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Row spacing and planting density effects on the growth and yield of sugarcane. 3. Responses with different cultivars

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Abstract. The promotion of controlled traffic (matching wheel and row spacing) in the Australian sugar industry is necessitating a widening of row spacing beyond the standard 1.5 m. As all cultivars grown in the Australian industry have been selected under the standard row spacing there are concerns that at least some cultivars may not be suitable for wider rows. To address this issue, experiments were established in northern and southern Queensland in which cultivars, with different growth characteristics, recommended for each region, were grown under a range of different row configurations. In the northern Queensland experiment at Gordonvale, cultivars Q187⁽ᵖ⁾, Q200⁽ᵖ⁾, Q201⁽ᵖ⁾, and Q218⁽ᵖ⁾ were grown in 1.5-m single rows, 1.8-m single rows, 1.8-m dual rows (50 cm between duals), and 2.3-m dual rows (80 cm between duals). In the southern Queensland experiment at Farnsfield, cvv. Q138, Q205⁽ᵖ⁾, Q222⁽ᵖ⁾ and Q188⁽ᵖ⁾ were also grown in 1.5-m single rows, 1.8-m single rows, 1.8-m dual rows (50 cm between duals), while 1.8-m-wide throat planted single row and 2.0-m dual row (80 cm between duals) configurations were also included.

There was no difference in yield between the different row configurations at Farnsfield but there was a significant row configuration × cultivar interaction at Gordonvale due to good yields in 1.8-m single and dual rows with Q201⁽ᵖ⁾ and poor yields with Q200⁽ᵖ⁾ at the same row spacings. There was no significant difference between the two cultivars in 1.5-m single and 2.3-m dual rows.

The experiments once again demonstrated the compensatory capacity that exists in sugarcane to manipulate stalk number and individual stalk weight as a means of producing similar yields across a range of row configurations and planting densities.

There was evidence of different growth patterns between cultivars in response to different row configurations (*viz*. propensity to tiller, susceptibility to lodging, ability to compensate between stalk number and stalk weight), suggesting that there may be genetic differences in response to row configuration. It is argued that there is a need to evaluate potential cultivars under a wider range of row configurations than the standard 1.5-m single rows. Cultivars that perform well in row configurations ranging from 1.8 to 2.0 m are essential if the adverse effects of soil compaction are to be managed through the adoption of controlled traffic.

Additional keywords: soil compaction, controlled traffic, multiple rows, stalk number/stalk weight compensation, growth habit.

Introduction

Soil compaction, stool damage, and yield loss (Braunack and Peatey 1999; Garside 2004; Garside *et al*. 2008) associated with heavy harvesting and haul-out machinery and mis-matched wheel (1.8–1.9 m) and row (1.5 m) spacing are major problems in the Australian sugar industry (Robotham 2000). The adoption of controlled traffic is a means by which the adverse effects of soil compaction can be managed. However, controlled traffic can only be implemented if either wheel spacing is narrowed or row spacing widened. A major reason for harvester and haul-out wheel spacing being set at 1.8–1.9 m was for the stability of the heavy machinery in undulating cane fields (Robotham 2000). Further, harvesters and haul-outs represent a major investment in capital equipment. Consequently, the widening of row spacing appears to be a more attractive option for the implementation of controlled traffic providing productivity can be maintained. However, there has been reluctance on the part of growers to adopt wider row spacings for fear of yield penalties. This is not surprising given that a review of row spacing research in the Australian sugar industry by Ridge and Hurney (1994) indicated that yields would be reduced if wider row spacings than 1.65 m were adopted.

In the first two papers of this series (Garside and Bell 2009; Garside *et al*. 2009) it has been shown that, providing soil health is adequate, sugarcane possesses a degree of physiological and environmental plasticity that allows similar yields to be produced from row configurations ranging from 1.5-m single rows up to 2.3-m triple rows, thus permitting the

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adoption of controlled traffic without the concern of yield penalties. Much of the plasticity in sugarcane is associated with the compensatory capacity between stalk number and stalk weight, which appears to be enhanced in healthy soils.

However, there were also indications in the previous reports (Garside and Bell 2009; Garside *et al*. 2009) that when soil health was adequate there were likely to be differential responses to row spacing between current sugarcane cultivars. Thus it was decided to evaluate several regionally adapted cultivars under a range of row spacings in experiments in northern and southern Queensland. In cultivar selection, consideration was given to including cultivars with known differences in growth characteristics (e.g. propensity to tiller and lodge) in order to investigate whether particular growth habits may be best suited to particular row configurations.

Materials and methods

Experiments were established in Queensland cane-growing regions at Gordonvale (17°03′S, 145°47′E) near Cairns in northern Queensland and at Farnsfield (25°101′S, 152°30′E) near Childers in southern Queensland, between 28 June–1 July 2004 and 23–30 September 2005, respectively. Soils were a Brown Dermosol at Gordonvale and a Yellow Dermosol at Farnsfield (Isbell 1996). Both experiments were planted on fully prepared land following well-grown soybean crops with the soybean residue incorporated. The soybean crop at Farnsfield was harvested for grain while the Gordonvale crop was grown as a green manure crop. Treatments varied between experiments, but both included 4 cultivars and split-plot designs with row configurations as main plots and cultivars as subplots. There were 4 and 3 replications in the Gordonvale and Farnsfield experiments respectively.

Four row configurations were used in the Gordonvale experiment: 1.5-m single rows, 1.8-m single rows, 1.8-m dual rows (50 cm between duals), and 2.3-m dual rows (80 cm between duals). All were planted with double-disc opener whole-stalk planters. In the Farnsfield experiment, 5 row configurations were used. These consisted of 1.5-m and 1.8-m single rows and 1.8-m dual rows in common with Gordonvale, plus 2.0-m dual rows (80 cm between duals) and 1.8-m-wide throat single rows. This latter treatment was achieved by using a wide board on the planter shoot to open a furrow 37.5 cm wide into which cane was deposited through a billet planter. All other treatments at Farnsfield were planted with whole-stalk planters but unlike Gordonvale, mouldboard openers were used for all configurations.

Cultivars were selected from the most prominent cultivars used in each region that had relatively diverse growth habits, particularly in terms of their rate of development and sprawling characteristics. On a relative scale from the most sprawling to the most erect, cultivars at Farnsfield were Q138, Q222$^{\phi}$, Q205$^{\phi}$ and Q188$^{\phi}$ and at Gordonvale were Q187$^{\phi}$, Q200$^{\phi}$, Q218$^{\phi}$ and Q201$^{\phi}$. One cultivar at each site (Q188$^{\phi}$ and Q201$^{\phi}$) was reputedly slower developing and less prone to profuse tillering than the others.

Plot size varied in accordance with row configuration at each site. In the Farnsfield experiment, main plots varied from 10.8 to 12 m wide and consisted of 6–8 single or dual rows. Main plot length was 120 m, which was split to 4 × 28 m subplots (the 4 cultivars) with 2-m gaps between each subplot. At Gordonvale, main (row spacing) and subplots (cultivars) were of a similar length as at Farnsfield but all plots were 6 single or dual rows wide with a 5-m gap being left between subplots to allow better access for sampling, making the overall length of each main plot 135 m.

The flow rate for the planters remained the same for the whole-stalk plantings in each experiment, so planting rate was dependent on row configuration. Planting rates were not recorded at Gordonvale but in the Farnsfield experiment the planting rates were 5.23, 4.88, 8.77, and 6.61 eyes/m^2 for the 1.5-m single rows, 1.8-m single rows, 1.8-m dual rows, and 2-m dual rows respectively. Similar relativities can be assumed for Gordonvale. The planting rate of the 1.8-m-wide throat billet planting at Farnsfield was 9.88 eyes/m^2.

Experiment maintenance

Gordonvale

Shirtan® fungicide was applied with the setts at planting to control sett diseases. No fertiliser was applied at planting and in fact the only fertiliser used in the experiment was 112 kg/ha K applied as muriate of potash on 10 September (approx. 70 days after planting, DAP). Adequate nitrogen (approx. 250 kg N/ha) was supplied from the very good soybean green manure crop and plant available phosphorus concentrations were more than adequate for crop growth (60 mg/kg bicarbonate-extractable P). Weed-control strategies were applied as necessary and involved the whole experiment being sprayed with a herbicide mixture of Gesapax Combi® (25% w/v atrazine and 25% w/v ametryn) at 6.8 L/ha and 2,4D at 1.6 L/ha on 27 July (one month after planting). In addition, the herbicides Gesaprim® (60% w/v atrazine) at 2.6 L/ha and 2,4-D at 1.3 L/ha were applied on 29 September, and Velpar K4® (468 g/kg diuron and 132 g/kg hexazinone) at 2.4 kg/ha and Grammoxone® (250 g/L paraquat) at 0.8 L/ha on 30 November. All plots received a light scarifying on 23 October for harvester presentation.

The experiment had supplementary irrigations of 80 mm applied on 17 September, 10 October, and 17 November, but the crop was otherwise rain grown. Hand harvesting of the plant crop was carried out between 25 and 28 July 2005. As the farm had been sold before harvest it was not possible to get machine-harvested yields and there was no chance of taking the experiment into a ratoon.

Farnsfield

Recommended applications of the insecticide Lorsban 500EC® (500 g/L chlorpyrifos, 495 g/L liquid hydrocarbon) at 1.5 L/ha and the fungicide Sportak® (450 g/L prochloraz) at 20 mL/100 L were made at planting. Weed-control strategies were implemented as deemed necessary with the experiment being sprayed with post-plant applications of a mixture of Atradex® (900 g/kg atrazine) at 3 kg/ha, Stomp Xtra® (455 g/L pendimethalin) at 3 L/ha and Sprayseed® (135 g/L paraquat, 115 g/L diquat) at 1.6 L/ha. This was followed by an in-crop directed spray of Sprayseed® at 1.6 L/ha and Velpar K4® (468 g/kg diuron, 132 g/kg hexazinone) at 3 kg/ha shortly after fertiliser side-dressing 2 months after planting. All plots were hilled up using various combinations of tined implements to ensure suitable harvester presentation.

Fertiliser was applied to the experiment to ensure that plant nutrition was adequate. The trial received basal nutrients (42 kg N/ha, 27 kg P/ha, 51 kg K/ha, 23 kg S/ha, 9 kg Zn/ha and 7 kg Cu/ha) as a pre-planting broadcast application that was incorporated during tillage operations. Side-dressing was undertaken 2 months after planting, with 2 bands supplying 100 kg N/ha, 10 kg P/ha, and 72 kg K/ha applied into the outside of each planting bed. Bands were therefore 75-cm apart in the 1.5-m and 1.8-m single row treatments, but 100-cm (1.8-m dual rows) and 130-cm (2.0-m dual rows) apart in the dual row treatments. The application of more nitrogen fertiliser in this experiment compared with Gordonvale was to compensate for the additional N removal during harvest of the soybean seed. Plots were irrigated immediately after planting using a water winch, and then at regular intervals throughout the growing period to avoid any water stress.

Measurements and data collection

Gordonvale

Soon after establishment, permanent areas of 15 m^2 were marked out in the centre 2 rows of each plot to carry out temporal shoot and stalk counts. Shoot counts were carried out at approximately 3-week intervals between 33 and 224 DAP (9 February 2005). Crop density and lodging prevented useful shoot counts being undertaken after this date.

The experiment was also sampled 3 times for biomass accumulation: on 9–10 November 2004, 21–22 February 2005, and 25–28 July 2005 (final harvest), ~4, 8, and 13 months after planting. At each sample time the shoots/stalks in 15 m^2 were counted, cut off at ground level and immediately weighed in the field to measure total fresh biomass. With the 4- and 8-month samples a subsample was taken from each plot, mulched, weighed to measure the fresh weight and then placed in an oven at 70°C until a constant dry weight was attained.

A different procedure was followed with the 13-month final harvest sample in that after the total fresh biomass was measured as above, 15 stalks were randomly selected from the sample and divided into millable stalk (harvestable cane) and tops (immature stalk and leaf) by cutting each stalk between the 5th and 6th youngest leaves. Fresh weight of both was obtained and this allowed the calculation of the percent millable stalk in each biomass sample and thus the millable stalk weight. Subsamples of millable stalk and tops (immature stalk and leaves) were mulched, weighed, and dried (as above) to measure dry weight. Six whole stalks were randomly selected from each plot to measure commercially recoverable sugar (CCS) using NIR methodology (Berding *et al*. 2003). The final harvest area was the permanently marked area where temporal shoot counts had been carried out during the growing period. This allowed a good estimate of the time course of shoot dynamics for the different cultivars and row configurations without confounding effects of within-plot variability.

Farnsfield

Shoot counts were repeatedly taken during the season in a fixed subplot consisting of 5-m length in the centre 2 beds in each plot, with each 'bed' consisting of either a single or a dual row, depending on treatment (i.e. a total sample area, including the associated inter-row space, of 15–20 m^2). These sections were also used for the final harvest area.

Destructive samples to determine crop biomass were taken on 6 January and 4 April 2006, *c*. 3 months and 6 months after planting, from randomly chosen 1-m lengths of the centre 4 beds in each plot, so sample areas (including the associated inter-row space) varied from 6 to 8 m^2, depending on row configuration. Fresh and dry weights were determined from these samples.

At final harvest in late August 2006 (11 months after planting) the marked 5-m lengths × 2 bed areas used for shoot counts during the season were cut by hand from each plot. Subsequent procedures were similar to those detailed for Gordonvale except that CCS was determined by the small-mill method (BSES 1984).

After harvest, fertilisation and weed control measures were implemented and the experiment was grown through to the harvesting of a first ratoon crop in August 2007. Only final cane and sugar yield were measured in the first ratoon crop.

All data for both experiments were subjected to analysis of variance using the GENSTAT statistical package.

Results

Shoot and stalk dynamics

There were significant effects of row configuration and cultivar on shoot development at each site during early growth but these had largely dissipated by harvest maturity: 335 and 390 DAP at Farnsfield and Gordonvale, respectively (Tables 1 and 2). In addition, at Farnsfield there were significant row configuration × cultivar interactions up until maximum shoot numbers were recorded at 104 DAP (Table 2), after which the interaction was no longer significant. At no stage was there a significant row configuration × cultivar interaction at Gordonvale, where maximum shoot numbers were recorded at 146 DAP. The earlier achievement of maximum shoot number at Farnsfield was largely due to this experiment being planted in spring (late September), whereas Gordonvale was planted in winter (late June).

The largest difference in shoot numbers between configurations generally occurred during early growth and was consistent with the different planting rates. These differences decreased as the crop progressed, such that at final harvest there were relatively minor differences in stalk numbers between the different configurations, with the exception that in both experiments there were relatively low final stalk numbers in the 1.8-m single rows (12–20% lower than in 1.5-m single rows, Tables 1 and 2).

Wide throat billet planting greatly enhanced initial shoot numbers at Farnsfield but this effect was very short lived, with 80% more shoots than the 1.5-m configuration recorded at 40 DAP but no difference at 77 DAP (Table 2), presumably due to loss through overcrowding with the wide throat planting. Further, the wide throat planting continued to decline

Table 1. Temporal shoot/stalk growth (shoots/m²) for cvv. Q187ᵠ, Q200ᵠ, Q218ᵠ, and Q201ᵠ planted on row configurations of 1.5-m singles, 1.8-m singles, 1.8-m duals and 2.3-m duals at Gordonvale

Percent data in parentheses are variation from 1.5-m configuration for each sample time

Row config.	Cultivar	71 DAP	106 DAP	146 DAP	206 DAP	390 DAP
1.5-m singles	Q187ᵠ	2.89	7.18	13.78	11.11	8
	Q200ᵠ	2.58	8.8	16.76	13.67	11.48
	Q218ᵠ	2.4	4.78	10.87	10	7.23
	Q201ᵠ	2.09	4.73	11.24	10.76	9.32
	Mean	2.49	6.37	13.16	11.38	9.01
1.8-m singles	Q187ᵠ	2.98	8.62	12.62	10.16	7.68
	Q200ᵠ	3.31	8.27	15.09	11.96	9.07
	Q218ᵠ	1.98	4.51	9.93	8.6	6
	Q201ᵠ	2.07	4.91	11.65	10.38	9.43
	Mean	2.58 (+4%)	6.58 (+3%)	12.32 (–9%)	10.27 (–10%)	8.05 (–12%)
1.8-m duals	Q187ᵠ	4.87	8.58	17.8	13.29	8.91
	Q200ᵠ	5.27	15.29	24.22	15.82	11.6
	Q218ᵠ	4.38	8.98	15.71	12.07	8.23
	Q201ᵠ	4.49	10.89	18.96	14.58	11.37
	Mean	4.75 (+90%)	10.93 (+72%)	19.17 (+46%)	13.94 (+22%)	10.03 (+12%)
2.3-m duals	Q187ᵠ	3.4	9.53	15.35	12.47	8.12
	Q200ᵠ	3.64	13.11	21.33	15	11.58
	Q218ᵠ	2.58	5.62	13.11	10.91	7.21
	Q201ᵠ	2.42	5.93	15.18	12.98	9.85
	Mean	3.01 (+21%)	8.55 (+34%)	16.24 (+23)	12.84 (+13%)	9.19 (+2%)
Sig. effects (l.s.d. 5%)	*Config.*	*P < 0.05 (1.45)*	*P = 0.05 (3.35)*	*P < 0.01 (2.51)*	*P < 0.001 (1.13)*	*n.s.d.*
	Cult.	*P < 0.05 (0.68)*	*P < 0.001 (1.61)*	*P < 0.001 (1.20)*	*P < 0.001 (0.81)*	*n.s.d.*
	Config. × Cult.	*n.s.d.*	*n.s.d.*	*n.s.d.*	*n.s.d.*	*n.s.d.*

relative to the standard 1.5-m planting such that the wide throat treatment had 20% fewer shoots at 104 DAP (peak shoot numbers) and 9% fewer stalks at final harvest, although differences were not statistically significant at the latter sampling. It was also interesting to note the numerical differences between the wide throat planting, the single rows on 1.8 m and the dual rows on 1.8 m. The planting rates were 4.88, 8.77, and 9.88 eyes/m² for the 1.8-m single rows, 1.8-m dual rows and 1.8 m single wide throat rows, respectively, yet at final harvest the wide throat had only 9% more stalks than the 1.8-m singles rows and 13% fewer stalks than the 1.8-m dual rows (Table 2).

Cultivar differences largely reflected rapid early growth and tillering of Q200ᵠ at Gordonvale and Q138 at Farnsfield and slower development of the other three cultivars at each site, particularly Q188ᵠ at Farnsfield and Q201ᵠ at Gordonvale. The cultivars with rapid early growth and tillering (Q138 at Farnsfield and Q200ᵠ at Gordonvale) tended to lodge quite badly before crop harvest, whereas the slower developing cultivars, Q188ᵠ at Farnsfield and Q201ᵠ at Gordonvale, tended to remain erect through to final harvest.

Seasonal biomass production

There were significant cultivar differences in biomass production for all sampling dates in both experiments but these were not necessarily consistent between sampling dates (Tables 3 and 4). At Gordonvale, with the exception of the 4-month sampling date, Q187ᵠ always produced the lowest biomass regardless of row configuration. Cultivar Q218ᵠ was only slightly better and its shoot/stalk numbers were always lower than for the other cultivars, although it seemed to perform better in 1.8-m dual rows (8- and 13-month samples; Table 3). The early sample date (4 month) provided an indication of the early growth rates of the cultivars, with Q200ᵠ and Q187ᵠ growing rapidly compared with Q201ᵠ, and Q218ᵠ being intermediate (Table 3). These relativities changed with later samplings, with the most interesting responses revolving around the growth of Q200ᵠ and Q201ᵠ in the different row configurations. For the 8- and 13-month samples these two cultivars produced the highest biomass (Table 3), but each cultivar was advantaged by different row configurations. A significant row configuration × cultivar interaction for both the 8 ($P < 0.01$) and 13 ($P < 0.05$) month samples showed Q200ᵠ having the highest biomass in 1.5-m single and 2.3-m dual rows while Q201ᵠ had the highest biomass in the 1.8-m single and dual rows.

Except for the first sampling at 4 months, there was no significant main effect of row configuration. It was also interesting to consider the biomass accumulation during the different parts of the growing season, particularly for the final period (8–13 months, Table 3). These data show that Q201ᵠ and Q218ᵠ accumulated a greater percentage of their final biomass during this period compared with Q200ᵠ, which was lodged during this final growing period. Further, the percent dry matter in the stalks harvested at 13 months was higher in Q200ᵠ at 32.7% compared with the other cultivars, which were all around 29% (data not presented). These data tend to suggest that Q200ᵠ was drier and probably more mature than the other cultivars at final harvest.

Table 2. Temporal shoots/m^2 for cvv. Q138, Q222$^{\Phi}$, Q205$^{\Phi}$ and Q188$^{\Phi}$ planted on row configurations of 1.5-m singles, 1.8-m singles, 1.8-m wide throat, 1.8-m duals and 2.3-m duals at Farnsfield

Percent data in parentheses are variation from 1.5-m configuration for each sample date

40 DAP	77 DAP	104 DAP	138 DAP	187 DAP	335 DAP
4.2	16.29	18.93	13.78	11.71	10.73
4.47	14.53	14.2	11.31	10.73	10.6
4.82	15.11	15.09	11.95	9.8	10.18
3.47	11.4	12.47	10.56	9.8	9.36
4.24	14.33	15.17	11.89	10.5	10.21
3.94	11.26	13.87	11.31	10.07	9.11
3.57	10.26	9.37	8.59	8.2	8.35
3.76	10.76	10.26	9.13	8.46	8.02
2.33	7.65	8.22	7.28	7.61	7.13
3.40 (–20%)	9.98 (–31%)	10.43 (–32%)	9.08 (–24%)	8.59 (–19%)	8.15 (–20%)
8.33	17.89	15.3	11.94	10.93	10.24
7.3	11.56	9.7	9.2	9.07	9.32
9.13	15.65	12.69	10.2	9.3	9.09
6.02	12.7	10.54	9.28	8.83	8.69
7.69 (+80%)	14.45 (0%)	12.06 (–21%)	10.16 (-15%)	9.53 (–9%)	9.33 (–9%)
6.32	20.76	24.52	16.22	12.37	11.43
4.72	16.07	15.17	12.74	10.94	11.06
6.04	17.5	17.43	12.96	9.91	10.11
4.11	14.56	15.13	12.61	9.82	9.85
5.30 (+25%)	17.22 (+20%)	18.06 (+19%)	13.63 (+15%)	10.76 (+2%)	10.61 (+4%)
5.55	18.12	19.97	15.18	11.83	10.92
4.67	15.33	15.28	13.17	11.4	10.35
5.17	15.82	16.33	13.23	10.77	10.33
3.52	12.72	14.68	11.87	10.12	9.77
4.73 (+12%)	15.50 (+8%)	16.57 (+9%)	13.36 (+12%)	11.03 (+5%)	10.34 (+1%)
P < 0.001 (0.73)	*P < 0.001 (1.77)*	*P < 0.001 (1.25)*	*P < 0.001 (1.18)*	*P < 0.01(0.93)*	*P < 0.001(0.91)*
P < 0.001 (0.35)	*P < 0.001 (0.77)*	*P < 0.001 (0.74)*	*P < 0.001 (0.43)*	*P < 0.001(0.44)*	*P < 0.001(0.40)*
P < 0.05 (0.95)	*P < 0.01 (2.18)*	*P < 0.01 (1.80)*	*n.s.d.*	*n.s.d.*	*n.s.d.*

Similar overall trends were apparent at Farnsfield, where there were significant cultivar differences at each sample date. As with Q201$^{\Phi}$ at Gordonvale, Q188$^{\Phi}$ had significantly lower biomass than the other cultivars at 4 months, but its relative biomass production increased substantially with the 8- and 11-month samples. There was also a clear similarity in the behaviour of Q138 at Farnsfield and Q187$^{\Phi}$ at Gordonvale, with Q138 having similar biomass to the other cultivars (Q222$^{\Phi}$, Q205$^{\Phi}$) at 4 months but significantly lower thereafter. After the 4 month sampling there was no significant effect of row configuration, and unlike Gordonvale, there was no significant row configuration × cultivar interaction.

Plant cane yield, yield components, CCS, and sugar yield

In the Farnsfield experiment, row configuration had no effect on plant cane yield, CCS or sugar yield (Table 5). However, row configuration did have a significant effect on the final number of stalks/m^2 and individual stalk weight such that lower stalk numbers resulted in higher individual stalk weights and *vice versa*. This compensatory ability therefore limited the effects of either attribute on cane yields. For example, stalk populations of 10.61/m^2 in the 1.8-m dual rows weighed 1.14 kg/stalk, while stalk populations of 8.15 stalks/m^2 in 1.8-m single rows weighed 1.44 kg/stalk (Table 5).

There were substantial cultivar differences for all yield components, with Q205$^{\Phi}$ and Q222$^{\Phi}$ producing higher cane and sugar yields than Q138. The latter cultivar lodged badly in this experiment and this is likely to have contributed to the poor yields.

In large part the Gordonvale responses were similar to Farnsfield (Table 6). There was no main effect of row configuration on plant cane yield, CCS, or sugar yield but there were significant cultivar effects, with Q201$^{\Phi}$ out-yielding the other cultivars for both cane and sugar yield. The compensatory stalk number/individual stalk weight responses noted at Farnsfield were also evident, with the compensatory effect particularly noticeable in the 2.3-m dual row configuration where final yield for each cultivar was very similar (122–126 t/ha). In this instance, 7.22 stalks/m^2 of Q218$^{\Phi}$ each weighed 1.74 kg while 11.58 stalks/m^2 of Q200$^{\Phi}$ only weighed 1.05 kg each. The big difference between the Farnsfield and Gordonvale experiments was that there were significant row configuration × cultivar interactions for cane and sugar yield in the latter experiment. These responses mainly revolved around the growth of Q200$^{\Phi}$ and Q201$^{\Phi}$ in the different row configurations. Essentially, Q200$^{\Phi}$ yielded as well for both cane and sugar as Q201$^{\Phi}$ in the 1.5-m single rows and the 2.3-m dual rows but significantly less in the 1.8-m single and dual rows (Table 6).

Table 3. Temporal biomass production (t/ha dry weight) for cultivar Q187$^{\Phi}$, Q200$^{\Phi}$, Q218$^{\Phi}$ and Q201$^{\Phi}$ grown in row configurations of 1.5 m singles, 1.8 m singles, 1.8 m duals and 2.3 m duals at Gordonvale

Data in parentheses for the July 2005 sample represents the percentage of the final biomass accumulated in the last 5 months

Sample date	Row config.	Cultivar				Mean	Level of signif.	l.s.d. 5%
		Q187$^{\Phi}$	Q200$^{\Phi}$	Q218$^{\Phi}$	Q201$^{\Phi}$			
4 month (Nov. 2004)	1.5-m single	1.64	1.99	1.31	0.86	1.45	*P* < *0.05*	*0.50*
	1.8-m single	1.82	1.51	1.02	1.06	1.35		
	1.8-m dual	2.02	2.29	2.18	1.89	2.09		
	2.3-m dual	2.4	2.49	1.56	0.93	1.85		
	Mean	1.97	2.07	1.52	1.19			
	Level of signif.		*P* < *0.001*				*Config.* × *cultivar, n.s.d.*	
	l.s.d. 5%		*0.36*					
8 month (Feb. 2005)	1.5-m single	12.44	18.25	15.14	14.36	15.05	*n.s.d.*	
	1.8-m single	14.05	15.29	13.31	19.48	15.53		
	1.8-m dual	11.73	17.14	18.82	18.06	16.42		
	2.3-m dual	19.39	19.89	12.61	13.4	16.32		
	Mean	14.4	17.9	14.68	16.33			
	Level of signif.		*P* = *0.01*				*Config.* × *cultivar, P* < *0.01*	
	l.s.d. 5%		*2.21*				*4.69*	
13 month (July 2005)	1.5-m single	37.73	46.05	39.67	44.19	41.91	*n.s.d.*	
	1.8-m single	38.98	36.11	35.16	45.09	38.83		
	1.8-m dual	36.75	40.99	43.9	49.18	42.71		
	2.3-m dual	38.28	43.49	41.48	40.06	40.83		
	Mean	37.93 (*62%*)	41.66 (*57%*)	40.05 (*63%*)	44.63 (*64%*)			
	Level of signif.		*P* < *0.01*				*Config.* × *cultivar, P* < *0.05*	
	l.s.d. 5%		*3.3*				*6.4*	

Table 4. Temporal biomass production (t/ha dry weight) for cvv. Q138, Q222$^{\Phi}$, Q205$^{\Phi}$ and Q188$^{\Phi}$ grown in row configurations of 1.5-m singles, 1.8-m singles, 1.8-m wide throat planting, 1.8-m duals and 2.3-m duals at Farnsfield

Data in parentheses for the August 2006 sample represents the percentage of final biomass accumulated in the last 5 months

Sample date	Row config.	Cultivar				Mean	Level of signif.	l.s.d. 5%
		Q138	Q222$^{\Phi}$	Q205$^{\Phi}$	Q188$^{\Phi}$			
3 month (Jan. 2006)	1.5-m single	5.42	6.14	5.36	4.23	5.29	*P* < *0.01*	*0.71*
	1.8-m single	3.96	4.72	4.08	2.67	3.86		
	1.8-m WT	6.24	5.88	7.11	4.2	5.86		
	1.8-m dual	5.06	6	5.75	4.34	5.29		
	2.0-m dual	5.34	6.44	6.39	4.18	5.59		
	Mean	5.2	5.84	5.74	3.92			
	Level of signif.		*P* < *0.001*				*Config.* × *cultivar, n.s.d.*	
	l.s.d. 5%		*0.48*					
6 month (Apr. 2006)	1.5-m single	31.23	36.29	34.54	33.2	33.82	*P* = *0.08*	
	1.8-m single	28.14	35.14	30.47	35.49	32.32		
	1.8-m WT	35.08	38.35	42.52	36.19	38.04		
	1.8-m dual	33	32.8	33.51	37.69	34.25		
	2.0-m dual	31.57	38.82	32.52	33.98	34.22		
	Mean	31.8	36.28	34.71	35.31			
	Level of signif.		*P* < *0.05*				*Config.* × *cultivar, n.s.d.*	
	l.s.d. 5%		*2.83*					
11 month (Aug. 2006)	1.5-m single	37.05	49.07	46.58	47.06	44.39	*n.s.d.*	
	1.8-m single	41.71	48.1	44.15	44.33	44.57		
	1.8-m WT	41.12	49.4	48.85	44.59	45.99		
	1.8-m dual	41.25	52.24	46.63	47.69	46.95		
	2.0-m dual	42.57	47.64	47.8	45.69	45.92		
	Mean	40.74 (*22%*)	49.07 (*26%*)	46.58 (*26%*)	45.87 (*23%*)			
	Level of signif.		*P* < *0.001*				*Config.* × *cultivar, n.s.d.*	
	l.s.d. 5%		*2.13*					

Table 5. Cane yield (t/ha), stalks/ m^2, stalk weight (ISW) (kg), CCS (% fresh wt) and sugar yield (t/ha) for cvv. Q138, Q222$^{\phi}$, Q205$^{\phi}$ and Q188$^{\phi}$ planted in 1.5- and 1.8-m single rows, 1.8-m wide throat rows, and 1.8- and 2.3-m dual rows at Farnsfield

Row config.	Parameter	Cultivar				Row config.	*Level of signif. & l.s.d.5%*	
		Q138	Q222$^{\phi}$	Q205$^{\phi}$	Q188$^{\phi}$	means	Row config.	Row config. × cultivar
1.5-m single	Cane yield	115	114	128	115	118	*n.s.d.*	*n.s.d.*
	Stalks/m^2	10.73	10.6	10.18	9.36	10.22	*P = 0.001, 0.91*	*n.s.d.*
	ISW	1.06	1.13	1.28	1.23	1.15	*P < 0.01, 0.12*	*n.s.d.*
	CCS	11.23	14.09	12.03	13.32	12.67	*n.s.d.*	*n.s.d.*
	Sugar yield	12.91	16.12	15.51	15.36	14.98	*n.s.d.*	*n.s.d.*
1.8-m single	Cane yield	107	125	119	113	116		
	Stalks/m^2	9.11	8.35	8.02	7.13	8.15		
	ISW	1.25	1.43	1.45	1.62	1.44		
	CCS	11.14	13.18	12.76	13.79	12.72		
	Sugar yield	12.57	16.65	15.13	15.5	14.96		
1.8-m wide throat	Cane yield	113	122	129	116	120		
	Stalks/m^2	10.24	9.32	9.09	8.69	9.33		
	ISW	1.09	1.36	1.47	1.5	1.35		
	CCS	12.08	14.64	13.17	13.11	13.25		
	Sugar yield	13.66	17.85	16.96	15.08	15.89		
1.8-m duals	Cane yield	111	123	118	117	117		
	Stalks/m^2	11.43	11.06	10.11	9.85	10.61		
	ISW	1.08	1.15	1.14	1.2	1.14		
	CCS	11.21	13.57	13.36	13.88	13		
	Sugar yield	12.42	16.71	15.76	16.07	15.24		
2.0-m duals	Cane yield	113	121	124	113	118		
	Stalks/m^2	10.92	10.35	10.33	9.77	10.34		
	ISW	1.02	1.16	1.15	1.35	1.17		
	CCS	9.92	13.65	13.3	13.51	12.59		
	Sugar yield	11.9	16.41	15.54	15.26	14.78		
Cultivar means	Cane yield	112	121	124	115			*P < 0.01, 6.57*
	Stalks/m^2	10.49	9.93	9.55	8.96			*P < 0.001, 0.40*
	ISW	1.1	1.25	1.28	1.38			*P < 0.001, 0.06*
	CCS	11.11	13.83	12.92	13.52			*P < 0.001, 0.67*
	Sugar yield	12.69	16.75	15.78	15.46			*P < 0.001, 1.03*

First ratoon cane and sugar yield

The Farnsfield experiment was taken into a first ratoon crop and harvested in August 2007 at 12 months of age. There were no significant row configuration effects on cane yield, CCS, or sugar yield (Table 7), although there was a trend for higher cane and sugar yields for the 1.8-m wide throat planting ($P = 0.11$ for cane and 0.09 for sugar). Cultivar differences were again highly significant, with Q205$^{\phi}$ producing the highest cane and sugar yields. Interestingly, although Q222$^{\phi}$ produced similar cane and a higher sugar yield than Q205$^{\phi}$ in the plant crop, it produced the lowest cane yield in the first ratoon. Whether this was associated with harvester damage while harvesting the plant crop is not known.

Discussion

The damage caused by soil compaction during sugarcane harvest and haulage is increasingly being recognised as a major constraint to the long-term profitability and sustainability of the Australian sugar industry. Similarly, there is increasing recognition that controlled traffic cropping systems will address many of these compaction issues, while also enabling cost savings and other benefits from minimum or zero tillage (Garside *et al*. 2005; Stirling 2008). In order to facilitate the change to controlled traffic, adoption of row spacings that match machinery wheel spacings and that are wider than the current 1.5 m is essential (Robotham 2000). However, there remains considerable confusion about which row spacing to adopt, and what planting rate (whole stalk planting *v.* billet planting) and configuration (single row *v.* dual row) to use in different situations (irrigated *v.* dryland, northern *v.* southern production areas). The results presented in this paper address some of those issues, but also raise the possibility of significant genotype × row configuration interactions in which cultivar growth habit (propensity to tiller, time to 'maturity'/optimum sugar yield, susceptibility to lodging, and ability to compensate for lower stalk numbers by increasing individual stalk weight) requires further study.

In these experiments, contrasting environments in northern and southern Queensland were combined with carefully selected cultivars with different growth habits, particularly in terms of early growth and tillering and propensity to lodge. It was envisaged that cultivars with rapid early growth and tillering (i.e. Q138, Q187$^{\phi}$, Q200$^{\phi}$) may be best suited to wide row configurations (e.g. 1.8-m single rows), as they would achieve

Table 6. Cane yield (t/ha), stalks/ m^2, stalk weight (ISW) (kg), CCS (% fresh wt) and sugar yield (t/ha) for cvv. Q187$^{\phi}$, Q200$^{\phi}$, Q218$^{\phi}$ and Q201$^{\phi}$ planted in 1.5- and 1.8-m single rows and 1.8- and 2.3-m dual rows at Gordonvale

Row config.	Parameter	Cultivar Q187$^{\phi}$	Q200$^{\phi}$	Q218$^{\phi}$	Q201$^{\phi}$	Row config. means	*Level of signif. & l.s.d.5%* Row config.	Row config. × cultivar
1.5-m single	Cane yield	117	124	123	131	124	*n.s.d.*	*P* < 0.01, 17.6
	Stalks/m^2	8	11.48	7.23	9.32	9.0	*P* < 0.01, 0.94	*P* < 0.05, 1.2
	ISW	1.47	1.08	1.71	1.4	1.42	*P* < 0.01, 0.10	*n.s.d.*
	CCS	14.95	16.15	16.11	14.9	15.53	*n.s.d.*	*n.s.d.*
	Sugar yield	17.48	20.08	19.82	19.35	19.18	*n.s.d.*	*P* < 0.01, 3.03
1.8-m single	Cane yield	118	104	111	139	118		
	Stalks/m^2	7.68	9.07	6	9.43	8.05		
	ISW	1.53	1.15	1.85	1.48	1.5		
	CCS	15.85	16.38	15.34	14.75	15.58		
	Sugar yield	18.63	17.07	16.96	20.41	18.26		
1.8-m duals	Cane yield	104	113	132	151	125		
	Stalks/m^2	8.91	11.6	8.23	11.37	10.03		
	ISW	1.17	0.98	1.61	1.33	1.27		
	CCS	16.28	16.06	14.73	15.68	15.69		
	Sugar yield	16.99	18.21	19.4	23.65	19.56		
2.3-m duals	Cane yield	124	122	126	122	124		
	Stalks/m^2	8.12	11.58	7.22	9.85	9.19		
	ISW	1.53	1.05	1.74	1.25	1.39		
	CCS	15.73	16.53	15.21	14.84	15.58		
	Sugar yield	19.44	20.19	20.2	18.09	19.48		
Cultivar means	Cane yield	115	116	123	136		*P* < 0.001, 8.27	
	Stalks/m^2	8.12	10.93	7.17	9.99		*P* < 0.001, 0.48	
	ISW	1.43	1.07	1.73	1.37		*P* < 0.001, 0.09	
	CCS	15.71	16.28	15.35	15.04		*P* < 0.001, 0.58	
	Sugar yield	18.13	18.89	19.09	20.37		*P* < 0.05, 1.42	

Table 7. First ratoon cane yield (t/ha), CCS and sugar yield (t/ha) for cvv. Q138, Q222$^{\phi}$, Q205$^{\phi}$ and Q188$^{\phi}$ planted in 1.5- and 1.8-m single rows, 1.8-m wide throat rows, and 1.8- and 2.3-m dual rows at Farnsfield

Row config.	Parameter	Cultivar Q138	Q222$^{\phi}$	Q205$^{\phi}$	Q188$^{\phi}$	Row config. means	*Level of signif. & l.s.d.5%* Row config.	Row config. × cultivar
1.5-m single	Cane yield	109	111	117	122	115	*n.s.d.*	*n.s.d.*
	CCS	13.27	15.56	14.27	14.77	14.67	*n.s.d.*	*n.s.d.*
	Sugar yield	14.54	17.5	18.83	17.82	16.63	*n.s.d.*	*n.s.d.*
1.8-m single	Cane yield	114	102	144	111	119		
	CCS	13.33	15.66	14.72	15.02	14.68		
	Sugar yield	15.21	16	21.19	15.21	17.51		
1.8-m wide throat	Cane yield	126	115	140	130	128		
	CCS	13.5	16.33	14.17	15.07	14.77		
	Sugar yield	16.91	18.81	19.8	19.6	18.78		
1.8-m duals	Cane yield	122	107	131	114	119		
	CCS	12.73	16.41	14.67	15.21	14.75		
	Sugar yield	14.47	17.58	19.29	17.25	17.15		
2.0-m duals	Cane yield	123	115	113	111	116		
	CCS	12.62	15.59	14.47	14.86	14.39		
	Sugar yield	15.54	17.89	17.16	16.54	16.78		
Cultivar means	Cane yield	119	110	129	119		*P* = 0.01, 10.57	
	CCS	13.09	15.91	14.46	14.99		*P* = 0.001, 0.41	
	Sugar yield	15.33	17.5	18.83	17.82		*P* = 0.001, 1.62	

full ground cover more rapidly and make better use of incident solar radiation. Conversely, cultivars with a lower tillering propensity were expected to be more suited to narrower row configurations. In effect, the responses here indicate that the reverse may often occur, with cultivars that have rapid early growth and tillering often lodging and yielding poorly in wider rows (e.g. the relatively low yield of the rapid early developing cv. Q200$^{\phi}$ and the relatively high yield of the slow late developing cv. Q201$^{\phi}$ in 1.8-m rows at Gordonvale).

Overall, the data from these experiments showed that there were cultivar differences in the response to row configuration, with clear differences in the rate of shoot development (Table 2) and biomass accumulation (Table 3) between cultivar–row configuration combinations in each experiment. Additionally, we observed that in the 1.8-m dual rows the individual rows in Q187$^{\phi}$ and Q200$^{\phi}$ at Gordonvale and Q138 at Farnsfield tended to display ‘shyness’ and grow away from each other and this tended to promote lodging. By contrast, Q201$^{\phi}$ at Gordonvale and Q188$^{\phi}$ at Farnsfield developed more slowly, produced fewer tillers, and did not lodge in any of the row configurations. In fact, Q201$^{\phi}$ and Q188$^{\phi}$ were characterised by fewer larger stalks that remained erect, with this slower and more ordered development helping to maximise biomass production by the time of the final harvest.

The differences in developmental cultivar response to row configuration were not necessarily reflected in cane yields (Tables 5 and 6), due to a combination of stalk number/stalk weight compensation and differences in lodging and rates of late season biomass accumulation (‘maturity’). We detected no significant effects of row configuration on CCS in these studies, although there certainly were cultivar differences (Tables 5, 6 and 7), so any differences in sugar yields were driven by the differences in cane yields which form the basis of all subsequent discussions.

As with the results presented in the first two papers of this series (Garside and Bell 2009; Garside *et al*. 2009) there was strong evidence of the physiological plasticity that sugarcane possesses in being able to compensate for fewer stalks with larger stalks (Tables 5 and 6). In the Farnsfield experiment there was no response to row configuration across a range of quite diverse cultivars because of this capacity to compensate, with the average 30% greater stalk numbers in 1.8-m dual rows compensated by individual stalk weights that were on average 26% greater in 1.8-m single rows (Table 5), and no significant cultivar × row configuration interaction. However, while cultivars in the Gordonvale experiment also showed these compensatory characteristics (Table 6), there were significant cultivar × row configuration interactions for stalk number and cane yield, indicating that under the northern Queensland environment not all cultivars were able to fully compensate for fewer stalks by proportional increases in individual stalk weight. Possibly late-season water stress may have been implicated in these responses.

It seems that the cultivars exhibiting profuse tillering and rapid early growth traits (Q138, Q187$^{\phi}$ and Q200$^{\phi}$) also tended to lodge earlier, and although we cannot say whether this resulted in yield loss in this study (due to the relatively infrequent biomass samplings), there is certainly evidence that the relative rate of biomass production in these cultivars slowed in the second half of the growing season after lodging had occurred (Tables 3 and 4). In other studies, Muchow *et al*. (1994) and Singh *et al*. (2002) both showed that lodging can result in either cessation of biomass accumulation in the latter stages of crop growth, or even biomass loss if the lodging is associated with substantial stalk death.

Interestingly, the treatments where the gap between the dual rows was 50 cm tended to lodge earlier than the single rows and the 2.3-m dual row configuration where there was an 80-cm gap between the dual rows. This was consistent with the earlier observation that closely spaced dual rows tended to bow out and away from each other in some cultivars, so it would appear that the issue of the gap between rows within dual row configurations warrants further investigation.

The issue of relative maturation of the different cultivars and the potential advantages of differences in rates of maturation may also be an important component in relative performance in differing row configurations. An example may be Q200$^{\phi}$, which yielded poorly in the Gordonvale experiment despite being regarded as one of the most suitable cultivars for northern Queensland environments. The exact reasons cannot be identified from these experiments, but one possibility lies in relative rates of maturation of Q200$^{\phi}$ compared with the other cultivars in the study. The relatively infrequent biomass sampling did not allow the rate of dry matter accumulation to be used to assess relative maturity in this study. However, Q200$^{\phi}$ had higher stalk % dry matter than the other three cultivars grown at Gordonvale (data not shown), with this characteristic often associated with more advanced stalk maturation. This observation, combined with the early advantages in dry matter production followed by relatively poor dry matter production from 8 to 13 months after planting (Table 3), suggests that Q200$^{\phi}$ may have performed better in relative terms if the experiment had been harvested earlier (e.g. at 11–12 months). Conversely, the lower stalk % dry matter recorded by Q201$^{\phi}$, combined with a developmental pattern that produced fewer large erect stalks with no lodging, may have contributed to Q201$^{\phi}$ producing the most biomass in that study.

The situation at Farnsfield was less clear because at that site the cultivar which was characterised by slow early growth, a low number of large erect stalks and no lodging was Q188$^{\phi}$ (Table 4), which had the second highest stalk % dry matter (28.0%, compared with Q222$^{\phi}$ with 28.9%). While it is tempting to speculate that the reason Q188$^{\phi}$ did not overtake Q205$^{\phi}$ and Q222$^{\phi}$ in biomass production (despite the latter two cultivars experiencing some lodging) was due to the shorter (11-month) growing season reducing the effect of greater relative growth rates late in the season (as observed for Q201$^{\phi}$), it may also have been partly due to earlier maturity. The only cultivar at Farnsfield that showed relatively slower biomass accumulation during the second half of the growing season was Q138, which had the lowest stalk % dry matter (24.4%) but also lodged the earliest and the most extensively. Further investigation of the relative importance of such cultivar characteristics to yield potential and performance in contrasting environments is clearly warranted.

Collectively, these studies suggest that in addition to soil health and environmental factors (Garside *et al*. 2009) affecting the relative performance of different row configurations and planting densities, the Gordonvale results suggest that cultivars may also be an important consideration. At this site, Q200$^{\phi}$ and Q187$^{\phi}$ performed quite differently in the

1.8-m single rows, with the former yielding very poorly while Q187$^{\phi}$ produced as good a yield as in the 1.5-m singles and 2.3-m dual rows. Both Q200^{A} and Q187$^{\phi}$ performed particularly poorly in the 1.8-m dual rows while Q201$^{\phi}$ yielded exceptionally well in the same configurations (Table 6). This type of genotype × row configuration interaction may be part of the reason for the reluctance of many growers to change to 1.8-m dual rows to achieve controlled traffic. Although there have been numerous reports that yields can be maintained with 1.8-m row spacing if dual rows are used (Hurney *et al*. 1979; Ridge and Hurney 1994; Garside *et al*. 2009), previous commercial results with dual row plantings on 1.8-m row configurations have been variable. An example would be the relatively poor yield with Q170$^{\phi}$ in dual rows at Mackay in these experiments (Garside *et al*. 2009).

These results suggest that attention needs to be devoted to determining whether the current practice of selecting all cultivars under a single (currently 1.5-m single rows) row configuration is still appropriate. The cultivar × row configuration responses measured with Q200$^{\phi}$ and Q201$^{\phi}$ at Gordonvale suggest that there is diversity in the genetic pool that may be used to improve productivity under the wider row configurations that will characterise future controlled traffic farming systems. Interestingly, the differential performance in 1.8-m rows by these cultivars was accompanied by no significant differences in cane yield between the cultivars when they were grown on 1.5-m single rows (Table 6). Further work in this area is clearly warranted.

In the interim, the move towards wider rows and controlled traffic by growers needs to consider the environmental conditions under which the sugarcane crop will be grown. The data presented in the previous and current papers of this series indicate that yield penalties are not likely to result with row spacings between 1.8 m and 2.3 m providing dual rows are used. However, under conditions in which there is every opportunity to compensate for lower stalk numbers by maximising dry matter accumulation, and hence individual stalk weights, during stalk filling there is likely to be little, if any, yield difference between 1.8-m single and dual rows. These conditions would be met under drier tropical and subtropical environments with irrigation. It is unlikely, however, that this could be extrapolated to 2.0-m single rows without a yield penalty, at least with the plant crop, although this has not been tested here.

One essential consideration in moving to wider rows will be to ensure adequate plant densities in the row, especially in 1.8-m single rows. The instances where 1.8-m single rows yielded less than 1.5-m single rows (Garside *et al*. 2009) were often where establishment in those arrangements was poor and the number of primary shoots was low. This can often be the result of a combination of poor quality planting material and whole stalk planters, and can be overcome by billet planting with a wide throat planting shoot, as undertaken at Farnsfield (Table 2). Although this method provided no significant yield advantage in the plant or 1st ratoon crop in that study (Tables 5 and 7), and required *c.* twice the amount of planting material per hectare, there were greater stalk numbers in this treatment compared with the 1.8-m single rows (14% in the plant crop and 11% in the 1st ratoon). This suggests that 1.8-m wide throat billet planting may be less susceptible to yield losses associated with suboptimal growing conditions during stalk filling, and so may represent a less risky option of achieving controlled traffic without adopting dual rows. Further studies of the relative susceptibility of whole stalk and wide throat billet planted single rows under stress conditions during stalk filling are required to confirm this hypothesis.

Finally, there are many benefits to be gained from the adoption of controlled traffic in sugarcane cropping systems (Garside *et al*. 2005). The studies reported in this paper and others in the series (Garside and Bell 2009; Garside *et al*. 2009) suggest that there are several ways of achieving these outcomes in the farming system, using currently available cultivars, with minimal or no risk of a loss in productivity. However, further studies will be needed to ensure that plant improvement programs continue to produce cultivars that are suited to the changing row configurations necessary to optimise system productivity in the longer term. A better understanding of the desirable characteristics of cultivars to best suit wider row spacings should be a primary objective of future research in this area.

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