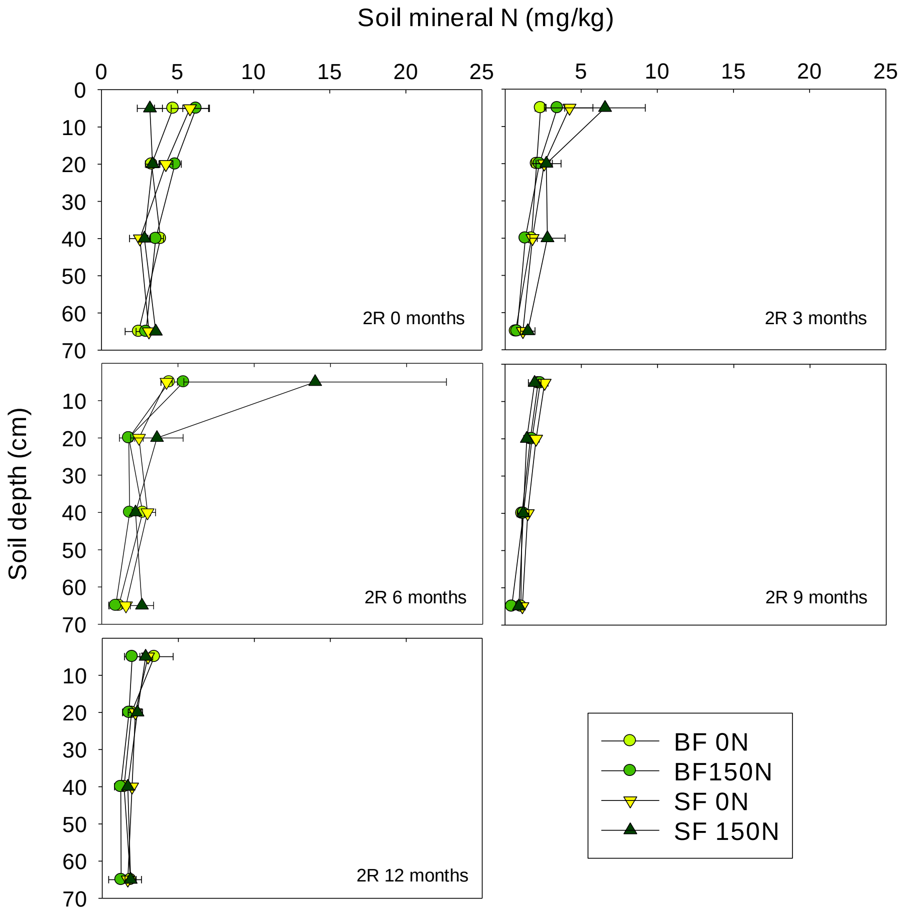

Figure 2. Soil-profile mineral-N concentrations (mg/kg) for the second-ratoon crop at 0, 3, 6, 9 and 12 months after harvesting. Bare fallow (BF); Soybean fallow (SF). Error bars ± SEM.

Table 3. Effect of N rates and farming systems on sugarcane yield (t/ha), CCS and sugar yield (t/ha) at harvest of the first-ratoon (1R) and second-ratoon (2R) crops.

Crop	Farming system (FS)	Sugarcane yield (t/ha)			Commercial cane sugar (%)			Sugar yield (t/ha)		
		N applied (kg/ha)		Mean	N applied (kg/ha)		Mean	N applied (kg/ha)		Mean
		0	150		0	150		0	150	
1R	Bare	59.7	92.6	76.1	15.51	15.16	15.34	9.3	14.0	11.6
	Soybean	50.7	98.1	74.4	15.86	15.33	15.59	8.0	15.0	11.5
	Mean	55.2	95.3		15.69	15.25		8.7	14.5	
	LSD$^{0.05}$	*FS ns (P=0.49); N 3.4 (P<0.01) FS x N 6.7 (P<0.01)*			*FS ns (P=0.28); N 0.27 (P<0.01) FS x N ns (P=0.44)*			*FS ns (P=0.71); N 0.5 (P<0.01) FS x N 0.8 (P<0.01)*		
2R	Bare	28.4	67.5	47.9	17.51	18.80	18.15	5.0	12.7	8.8
	Soybean	31.5	69.4	50.5	17.92	18.69	18.30	5.6	13.0	9.3
	Mean	29.9	68.5		17.72	18.74		5.3	12.8	
	LSD$^{0.05}$	*FS ns (P=0.10); N 4.1 (P<0.01) FS x N ns (P=0.74)*			*FS ns (P=0.50); N 0.18 (P<0.01) FS x N 0.60 (P=0.01)*			*FS ns (P=0.08); N 0.8 (P<0.01) FS x N ns (P=0.59)*		

In the first-ratoon crop, higher N uptake (150N) in the soybean fallow system resulted in higher percent additional kg N uptake/kg fert applied (NUpEfert) (Table 4). However, as yields were similar, N utilisation-efficiency (NUtE) was lower in the soybean fallow system. N use-efficiency (NUE) was lower in the second-ratoon crop due to a decline in sugarcane yield and crop-N uptake, both potentially associated with dry growing conditions. NupEfert was low for both first- and second-ratoon crops, the highest efficiency being 31.1% of fertiliser N taken up by the crop in the above-ground biomass.

Table 4. Effect of N rates and farming systems on nitrogen use-efficiency in the first- (1R) and second-ratoon (2R) crops.

Crop	Yield and efficiency factors	Bare		Soybean	
		N applied (kg/ha)			
		0	150	0	150
1R	Mean yield (TCH, t cane/ha)	59.7	92.6	50.7	98.1
	tc/kg N applied	-	0.6	-	0.7
	kg N applied/tc	-	1.6	-	1.5
	Agron Efffert (kg N/additional TCH)	-	4.6	-	3.9
	Crop N uptake (kg N/ha)[1]	37.0	61.1	32.1	78.8
	NUtE (TCH/kg crop N)	1.62	1.52	1.58	1.24
	Fertiliser N uptake (kg N/ha)	-	24.1	-	46.7
	NUpEfert (additional kg N uptake/kg fert applied) %	-	16.1	-	31.1
2R	Mean yield (TCH, t cane/ha)	28.4	67.5	31.5	69.4
	tc/kg N applied	-	0.4	-	0.5
	kg N applied/tc	-	2.2	-	2.2
	Agron Efffert (kg N/additional TCH)	-	3.8	-	3.2
	Crop N uptake (kg N/ha)[1]	27.3	59.0	27.8	51.0
	NUtE (TCH/kg crop N)	1.0	1.1	1.1	1.4
	Fertiliser N uptake (kg N/ha)	-	31.8	-	23.3
	NUpEfert (additional kg N uptake/kg fert applied) %	-	21.2	-	15.5

In this experiment, it appears the soybean fallow had no lasting N contribution through the crop cycle when N rates in the plant cane crop were reduced as recommended in the SIX EASY STEPS. This result contradicts suggestions that legumes can contribute N throughout the sugarcane crop cycle (Park *et al.* 2010*).* Legume crop biomass in our study was average-good for the Mackay region, but a low N content (2.1%) meant that total contribution of N from the legume crop was relatively low. It was significantly lower than the actual and simulated N content at the field site reported by Park *et al.* (2010). Testing legume crops for their N content and measuring biomass provides a better understanding of N input than the generalised values used in the SIX EASY STEPS and will allow more informed decisions regarding fertiliser practices.

Past fertiliser history

In the third-ratoon crop treatments were changed to investigate the effect of N-rate history. There was significantly higher dry biomass and crop-N content where there was a history of 150N than a history of 0N (Table 5). This was an indication of the contribution past fertiliser practices have on the availability of nitrogen in a given season and/or it reflects a healthier crop, not previously N stressed, being able to take up additional N. A significant crop age by N-rate interaction was found for both dry biomass and crop N content. For dry biomass, this was due to there being no differences between N-rate treatments at 3 months, but the 150N rate was higher than the 0N rate at 6, 9 and 12 months. For crop-N, this significant effect was due to crop-N increasing rapidly and reaching a maximum between 3 and 6 months in the 150N treatment whereas in the 0N treatment crop-N increased more slowly and reached a maximum at 9 months. There was a decline in crop-N content between 9 and 12 months in both 0N and 150N treatments. The effect of N rate history on dry biomass and crop-N content was not significant in the fourth-ratoon crop.

Crop-N content at 3 months in the third- and fourth-ratoon crops (Table 5), where 150N was applied, were substantially higher than crop N content at 3 months in the second-ratoon crop (Table 1). This is most likely due to better rainfall during spring and early summer in the third- and fourth-ratoon crops and suggests that irrigation through this period could potentially have a large effect on crop-N uptake and therefore NUE.

In the third- and fourth-ratoon crops, sugarcane that received 150N had higher third-leaf N concentration than sugarcane that received 0N (Table 6). There was no statistically significant difference due to N-rate history and no interaction for both third- and fourth-ratoon crops. In the third ratoon, plots that received 0N with a history of 150N had higher mean third-leaf N concentration (1.75) than plots with a history of 0N (1.68). Although not statistically significant, this may be an indication of the residual effect from N-application history. This observation was not present in the fourth-ratoon crop. Overall, the 150N treatment maintained third-leaf N concentrations at or slightly above the critical value. Plots that received 0N were below the critical value and clearly N deficient.

Table 5. Effect of N rate and N-rate history on dry biomass production (t/ha) and crop N (kg/ha) at 3, 6, 9 and 12 months after harvest for the third- (3R) and fourth-ratoon (4R) crops.

Crop	N-rate history (NH)	Age (months)	Dry biomass (t/ha)			Crop-N (kg/ha)		
			N applied (kg/ha)			N applied (kg/ha)		
			0	150	Mean	0	150	Mean
1R	0	3	1.2	1.8	1.5	9.3	27.6	18.5
		6	6.1	12.0	9.0	25.9	69.6	47.8
		9	14.9	20.2	17.5	48.3	64.3	56.3
		12	8.6	24.3	16.5	16.9	48.9	32.9
		Mean	7.7	14.6	11.1	25.1	52.6	38.9
	150	3	1.0	1.6	1.3	10.2	27.2	18.7
		6	8.3	13.8	11.1	35.5	84.5	60.0
		9	15.6	26.6	21.1	55.9	86.2	71.0
		12	11.2	24.3	17.7	23.0	47.2	35.1
		Mean	9.0	16.6	12.8	31.2	61.3	46.2
	Mean		8.3	15.6		28.1	57.0	
	LSD$^{0.05}$		*NH 1.1 (P=0.02); N 1.1 (P<0.01); NH x N ns (P=0.39); A x NH ns (P=0.30); A x NH x N ns (P=0.21)*			*NH 2.5 (P<0.01); N 2.5 (P<0.01); NH x N ns (P=0.19); A x NH ns (P=0.18); A x NH x N ns (P=0.50)*		
2R	0	3	1.1	1.3	1.2	9.1	19.8	14.5
		9	11.0	24.8	17.9	23.8	52.8	38.3
		Mean	6.1	13.1	9.6	16.4	36.3	26.4
	150	3	1.3	2.1	1.7	12.3	33.6	22.9
		9	11.2	24.9	18.0	24.8	53.5	39.2
		Mean	6.2	13.5	9.8	18.6	43.5	31.0
	Mean		6.1	13.3		17.5	39.9	
	LSD$^{0.05}$		*NH ns (P=0.86); N 4.3 (P=0.02); NH x N ns (P=0.93); A x NH ns (P=0.89); A x NH x N ns (P=0.90)*			*NH ns (P=0.22); N 9.5 (P<0.01); NH x N ns (P=0.46); A x NH 9.0 (P0.03); A x NH x N ns (P=0.07)*		

Table 6. Third-leaf N concentration (%DM) as influenced by N rate and N-rate history for the third- (3R) and fourth-ratoon (4R) crops.

Crop	N-rate history (NH)	Third-leaf N values (%DM)		
		N applied (kg/ha)		Mean
		0	150	
3R	0	1.68	2.06	1.87
	150	1.75	2.03	1.89
	Mean	1.71	2.04	
	LSD$^{(0.05)}$: NH ns (P=0.54); N 0.09 (P<0.01); NH x N ns (P=0.22)			
4R	0	1.64	1.90	1.77
	150	1.65	1.90	1.78
	Mean	1.64	1.90	
	LSD$^{(0.05)}$: NH ns (P=0.57); N 0.04 (P<0.01); NH x N ns (P=0.57)			

Soil mineral-N at harvest of the second-ratoon crop (Figure 2) was low. This indicates that any historical effect of past fertiliser history is unlikely to be associated with residual mineral-N remaining in the soil profile at the end of a season, but rather other soil-N pools. In the third ratoon, soil mineral-N decreased with sampling depth at all sampling times (Figure 3). Few other statistically significant effects were found. This may have been due to high levels of variation and the low number of replicates that were sampled. Despite the lack of statistical significance, there appeared to be higher soil mineral-N at 3 months where 150N was applied to the crop. N-rate history did not have any statistically significant effect on soil mineral-N at any sampling time. Soil samples were also collected at the commencement and after harvesting of the fourth-ratoon crop (Figure 3). Soil mineral-N was low at both times. The change in soil mineral-N with depth was not statistically significant in the fourth-ratoon crop. However, mean values were consistent with a decline with soil depth. While a significant N-rate history by soil-depth interaction was found at the commencement of the fourth-ratoon crop (not shown), differences were small and likely to be of little consequence.

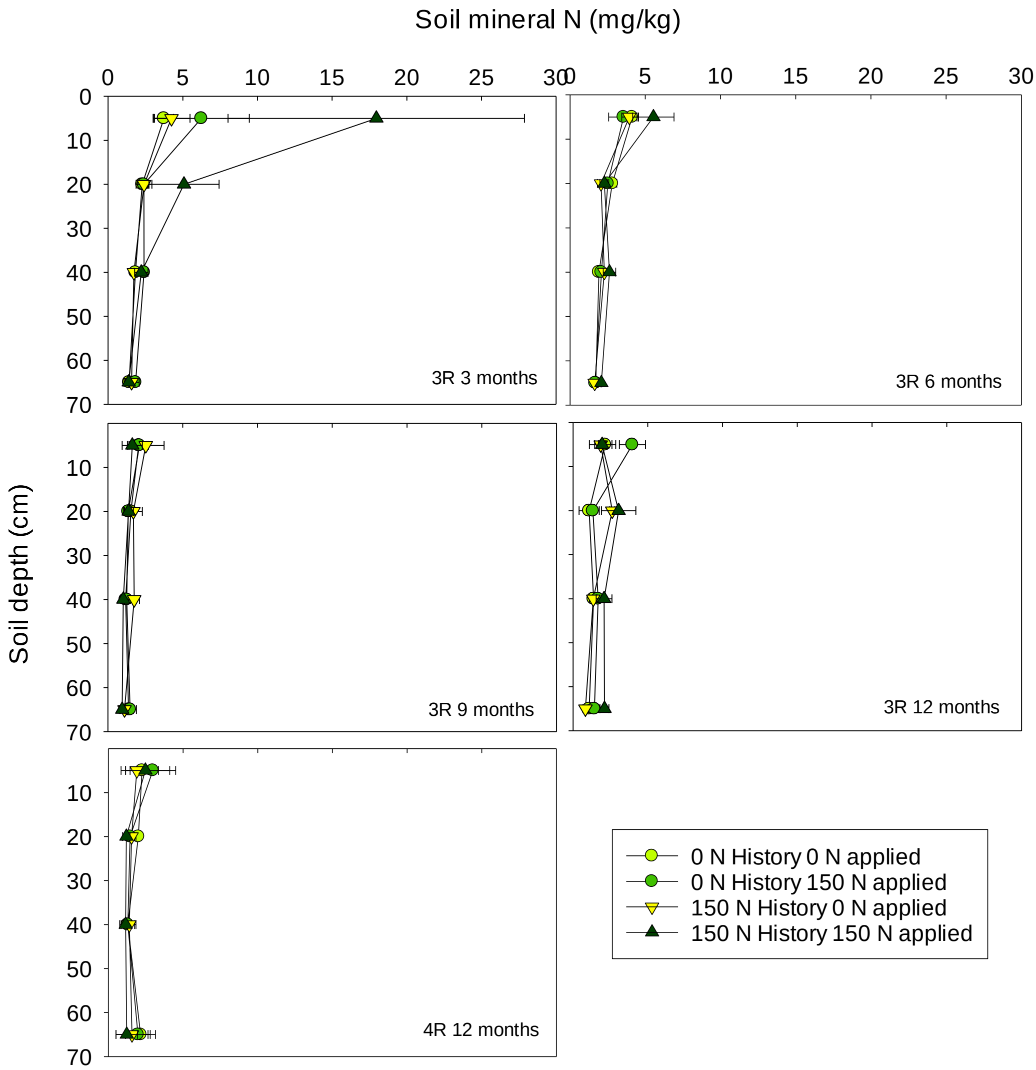

Figure 3. Soil profile mineral-N concentrations (mg/kg) for the third-ratoon crop at 3, 6, 9 and 12 months after harvest and the fourth-ratoon crop at 12 months after harvest. Error bars ± SEM.

Sugarcane yield was affected by a significant interaction between N-rate history and N-rate in the third-ratoon crop (Table 7). In the 0N treatment, sugarcane and sugar yield were significantly higher where there was a history of applying 150N in comparison to a history of 0N. There was no difference between histories where 150N was applied to the crop. An additional 10.2 t cane/ha appeared to be supported by residual-N in the soil pool due to fertiliser history and/or better crop condition and N uptake due to the N-application history. This effect was not present in the fourth-ratoon crop, where the only significant difference was due to N applied in that season. This suggest that the fertiliser history effect was small and short lived. This is consistent with results from other studies (Chapman *et al.* 1983, 1992; Meier *et al.* 2006).

In the third-ratoon crop CCS was significantly lower in the 0N treatment than the 150N treatment. This effect was not present in the fourth-ratoon crop. There was no effect of N-rate history or interaction between N-rate history and N rate on CCS in either the third- or fourth-ratoon crops.

NUpEfert in both third- and fourth-ratoon crops was poor ranging from 10.6-20.2% of applied fertiliser (Table 8). However, as shown in this experiment, some of the fertiliser-N not taken up by the crop may be available to following crops.

Table 7. Effect of N rates and N-rate history on sugarcane yield (t/ha), CCS and sugar yield (t/ha) at harvest of the third-ratoon (3R) and fourth-ratoon (4R) crops.

Crop	N-rate History (NH)	Sugarcane yield (t/ha)			Commercial cane sugar (%)			Sugar yield (t/ha)		
		N applied (kg/ha)		Mean	N applied (kg/ha)		Mean	N applied (kg/ha)		Mean
		0	150		0	150		0	150	
3R	0	28.0	73.8	50.9	14.35	15.08	14.72	4.0	11.1	7.6
	150	38.2	73.2	55.7	14.22	14.98	14.60	5.4	11.0	8.2
	Mean	33.1	73.5		14.29	15.03		4.7	11.0	
	$LSD^{0.05}$	*NH 3.7 (P=0.01); N 3.7 (P<0.01); NH x N 5.3 (P<0.01)*			*NH ns (P=0.50); N 0.33 (P<0.01); NH x N ns (P=0.93)*			*NH 0.6 (P=0.03); N 0.6 (P<0.01); NH x N 0.8 (P<0.01)*		
4R	0	27.9	82.8	55.4	16.71	16.91	16.81	4.7	14.0	9.3
	150	32.7	81.4	57.0	16.89	16.72	16.80	5.5	13.6	9.6
	Mean	30.3	82.1		16.80	16.82		5.1	13.8	
	$LSD^{0.05}$	*NH ns (P=0.50); N 5.0 (P<0.01); NH x N ns (P=0.22)*			*NH ns (P=0.95); N ns (P=0.91); NH x N ns (P=0.17)*			*NH ns (P=0.61); N 0.9 (P<0.01); NH x N ns (P=0.15)*		

Table 8. Effect of N rate and N-rate history on nitrogen use-efficiency in the third- (3R) and fourth-ratoon (4R) crops.

Crop	Yield and efficiency factors	N-rate history (kg/ha)			
		0		150	
		N applied (kg/ha)			
		0	150	0	150
3R	Mean yield (TCH, t cane/ha)	28.0	73.8	38.2	73.2
	tc/kg N applied	-	0.5	-	0.5
	kg N applied/tc	-	2.0	-	2.0
	Agron Efffert (kg N/additional TCH)	-	3.3	-	4.3
	Crop N uptake (kg N/ha)[1]	48.3	64.3	55.9	86.2
	NUtE (TCH/kg crop N)	0.6	1.1	0.7	0.8
	Fertiliser N uptake (kg N/ha)	-	15.9	-	30.3
	NUpEfert (additional kg N uptake/kg fert applied) %	-	10.6	-	20.2
4R	Mean yield (TCH, t cane/ha)	27.9	82.8	32.7	81.4
	tc/kg N applied		0.6		0.5
	kg N applied/tc		1.8		1.8
	Agron Efffert (kg N/additional TCH)		2.7		3.1
	Crop N uptake (kg N/ha)[1]	23.8	52.8	24.8	53.5
	NUtE (TCH/kg crop N)	1.2	1.6	1.3	1.5
	Fertiliser N uptake (kg N/ha)	-	29.1	-	28.7
	NUpEfert (additional kg N uptake/kg fert applied) %	-	19.4	-	19.1

CONCLUSIONS

Ratoon crops following a soybean fallow did not acquire additional N in comparison to a bare fallow. There was evidence from the first-ratoon crop that there may have been less N in the soil pool in the soybean-fallow system due to lower sugarcane yield at the 0N rate. This was possibly due to the significantly reduced fertiliser-N in the plant crop following the soybean fallow. Given this result, the SIX EASY STEPS guidelines for ratoon crops following a soybean fallow are justified, particularly if N applications are reduced in the plant crop to account for legume-N.

The experiment to investigate the effect of fertiliser history showed that N from past fertiliser applications could be available to following crops, but the amount was likely to be small and did not persist beyond the first crop. It is not possible to determine from our study whether the additional N acquired with a history of 150N was due to N availability or whether better crop condition allowed greater N uptake. However, if the response was due to N availability, it indicates that a portion of fertiliser-N, which may be assumed as lost to the environment, is incorporated into soil pools and becomes available through mineralisation events.

In both experiments, crop-N uptake was low in the first 3 months after harvesting. The majority of N uptake occurred between 3 and 6 months, which coincides with tillering and stalk-elongation phases.

Nitrogen use-efficiency was poor at this site and technology and practices to improve NUE whilst maintaining productivity and profitability are required.

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