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FINAL REPORT - SRDC PROJECT BSS212

INVESTIGATION OF THE LIMITS TO HIGH DENSITY PLANTING

by

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SD02016

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SUMMARY

Plant-density trials were successful in demonstrating the effect of row spacing and within-row plant spacing on cane yield. Increasing plant density resulted in an increase in cane yield and stalk numbers at harvest. Cane yield increases almost linearly as row spacing reduces from 1.5 m to 0.5 m, but there was little change in cane yield as row space reduced further to 0.125 m. Increasing within-row plant spacing by double and quadruple the planting rate tended to result in significant, but relatively small, increases in cane yield in all three row-spacing treatments. Altering row spacing had a larger effect on cane yield than increasing the within row planting rate. Both trials show the importance of good establishment regardless of row spacing used. No significant cultivar interaction was measured for any of the yield attributes measured in the trials.

Irrigation rate trials successfully demonstrated that with the same inputs the four rows on 2.1 m bed-system increased cane production and water-use efficiency particularly under low-water regimes. A yield response to the irrigation regimes was measured in both trials. The soil-moisture monitoring equipment was not able to measure a difference in water use between the two row spacings or any increase in rainfall infiltration between the row spacings. Anecdotal evidence suggests that the four rows on 2.1 m beds use more water earlier in crop growth and may require slightly different irrigation scheduling.

Very little response to nitrogen application was measured in either row-spacing treatments of the nitrogen rate trials.

The benefits of higher-density planting and controlled traffic have already been recognised by many growers throughout the industry. In recent years there has been a dramatic increase in the area planted to dual rows on 1.8 m centres. Growers in the Bundaberg, Mackay, Maryborough, and Ingham districts are also presently investigating new farming systems consisting of in two and three rows on 2 m wheel spacings. Results from the present project show that cane grown in these configurations will increase yields and may reduce production costs. Most existing planting, fertilising and weed control equipment can be modified to suit these systems. The major cost has been modification of the harvesting equipment.

These row-spacing and plant-spacing trials do not provide enough information about the effect of plant density on yields of ratoon crops. Many of the previously established high-density trials harvested as second ratoons in 2002 showed no difference in yield between the 1.5 m singles and the higher-density configurations. These trials are now third ratoons and the higher-density configurations appear gappy compared to the single rows. Because the closer rows tend to have fewer stalks per stool, they may be more vulnerable to stool damage at harvest. Perhaps the high-density harvester is causing excessive stool damage and needs to be redesigned. Either way the closer rows do not seem to be as robust and may not perform as well under commercial conditions. This needs to be determined in well-designed trials to provide data for useful comparisons of systems.

1.0 BACKGROUND

In most sugarcane industries the distance between sugarcane rows has been dictated by the width of the animal or equipment used for farming operations. The Australian sugar industry has been no exception. Ever since complete mechanisation in the 1970s, the equipment used has gradually become heavier and wheel spacings have become wider. Consequently, in an effort to match row spacing to equipment, the gap between cane rows has also become wider, causing a gradual reduction in plant density. Previous research (Bull 1975) has indicated that a relationship exists between plant density and cane yield, but the scope of the yield variation has not been fully explored. The effect of water and nutrient application on the density response has not been investigated.

This project was designed to define the upper limit to yield response obtained from higher density planting and to develop a commercially viable production system to maximise the yield benefits. The effects of different row spacings and within-row plant densities on cane production were measured. The impacts of various irrigation and nutrient applications were investigated to develop an optimum management strategy.

2.0 OBJECTIVES

- Determine whether higher planting densities will increase potential yield;
- Decide on optimal planting density strategies;
- Develop suitable irrigation scheduling to optimise water use efficiency in high density crops;
- Define the effect of planting density by water supply interaction for several cultivars;
- Define optimum fertiliser strategy for different planting densities.

This project was successful in showing that higher planting densities will increase cane yield in the plant crop. Trial results show that cane yield increases almost linearly as row spacing reduces from 1.5 m to 0.5 m, but there was little change in cane yield as row space reduced further to 0.125 m. Due to poor and uneven ratooning, the first-ratoon results were inconclusive.

In the process of designing a new farming system a large number of economic, legal and environmental factors need to be considered. With due consideration to the effect of plant density on cane yield there may be several farming configurations. Farming systems such as dual rows on 1.8 m, or two, three and even four rows on 2 m may all prove to be economically beneficial for different reasons.

The irrigation trials showed that a system of four rows on 2.1 m beds can increase cane yield with no increase in irrigation application; as a result the system will improve water-use efficiency. The soil-moisture monitoring equipment was not successful at measuring any differences in the scheduling of irrigation water between the 1.5 m rows and the 2.1 m beds. The fertiliser rate trials were not successful in measuring a response to nitrogen application in either of the two row spacings.

3.0 METHODS

3.1 Effect of plant density on sugarcane yield

Plant density is a function of row spacing and plant spacing within the row. To further define the effect of plant density on cane yield two trials were conducted. The cultivars Q124, Q151 and Q170$^{\phi}$ were used in the trials. Both trials were planted in August 1999 on a red ferrosol (euchrozem) at the BSES station Bundaberg and were fertilised and irrigated to minimise the effect of moisture and nutrition on growth. Regular stalk-count measurements were collected. The internal rows of the plots were hand harvested and weighed at 12 months of age. Random six-stalk samples were taken from each plot for CCS estimation through the small mill. Weight and CCS results were used to estimate cane and sugar yield.

3.1.1 Row-spacing trial

The three cultivars were planted at six row spacings of 0.125, 0.25, 0.5, 0.75, 1.0 and 1.5 m using 30 cm-long two-eye billets planted end to end. Four replicates were planted in split plots in a randomised complete-block design, with cultivars as the splits. The plot size was 3 m long and 3.5 m wide with a 1 m gap between plots along the row.

3.1.2 Within-row-spacing trial

The three cultivars were planted in three row spacings of 0.5, 1.0 and 1.5 m. The 10 cm-long single-eye billets were planted at intra-row plant spacings of 0.1, 0.2 and 0.4 m between each billet. Four replicates were planted in a split-split plot design in a randomised complete-block design with intra-row space as the first split and cultivar as the second split. Plots were 3 m long and 3.5 m wide with a 1 m gap between plots along the row.

3.2 Development of optimal planting-density strategies

The results from plant-density trials were used to assist in the development of new farming systems that optimise the plant-density relationship while taking into account other economic, environmental and legal constraints.

3.3 Definition of the interaction between irrigation application and scheduling on the response to planting density

Two trials planted in March 2000 were established to ascertain the water requirements of higher density crops and to measure any differences in water use between the faming systems. The high- and low-irrigation treatments were applied by using trickle tape with different emitter sizes. Four different types of trickle tape were used to impose the irrigation treatment, so that the two row spacings received equivalent amounts of water per hectare. The irrigation treatments were joined to a common main line, so that water was applied to the high and low treatments at the same time and duration but at different amounts. Soil-water levels were monitored with an EnviroSCAN® and soil tensiometers. The block was split in half, with the high treatment received a full irrigation and the low treatment received about half the full water rate. Due to limitations in paddock size it was not possible to replicate the irrigation treatments. The row-spacing and cultivar treatments were applied to each irrigation treatment in a randomised complete-block design, replicated three times.

The trial plots were all harvested with the prototype multi-row harvester and a weighing tipper bin on 2.1 m track widths. Weights were taken from the internal two rows or beds in each plot and yield per hectare computed. Random six-stalk samples were collected from each plot and crushed in a small mill. The CCS and cane yield estimates were used to calculate sugar yield.

3.3.1 Irrigation trial (Churchward)

The cultivars Q138, Q151, and Q182$^{\oplus}$ were planted in a split-plot design in two row spacings of 1.5 m single and four 0.5 m rows on 2.1 m wide beds with three replications. This trial was planted on a grey sandy loam (yellow chromosol) at Churchward's farm, Moore Park Rd, Bundaberg. Nutrients were applied uniformly to all treatments according to soil test results.

3.3.2 Irrigation and nitrogen-rate trial (Harte)

Three cultivars, Q138, Q150 and Q124, were planted in a split-plot design at two row spacings of 1.5 m single and four 0.5 m rows on 2.1 m beds. This trial was planted on a yellow kandosol (yellow earth) at Harte's farm, Chapman's Rd, Bundaberg. The plant crop had five levels of nitrogen at 45, 75, 105, 135 and 195 kg N/ha applied to both irrigation treatments. In the first ratoon, 150 kg/ha of nitrogen and 100 kg/ha potassium were applied to all treatments and the trial formed a simple test of irrigation response.

3.4 Optimum fertiliser strategy for different plant densities

Two trials were conducted to measure the nitrogen requirement of higher density crops. Nitrogen treatments were applied in a split-plot design with three replications. All the trials were irrigated with trickle tape with emitter sizes graduated to ensure a uniform water application to the trial. Nutrients such as phosphorus and potassium were applied according to soil test results. Third-leaf samples were collected to identify nitrogen deficiencies. Rainfall and soil moisture were monitored with tensiometers and EnviroSCAN® equipment. Both trials were harvested with the prototype multi-row harvester and weighing tipper bin on 2.1 m track widths. Weights were taken from the internal two rows, or beds in each plot and yield per hectare computed. Random six-stalk samples were taken from each plot for CCS estimation through a small mill. One of the nitrogen-rate trials was superimposed over an irrigation trial, method included in section 3.3.2; the other is detailed below.

3.4.1 Nitrogen-rate trial (Churchward)

The nitrogen rate trial was planted in September 1998 on a grey sandy loam (yellow chromosol) at Churchward's farm, Moore Park Rd, Bundaberg. The cultivars, Q124 and Q170$^{\Phi}$, were planted in three row spacings of 1.5 m single, dual rows at 1.8 m centres, and four 0.5 m rows on 2.1 m-wide beds in split-plot design with three replications. Five nitrogen treatments (0, 60, 120, 180 and 240 kg N/ha) were applied to subplots as a side dressing with a variable-rate coulter fertiliser rig. 100 kg/ha of potassium was applied to all treatments at this stage. To assess fertiliser uptake samples of the third leaf were collected in March 1999. The same nitrogen treatments were applied to the plant, first- and second-ratoon crops. The soil moisture contents of the three row spacings were monitored using tensiometers located in the row at depths of 300 and 600 mm. Crop-water use was measured with an EnviroSCAN®. The sensor tubes were placed beside the drip tape, in the cane row and approximately 400 mm from the cane row in 1.5 m single and dual rows. In the close rows, tubes were placed in the row and midway between rows adjacent to the drip tape.

4.0 RESULTS

4.1 Effect of plant density on cane yield

4.1.1 Row-spacing trial

4.1.1.1 Plant crop

Stalk counts over the duration of the plant crop show a substantial increase in stalk numbers with closer row spacings in the three cultivars Q124, Q151 and Q170$^{\Phi}$ (Figures 1-3). Initially this difference was very large, but it had declined markedly by canopy closure. In all row spacings, the cultivar Q151 had significantly more stalks than Q124 or Q170$^{\Phi}$. However, there was no significant cultivar by row-spacing interaction. Most of the initial loss in stalk numbers was associated with the loss of small tillers due to plant competition. This loss represents a relatively minor loss in total biomass. The higher-density treatments had significantly more millable cane stalks than the 1.5 m rows from 224 days after planting (DAP) until harvest.

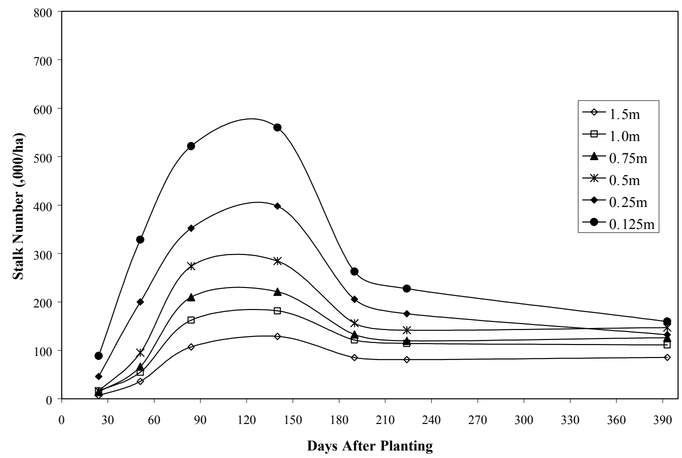


Figure 1 - The effect of row spacing on progressive stalk numbers for cultivar Q124

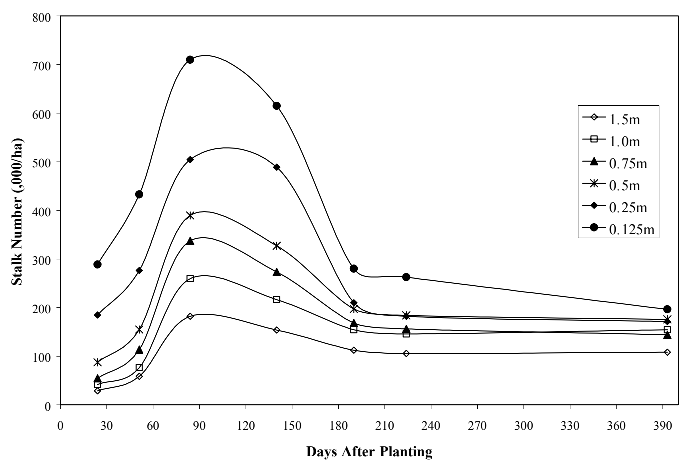


Figure 2 - The effect of row spacing on progressive stalk numbers for cultivar Q151

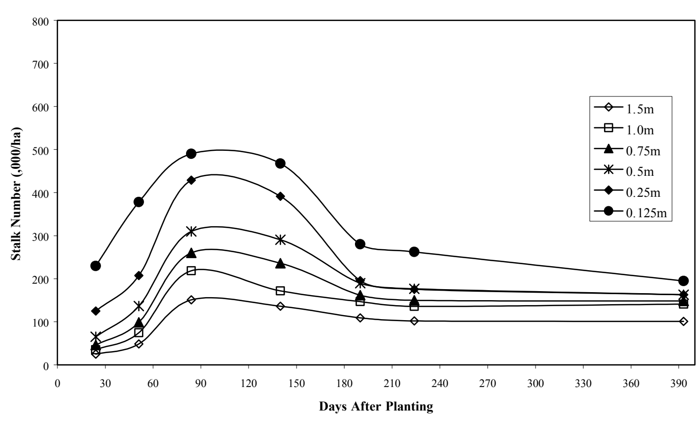


Figure 3 - The effect of row spacing on progressive stalk number for cultivar Q170[Φ]

Analysis of the mean stalk numbers collected from the three cultivars (Table 1) shows that row spacing had a significant effect on stalk numbers in all samplings. By comparing initial planting density with stalk counts, germination was fully completed by 51 DAP (days after planting). Tillering for all rows was advanced by 84 DAP. The progression of stalk numbers at each row spacing shows a trend for stalk numbers in the higher planting densities to fluctuate at a greater rate than the 1.5 m and 1.0 m row spacings. At harvest, the 0.125 m and 0.25 m row spacings had fewer stalks than at planting, signifying that many of the primary stalks that germinated were lost during crop growth. In comparison with early stalk counts, the 1.5 m and 1.0 m spacings had more than twice as many stalks at harvest. This indicates that final stalk number in wider row spacings is heavily reliant on the survival of secondary shoots. At about 200 DAP, stalk numbers stabilised and the majority of stalks present at this stage survived until harvest. The progressive stalk counts clearly show the effect of plant density on early plant competition on secondary shooting, stalk survival and ultimately cane yield.

Table 1 - Effect of row spacing on mean stalk numbers (000/ha) of cultivars Q124, Q151 and Q170$^{\Phi}$ in the plant crop

Row spacing (m)	**Planting density (,000/ha)**	**Days after planting***						
		24	**51**	**84**	**140**	**190**	**224**	**394**
0.125	480	202.4 a	379.9 a	573.9 a	547.5 a	274.2 a	250.8 a	183.5 a
0.250	240	118.6 a	227.9 b	428.5 b	425.9 b	203.7 b	177.8 b	155.4 b
0.5	120	56.1 c	128.9 c	324.4 c	300.7 c	180.9 c	167.4 b	161.9 b
0.75	80	38.1 cd	92.8 d	269.1 cd	243.5 d	154.3 d	141.9 c	139.6 c
1.0	60	30.9 d	68.6 de	213.4 de	189.9 e	140.8 e	131.9 c	135.6 c
1.5	40	20.1 d	47.7 e	146.7 e	139.6 f	102.1 f	96.2 d	98.2 d
LSD 5%		23.9	26.8	75.6	26.7	12.8	12.0	7.6

*Means within a column followed by the same letter are not significantly different (P=0.05)

Analysis of the harvest data indicated highly significant ($P < 0.001$) row-spacing and cultivar effects on stalk weight, cane and sugar yield. No cultivar by row-spacing interaction was detected. There was a significant cultivar effect on CCS. Harvest data (Table 2) shows that cane yield increased almost linearly as row space reduced from 1.5 to 0.5 m but there was then little change in yield as row space reduced to 0.125 m (Figure 4). Although the row-spacing effect on stalk weight was significant, the trend was not consistent and, to all practical purposes average stalk weight was only marginally affected by row spacing.

Table 2 - Effect of row spacing on stalk weight and yield

Row spacing (m)	Stalk weight (kg)	Cane yield (t/ha)	CCS	Sugar yield (t/ha)
1.5	1.10 ab	107 d	15.20	16.41 d
1.0	1.05 cd	141 c	16.15	22.88 c
0.75	1.13 ab	157 b	15.86	24.92 bc
0.5	1.07 c	173 a	15.63	27.04 ab
0.25	1.12 a	179 a	16.09	28.80 a
0.125	0.98 d	179 a	15.58	27.92 a
LSD 5%	0.091	13.05	ns	2.48

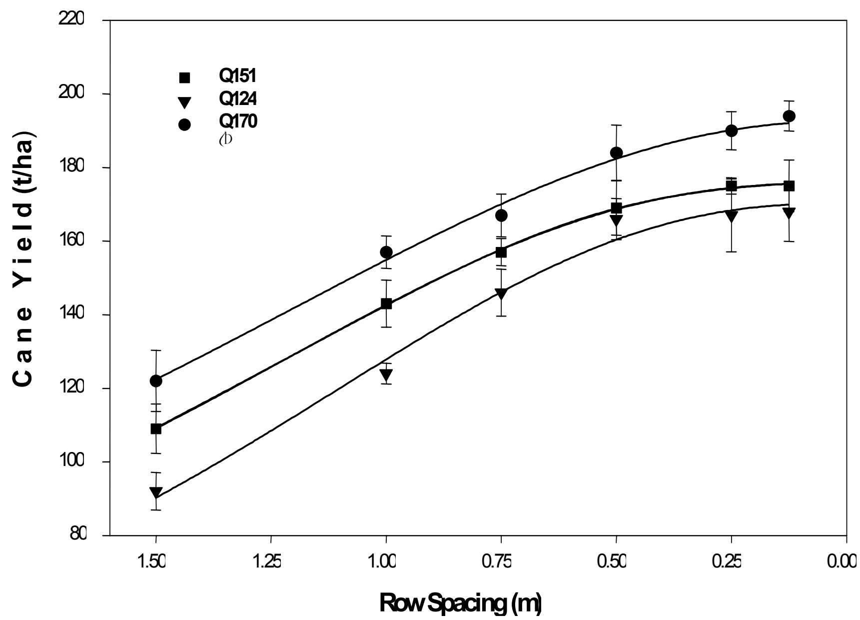


Figure 4 - Impact of row spacing on cane yield in the plant crop in three cultivars

4.1.1.2 First-ratoon crop

Large variations in ratooning between the plots were caused by several factors:

- The large amount of trash left after the plant-crop harvest was burnt to remove the effect of trash blanket on ratooning. However, larger amounts of trash left in the higher yielding plots resulted in a hotter fire that burnt and subsequently killed those stools.
- The weather before and after harvest of the plant crop was extremely dry and cool, which also caused poor ratooning.
- The plant crop of Q124 was heavily infested with orange rust particularly in the narrow row-spacing treatments.

All of these factors contributed to a poor ratooning and affected plant density in the first ratoon. It is difficult to draw any useful conclusions from the harvest result.

The first ratoon of this trial was hand harvested in August 2001 at an age of 10 months. Analysis of the harvest data (Table 3) shows that row spacing had a significant effect on stalk numbers and cane yield across all cultivars, but there was no significant effect on stalk weight.

Table 3 - Summary of ANOVA for the first ratoon of the row-spacing trial

Source	df	Stalk number/ha		Stalk weight (kg)		Cane yield (t/ha)	
		F value	P	F value	P	F value	P
Row spacing	5	2.44	0.0006	6.71	0.070	4.37	0.010
Rep * Row spacing	14	2.40	0.25	2.75	0.22	1.60	0.39
Cultivar	46	4.13	0.13	1.47	0.43	1.68	0.38

There was a trend to more stalks per hectare in the closer-row spacings (Figure 5), with the 0.125 m row spacing having significantly more stalks per hectare than the 0.75 m and 1.5 m row spacings. Although the differences in stalk weights among row spacings were not significantly different (Figure 6), there appears to be a trend to lighter stalks with closer row spacings. There was a significantly more cane in the 0.125 m row spacing than in the 0.75 m row spacing (Figure 7).

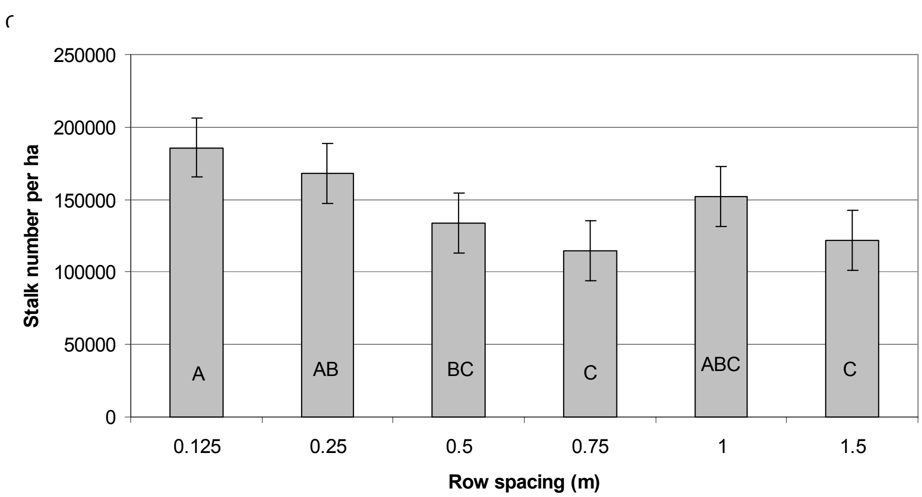


Figure 5 - Impact of row spacing on stalk numbers per hectare in the plant crop

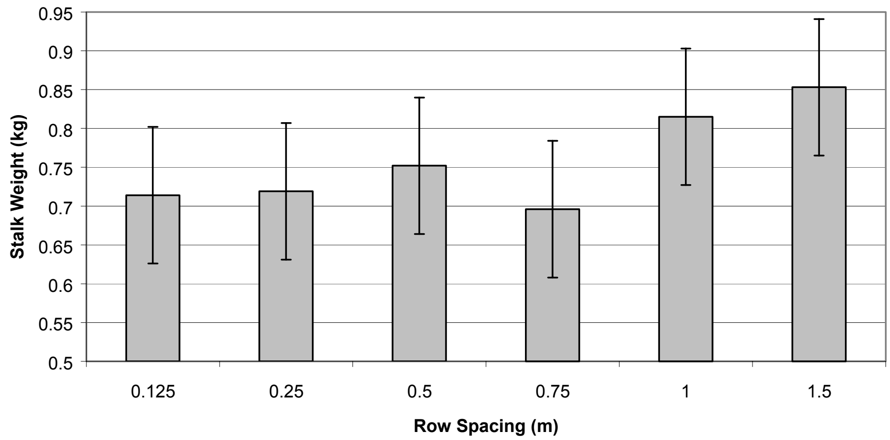


Figure 6 - Impact of row spacing on stalk weight in the plant crop

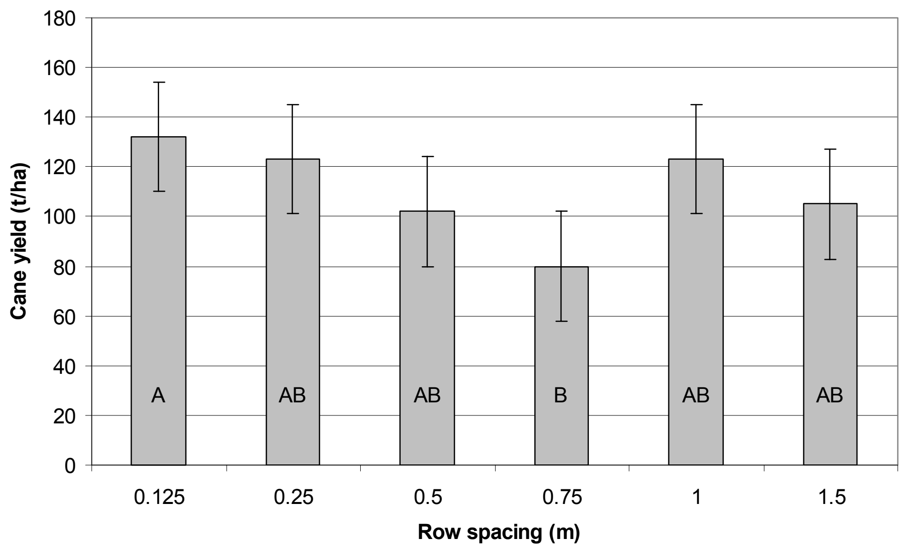


Figure 7 - Impact of row spacing on cane yield in the plant crop

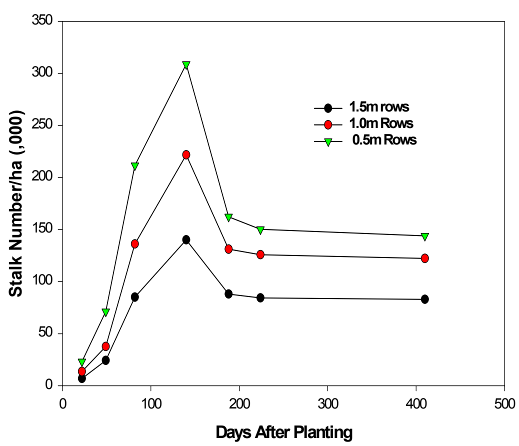
4.1.2 Within-row spacing trial

4.1.2.1 Plant crop

Stalk counts over the duration of the plant crop showed significant effects ($P < 0.001$) of row spacing, within-row spacing and cultivar. There was a significant row-spacing by within-row spacing interaction in stalk counts on days 22, 49 and 82 after planting (Table 4). This interaction became insignificant after the day 82 count. No row-spacing by cultivar or within-row spacing by cultivar interaction was measured in any of stalk counts. The cultivars Q151 and Q170[⌽] had significantly more stalks than Q124 in all counts.

Table 4 - Effect of row spacing and within row planting density on mean stalk numbers (000/ha) of cultivars Q124, Q151 and Q170$^{\Phi}$ in the plant crop

Row width (m)	Within-row space (eyes/m)	Planting density (,000/ha)	Days after planting						
			22	49	82	140	188	224	410
0.5	10	200	34.9 a	105.0 a	269.6 a	333.3	174.4	165.9	157.1
0.5	5	100	22.6 b	69.9 b	228.8 b	327.4	159.1	152.4	146.6
1.0	10	100	19.7 b	55.8 c	173.9 c	238.4	139.2	135.4	131.3
1.5	10	67	11.7 c	37.3 d	116.2 e	155.2	102.9	97.4	97.7
0.5	2.5	50	12.2 c	39.0 d	136.7 d	266.3	153.8	132.7	128.4
1.0	5	50	12.9 c	35.3 d	136.5 d	233.3	135.0	129.0	122.3
1.5	5	33	5.2 de	21.8 e	79.8 f	140.3	85.3	84.1	80.7
1.0	2.5	25	8.2 d	22.1 e	98.1 f	194.0	119.4	113.2	113.2
1.5	2.5	17	3.6 e	13.7 f	59.3 g	125.1	76.3	71.7	70.6
LSD 5%			3.0	5.7	14.9	ns	ns	ns	ns



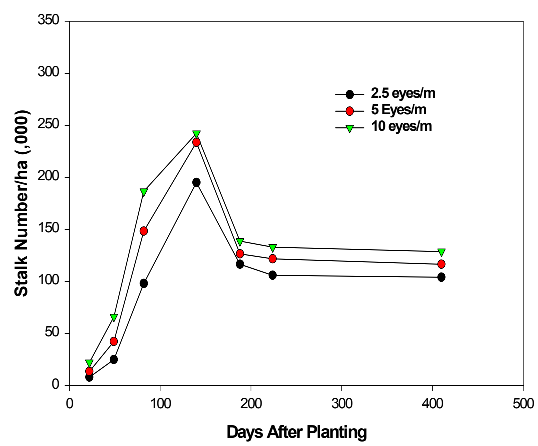


Figure 8 - Effect of row spacing and within row planting density on stalk numbers of cultivars Q124, Q151 and Q170$^{\Phi}$ in the plant crop

There were significantly more stalks in the closer rows and the closer within-row spacing in all three cultivars (Figure 8). Initial major increases in numbers at the higher within-row planting densities became progressively reduced with time. The within-row spacing treatments of 2.5, 5 and 10 eyes/m at planting effectively doubled and quadrupled the planting density at the same row spacing, respectively. However, whilst it was still significant, the increase in stalk number due to within row density was relatively minor (about 25%) for the duration of the crop (Figure 8).

At harvest (Table 5), increasing planting density by decreasing row spacing or by increasing the planting density within the row both significantly increased stalk numbers, cane yield and sugar yield. Analysis of the harvest data (Table 6), shows that there was a significant cultivar, row and within-row spacing effect on stalk weight. There was a significant cultivar affect on stalk weight, with Q124>Q170$^{\Phi}$>Q151. None of the cultivar interactions were significant. The 1.5 m rows had slightly heavier stalks than the 1.0 and 0.5 m rows and the 2.5 eyes/m treatments had slightly heavier stalks than the 10 eyes/m treatments. No row spacing by within row spacing interaction was detected. The stalk weight effect was not large enough to nullify the increase in stalk numbers and as a result there was a significant plant density affect on cane yield. There was a much greater increase in yield obtained from decreasing row spacing than from increasing within-row plant spacing (Table 7).

Table 5 - Relative impact of inter-row and intra-row spacing on key yield parameters of cultivars Q124, Q151 and Q170$^{\Phi}$

Row spacing (m)	Within-row space (eyes/m)	Eyes planted (,000/ha)	Stalk number (,000/ha)	Weight /stalk (kg)	Cane yield (t/ha)	CCS	Sugar yield (t/ha)
1.5	2.5	17	70.6	1.25	88	16.6	15.6
1.5	5	33	80.7	1.19	96	16.9	17.0
1.5	10	67	97.7	1.12	112	17.4	20.1
1.0	2.5	25	113.2	1.07	123	16.6	23.3
1.0	5	50	122.3	1.13	138	16.6	24.4
1.0	10	100	131.3	1.04	137	15.8	23.9
0.5	2.5	50	128.4	1.17	150	16.0	24.3
0.5	5	100	146.6	1.08	159	16.2	27.2
0.5	10	200	157.1	1.04	164	16.8	31.1

Table 6 - Summary of ANOVAs from the analysis of variance for the plant-crop data

Source	df	Stalk number		Stalk weight		Cane yield	
		F value	P	F value	P	F value	P
Row Spacing	2	35.76	0.0005	8.10	0.019	27.42	0.001
Within-row Spacing	2	45.62	0.0000	4.81	0.021	12.25	0.0004
Row * Within-row spacing	4	1.28	0.32	0.88	0.49	1.0	0.43
Cultivar	2	35.82	0.0000	14.30	0.0000	21.65	0.0000
Row space * Cultivar	4	2.28	0.073	1.48	0.22	1.60	0.19
Within row spacing * Cultivar	4	1.01	0.41	0.87	0.48	0.94	0.45
Row*Within-row spacing * Cultivar	8	0.46	0.88	0.96	0.47	0.59	0.70

Table 7 - Comparisons of percent yield gains from inter-row spacing versus 1.5 m rows and from intra-row spacing versus 2.5 eyes planted/m of row

Inter-row spacing (m)	% Yield increase vs 1.5 m rows Intra-row spacing (eyes/m)			% Yield increase vs 2.5 eyes/m Intra-row spacing (eyes/m)		
	2.5	**5**	**10**	**2.5**	**5**	**10**
1.5	-	-	-	-	14	38
1.0	60	52	34	-	8	16
0.5	82	82	61	-	14	22

The harvest results show that at the same planting rate, reducing the row spacing caused a larger increase in yield compared to increasing within-row planting rate. For example, in 1.5 m rows doubling the planting density in the row from 2.5 eyes/m to 5 eyes/m caused a 14% increase in yield; quadrupling the planting rate in the row to 10 eyes/m increased yield by 38%. However, by changing to 1.0 m row space increased the planting rate 1.5 times, but gave a yield increase of 32%. The 0.5 m row spacing increased the planting rate three times, but increased yields by 46%. These results are based on single-eye setts so that high packing densities do not interfere with sett-soil contact or germination. Attempts to achieve similar densities along a row using conventional billets will adversely affect billet/soil contact and germination conditions.

The response to increased within-row planting density tended to be similar at each row spacing (Figure 8), suggesting that row spacing and within-row density effects might be additive at this stage of growth.

4.1.2.2 First-ratoon crop

Large variations in ratooning also occurred among the plots for the same reasons as in the row-spacing trial. Hence, it is difficult to draw any useful conclusions from the first-ratoon of this trial. The first-ratoon of this trial was hand harvested in August 2001 at an age of 10 months. Analysis of the harvest results of this trial (Table 8) shows there were no significant effects of row spacing or with-in row plant spacing on stalk numbers or cane yield. There was, however, a significant effect of row spacing on stalk weights. The average stalk weight in the 1.5 m spacings was 0.19 kg heavier than the stalks grown at 0.5 m spacings (Table 9). There was no significant row spacing or within-row-density by cultivar interaction.

Table 8 - Summary of ANOVA from the analysis of variance of the first ratoon

Source	df	Stalk number per ha		Stalk weight (kg)		Cane yield (t/ha)	
		F value	P	F value	P	F value	P
Row spacing	2	1.71	0.25	2.78	0.14	3.59	0.094
Within-row density	2	1.03	0.38	6.27	0.008	0.83	0.45
Row spacing*within-row density	4	0.46	0.76	0.66	0.62	0.47	0.76
Cultivar	2	19.01	<0.0001	0.74	0.48	7.95	0.0009
Row spacing x Cultivar	4	1.90	0.12	0.74	0.57	1.16	0.34
Within-row density x Cultivar	4	1.18	0.33	1.23	0.31	0.82	0.52

Table 9 - Impact of row spacing on average stalk weight in the first ratoon

Intra-row spacing (m)	Average stalk weight (kg)	Tukey grouping	Critical value
1.5	0.95	A	0.07
1.0	0.81	A B	
0.5	0.76	B	

There was also a significant cultivar effect on stalk number and cane yield. Q170$^{\Phi}$ and Q151 had significantly more stalks per hectare compared to Q124 in all row spacings and within-row densities. There was no difference in stalk weight of the three cultivars, and Q170$^{\Phi}$ and Q151 produced significantly more tonnes of cane per hectare compared to Q124 (Table 10).

Table 10 - Effect of cane cultivar on stalk number, stalk weight and cane yield

Cultivar	Stalk number		Stalk weight (kg)		Cane yield	
	Count/ha	Tukey grouping	kg per stalk	Tukey grouping	t/ha	Tukey grouping
Q151	128,538	A	0.82	A	104	A
Q170$^{\Phi}$	122,884	A	0.84	A	104	A
Q124	9,375	B	0.86	A	84	B

4.2 Development of optimal planting density strategies

The row-spacing and within-row spacing trials show that in the plant crop there is a positive yield response from closer plant spacing. Increasing plant density resulted in an increase in cane yield and stalk numbers at harvest with a slight trend towards lighter stalk weight. Cane yield increases almost linearly as row spacing reduces from 1.5 m to 0.5 m, but there was little change in cane yield as row space reduced further to 0.125 m. This yield increase was confirmed by the within-row spacing trial. Increasing within-row plant spacing by doubling and quadrupling the planting rate tended to result in significant, but relatively small, increases in cane yield in all three row-spacing treatments. Altering row spacing had a larger effect on cane yield than increasing the within-row planting rate. Both trials show the importance of good establishment regardless of which row spacing is used.

Unfortunately, due to several environmental factors, both trials failed to ratoon evenly, making it difficult to make any useful conclusions from the first-ratoon crop. Sugar cane is currently commercially grown for a plant and three to four ratoon crops; the number of ratoons and the production in those ratoons is just as important as plant crop production. Without ratoon results, it is premature to make claims based on these trials as to the row spacing that will maximise cane production over the entire crop cycle.

The progressive stalk counts clearly show the effect of plant density and early plant competition on secondary shooting, stalk survival and ultimately cane yield. At harvest the 0.125 m and 0.25 m row spacings had fewer stalks than at planting, signifying that in these row spacings many of the primary stalks germinated were lost and that the majority of the stools had single sticks at harvest. Even with vary careful harvesting, it would be expected that these small stools would suffer more damage and fail to ratoon. Stool damage caused during mechanical harvesting would further magnify this affect. It is possible that due to stool loss, a row spacing closer than 1 m may not produce any increase in yield in older ratoons. This theory requires further investigation; an assessment of stool survival in older ratoons of grower trials may be all that is required.

In the process of designing a new farming system a large number of economic, legal and environmental factors need to be considered. In some systems, the estimated yield increase from closer rows may not be sufficient to counteract increases in costs and other limitations. Ultimately there may be several farming configurations that prove to be economically beneficial for different reasons. A few growers throughout the industry have recently been investigating the benefits of several row spacing configurations including dual rows on 1.8 m, two three and four rows on 2 m, two and three rows on 3 m. Many of the new farming systems have aimed to include controlled traffic, mound planting and minimum tillage concepts. Growers have generally found that the design and availability of planting and harvesting equipment have been large limitations to implementation of the new systems.

4.3 Define the interaction between irrigation application and scheduling on the response to planting density

4.3.1 Irrigation trial (Churchward)

The rapid increase and decrease in stalk numbers seen in September-planted crops did not occur to the same extent in the March-planted crop (Figure 9). There was a significant effect of row spacing and cultivar on stalk population. In all samplings the 0.5 m row spacing had substantially more stalks than the 1.5 m rows (Figure 9). The row spacing by cultivar interaction was not significant. Statistical analysis of the irrigation regimes could not be done due to a lack of replication. However, the stalk-count data show a minor trend toward higher stalk counts in the high irrigation treatment. None of the interactions were significant. The crop lodged before stalk numbers in the close rows had stabilised.

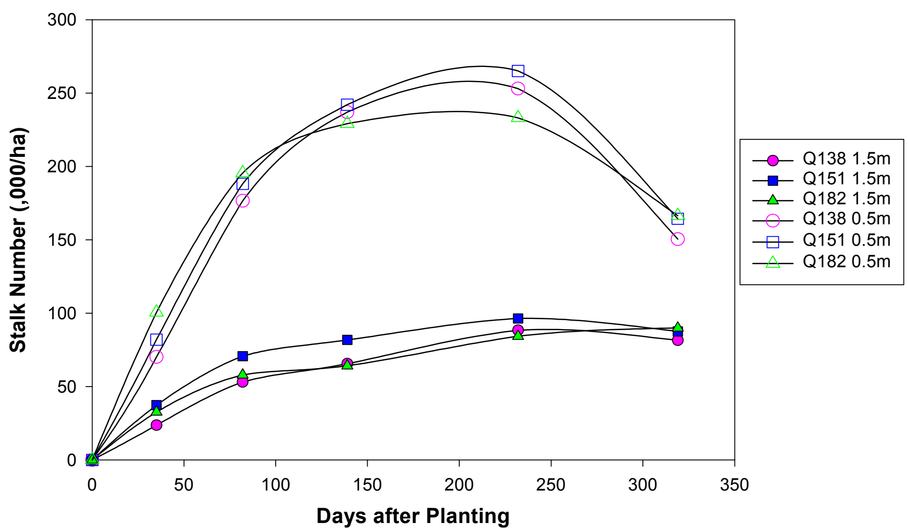


Figure 9 – Effect of row spacing on stalk numbers in the plant crop

The closer rows achieved maximum light interception about 100 days earlier than the 1.5 m rows, although neither row space treatment achieved full canopy closure (Figure 10). Estimates indicate that the 2.1 m beds intercepted about 46% more light than the 1.5 m rows in the period up to day 300.

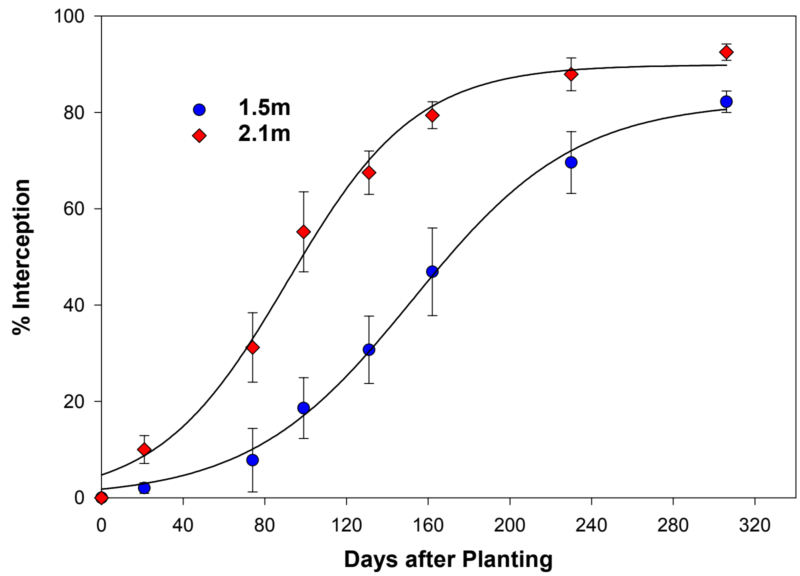


Figure 10 - Impact of row spacing on light interception in the plant crop

Table 11 - Impact of row spacing on yield components of three cultivars under high and low irrigation regimes

(a) High irrigation	**(2.1 ML/ha irrigation applied at time of sampling)**					
	Stalks/ha		**Weight/stalk (kg)**		**Tonnes cane/ha**	
	1.5 m	**2.1 m**	**1.5 m**	**2.1 m**	**1.5 m**	**2.1 m**
Q138	79,333	158,254	0.882	0.593	70	93
Q151	86,556	162,698	0.529	0.687	47	111
Q182$^{\phi}$	87,333	165,238	0.533	0.468	46	78
Mean	**84,407**	**162,063**	**0.648**	**0.583**	**54**	**94**

(b) Low irrigation	**(1.0 ML/ha irrigation applied at time of sampling)**					
	Stalks/ha		**Weight/stalk (kg)**		**Tonnes cane/ha**	
	1.5 m	**2.1 m**	**1.5 m**	**2.1 m**	**1.5 m**	**2.1 m**
Q138	83,667	142,698	0.608	0.493	51	69
Q151	88,667	166,190	0.589	0.477	52	79
Q182$^{\phi}$	92,667	167,619	0.506	0.421	47	70
Mean	**88,333**	**158,836**	**0.568**	**0.464**	**50**	**73**

At the sample harvest 16 March 2001 (321 days) the closer rows had significantly higher stalk numbers (F=259, P= 0.0001) and cane yield (F=195, P= 0.0002) than the 1.5 m rows (Table 11). No significant stalk-weight effect was measured (F=0.29, P= 0.076). There was also a significant cultivar effect, but no cultivar by row spacing interaction on stalk number, stalk weight or cane yield

The additional water applied in the high irrigation regime appears to have increased stalk numbers and cane yield in the close-row treatment but not in the single-row treatment. Under the limited irrigation the close rows increased average cane yield by 23 t/ha; at the high irrigation level this increased to 40 t/ha.

The trial was harvested in September 2001 (590 DAP). The harvest results from the 2001 season plant crop are presented in Table 12.

There was no significant difference in CCS among the cultivars in any spacing in either the high or low irrigation regimes.

Under both the high and low irrigation regimes the 2.1 m beds produced significantly more cane and sugar per hectare, with an extra 24-65 t cane/ha or 29-75% more cane. As a result there was a highly significant increase in sugar production per ha.

Although it was not possible to statistically analyse across irrigation regimes, there appears to be a positive response to irrigation with the high-irrigation regime producing more cane in both row configurations and the difference in yield between the two row spacings increasing as more water was applied.

The 2.1 m beds produced an average of 46% more cane under the low-water regime, while under the high-water regime the 2.1 m beds increased yield by 57%. This indicates that the 2.1 m beds use available irrigation water more efficiently. The soil moisture monitoring equipment (data not shown) was not able to measure a difference in water use between the two row spacings. Anecdotal evidence suggests that 2.1 m rows use more water earlier in crop growth and may require slightly different irrigation scheduling. This effect may have been measured with more sensors and better placement of the sensors near the trickle emitters.

The water application and effective rainfall for each treatment were monitored and the cane water index (CWI) calculated (Table 13). Under both irrigation regimes, the close-row treatment had a higher CWI, indicating that it used the available water more efficiently than the single rows.

The farm on which this trial was situated was sold in November 2001 and the trial was discontinued.

Table 12 - Harvest results of the plant crop of the irrigation trial

Irrigation amount	Cultivar	CCS		Sugar yield (t/ha)				Cane yield (t/ha)					
		1.5 m rows	2.1 m beds	1.5 m rows	2.1 m beds	Analysis		1.5 m rows	2.1 m beds	Yield difference		Analysis	
						P	LSD 5%			t/ha	%	P	LSD 5%
High	Q138	14.29	15.18	15.4	23.2			108	153	45	41		
	Q151	15.58	15.46	13.5	23.5			87	152	65	75		
	Q182[(b]	15.82	15.00	12.3	19.2			83	128	45	54		
	Mean	**14.89**	**15.21 ns**	**13.7**	**21.9**	**0.0001**	**1.8**	**93**	**144**	**52**	**57**	**0.0001**	**8.54**
Low	Q138	15.74	15.82	12.8	20.5			81	130	48	59		
	Q151	16.42	16.46	13.0	19.6			79	119	40	51		
	Q182[(b]	15.71	15.86	13.2	17.1			84	108	24	29		
	Mean	**15.93**	**16.06 ns**	**13.0**	**19.1**	**0.0038**	**2.93**	**81**	**119**	**37**	**46**	**0.0026**	**17.39**

Table 13 - Effect of row spacing on water-use efficiency

Irrigation amount	Row spacing (m)	Effective rainfall (mm)	Irrigation (mm)	Total water (ML/ha)	Yield (t/ha)	CWI (t/ML)
High	1.5	418	400	818	93	11.4
	2.1	418	400	818	144	17.6
Low	1.5	418	200	618	81	13.1
	2.1	418	200	618	119	19.3

4.3.2 Irrigation and nitrogen-rate trial (Harte)

Due to the lack of response to nitrogen in the Churchward nitrogen trial (Section 4.4.1), a second nitrogen trial was planted in March 2000. Initial soil test results showed that residual soil nitrogen at this site was low. The irrigation water used on the trial was sourced from the Burnett irrigation scheme, which contains low levels of nitrogen.

The plant crop had five levels of nitrogen at 45, 75, 105, 135 and 195 kg N/ha applied to both irrigation treatments. In the first ratoon, 150 kg/ha of nitrogen and 100 kg/ha potassium were applied to all treatments and the trial formed a simple test of irrigation response.

4.3.2.1 Plant crop

Little impact of nitrogen level or irrigation rate on light interception or stalk number was detected in the plant crop. A plot of light interception readings for each row spacing (Figure 11) shows that the closer rows on 2.1 m beds achieved canopy closure earlier and more completely than the 1.5 m rows. Estimation of the area under the curves shows the 0.5 m rows intercepted about 50% more radiation by the time (approx. 210 days) that the 1.5 m rows achieved canopy closure. Although the cumulative percentage gain in light interception declines after canopy closure (eg 36% by 310 days), the initial 50% gain occurs at the time of 'grand growth' for the crop and establishes the yield increment from close rows.

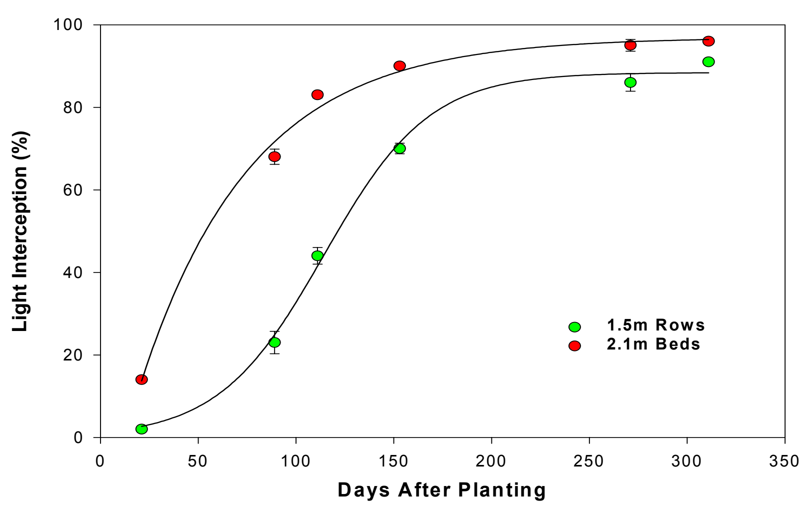


Figure 11 - Impact of row spacing on light interception

Progressive counts of stalk populations (Figure 12) confirmed that the closer rows established about three times as many plants as the 1.5 m rows. Normal attrition of the small tillers in the close rows soon after canopy closure resulted in final stalk numbers that were about 50% higher than 1.5 m rows.

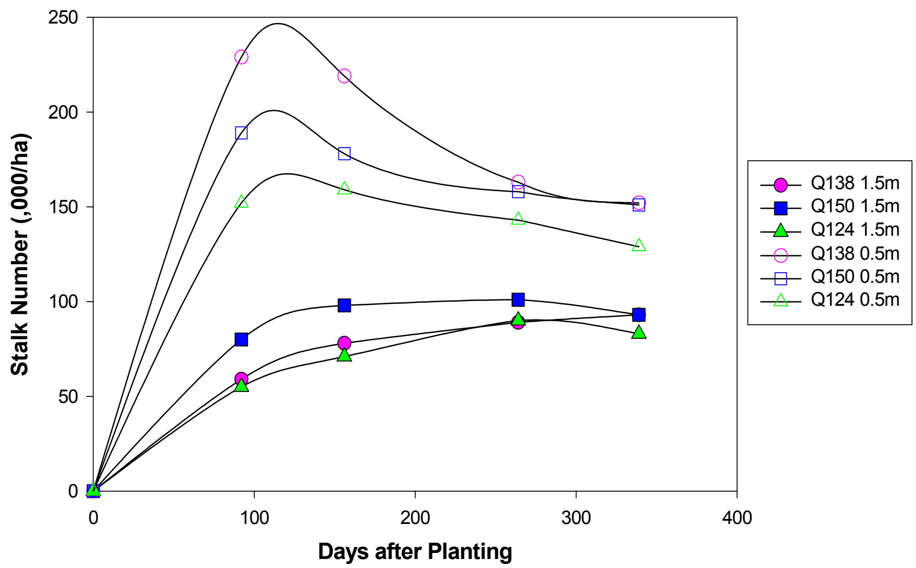


Figure 12 - Effect of row spacing on stalk numbers of three cultivars

The trial was sample harvested on 13 February 2001 (345 DAP), the results are presented in Table 14. Estimated cane yields show that row spacing had a highly significant effect on stalk number and cane yield but not on stalk weight. The 2.1 m beds increased cane yield by 63 t/ha. Nitrogen levels affected stalk weight and, as a consequence, cane yield. However, this effect was largely associated with a less than expected response to the 105 kg N/ha treatment. The irrigation treatments had no impact on stalk numbers, weights or cane yield. The Q124 was heavily infested by orange rust, which would have reduced yield and caused a reduction in stalk numbers of this cultivar.

The trial was harvested in September 2001 (550 DAP) and the results are presented in Table 15. Under the high irrigation rate and at each of the nitrogen rates there was no significant difference between the two row spacings in CCS, cane yield and sugar yield. There appears to be no trends in any of the yield parameters across the nitrogen rates.

Table 14 - Main effects of nitrogen level and row spacing on stalk number, stalk weight and cane yield (sample harvest February 2001)

Nitrogen kg/ha	Stalk number per hectare			Stalk weight (kg)			Cane yield (t/ha)		
	1.5 m	**2.1 m**	**Mean**	**1.5 m**	**2.1 m**	**Mean**	**1.5 m**	**2.1 m**	**Mean**
45	87,000	147,143	117,071	1.296	1.212	1.254	112	180	146
75	101,056	145,437	123,246	1.205	1.201	1.203	120	176	148
105	86,556	140,437	113,496	1.100	1.045	1.073	94	147	121
135	88,000	149,087	118,544	1.235	1.179	1.207	108	176	142
195	88,333	149,246	118,790	1.264	1.198	1.231	111	179	145
Mean	90,189	146,270		1.220	1.167		109	172	
LSD Means	21,032		ns	ns		0.064	34		14

Under the low irrigation rate and at all nitrogen rates except the 45 kg N/ha (where there was a strong trend), the 2.1 m beds produced significantly more cane per ha than the 1.5 m rows, increasing cane yield by 30-43 t/ha or 25-39%. At the high nitrogen rates, this translates to significantly higher sugar yield in the 2.1 m beds (with strong trends at the lower nitrogen rates).

4.3.2.2 First ratoon

Due dry weather, irrigation allocations for the 2001-02 season were low, as a result the high and low irrigation treatments received only 2.2 ML/ha and 1.0 ML/ha, respectively. The effective rainfall for this season was approximately 5.25 ML/ha. The first ratoon was harvested in September 2002, 347 days after harvest. Harvest results (Table 16) show that in both irrigation treatments the 2.1 m beds produced significantly more cane and sugar per hectare than the 1.5 m rows. Due to the lack of replication of the irrigation treatments, it is not possible to statistically analyse the irrigation effect. The irrigation treatment appears to have affected cane growth with the high water treatment producing 15 t more cane/ha and 2.5 t more sugar/ha than the low water treatment. The yield difference between the two row spacings was less under the high water regime.

The water application and effective rainfall for each treatment was monitored and the cane water index (CWI) calculated (Table 17). Under both irrigation regimes the close-row treatment had a higher CWI, indicating that it used the available water more efficiently than the single rows.

Table 15 - Harvest results of plant crop of the second nutrition trial (Row spacing * Cultivar * Nitrogen rate * Irrigation rate)

Irrigation Rate	Nitrogen rate (kg/ha)	Cultivar	CCS		Sugar yield (t/ha)			Cane yield (t/ha)					
			1.5 m rows	2.1 m beds	1.5 m rows	2.1 m beds	Analysis P	1.5 m rows	2.1 m beds	Yield difference		Analysis	
										t/ha	%	P	LSD
High	45	Q138	14.17	14.56	17.4	22.7		124	153				
		Q150	15.38	14.87	21.7	22.8		141	155				
		Q124	14.61	13.11	15.3	18.1		104	139				
		Mean	14.58	14.28 ns	17.9	21.6	0.35 ns	123	150 ns	27	22	0.15	ns
	75	Q138	14.52	14.65	17.0	22.5		117	154				
		Q150	15.17	15.43	21.4	24.2		141	157				
		Q124	14.84	13.23	15.6	17.4		105	129				
		Mean	14.76	14.49 ns	17.7	21.6	0.16 ns	120	148 ns	28	23	0.16	ns
	105	Q138	14.52	14.26	16.9	20.4		114	143				
		Q150	14.76	13.26	21.6	20.7		146	155				
		Q124	13.76	13.21	14.2	17.0		102	129				
		Mean	14.39	13.75 ns	17.4	19.6	0.41 ns	119	142 ns	23	19	0.24	ns
	135	Q138	14.62	14.49	18.2	22.9		124	156				
		Q150	15.42	14.53	24.8	24.7		160	169				
		Q124	15.16	14.36	14.9	22.6		97	159				
		Mean	14.95	14.47 ns	19.0	23.3	0.12 ns	126	160 ns	34	27	0.10	ns
	195	Q138	14.14	14.82	20.9	22.9		147	154				
		Q150	15.19	14.88	20.3	21.8		134	146				
		Q124	14.10	14.55	17.6	20.3		124	139				
		Mean	14.77	14.39 ns	19.9	21.9	0.24 ns	138	149 ns	11	8	0.30	ns

Irrigation rate	Nitrogen rate (kg/ha)	Cultivar	CCS		Sugar yield (t/ha)				Cane yield (t/ha)					
			1.5 m rows	2.1 m beds	1.5 m rows	2.1 m beds	Analysis		1.5 m rows	2.1 m beds	Yield difference		Analysis	
							P	LSD			t/ha	%	P	LSD
Low	45	Q138	13.81	14.85	17.6	23.4			128	157				
		Q150	15.29	15.66	16.8	26.5			110	169				
		Q124	14.21	14.40	16.9	17.3			119	120				
		Mean	14.28	14.93 ns	17.2	22.6 ns	0.068	ns	121	151 ns	30	25	0.067	ns
	75	Q138	14.92	14.97	15.4	20.5 *	0.0088		103	137				
		Q150	14.83	14.92	15.9	25.0 *	0.0015		107	168				
		Q124	15.03	13.91	14.6	17.0 ns	0.61		97	122				
		Mean	14.93	14.69 ns	15.3	20.7	Signif var *space interaction		103	141*	38	37	0.027	27
	105	Q138	14.04	14.63	17.6	24.8			125	170				
		Q150	15.25	15.22	16.3	24.1			107	159				
		Q124	14.81	14.54	16.2	16.9			109	116				
		Mean	14.54	14.75 ns	16.9	22.7 ns	0.053	ns	117	154*	37	32	0.027	23
	135	Q138	14.72	15.06	17.0	22.4			116	148				
		Q150	15.06	15.10	17.2	22.1			114	146				
		Q124	14.05	15.30	12.4	22.4			88	146				
		Mean	14.64	15.13 ns	15.9	22.3*	0.025	4.47	108	147*	39	36	0.011	18
	195	Q138	14.33	14.50	15.9	21.6			112	149				
		Q150	14.63	15.49	16.6	26.7			114	173				
		Q124	14.96	14.63	16.1	21.2			107	145				
		Mean	14.56	14.78 ns	16.1	22.8*	0.004	1.79	111	154*	43	39	0.0015	7

Table 16 - Harvest results of the first-ratoon of the Harte irrigation trial

Treatment	CCS		Cane yield (t/ha)				Sugar yield (t/ha)	
	1.5 m rows	2.1 m beds	1.5 m rows	2.1 m beds	Yield difference %	Yield difference t/ha	1.5 m rows	2.1 m beds
High Water								
Q138	14.60	14.60	107	121	13	14	15.6	17.8
Q150	13.70	14.68	93	123	32	30	12.6	18.1
Q124	14.60	14.40	85	93	9	8	12.5	13.3
Mean	**14.30**	**14.56**	**95**	**112**	**18**	**17**	**13.6**	**16.4**
LSD 5%	ns		10.6				0.96	
Low Water								
Q138	13.98	13.71	84	107	27	23	11.8	14.6
Q150	13.58	14.28	73	103	41	30	9.8	14.7
Q124	14.10	14.52	78	83	6	5	11.0	12.0
Mean	**13.88**	**14.17**	**78**	**98**	**26**	**20**	**10.9**	**13.8**
LSD 5%	**ns**		**10.6**				**1.66**	

Table 17 - Effect of row spacing on water-use efficiency in the Harte trial

Irrigation amount	Row spacing (m)	Effective rainfall (mm)	Irrigation (mm)	Total water (ML/ha)	Yield (t/ha)	CWI (t/ML)
High	1.5	525	220	745	95	12.7
	2.1	525	220	745	112	15.0
Low	1.5	525	100	625	78	12.5
	2.1	525	100	625	98	15.7

4.4 Optimum fertiliser strategy for different plant densities

4.4.1 Nitrogen-rate trial (Churchward)

Stalk count and harvest weights showed that the nitrogen rate treatments had very little effect on cane yield in the plant, first- or second-ratoon crops. Analysis of the bore water used to irrigate this trial indicated that nitrate nitrogen levels were between 5 and 25 ppm. During each crop the trial was irrigated with approximately 3 ML/ha, which would have supplied an additional 17-78 kg N/ha. This is a probable reason for the lack of response to nitrogen. In all three crops the 0.5 m spacing had significantly higher stalk numbers, cane and sugar yield than the 1.5 and 1.8 m row spacing.

4.4.1.1 Plant crop

Stalk numbers in January 1999 (Table 18 and Figure 11) and March 1999 (Table 19 and Figure 12), 5 and 7 months, respectively, after planting, show no significant effect of nitrogen application on stalk number in any of the treatments. There was a highly significant ($P < 0.001$) increase under the higher planting densities (Table 18). Compared to the 1.5 m rows there was 15% more stalks in the dual rows and 71% more in the 0.5 m row treatments. This trial heavily lodged at 10 months, so it was not possible to collect stalk counts after this time.

Table 18 - Effect of row spacing and nitrogen on stalk number per ha (January 1999)

Nitrogen rate (kg N/ha)	Q124			Q170$^{\Phi}$		
	1.5 m	**1.8 m**	**0.5 m**	**1.5 m**	**1.8 m**	**0.5 m**
0	82,667	104,444	147,500	108,000	108,333	175,500
60	100,000	96,111	151,500	114,667	120,000	169,500
120	106,000	110,000	173,000	109,333	102,222	166,500
180	88,667	118,889	180,500	115,333	123,889	182,000
240	85,333	117,778	165,000	114,667	118,333	204,000
Mean	92,533	109,444	163,500	112,400	114,556	179,500
LSD 5%	22,599					

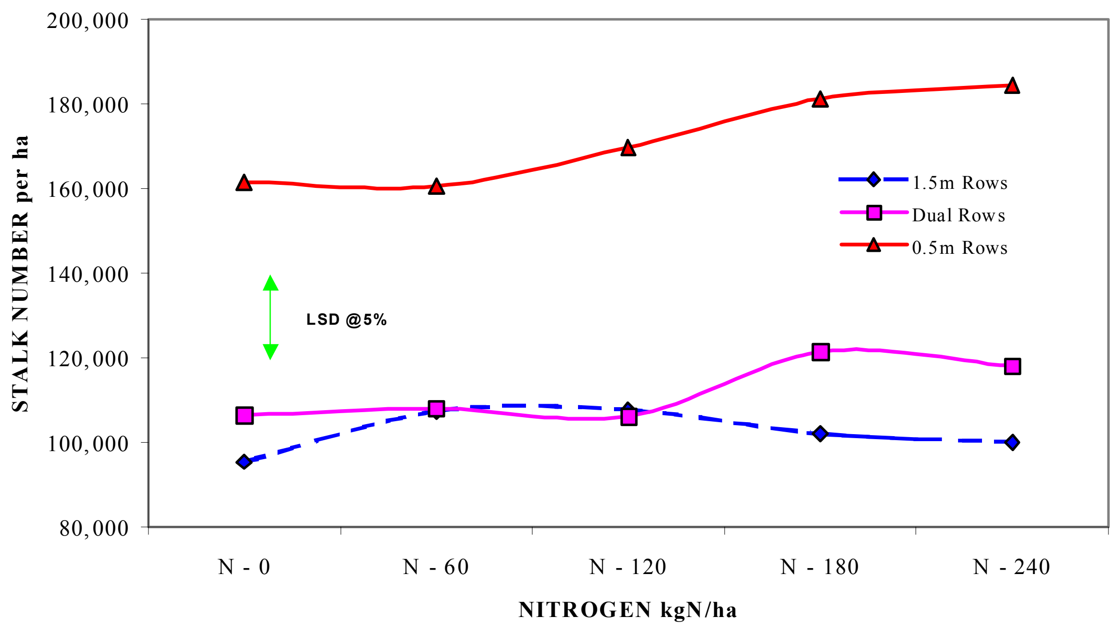


Figure 13 - Impact of row spacing and nitrogen on stalk numbers per ha (January 1999)

Table 19 - Effect of row spacing and nitrogen on stalk number per ha (March 1999)

Nitrogen rate (kg N/ha)	Q124			Q170[Φ]		
	1.5 m	1.8 m	0.5 m	1.5 m	1.8 m	0.5 m
0	66,222	102,222	120,909	79,333	95,000	121,212
60	73,778	95,185	113,333	81,333	96,111	112,121
120	76,667	94,074	122,424	76,667	98,333	118,788
180	70,222	107,037	124,242	77,333	97,222	124,848
240	65,778	99,630	116,667	80,667	98,889	138,182
Mean	70,400	99,630	119,515	79,067	97,111	123,030
LSD 5%	6,334					

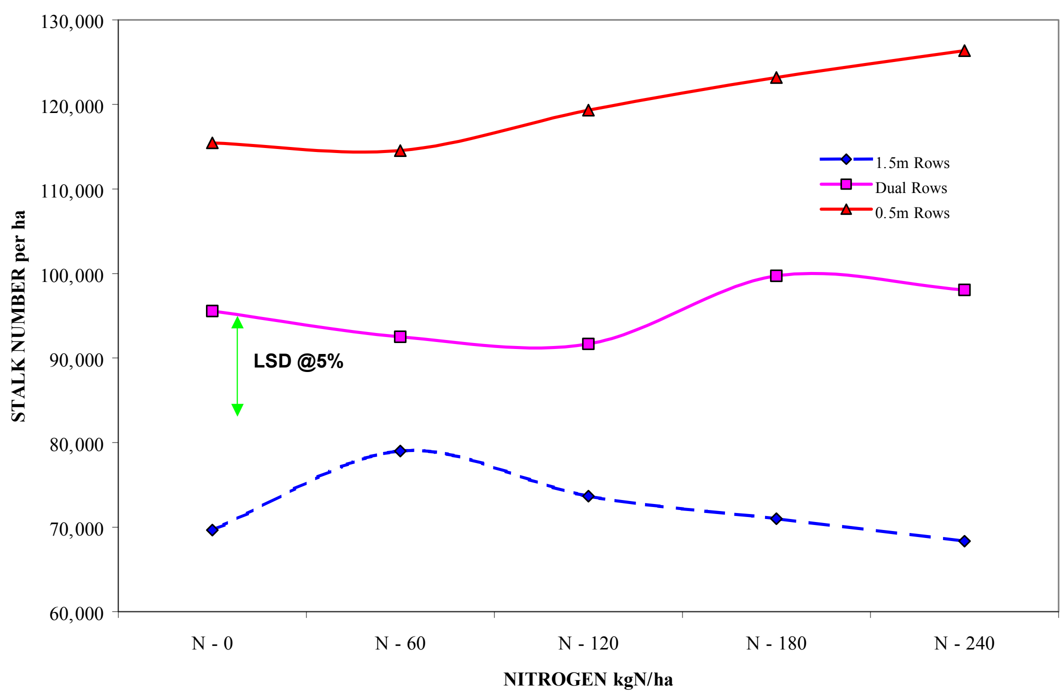


Figure 14 - Effect of row spacing and nitrogen application on stalk number per ha (March 1999)

Soil-moisture content measured with the tensiometers from December 1999 to harvest are summarised in Figures 13 and 14. These show very little difference in moisture stress in the root-zone between row spacings and that the crop suffered little stress during growth. The critical tensiometer reading for reduced growth in a sandy soil was about 40 cbars.

Early in crop growth, prior to commencement of irrigation in mid January, most water use occurred under or close to the cane row for the 1.5 m and dual-row spacings, with little water use in the inter-space region. In the close rows, water use was spread across the whole of the 2.1 m bed. This meant that the effective proportion of the area for utilisation of stored rainwater by close rows was approximately 78%, compared to 50% in dual rows and 26% in single rows. This trend was less pronounced in mature cane from February to August where there was some water usage in the inter-space of the 1.5 m and 1.8 m rows.

The better use of stored rainfall early by close rows may explain their apparently higher water-use efficiency.

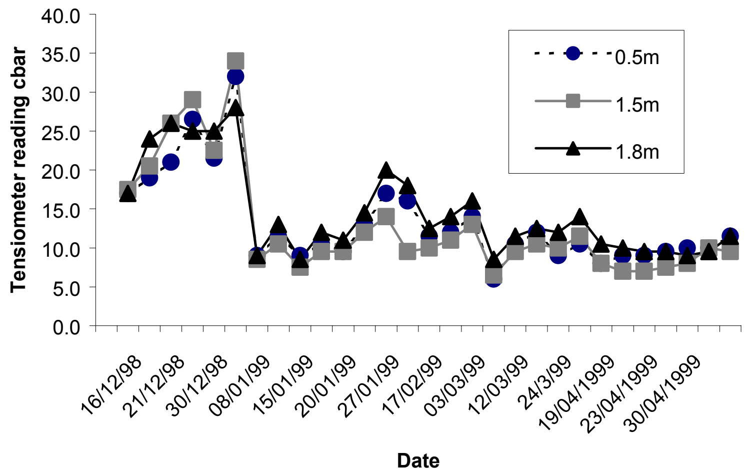


Figure 15 - Soil moisture at 30 cm versus row spacing

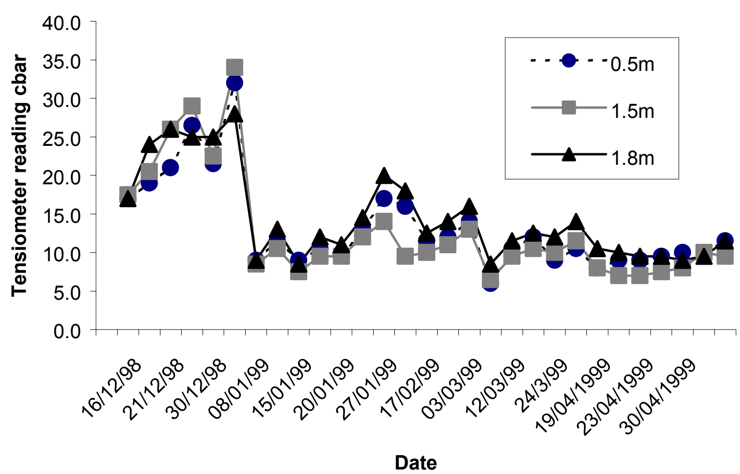


Figure 16 - Soil moisture at 60 cm versus row spacing

Leaf samples were taken in March 1999 to assess fertiliser uptake in the different treatments. Results for nitrogen levels are summarised in Tables 20 and 21. There is no clear effect of nitrogen treatment on third leaf nitrogen levels (Table 20). Severe yellowing was observed in the zero-nitrogen plots prior to commencement of irrigation. The yellowing gradually disappeared as irrigation was applied. Analysis of the bore water used to irrigate this trial indicated that nitrate nitrogen levels varied by between 5 and 25 ppm over the crop cycle. During each crop the trial was irrigated with approximately 3 ML/ha, which would have supplied an additional 17-78 kg N/ha. This may explain the lack of response to nitrogen. The nitrogen treatments imposed on this trial were unsuccessful developing a response to nitrogen application. The stalk-count, leaf-sampling and final-yield data suggest that sufficient nitrogen was supplied from irrigation water and possibly from soil nitrogen reserves to maximise crop growth.

Table 20 - Mean third-leaf nitrogen levels versus nitrogen rate

Nitrogen rate (kg N/ha)	Third-leaf N %
0	1.80
60	1.83
120	1.78
180	1.82
240	1.85
LSD 5%	0.06

Table 21 - Mean third-leaf nitrogen versus row spacing

Row spacing	Third-leaf N %		
	Mean	Q124	Q170[Φ]
1.5 m	1.87	1.96	1.79
1.8 m duals	1.83	1.96	1.71
0.5 m	1.74	1.84	1.65
LSD 5%	n.s.		

There was no significant trend between the leaf nitrogen levels measured in the two cultivars. The Q124 leaf samples all exceeded the critical level of 1.8% N whereas the Q170[Φ] was consistently below the critical level (Table 21). This effect has been noted for these cultivars in other trials.

Table 22 - Impact of row spacing on yield parameters

Cultivar	Cane yield (t/ha)			Sugar content (CCS)			Sugar yield (t/ha)		
	1.5 m	Duals	0.5 m	1.5 m	Duals	0.5 m	1.5 m	Duals	0.5 m
Q124	128	138	161	15.7	16.3	16.1	20.1	22.4	26.0
Q170[Φ]	132	141	168	14.9	15.6	14.9	19.9	21.4	25.1
Mean	130	139	165	15.4	16.0	15.5	20.0	21.9	25.6
LSD 5%	10.5			ns			2.2		

The trial was harvested in October 1999 at approximately 12 months age. A summary of CCS, cane- and sugar-yield results is shown in Table 22. The 0.5 m row spacing produced significantly (P>0.01) more cane and sugar per hectare than the 1.5 m spacing. The 0.5 m treatment increased cane yield by 35 t/ha and sugar production by 5.7 t/ha, compared to the 1.5 m single-row treatment. There was no significant difference in yield between the 1.5 m and 1.8 m dual rows. There was no significant nitrogen effect on CCS, cane or sugar yield in any of the row-spacing treatments.

Water use efficiency in the different row spacings was estimated from effective rainfall, measured irrigation water applied and cane yield (Table 23). The effective rainfall was estimated from EnviroSCAN® readings in the cane row. The Cane Water Index (CWI) for each treatment calculated as cane yield per mega litre water (effective rainfall plus irrigation) is given in Table 3. In this case the four-row beds were about 26% more efficient than 1.5 m rows in their use of available water.

Table 23 - Effect of row spacing on water-use efficiency

Row spacing	Rainfall (mm)	Effective rainfall (mm)	Irrigation (mm)	Cane yield (t/ha)	CWI t/ML
1.5 m	1091	853	324	130	11.0
1.8 m duals	1091	853	311	139	11.9
0.5 m	1091	853	342	165	13.8

4.4.1.2 First-ratoon crop

Stalk counts measured in January 2000 (Table 24) showed that there were significantly (P=0.000) more stalks per hectare in the 0.5 m row spacing compared to the 1.5 m and dual-row treatments. However, the overall response to nitrogen application still remained slight and insignificant (Figure 17). This result is consistent with the stalk count and harvest results from the plant crop.

Table 24 - Effect of row spacing and nitrogen application on stalk counts (,000/ha) in the two cultivars

Nitrogen	Q124			Q170[Φ]			Mean		
(kg/ha)	1.5 m	Duals	0.5 m	1.5 m	Duals	0.5 m	1.5 m	Duals	0.5 m
0	83.2	106.7	193.3	115.7	152.7	217.0	95.1	125.4	205.2
60	85.9	122.8	185.8	110.3	146.0	258.2	95.7	131.7	222.0
120	96.7	125.9	194.2	130.7	136.2	241.5	76.7	129.1	217.9
180	113.0	122.0	206.1	123.4	156.1	239.4	116.7	136.6	222.7
240	93.8	114.6	180.0	121.5	147.4	253.9	106.2	131.5	217.0
Mean	94.5	118.4	191.9	120.3	147.7	242.0	104.8	130.9	216.9
LSD 5%							16.5		

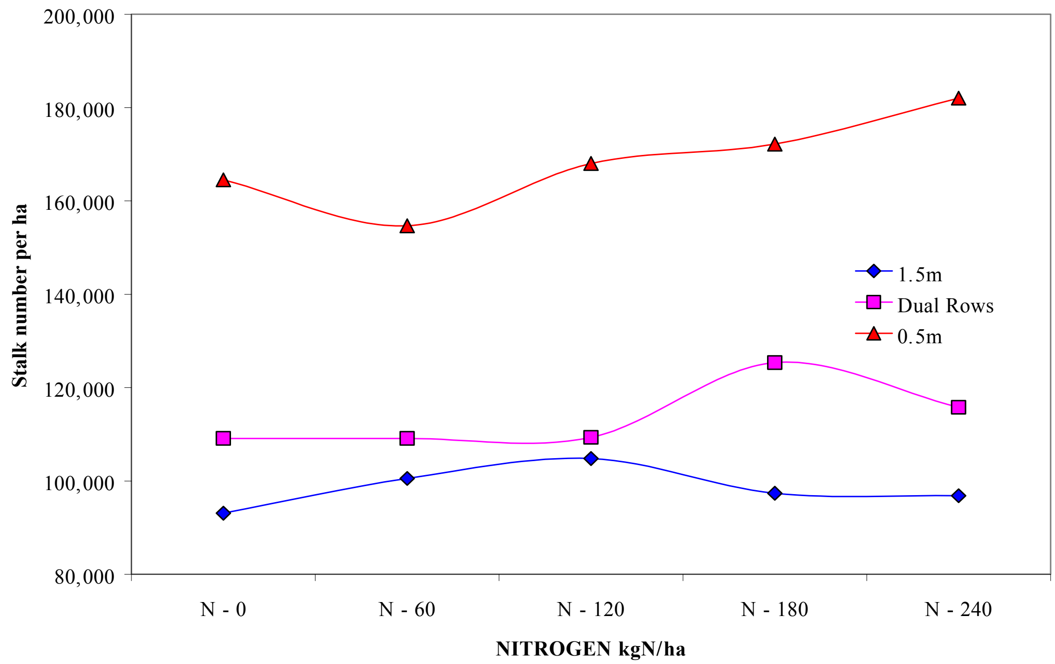


Figure 17 - Effect of row spacing and nitrogen application on stalk number

Leaf samples were taken in November 2000 to assess fertiliser uptake in the different treatments. Results for nitrogen levels are summarised in Tables 25 and 26.

Table 25 - Mean third-leaf nitrogen levels versus nitrogen rate

Nitrogen rate (kg N/ha)	Third-leaf N %
0	1.79
60	1.88
120	2.00
180	2.04
240	2.06
LSD 5%	0.073

Table 26 - Mean third-leaf nitrogen versus row spacing

Row spacing	Third Leaf N %		
	Mean	Q124	Q170$^{\Phi}$
1.5 m	1.99	2.09	1.83
1.8 m Duals	1.98	2.07	1.85
0.5 m	1.89	2.03	1.76
LSD 5%	0.05		

As nitrogen rate increased there was a corresponding slight increase in third-leaf nitrogen levels (Table 25). The critical level of 1.8 % N was exceeded in all but the zero-nitrogen rate. As measured in the plant crop, the Q124 samples all had slightly higher leaf-nitrogen levels than the Q170[l]. The third-leaf nitrogen levels suggest that there was sufficient nitrogen available for maximum crop growth

At the harvest of the 11-month-old first-ratoon crop (Table 27) there was a significant cane and sugar yield increase due to closer row spacing (P=0.012 and 0.02, respectively). There was also a minor, but significant, nitrogen-rate effect on cane yield, CCS and sugar yield (P=0.0013, 0.000, 0.000, respectively). There was little impact of nitrogen on yield at rates higher than 75 kg N/ha in any row spacing. The row spacing by nitrogen rate interaction was not significant indicating that in this trial there was no difference in nitrogen requirement in the three row spacings tested.

These results are in general agreement with those obtained for the plant crop. In this trial an application rate of 100 kgN/ha would have been more than adequate for all row-space treatments tested.

Table 27 - Response of yield parameters to nitrogen application rate and row spacing

Nitrogen (kg/ha*)	Cane yield (t/ha)				CCS				Sugar yield (t/ha)			
	1.5 m Rows	Dual rows	2.1 m beds	Mean	1.5 m rows	Dual rows	2.1 m beds	Mean	1.5 m rows	Dual rows	2.1 m beds	Mean
15	101	105	113	106	16.7	16.5	16.5	16.6	16.8	17.4	18.6	17.6
75	107	114	129	117	16.2	16.9	16.5	16.5	17.2	19.2	21.4	19.3
135	108	116	133	119	16.2	16.2	16.3	16.2	17.6	18.8	21.7	19.4
195	110	114	135	120	16.3	16.7	16.1	16.4	17.9	19.1	21.6	19.5
255	112	117	134	121	16.6	16.2	15.9	16.2	18.5	19.0	21.4	19.6
Mean	108	113	129		16.4	16.5	16.3		17.6	18.7	20.9	
LSD	10.7				ns				0.87			

- nitrogen application rate includes the 15 kg N/ha supplied in the irrigation water

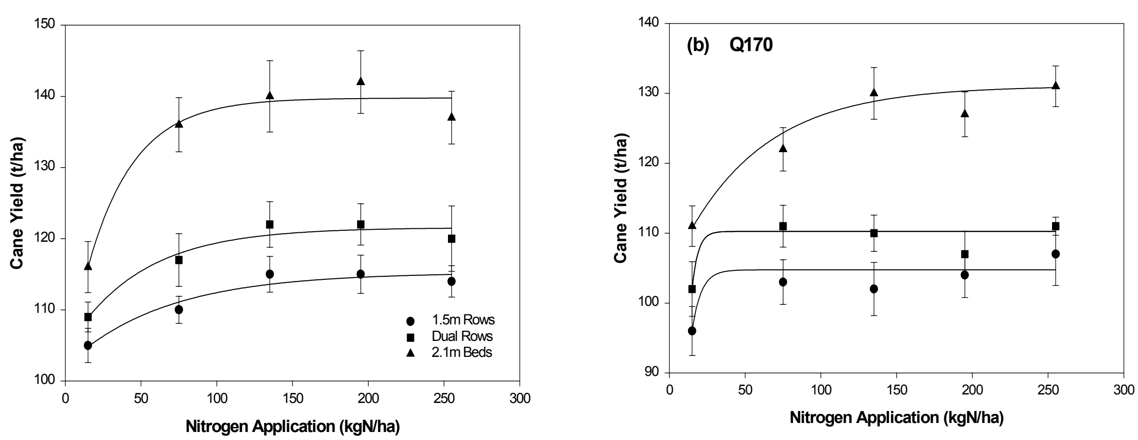


Figure 18 - Effect of nitrogen application on cane yield

The water application and effective rainfall for each row space treatment was monitored during this trial and water use efficiencies (tonnes cane/ML water) were improved at the closer row spacings (Table 28). This result is consistent with the trend reported for the plant crop (Table 29). In the ratoon crop, effective rainfall was 1 ML/ha lower and no additional irrigation water was available, resulting in a reduction in cane and sugar yields. Stool damage during harvest may have also reduced cane growth. In both the plant and first-ratoon crops, the closer row spacings had higher water-use efficiencies.

Table 28 – Water-use efficiencies in the first-ratoon crop

Row spacing	Irrigation ML	Eff. rainfall ML	Total water ML	Yield t cane/ha	WUE t cane/ML
1.5 m	2.9	4.5	7.4	108	14.6
Duals	3.1	4.5	7.6	113	14.9
0.5 m	3.3	4.5	7.8	129	16.5

Table 29 – Water-use efficiencies in the plant crop

Row spacing	Irrigation ML	Eff. rainfall ML	Total water ML	Yield t cane/ha	WUE t cane/ML
1.5 m	3.2	5.5	8.7	130	14.9
Duals	3.1	5.5	8.6	139	16.2
0.5 m	3.4	5.5	8.9	165	18.5

4.4.1.3 Second-ratoon crop

Progressive stalk counts on the second ratoon crop show the usual responses to dual and close rows until day 189 after ratooning, when the trial lodged and precluded further counting (Figure 19). At that time, the close rows had 56% more stalks and the dual rows had about 36% more than the conventional planting and counts appeared to have stabilised.

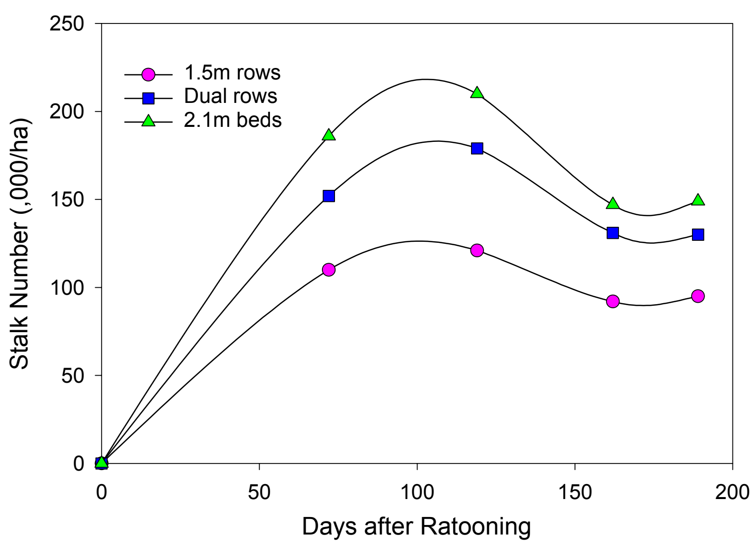


Figure 19 – Progressive stalk numbers at three row spacings

Results from the analysis of variance for the sample harvest conducted on 9 April 2001 (189 days after ratooning) are summarised in Table 30. Row spacing and nitrogen main effects were significant for stalk number, stalk weight and cane yield. A cultivar by row spacing interaction occurred with stalk weight, but not on stalk number or cane yield. All other interactions were insignificant.

Table 30 - Summary of F values and the associated probabilities form the analysis of the second ratoon sample harvest.

Source	df	Stalk number		Stalk weight		Cane yield	
		F value	P	F value	P	F value	P
Row Space	2	196.36	0.0001	16.6	0.012	35.22	0.003
Cultivar	1	22.54	0.0032	8.91	0.025	2.3	0.18
Row space * Cultivar	2	0.44	0.66	7.67	0.023	3.11	0.11
Nitrogen	4	5.16	0.0015	5.78	0.0007	5.96	0.0006
Nitrogen * Row space	8	1.41	0.21	1.81	0.33	0.4	0.91
Nitrogen * Cultivar	4	1.23	0.31	0.51	0.72	0.84	0.50
Nitrogen * Cultivar * Row	8	0.89	0.53	0.4	0.91	0.66	0.72

In this crop there was a significant increase in yield and stalk weight from a nitrogen application of 60 kg N/ha, but little effect of higher application rates (Table 31). The main effect of nitrogen on stalk numbers was only evident at rates of 180 kg N/ha and above. Dual and close rows significantly increased stalk numbers and cane yields but, in this trial, they were accompanied by decreased stalk weights. Yield increases of about 16% and 34% were obtained from dual and close rows, respectively, at all nitrogen application levels.

Table 31 - Nitrogen rate and row spacing effects on yield components measured in the sample harvest, 189 days after ratooning. Average of two cultivars.

Nitrogen (kg N/ha)	Stalk number per ha				Stalk weight (kg)				Cane yield (t/ha)			
	1.5 m rows	Dual rows	2.1 m beds	Mean	1.5 m rows	Dual rows	2.1 m beds	Mean	1.5 m rows	Dual rows	2.1 m beds	Mean
0	90,333	127,963	150,317	122,871	0.725	0.641	0.616	0.661	65.2	83.9	93.0	80.7
60	97,333	122,963	157,302	125,866	0.901	0.761	0.734	0.799	87.3	95.0	115.5	99.3
120	97,000	123,519	148,095	122,871	0.782	0.752	0.660	0.731	75.4	92.4	97.8	88.5
180	102,333	139,815	167,937	136,695	0.843	0.680	0.693	0.738	84.9	94.8	115.4	98.4
240	97,222	144,630	155,079	132,310	0.880	0.662	0.732	0.758	85.5	95.7	112.4	97.9
Mean	96,844	131,778	155,746		0.826	0.699	0.687		79.7	92.4	106.8	
LSD means	8,300			7,701	0.074			0.060	9.0			9.4

The second ratoon crop of this trial was harvested at 346 days after ratooning (Table 32). Analysis of the harvest data showed no significant effects of row spacing, nitrogen rate or nitrogen by row space interaction on cane yield and sugar yield of either Q124 or Q170$^{\Phi}$ (Tables 33 and 34).

There was a significant difference in mean CCS in Q170[(b)], with the mean CCS of 15.3 in the 2.1 m beds significantly higher than the mean CCS in the 1.5 m rows of 14.1. There was no similar effect in Q124. The difference in CCS was not strong enough to give a significant increase in sugar yield.

The highly significant yield difference between the three row spacings measured in the plant and first-ratoon crop harvests and the sample harvest were not apparent in the final harvest. The harvest results show there was no response to nitrogen; even the zero nitrogen treatment caused no significant reduction in cane or sugar production. No visual leaf-deficiency symptoms were recorded in any of the treatments. It was expected that soil nitrogen reserves after the plant crop should have been depleted sufficiently for a response to nitrogen to be measured in the ratoons. To maintain production for a plant and two ratoon crops nitrogen must have been sourced from elsewhere, perhaps the irrigation water used on the trial supplied sufficient nitrogen for crop growth but this has by no means been confirmed.

Table 32 - Harvest results of the second ratoon crop

Cultivar	**Nitrogen rate (kg/ha)**	**CCS**			**Cane yield (t/ha)**			**Sugar yield (t/ha)**		
		1.5 m rows	**1.8 m dual rows**	**2.1 m beds**	**1.5 m rows**	**1.8 m dual rows**	**2.1 m beds**	**1.5 m rows**	**1.8 m dual rows**	**2.1 m beds**
Q124	0	16.1	14.8	15.7	78	74	79	12.6	11.0	12.4
	60	15.1	12.3	15.1	78	81	89	11.8	10.0	13.3
	120	15.2	13.3	15.2	83	84	83	12.5	11.1	12.6
	180	14.0	15.1	15.1	84	75	82	11.9	11.3	12.4
	240	14.8	15.0	15.3	81	74	82	12.1	11.1	12.5
	Mean	15.0	14.1	15.3 *	81	77	83	12.2	10.9	12.7
Q170[(b)]	0	15.7	15.6	15.6	76	91	76	11.9	14.2	11.9
	60	15.2	13.8	15.9	99	90	83	15.1	12.5	13.2
	120	14.1	14.6	15.4	78	85	109	11.0	12.4	16.8
	180	15.6	14.5	15.4	78	87	96	12.2	12.6	14.9
	240	14.6	13.5	15.0	82	83	96	12.1	11.2	14.4
	Mean	15.0	14.4	15.5	83	87	92	12.5	12.6	14.2

Table 33 - Summary of F values and the associated probabilities from the analysis of the second ratoon harvest results, cultivar Q124

Source	**df**	**CCS**		**Cane yield (t/ha)**		**Sugar yield (t/ha)**	
		F value	**P**	**F value**	**P**	**F value**	**P**
Row spacing	2	4.96	0.17	0.38	0.72	0.50	0.66
Nitrogen rate	4	1.39	0.29	0.26	0.89	0.18	0.94
Row spacing * Nitrogen	8	0.46	0.86	0.81	0.61	0.89	0.55

Table 34 - Summary of F values and the associated probabilities from the analysis of the second ratoon harvest results, cultivar Q170$^{\Phi}$

Source	df	CCS		Cane yield (t/ha)		Sugar yield (t/ha)	
		F value	P	F value	P	F value	P
Row spacing	2	8.94	0.03	0.20	0.98	3.13	0.15
Nitrogen rate	4	2.54	0.06	0.35	0.84	0.05	0.99
Row spacing * Nitrogen	8	2.21	0.06	0.20	0.98	0.20	0.98

5.0 OUTPUTS

The plant-density trials were successful in demonstrating the effect of row spacing and within-row plant spacing on cane yield. Increasing plant density resulted in an increase in cane yield and stalk numbers at harvest. Cane yield increases almost linearly as row spacing reduces from 1.5 m to 0.5 m, but there was little change in cane yield as row space reduced further to 0.125 m. Increasing within-row plant spacing by double and quadruple the planting rate tended to result in significant, but relatively small, increases in cane yield in all three row-spacing treatments. Altering row spacing had a larger effect on cane yield than increasing the within row planting rate. Both trials show the importance of good establishment regardless of row spacing is used. No significant cultivar interaction was measured for any of the yield attributes measured in the trials.

The irrigation rate trials successfully demonstrated that with the same inputs the four rows on 2.1 m bed-system increased cane production and water-use efficiency particularly under low-water regimes. A yield response to the irrigation regimes was measured in both trials. The soil-moisture monitoring equipment was not able to measure a difference in water use between the two row spacings or any increase in rainfall infiltration between the row spacings. Anecdotal evidence suggests that the four rows on 2.1 m beds use more water earlier in crop growth and may require slightly different irrigation scheduling.

Very little response to nitrogen application was measured in either row spacing treatments of the nitrogen rate trials.

6.0 EXPECTED OUTCOMES

The benefits of higher-density planting and controlled traffic have already been recognised by many growers throughout the industry. In recent years there has been a dramatic increase in the area planted to dual rows on 1.8 m centres. Growers in the Bundaberg, Mackay, Maryborough, and Ingham districts are also presently investigating new farming systems consisting of in two and three rows on 2 m wheel spacings. Results from the present project show that cane grown in these configurations will increase yield and may reduce production costs. Most existing planting, fertilising and weed control equipment can be modified to suit these systems. The major cost has been modification of the harvesting equipment.

Dual rows can be managed with existing farm and harvesting equipment with only slight modifications. This is the first step towards obtaining the yield benefits demonstrated by this and other R&D projects. If correctly managed, the shift to dual rows can be expected to lift cane production by about 15% and provide significant reductions in production costs. Based on annual industry production value of $1 billion, the gross benefit to the industry if only 50% of growers adopt dual rows will be at least $75 million. Significant cost savings associated with shorter travelling distance per hectare, reduced cultivation costs and increased rainfall infiltration rates will further increase the profits accruing from the 1.8 m dual row farming system. It can be expected that the two and three rows on 2 m systems will further reduce costs and increase cane yields.

This project demonstrated that the four rows on 2.1 m beds system increased water-use efficiency by producing more cane than the conventional 1.5 m rows under the same irrigation regime. Even under the low irrigation regime, the 2.1 m beds produced significantly more cane. These findings have very important implications for districts where crop growth is limited by the availability of sufficient quantities of irrigation and rainwater.

7.0 FUTURE RESEARCH NEEDS AND RECOMMENDATIONS

These row-spacing and plant-spacing trials do not provide enough information about the effect of plant density on yields of ratoon crops. Many of the previously established high-density trials harvested as second ratoons in 2002 showed no difference in yield between the 1.5 m singles and the higher-density configurations. These trials are now third ratoons and the higher-density configurations appear gappy compared to the single rows. Because the closer rows tend to have fewer stalks per stool, they may be more vulnerable to stool damage at harvest. Perhaps the high-density harvester is causing excessive stool damage and needs to be redesigned. Either way the closer rows do not seem to be as robust and may not perform as well under commercial conditions. This needs to be determined in well-designed trials to provide data for useful comparisons of systems.

The layout of the plant-density trials and the small number of guard rows between the row-spacing treatments were not optimal. Further data should be collected from the Yield Decline Joint Venture farming-system trials to be planted at Bundaberg Sugar Bingera farm in September 2003. This trail aims to compare up to six row-spacing configurations, and results will be compared to the results of this project.

The moisture monitoring equipment used at the irrigation trials was unsuccessful at measuring any difference in water use between the two row spacings. Higher-density configurations appear to stress several days before the single rows, particularly during the first few months of growth. The light-interception and stalk-count measurements show that the higher-density configurations will reach canopy closure much earlier than the single rows, as a result the higher-density configurations should have a higher water use up until when the single-row treatment reaches crop closure. Not enough sensors were used in the present trials and the EnviroSCAN® sensors could have been better placed.

8.0 PUBLICATIONS

The results of this project have been conveyed routinely to grower action groups already participating in the high density-planting program. The trial results as yet have not been published in any scientific papers.

9.0 ACKNOWLEDGMENTS

This project could not have been completed without the valued support of cooperating growers Ned Churchward and Brian Harte. Terry Bull championed the project and initiated the trials. Danny Leary, Les Poulsen and Greg Redgard put in many hours of difficult work to collect the data.

10.0 REFERENCE

Bull, T.A. (1975) Row spacing and potential productivity in sugarcane. *Agronomy Journal* 67: 421-423.