THE IMPACT OF COMBINATIONS OF TRASH MANAGEMENT AND TILLAGE ON GRAIN LEGUME AND SUBSEQUENT SUGARCANE PRODUCTIVITY IN THE BUNDABERG/CHILDERS DISTRICT

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Abstract

PRODUCERS IN THE Bundaberg/Childers and Maryborough districts are implementing various combinations of legume rotations, trash retention, reduced tillage and controlled traffic in new and evolving farming systems. There are challenges in successfully integrating these components. Two trial sites were established to measure the impact of different trash management (maintaining full GCTB, removing some trash via baling and full removal through burning) and tillage (conventional, strip-till and direct drill) techniques on grain legume production, with one site focussed on grain soybean productivity and the other on peanuts. The different tillage systems were reinstituted after harvest of the legume crop during the establishment of the plant cane crop. Impacts of tillage and additional nitrogen application on plant cane productivity were measured. The soybean trial site was established on a farm growing cane in 1.57 m row configuration, and neither trash management nor tillage affected soybean productivity. However there was a trend for lower plant cane productivity with reduced tillage and there was a 13% yield improvement through the application of fertiliser N in a very wet season. In contrast, the peanut trial site was established on a farm growing cane in 1.8 m row spacings. Sugarcane trash management didn't impact on peanut productivity, although yields were lower in reduced tillage treatments. In the following plant cane crop there was no impact of tillage on sugarcane productivity, and there was only a 5% response to N fertiliser application on cane productivity, but not sugar productivity. Data demonstrate that even though soybean productivity was unaffected, unamended soil compaction from the previous cane cycle can limit productivity of both fallow peanut crops and the next cane crop cycle. Further research may be able to improve productivity and harvest efficiency of peanuts in reduced tillage systems. However, it seems clear that appropriate row configurations to control traffic and minimise compaction are imperative to allow successful sugarcane production in reduced tillage farming systems.

Introduction

Sugar producers of the southern canelands (Bundaberg, Childers and Maryborough) have implemented many of the recommendations of the Sugar Yield Decline Joint Venture (SYDJV) program. The SYDJV advocated a sustainable sugarcane farming system that would have three key components: legume rotations with reductions in tillage and controlled traffic to minimise compaction and trash retention to maintain soil organic matter levels (Bell *et al.*, 2003). Legume rotations significantly improve the productivity of the subsequent cane crop (Garside *et al.*, 1999) and improve soil health via increasing beneficial soil biota (Pankhurst *et al.,* 2003; Stirling *et al.,* 2001). Cane trash blanket retention improves the soil carbon status (Bell *et al.,* 2001) and provides a labile carbon source essential to the development of soil suppression against plant parasitic nematode populations (Stirling, 2008). Controlled traffic and reduced tillage technologies have the potential to significantly improve the profitability of sugarcane farming (Braunack *et al.,* 1999; Halpin *et al.,* 2008).

One of the impediments in adopting these principals is the bulk of post harvest cane residue, coupled with the relatively short time period between the harvest of cane and the sowing of the grain legume crop. To facilitate a reduction in the number of tillage operations, producers either burn or bale the cane trash to reduce the quantity of trash. While burning the trash will result in some loss of the nutrients (especially nitrogen [N] and some sulphur [S]), most of the above ground organic matter is lost. Baling provides an additional income stream and while some trash remains, organic matter and associated nutrients are exported off site.

There have been several studies on the effect of tillage on the production of soybean and peanuts. Direct drilling of soybeans improved productivity (Herridge and Holland, 1992), or performed similarly to conventional tillage (Hughes and Herridge, 1989). There is evidence that it takes some time for the farming system to evolve to allow the productivity benefits of a reduced tillage system to become apparent. So *et al.* (2009) found that conventional tillage systems out-performed direct drill for the first four years of a long term trial in Grafton, but thereafter the trend reversed. The improvement in productivity was brought about by significant changes in soil physical properties. The direct drill treatment resulted in higher plant available water status due to increased soil macroporosity and better aggregate stability. Bell *et al.* (2003) noted similar increases in macroporosity associated with higher earthworm populations under direct drill.

The application of direct drill techniques has generally not improved the productivity of peanuts. (Hartzog and Adams, 1989) report on erratic responses to tillage in Alabama. Thiagalingam *et al.* (1991) found no negative impacts of direct drill in the Douglas-Daly district but later Thiagalingam *et al.* (1996) found reductions in productivity in the Pinnarendi district due to poor weed control. A grower group reported similar reductions in peanut productivity in Bundaberg (Halpin *et al.,* 2010), where they experienced difficulties establishing peanuts, applying inoculants and controlling weeds when trash blankets were retained in zero tillage systems.

Currently the sugarcane growing community of the southern canelands are adopting some components of the new farming system, but will not gain the full potential that the system has to offer unless they can implement all the components.

Producers are concerned about implementing reduced tillage techniques because there is a lack of information on how grain legumes will perform in the sugarcane farming system and because they believe that tillage is necessary to repair the compaction caused by the large amount of traffic required to harvest sugarcane. Similarly researchers are concerned that techniques employed to reduce cane trash levels will adversely affect soil health, through reductions in organic matter returns.

Two trial sites were established to evaluate the impact of different trash management and tillage techniques on grain legume production and subsequent cane productivity when the tillage techniques were reinstituted after the legumes.

Materials and methods

Combinations of three trash management techniques and three tillage treatments were employed in factorial combinations after the harvest of a third and final ratoon crop of Q151 at Bundaberg and a similar ratoon crop of Q190 at Childers. The treatments were randomly allocated in a factorial design at the Bundaberg site whereas the treatments were arranged as a split-plot design with tillage being the main plots and trash management the sub-plots for the Childers experiment. Each site had the treatments replicated three times in plots that were five cane rows wide by 20 m row length.

The trash treatments consisted of either a full green cane trash blanket (GCTB), or a trash blanket that was raked and removed via a commercial hay baler (Baled) or burnt in-situ (Burnt). The conventional tillage (CT) treatments had two passes of a rotary hoe, a deep ripping and a final rotary hoe operation. The Strip-till (ST) treatment of a coulter ripper with tynes 70 cm and 80 cm apart was used for the Bundaberg and Childers sites respectively, followed by a high speed pass of fluted coulters and crumble roller on the same zone as the ripper tyne. The ST operations provided a tilled zone 30 cm wide either side of the old cane stool. The direct drill (DD) treatment received no mechanical tillage, cane stool and weeds were destroyed with herbicides (glyphosate 540 g/L followed by a paraquat 135 g/L / diquat 115 g/L application).

The trash treatments were applied in September 2009 and August 2010 for the Bundaberg and Childers sites, respectively. Trash levels were determined post baling or burning by sampling a 2.35m^2 or 2.7m^2 quadrat in each of the trash treatments from the Bundaberg and Childers sites respectively . Lime was applied to the Bundaberg site to ameliorate soil pH to 6.5 (soil pH was adequate at the Childers site), prior to imposing the tillage treatments.

Tillage treatment effect on soil bulk density in the 'bed area' was determined prior to planting the legume crop by driving a 100 mm soil tube into the soil to a depth of 80 cm. The soil sample was cut into 10 cm increments, placed into a dehydrator at 105 °C for 48 hours and weighed (McKenzie *et al.,* 2002)

Soybeans were sown at the Bundaberg site on 24 November 2009 using a specially modified planter capable of handling the large trash levels, with a large coulter followed by a double disc opener. Seed of the cv. Fraser⅁ was metered by a vacuum plate plater calibrated to establish 350 000 plants/ha in paired rows 70 cm apart on a 1.57 m bed. Group H inoculant was supplied directly onto the seed and surrounding soil by water injection technology immediately prior to the seed drill being closed with twin inclined press-wheels. The water injection was supplied at 140 L/ha. The soil at the Bundaberg site was classified as a Red Kandosol in the Australian Soil Classification system (Donnollan *et al.,* 1998).

Peanuts were sown at the Childers site on 26 October 2010 using the same planter configuration but with the row spacing altered to two rows 80 cm apart on a 1.8 m bed. Seed of cv. Holt⅁ was sown to establish 120 000 plants/ha and group P inoculant was water injected. The Childers site was classified as a Red Dermosol in the Australian Soil Classification system (Wilson, 1997). Soil temperature probes with data loggers were installed 5 cm below the soil surface in the CT GCTB and DD GCTB treatments to measure treatment differences in soil temperature. Growing degree days were calculated by adding the average hourly temperature in a 24 hour period less a base temperature of 12 ^{0}C.

Both sites had plots in the different combinations of trash and tillage where legumes had been un-inoculated to assess treatment effect on nitrogen fixation (data not presented).

Both legume crops were grown using current commercial culture with weeds and volunteer cane controlled with herbicides in crop (Acifluoren 224 g/L, Haloxyfop 520 g/L). Foliar diseases in the peanut crop were controlled with a fungicide program where Chlorothalonil (720 g a.i./L) was applied on a cycle of 10–14 days. Pod sucking insects were controlled in the soybean crop by applications of the insecticide Deltamethrin (27.5 g a.i./L plus salt at 0.5% of spray solution). The crops were irrigated by high pressure travelling irrigator and the paddocks were irrigated as part of the farmer's normal irrigation schedule.

Differences in early stages of legume crop performance were measured by destructive sampling at 44–46 days after planting (DAP), maximum biomass was determined in the late stages of crop maturation and final yield was determined using mechanical harvesting. After harvesting, peanuts left in the soil of the differing tillage treatments that had GCTB trash management were sampled. The top 10 cm of soil in a 2 m by 1.83 m area was excavated and passed through a 10 mm sieve and unharvested peanuts were collected, dried, weighed and graded.

Re-institution of the tillage treatments occurred during the winter period after legume harvest. Conventional tillage was a rotary hoe to incorporate legume residue, followed by a deep ripping, then another pass with the rotary hoe to prepare the seed bed. The strip-till treatment consisted of one pass of a three tyne Yeoman® ripper (bed area only) fitted with a waisted crumble roller. The DD plots received no mechanical soil disturbance.

Sugarcane cv. KQ228 was planted with a conventional whole stick planter with the mouldboards removed to minimise soil disturbance in the last week of August in 2010 and 2011 at the Bundaberg and Childers sites, respectively. Fertiliser was applied at planting to meet site requirements determined by soil testing. Conventional fertiliser products or blends were used to supply 30 kg P/ha at the Bundaberg site and 40 kg N/ha, 3 kg P/ha and 30 kg K/ha at the Childers site.

The cane setts were treated with Mercury (120 g/L) and Chlorpyrifos (500 g/L) to ensure successful emergence. The remaining K fertiliser (120 and 90 kg K/ha for the Bundaberg and Childers sites, respectively) was applied at fill-in. The fill-in process was performed conventionally using a coil tyned cultivator. No extra N was supplied to the cane crop at fill-in with the exception of the plots that were un-inoculated during the legume phase. These plots received 140 kg N/ha at cane fill-in and were the N-fertilised Control plots in the cane cycle, allowing an assessment of treatment impact on N dynamics compared to this fertilised Control. Weeds were controlled in the cane crop with S-Metolachlor (960 g a.i./L) and Paraquat (135 g a.i./L) and Diquat (115 g a.i./L) applied pre-emergent, with directed in-crop applications of Fluroxypyr (333 g a.i./L), Atrazine (900 g a.i./kg) and 2,4-D amine (625 g a.i./L) applied later. All herbicides were applied at registered rates.

Final cane yield and CCS were determined by hand harvesting 5 m of the centre three rows of each plot. Total biomass was weighed from the harvested area, with a sub-sample partitioned into millable stalk and trash. A record was kept of total number of stalks, total biomass, sub-sample total weight and weight of millable stalk in the sub-sample.

A six stalk sub-sample was retained to determine CCS content using the small mill procedure. A sub-sample of whole stalk was mulched, dried and ground <2 mm and sent for analysis to determine nitrogen content (total Kjeldahl nitrogen).

All data was analysed with the GenStat® statistical package, with analysis of variance (ANOVA) used on all data sets. Significant differences between means were determined using pair-wise testing in the LSD procedure.

Results and discussion

Fallow legume crops

Trash and tillage

Initial trash loads at each site varied from 14.1 t/ha at Bundaberg to 17.6 t/ha at Childers. The quantity of trash in the GCTB treatments was reduced by 63% and 21% by baling and 95% and 61% by burning at the Bundaberg and Childers sites respectively. This was due in part to different seasonal conditions that effected the baling and burning operations.

Conventional tillage significantly reduced soil bulk density compared to the direct drill treatments in the beds at Bundaberg (0.93 and 1.15 g/cm^3 respectively) but not at Childers (1.20 and 1.26 g/cm^3 respectively). This could be as a result of the Childers site being on controlled traffic 1.8 m row spacing.

Soybean at the Bundaberg site

There was a trend ($p = 0.066$) for sugarcane trash management to affect soybean productivity in the early biomass sampling, where baling and burning trash improved productivity by 18%, but these effects proved to be transient. Strip (ST) and conventional (CT) tillage improved soybean establishment by 17% and 23%, respectively, over the direct drill (DD) treatment (Table 1).

Similarly tillage improved early crop biomass by 27% and 46% compared to the direct drill for ST and CT treatments, respectively. However there was no evidence of tillage affecting soybean productivity at the time of maximum biomass or grain yield sampling (Table 1). This result is similar to the findings of (Bell *et al.,* 2003). There was a significant effect of employing some tillage on crop height and height of the lowest pod (a key factor for soybean harvestability, as crop loss occurs if the pods are too close to the soil surface), with these findings not documented in other studies.

Table1—Tillage effect on soybean establishment, biomass, grain yield, plant and lowest pod height.

Tillage	Establishment	Biomass 46 DAP	Maximum biomass	Grain yield	Plant height	Lowest pod height
	Plants/ha	t/ha			cm	
Conventional	335 434[a]	1.91[a]	10.81	4.63	78.2[a]	9.2[a]
Strip	318 450[a]	1.66[a]	10.06	4.58	72.8[a]	9.0[a]
Direct drill	272 452[b]	1.31[b]	10.06	4.52	61.2[b]	7.3[b]
LSD (p = 0.05)	37 442	0.25	ns	ns	5.65	1.4
Trash						
GCTB	295 097	1.45	10.01	4.64	72.8	9.44
Baled	312 789	1.72	10.85	4.68	70.2	8.11
Burnt	318 450	1.71	10.07	4.40	70.1	8.00
LSD (p = 0.05)	ns	ns	ns	ns	ns	ns

Values in columns with the same letter are not different (p = 0.05)

Peanut at the Childers site

There was a significant trash management by tillage interaction on peanut biomass production 44 DAP for the Childers experiment. Trash management had no impact on productivity in CT situations, with 944 kg/ha (Burnt) and 956 kg/ha (GCTB) of above-ground biomass produced. However there was a significant reduction in biomass in the DD treatments, where peanut productivity increased by 28% in the Burnt treatments compared to those with trash retention (957 kg/ha versus 745 kg/ha for Burnt and GCTB respectively). This difference was not due to differences in plant population (data not shown). However the soil temperature was cooler under the DD trash retained treatment. In the first 5 days post emergence there was a trend (p = 0.067) for the CT trash retained treatment to accumulate an average of 21% more heat units (^{o}C d) than the DD trash retained systems.

In the following four days the DD trash retained plots were significantly cooler than the tilled treatment, with a range in p values for the four days from p = 0.009 to 0.027. Thereafter, as the canopy developed and soil shading became more extensive, the differences between the treatments reduced. It is likely that this reduction in soil temperature impacted on early biomass accumulation.

There were trends for increasing tillage and reducing trash to improve crop establishment but they were not statistically significant (Table 2). There was a trend for trash management to effect early biomass production driven by the DD GCTB treatment–probably resulting from the soil temperature issues discussed above.

A reduction in tillage, either as ST or DD, significantly reduced maximum biomass, nut-in-shell yield and gross crop value (Table 2). The reduced productivity of peanuts grown with reduced tillage is similar to that documented by Halpin *et al.* (2010), although in this current experiment peanuts were sown into cane beds that had one row of cane per bed. Halpin *et al.* (2010) speculated that the dual cane row configuration was partly responsible for the reduced peanut productivity of reduced tillage techniques in that experiment, but this was clearly not the case in this study.

Table 2—Trash and tillage effect on peanut establishment, early and maximum biomass production, yield and gross crop value.

Tillage	Establishment	Biomass 44 DAP	Maximum biomass	Nut in shell yield	Gross crop value
	Plants/ha	t/ha			$/ha
Conventional	151 247	0.95	11.08^{a}	5.66^{a}	4387^{a}
Strip	147 543	–	9.43^{b}	4.51^{b}	3346^{b}
Direct drill	132 109	0.85	9.52^{b}	4.72^{b}	3490^{b}
LSD (p = 0.05)	ns	ns	1.047	0.54	408.1
Trash					
GCTB	131 492	0.95	9.40	4.82	3611
Baled	145 073	–	9.75	5.07	3824
Burnt	154 333	0.851	10.87	5.00	3788
LSD (p = 0.05)	ns	ns	ns	ns	ns

Values followed by the same letter in the same column are not statistically different (p = 0.05)

There was a trend (p = 0.137) for peanut losses to be inversely proportional to the amount of tillage with 0.66 t/ha, 1.09 t/ha and 1.60 t/ha of un-harvested pods recovered from soil in the CT, ST and DD treatments, respectively. There was also a significant effect of tillage on the grade of these un-harvested peanuts, with higher proportions of the more valuable 'jumbo' grade peanuts lost with reductions in tillage (viz. DD 58% ≥ ST 56% > CT 45%). This is probably a reflection of the design of the peanut digger interacting with the hard inter-space area that impeded the cutter bar penetrating the soil. This would have caused the cutter bar to flex, resulting in a shallower cutting operation severing the peanuts from the peanut bush.

Plant cane productivity.

Bundaberg experiment

While tillage did not affect sugarcane productivity there was a definite trend for the DD treatment to have lower individual stalk weights and slightly lower CCS than the other tillage treatments (Table 3). The CT treatment had 3% and 5% more cane and sugar yield, respectively, than the DD treatment (Table 3). This result could be in-part due to the 1.57 m row configuration and resulting remnant compaction employed at this site. Encouragingly, the ST treatment was as productive as the CT treatment.

There was a significant effect of N fertiliser application at this experiment, with the addition of N improving cane yield by 13% despite the prior fallow legume (Table 3). While not statistically significant there was also a trend for the additional N to improve sugar yield (p = 0.100). However, despite the addition of 140 kg N/ha only an extra 21 kg N/ha could be accounted for in above-ground biomass and there was no difference in the soil mineral N profile to a depth of 90 cm at harvest of the plant cane crop (56 kg N/ha in CT GCTB cf. 50 kg N/ha in CT GCTB + N) demonstrating low N fertiliser use efficiency.

The application of N fertiliser significantly increased the number of stalks at harvest, although the 15% increase in stalk number was off-set to some extent by a 4% reduction in individual stalk weight (Table 3). There was a trend for the addition of N fertiliser to reduce CCS content

Childers experiment

There was a trend for a reduced plant stand with a reduction in tillage. Despite the trend for lower productivity in the DD treatment, tillage had no effect on final cane and sugar yield (Table 4). Unlike the Bundaberg experiment, this trial received 40 kgN/ha at planting–the recommended application in the Six-Easy-Steps guidelines (Schroeder *et al.,* 2007).

The application of an additional 100 kg N/ha supplied at fill-in significantly increased the number of stalks at harvest, maximum biomass and cane yield by 5, 6 and 5% respectively. However, this improvement did not result in a significant improvement in sugar yield.

Table 3—Tillage and nitrogen impact on plant cane population, individual stalk weight, CCS, cane and sugar yield from the Bundaberg site.

Tillage	Stalks/ha	Individual stalk weight (kg/stalk)	CCS	Cane yield (t/ha)	Sugar yield (t/ha)
Conventional	64 630	1.298	17.2	83.4	14.36
Strip	70 110	1.225	17.0	85.3	14.53
Direct drill	67 510	1.203	16.9	81.3	13.74
LSD (p = 0.05)	ns	ns	ns	ns	ns
Nitrogen					
N0	63 270[b]	1.342	17.21	82.3[b]	14.18
N140	72 470[a]	1.297	17.05	92.9[a]	15.84
LSD (p = 0.05)	5 400	ns	ns	10.29	ns

Values in columns with the same letter are not different (p = 0.05)

Table 4—Tillage and nitrogen impact on plant cane population, CCS, cane and sugar yield from the Childers site.

Tillage	Stalks/ha	CCS	Total biomass (t/ha)	Cane yield (t/ha)	Sugar yield (t/ha)
Conventional	76 632	14.95	152.3	116.2	17.36
Strip	74 615	14.65	147.7	114.4	16.77
Direct drill	73 504	15.11	141.3	111.7	16.87
LSD (p = 0.05)	ns	ns	ns	ns	ns
Nitrogen					
N40	75 541[b]	14.84	146.7[b]	112.4[b]	16.67
N140	79 245[a]	14.81	156.0[a]	117.5[a]	17.41
LSD (p = 0.05)	2 240	ns	5.3	5.06	ns

Values in columns with the same letter are not different (p = 0.05)

There was a significant difference in plant N uptake measured in the above-ground biomass at harvest, with the additional 100 kg N/ha applied at fill-in resulting in only an extra 29.8 kg N/ha in plant uptake. This low fertiliser N use efficiency was similar to that recorded at the Bundaberg site.

The response to N fertiliser additions after grain legume fallows in these two experiments differs from other experiments conducted in the region (Bell *et al.,* 2010; Bell *et al.,* 2003). However, both trials reported in this paper experienced seasonal rainfall that was significantly higher than average (+52% and +22% higher for the Bundaberg and Childers sites, respectively; Figure 1).

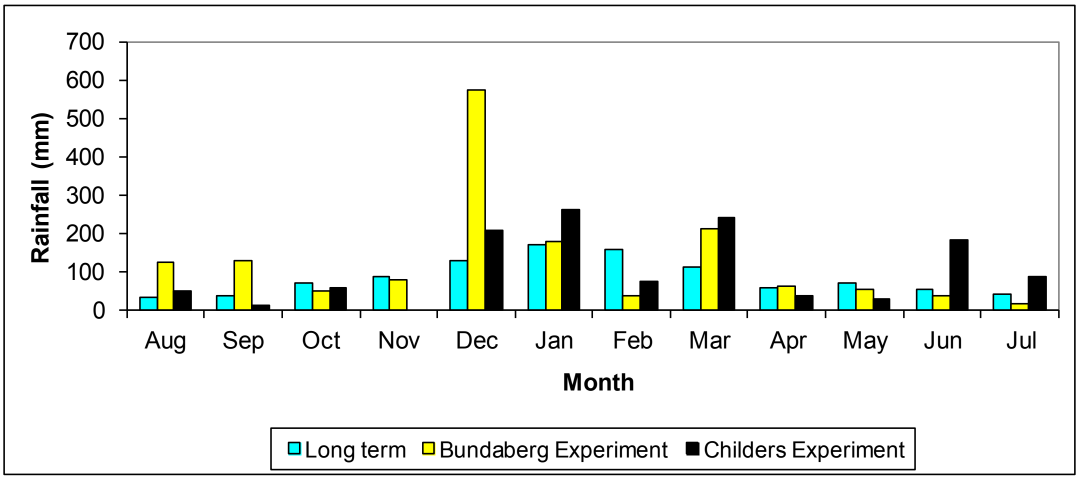

Fig. 1—Rainfall comparison between long term average and measured at the Bundaberg and Childers experiment sites.

This high rainfall could explain the response to additional fertiliser N input after a legume fallow (and indeed contribute to the apparently low fertiliser N use efficiency) as NO_3-N would have been lost through leaching and denitrification.

Conclusion

These data demonstrate that even though soybean productivity was unaffected, unamended soil compaction from the previous cane cycle can limit productivity of peanut break crops. There was also a trend for this remnant compaction to affect the subsequent cane crop. Cane harvest traffic is the most likely cause of this compaction and adoption of appropriate row configurations to minimise compaction is advised for successful reduced tillage farming systems. Further research and machinery modification may be able to improve productivity and harvest efficiency of peanuts in reduced tillage systems.

Retaining the GCTB did not affect legume productivity, particularly in a conventionally tilled system. These data also support previous studies where sugarcane can be successfully produced after legumes, utilising reduced tillage techniques without adversely effecting productivity. This represents a significant opportunity to reduce input costs in coastal farming systems.

Outcomes for future N management in these farming systems are still unclear. The variability between these studies, where positive responses to N fertiliser application were recorded after well grown fallow legumes, and previous findings where no response to additional N fertiliser occurred, present challenges to agronomists and farm managers in southern canelands and indeed across the industry.

The approach to N management after fallow legumes in Six-Easy-Steps (Schroeder *et al.*, 2007), which is to use fertiliser N at planting and reduce or eliminate later fertiliser N applications at fill-in, performed well under challenging seasonal conditions at Childers. However the inefficiency with which fertiliser N was used when applied, even with positive yield responses, represents poor economic returns as well as potential off site impacts through leaching and denitrification. In these studies, the returns on fertiliser N investment (excluding application costs) at current cane (\$39.60 /t cane) and fertiliser (\$1.60 / kg N) prices were <\$1.90 and <\$1.30 for each dollar invested in N fertiliser at Bundaberg and Childers, respectively.

These low returns on fertiliser investment do not include possible residual value in subsequent ratoons, but the lack of additional mineral N in the soil profile after plant crop harvest of treatments receiving additional fertiliser N suggests the residual benefits may be minimal and that losses may have been significant. Large apparent losses were recorded in other studies in both Bundaberg and Ingham (Bell *et al.*, 2010) and the minimisation of such losses is a significant future challenge for sugarcane farming systems. .

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