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GENOTYPE SELECTION AND MANAGEMENT STRATEGIES FOR EXPLOITATION OF RESPONSES TO HIGH PLANTING DENSITIES

by

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SUMMARY

The current inter-row spacing of commercial sugarcane crops (approx. 1.5m) has arisen in response to the increasing size of farm machinery required for mechanised operations and harvesting. It is a compromise configuration that is neither optimised for the efficient interception of light, water and nutrient resources nor for a correct match to prevailing equipment size, particularly harvester size. Any further increase in row spacing to minimise stool damage, limit losses from soil compaction and better match harvesting equipment is likely to exceed the productive potential of single rows. This is not a tenable option at a time when the cost/price squeeze is increasing appreciably, sugar prices are declining and the opportunities to expand laterally to contain production costs have all but disappeared. Hence, it is important for the industry to explore alternative strategies for improving productivity, providing vertical expansion and reducing the cost of production.

High density planting (HDP) provides one such strategy. HDP is not new to sugarcane and it has been researched in several countries, including Australia. In most cases, whilst research trials proved promising and gave significant increases in production from HDP, it was not possible to translate this potential into commercial gain. Consequently, rather than investigate the reasons behind this failure, most industries elected to ignore the potential benefits from HDP and chose not to seek ways to commercially exploit these benefits. It is difficult in hindsight to define the factors most likely to have contributed to the commercial failure of HDP. Some of the more likely include the use of unsuitable varieties, adoption of inappropriate inter and intra row spacings, a lack of specific HDP planting and harvesting equipment and an expectation that HDP could be managed under the prevailing farming systems.

This project sought to confirm that HDP has the potential to provide significant yield increases under a wide range of conditions, explore the physiology behind the yield increase from HDP and attempt to identify those practices that might be required to commercially exploit HDP.

Trial results showed that cane yield increased almost linearly from a planting density of 20,000 setts/ha (1.5m rows) through intermediate row configurations to a density of 60,000 setts per ha (0.5m rows). Yield responses of about 50% over 1.5m rows were obtained from 0.5m rows and up to 20% from dual rows in trials from Harwood (northern New South Wales) to Meringa (north Queensland), under rainfed and irrigated conditions, in plant first and second ratoon crops and in autumn and spring planted crops. A total of over 120 clones and cultivars were assessed and, although the significance of the genotype by row spacing interaction varied between populations, the genetic variance available in 0.5m rows was equal to or greater than that available in 1.5m rows. Hence, selection for genotypes that are more responsive to HDP is a distinct possibility.

Examination of light, water and nutrient responses in 1.5m and 0.5m rows indicated that 0.5m rows made more effective use of these resources. Close rows achieved a more rapid canopy cover than 1.5m rows and, in the period prior to canopy closure by 1.5m rows, they intercepted about 50% more of the incident radiation. This increase was translated into an increase in dry matter accumulation that was sustained throughout the life of the crop and delivered as an increased cane yield at harvest. In the plant crop close rows provided the 50% yield increase at the recommended rate of nitrogen application for standard 1.5m crops. In neither crop was yield increased by heavier applications of

nitrogen. Given the expectation that 0.5m rows were probably exploiting soil reserves of nitrogen it is possible that 0.5m rows may require heavier nitrogen applications in ratoon crops and this will be examined in future projects. A single irrigation trial comparing water use efficiency (tonnes cane/mega litre of water) in 1.5m, dual and 0.5m rows showed that 0.5m rows returned an increase of 38% in water use efficiency. Economic assessment of the benefits from high density conducted by this project and by two external economists confirmed that HDP conveyed significant economic advantage. The magnitude of this advantage depends upon the values assumed for yield in 1.5m rows, CCS level and sugar price. If the 1.5m rows yield 100 TCH, the CCS is 13 and the sugar price is $300/tonne then 0.5m rows can deliver an increase in profit of about $4,000/ha for a cycle of a plant and three ratoon crops. The cost of production per tonne of cane is reduced by 20-25% under HDP. The economic advantages of HDP are maximised when all 'best practices' are followed and production by 1.5m rows has already been optimised. A yield increase of about 10% (depending upon assumptions) is required to recoup the direct cost of establishing 0.5m crops. The additional capital costs required to switch to multi-row equipment will be minimised by adopting contract or group planting and harvesting and by using equipment which is compatible with 1.5m, dual and close rows. In this case much of the new multi-row equipment need only be purchased when the current equipment is scheduled for replacement. Actual equipment requirements will vary with the HDP system adopted and regional or district requirements for field operations.

The results of this research, the options for its application and the development of prototype multi-row equipment have been actively conveyed to the industry. They have roused great interest and grower awareness of the real advantages of an HDP based farming system is mounting. There has already been large-scale adoption of dual rows since growers feel they can readily test them under their own conditions without modifying existing machinery. Whilst this is not strictly true an educated guess suggests that there is already in excess of 3,000 ha under dual rows and this area is expanding rapidly. Not all growers have recognised the full requirements for the successful application of dual rows so some failures are to be expected but results from the more successful growers will rectify the situation. Dual rows may prove to be the stepping stone to close rows as growers recognise the potential to further reduce production costs, the need to develop more precise farming systems and the necessity of incorporating a complete package of best practices. However, close rows are difficult for growers to adopt in the absence of specific multi-row planting and harvesting equipment. Large scale evaluation and adoption will depend upon the successful establishment of regional or district pools of HDP equipment that will allow growers to test system options under their own conditions.

1.0 BACKGROUND

In common with most agricultural industries the sugar industry continues to face problems from an increasing cost/price squeeze. This factor has been exacerbated in recent years by increased competition on the international market and the resultant decline in the sugar price. Consequently the industry must explore all possible avenues to sustainably reduce production costs and improve the effective use of available resources. In many districts the option to expand on to new land in order to increase production and so make more efficient use of capital and other resources is no longer feasible. An increasing number of growers are becoming landlocked and, in addition, environment protection and conservation constraints continue to erode the land area available for crop production. The problem resolves very simply into a need to significantly increase production per unit of land area (ie productivity) with little or no increase in the use of available resources.

High density planting (HDP), which frequently translates into closer row spacing in the sugarcane context, is one approach that can be used to address this problem. The objective behind HDP is to improve the spatial arrangement of rows and plants so that the use of available light, water and nutrient resources by the crop is optimised. One has only to observe a commercial sugarcane crop to see that for a considerable portion of the growth period the crop has less than a full leaf canopy cover and light continues to fall on bare ground between the rows. The duration and extent of this period varies between regions. It can last five to six months after planting in the Bundaberg region and in north Queensland it is not uncommon to observe light still reaching the ground at harvest time. Clearly the current row spacing strategy represents a skewed arrangement of plants which is suboptimal for the efficient trapping of the major resource contributing to crop growth.

In the Australian sugar industry, and in many overseas industries, there has been an historic progression from animal traction and hand harvesting through to large tractors and fully mechanised harvesting. To accommodate these changes the industry has increased crop row spacings to suit the level of mechanisation and size of equipment. Currently the average row spacing for the industry is about 1.5m but this is an unsatisfactory compromise since harvester and haulout wheel track widths are 1.8m. This mismatch in spacing leads to stool damage during harvest operations and limits the yield of subsequent ratoons.. However, an increase in row spacing beyond about 1.6m has been shown to reduce yield in most countries (van Dillewijn, 1952: Thompson and du Toit, 1965; Matherne, 1971; Kanwar and Sharma, 1974; Irvine *et al*, 1980; Benda *et al*, 1987). It is apparent that productivity cannot be sustained by increasing the spacing between single rows and that a return to some configuration of narrower rows or high density planting is required.

HDP is not a new technology; it is widely used in many other agricultural and horticultural crops as a production strategy to improve yields, increase cropping frequency, enhance crop management or overcome specific environmental or production constraints. Neither is the concept of HDP new to the sugar industry in Australia or overseas where the impact of row spacing on potential productivity in sugarcane has been the subject of research. A trend for higher yields at reduced row spacing has been reported from research trials conducted in several countries. Singh and Singh (1963) and Kanwar and Sharma (1974) reported yield increases in India, Herbert *et al* (1965), Matherne (1974), Irvine and Benda, (1980 a,b), and Benda *et al* (1987) reported increases in Louisiana and Gascho and Shih, (1981) recorded a similar response in Florida. Thompson and du Toit (1965) and Boyce (1968) demonstrated higher yields at reduced row spacing in South Africa but claimed that soil moisture became limiting and restricted final expression of the yield increase. In Australia Bull (1975) reported a potential yield benefit of up to 80% from higher planting density, particularly if responsive genotypes were considered.

Despite the attractive research results most attempts to adopt high density planting under commercial production systems have been disappointing (Richard *et al* 1991). A review of row spacing research in Australia (Ridge and Hurney, 1994) concluded that there was little or no yield increase from close or dual rows. However, a study of the trial methods used shows that almost all of the attempts to carry these results to commercial operations were compromised because they used current farming systems, current farming equipment and current cultivars all of which had been developed or selected to suit the prevailing row spacing. Each of these factors alone might be expected to mitigate the performance of close rows and prevent the recovery of their full yield potential. In a recent preliminary trial where these factors were recognised and their impact avoided, Bull and Bull (1996) showed that correct management can provide yield increases in 1.0m rows and 0.5m rows of 17% and 56% respectively over standard 1.5m rows.

The potential to achieve this order of yield increase cannot be ignored. The challenge is to forget the past and to focus on new systems, new equipment and new cultivars that might be adopted in order to turn it into commercial reality.

2.0 OBJECTIVES

The objectives of this project were to:

- evaluate the potential for high density planting (close row spacings) to increase yields over a range of conditions
- assess the genetic potential available to exploit higher planting density in the current breeding population
- examine alternate row spacing strategies suited to grower farming systems and constraints (including irrigated and dry land)
- assess the potential ratoon yields from close row crops (by hand harvesting)
- encourage grower interest and participation in longer term activities to develop procedures and equipment to support close row management systems
- analyse the economic cost/benefit from adopting higher planting density.

3.0 METHODOLOGY

3.1 Geographical response

Replicated trials were conducted at six latitudes from 17°S to 30°S (Table 1). Trial layouts differed slightly between locations but all were randomised split plot designs involving three or four locally important commercial cultivars and three or four row spacings (1.5m, 0.5m, dual rows 0.5m apart at 1.8m centres and triple rows 0.5m apart at 2.0m centres) replicated three times. Plots varied from 8m to 15m long and from 6m to 9m wide at different locations. All sites were managed according to prevailing local commercial production practices with the exception that inputs were planned to be non-limiting for each treatment. Basal and side dressings of fertiliser were applied on a metre of row basis (ie the 0.5m row plots received three times as much fertiliser per ha as 1.5m rows). Irrigation treatments varied between sites from zero (rainfed) or supplementary (infrequent overhead sprays) to full (daily applications through trickle tape or regularly scheduled flood irrigations). Trials at Harwood, Bundaberg and Mackay were planted in September to October 1996 and trials at Ayr, Tully and Meringa were planted in August to September 1997. One trial in Bundaberg was planted following soil fumigation using Vapam at 200litres/ha.

3.2 Resource usage

Preliminary trials to assess the nutrient requirements at different row spacings were established at three sites on two soil types (Krasnozem and Gley Podsolic) in a randomised split plot design. Two cultivars were planted in 1.5m and 0.5m rows at each site and five nitrogen levels from 10kgN/ha to 300kgN/ha were applied in three replications. Plot size was 20 to 50m long and 8m wide. Trials were sampled for stalk numbers and stalk weights to estimate cane yields (TCH).

A further trickle irrigated trial was used to measure water use effectiveness in 1.5m and 0.5m rows. Two cultivars were planted in a split plot design at a single site on a Krasnozem soil. Plots were 20m long and 8m wide. Water applications to individual blocks were monitored and effective rainfall for the site estimated. The trial was sampled for stalk numbers and stalk weights to estimate cane yields (TCH).

3.3 Management response

A management trial was established in September 1996 in a randomised split plot design with three replications on a Krasnozem soil at the Bundaberg research station. Twenty-three clones from an early stage of selection and three commercial cultivars were planted in 1.5m, 1.0m and 0.5m rows and subjected to a high management or a low management treatment. The high management treatment involved daily applications of trickle irrigation (total of 10Ml/ha plus 5.8Ml/ha of rainfall) and the low management treatment involved weekly applications of trickle irrigation (total of 1.5Ml/ha plus rainfall). Nitrogen was applied at the rate of 28gN/m row in the high and 2.8gN/m row in the low management treatments. In the ratoon crop these irrigation and fertiliser rates were halved and rainfall was 7.2Ml/ha. P and K fertiliser was applied uniformly across all plots at the recommended rates of 20kgP and 100kgK per ha. Plots were 7m long and 6m wide.

The inclusion of 26 genotypes in this trial allowed an assessment of the genetic variance for response to high planting density.

3.4 Genotype response

In order to further assess the possible genetic variation for capacity to respond to high density 78 genotypes were selected at random from an early stage of the selection program. They were planted in 1.5m and 0.5m rows in a random split plot design with two replications on the Bundaberg research station in September 1996. All plots received the high management treatment detailed above and plot size was 7m long by 2m wide.

3.5 Ratooning response

A single trial to compare the effect of hand or machine harvesting on plant and ratoon yields at different row spacing was established on the Bundaberg station in September 1996. Two cultivars (Q141 and 85S7325) were grown in 1.5m and 0.5m rows in eight replications in a split plot design. Four replications of each cultivar by row spacing treatment were harvested by hand in the plant and ratoon crops. The other four replications were harvested by a conventional Austoft 7000 machine. Plots were 6m wide and 10m long. The trial was rainfed, receiving 5.8Ml/ha of effective rain in 1996/97 and 7.2Ml/ha in 1997/98. Plots were fertilised on a metre of row basis based on the recommended rate of 120kgN/ha, 100kgK/ha and 20kgP/ha for 1.5m spaced crops.

3.6 Sampling and measuring procedures

Light interception by plant and ratoon crops of 1.5m and 0.5m rows in the management trial was measured with a linear quantum sensor and datalogger (Li Cor) at regular intervals until canopy closure was attained. In addition 10 stalks were tagged in each plot of three clones in one replicate of this trial and stalk height measured on a weekly basis. Routine meteorological data for the site was collected.

In all trials the number of millable stalks per ha was estimated by counting stalk numbers in two 5m or 10m long quadrats from two rows per plot. Two samples of 20 contiguous stalks were cut from each plot and weighed to estimate the average fresh weight per stalk. Cane yield (tonnes cane per ha) was calculated from the product of stalk number and stalk weight. In addition the 1.5m plots were harvested with a commercial cane harvester and the cane weighed directly in a specialised weighing truck. The truck weight and stalk sampling estimates agreed to +/-5%. However, the configuration of the commercial harvester is not compatible with 0.5m rows and it could not be used to estimate plot weights in close rows with any degree of reliability. A sub-sample of 6 stalks was taken from each plot and processed through a small mill to provide juice samples for routine Brix and Pol measurements to estimate commercial sugar (CCS) levels (Bureau of Sugar Experiment Stations, 1991). Stalk number and weight samples were collected at least twice during the season and all plots were sampled in the plant and first ratoon crops.

Measurements of morphological traits were conducted in the plant crop of the 1.5m row spacing treatment in the trial involving 78 genotypes. Canopy height, stool habit, length and width of the leaf attached to the top visible dewlap, stalk number per ha and average individual stalk weights were recorded. Canopy height was measured in February (prior to crop lodging) and expressed in classes (1= <1m, 2= 1.1-1.5m, 3= 1.6-2.0m and 4= >2m). Stool habit was also assessed prior to lodging and expressed in classes, 1=fully recumbent, 2= mildly recumbent and 3= erect.

3.7 Technology transfer and grower interaction

Transfer of HDP results to growers was perceived as a crucial activity for this project. Past experience with "pineapple rows" in Queensland has built up a high degree of reticence concerning high density planting at all levels of the industry. Hence, it was important to keep growers and others as well briefed as possible at all stages of the project. This was required in order to gradually overcome residual negativity and to build a ground swell of awareness about the very significant benefits available from adoption of HDP.

A strong PR program based on presentations at official BSES information meetings and field days, TV, radio and press interviews, publication of an HDP Newsletter and the publication of articles in industry journals was pursued. Wherever possible trial sites were established with interested and innovative growers and included row spacing treatments of interest to individual growers.

4.0 RESULTS

4.1 Geographical response

Comparison of mean yields from all locations showed that close rows (0.5m) significantly ($P<0.05$) increased cane and sugar yields when compared with 1.5m rows at all locations and latitudes (Table 2). The magnitude of yield increase varied from 21 to 98 for tonnes cane/ha (TCH) and averaged 57 TCH and from 3.2 to 16.3 for tonnes sugar/ha (TSH) with an average of 8.4 TSH. The average yield increase from close rows across all locations represented gains of 48-49% for cane and sugar. One low response, but still a significantly improved yield, was recorded in this trial series. It was at low latitude (Tully) and the trial was harvested by a commercial mechanical harvester. However, responses in the stalk-sampled trial at a lower latitude (Meringa) were similar to the overall averages. Hence, the lower response at Tully is not consistent with latitude. It appears to be either a location specific effect or a result of the inherent difficulty of mechanically harvesting close rows with harvesters developed for 1.5m row spacing. Similar harvesting difficulties also occurred at the Ayr site where yields from close rows were only marginally better than those from dual rows. Lack of labour availability due to unforeseen circumstances forced mechanical harvesting of these two trial sites instead of the specified hand sampling procedure. The results confirm that significant cane losses can occur when harvesting close rows with current generation harvesters. The yield increase of about 50% from close rows is reflected in both cane and sugar yields and is robust across a wide range of latitudes and production systems in plant and first ratoon crops (Tables 2 and 3). Results from a single location indicate that the response to HDP is retained into second ratoons (Table 4) despite cumulative stool damage incurred by harvesting all plots with a conventional mechanical harvester. High density significantly increased millable stalk numbers per ha, marginally decreased individual stalk weight and had no significant effect on stalk sugar (CCS) content at any location. Increased cane yield was almost directly related to the increase in stalk numbers.

Yield response to the dual row configuration was much more volatile and not significantly different from 1.5m rows at two locations. Increase in cane yield over 1.5m rows ranged from 6 to 44 for TCH with an average of 23 TCH and from 1.1 to 7.2 for TSH with an average of 4.0 TSH. The average increases across all locations represent gains of 19% for cane and 21% for sugar. Given that close rows, requiring a 200% increase in planting material, increase average cane yields by 50% then dual rows, requiring a 67% increase in planting material, might be expected to increase yields by about 17%, very close to the observed average response.

Only trials at Harwood and Mackay included the triple row configuration and the yields were compared across plant and ratoon crops. Triple rows showed an average yield response of about 28%, a little higher than the average 22% response for dual rows (Table 5).

An aggregation of all cane yield versus row spacing data collected from all trials is summarised against planting density (setts/ha) in Table 6. In this table the number of plots represented at each row spacing varies and so biases crude average yields. To minimise this effect all results were transformed on a pro rata basis to reflect yields which might have been obtained if the 1.5m treatment in all trials had yielded 115 TCH, the overall average figure. A plot of these yields against planting density (Fig. 1) shows a linear response so that the prediction of expected yields at any planting density should be relatively simple.

The capacity of HDP to significantly increase sugarcane yields agrees with the previous results reported in Australia by Bull (1975), Bull and Bull (1996) and in Florida by Gascho and Shih (1981). However, the present trials were far wider in scope than the previously reported trials. They embraced latitudes from 17°S to 29.5°S, 13 cultivars, rainfed and irrigated conditions and yield estimation using mechanical harvesting or stalk sampling. Hence, the average responses can be expected to provide a reliable estimate of the potential benefits that can be obtained from HDP across a wide range of production conditions.

The confounding effects of cultivars, irrigation treatments and location present in trials conducted at different latitudes means that it is not possible to reliably assess trends caused by these individual factors. However, the results suggest that different cultivars may respond differently to row spacing (Table 7). Some cultivars (eg Q155, Q159, Q113) appeared to be highly responsive to high density while others (eg Q117, Q152) were probably less responsive. The impact of cultivar (genotype) could be an important consideration when assessing the potential commercial benefits from HDP. Screening elite clones and commercial cultivars at high density to detect responsive genotypes could be an essential pre-requisite for the commercial adoption of high density planting.

4.2 Use of resources

4.2.1 Light

Radiation interception curves for 1.5m and 0.5m rows in plant and ratoon crops show that the canopy closes in appreciably earlier in high density crops than it does in 1.5m row crops (Fig.2). Estimation of the area under the curves indicates that when the high density crops had achieved full canopy they had intercepted about 52% more photosynthetic radiation than 1.5m rows in plant crops (by day 125) and 53% more in ratoon crops (by day 112). This represents a marked improvement in the effective use of available radiation and suggests that the yield increase from high density is established in the period up to canopy closure and is then sustained during the remaining period of crop growth.

4.2.2 Nitrogen

To facilitate a comparison of the response to nitrogen application at two row spacings the yields from the three trials were transformed to a common base (Table 8). The average yield at the lowest nitrogen rate for each row spacing was standardised to a single value and other yields transformed proportionately (Fig. 3). Close rows (0.5m) provide an appreciable yield increase even at very low levels of applied nitrogen, reflecting access to soil reserves not used by 1.5m rows. The yields for both row spacings reach a plateau at about 50 to 75kgN/ha. Hence, for plant crops on these two soil types, the yield benefit from 0.5m rows was obtained at the nitrogen application rate recommended for 1.5m row crops (ie 120kgN/ha). Despite the relatively low requirement for additional nitrogen in these trials the 0.5m row crops clearly made more effective use of the available nitrogen (soil + fertiliser) than 1.5m row crops. The close rows returned a nitrogen use effectiveness of about 1.4 tonnes of cane per kgN versus about 0.9 tonnes of cane per kgN for 1.5m rows.

4.2.3 Water

This single trial provided indicative evidence that close rows make more effective use of available water supplies from rainfall and irrigation (Table 9). Although the close rows received a little more water than the 1.5m rows they made more effective use of the available water to return 16.9 tonnes of cane per Ml versus 12.0 tonnes by 1.5m rows, about a 38% increase in effective use.

The increase in effective use of light, nutrient and water resources by high density crops, at least in the plant crop, clearly indicates the magnitude of the production constraints being imposed by the current commercial production configuration of single rows at about 1.5m spacings.

4.2.4 Soil fumigation

The influence of soil fumigation with Vapam on subsequent crop yields in standard, dual and close rows and was examined at one site in Bundaberg. This site was also trickle irrigated on a daily schedule dictated by soil moisture status measured with an Enviroscan and side dressings of nitrogen were applied using fertigation through the trickle tapes. Results presented in Tables 2, 3 and 4 (Bundaberg site) show that performance of standard rows was excellent in plant, 1st and 2nd ratoons and that highly significant responses to dual and close rows were maintained. The response to HDP is clearly independent of soil treatments to rectify yield decline problems.

4.3 Management response

Results from the latitude trials were reinforced by results from the trial assessing the influence of row spacing on the yield of 26 clones grown under high and low management practices. Clone, management regime and row spacing significantly impacted on most of the major components of yield in both plant and ratoon crops (Tables 10 and 11). The responses of all yield components to row spacing were similar under both high and low management in the plant crop (Table 10). Although the low management regime restricted growth at all row spacings the proportionate yield increase from high density was largely unchanged. This effect was carried into the ratoons of the high management treatment but was diluted in ratoons of the low management treatment, possibly due to additional stool damage in the water stressed high density plots when the trial was commercially harvested using a conventional harvester.

Water and nitrogen regimes were applied on a metre of row basis in this trial. Consequently the close rows received three times as much water and nitrogen as the 1.5m rows on a per hectare basis in the plant crop and one and a half times as much in the ratoon crop. However, results from nitrogen application and irrigation trials (Tables 8 and 9) indicate that these luxury rates, which are well on to the plateau of any response curve, are unlikely to have contributed significantly to any bias in the relative performance at each row spacing.

Hence, the capacity of high density planting to increase cane and sugar yields is independent of water and nutrient status, although the actual increase in TCH will be smaller under poor growing conditions than it is under optimal conditions.

4.4 Genotype response

Analysis of the data for yield parameters for plant and ratoon crops in the management trial (26 genotypes) and the genotype trial (78 genotypes) revealed strong main effects for row spacing and clone (Tables 10 and 12). However, although no significant row spacing by clone interaction effect was detected in the management trial (Table 11) this interaction was significant for all yield parameters except CCS in the genotype trial (Table 13). Further analysis of the clonal variance components at 1.5m and 0.5m row spacing revealed that the genetic variance present in 0.5m rows was as large as or larger than the variance found in 1.5m rows (Table 14).

These results indicate that although there is a tendency for some clones to show a similar pattern of response to high density (Table 11), many other clones respond differently to high density planting (Table 13). In either case the genetic variance for response to high density was the same as that exhibited in populations at 1.5m and, hence, there is significant capacity to select for clones that are more responsive to high density. The frequency of responsive clones is summarised for three clonal populations separately and collectively in Figure 4. Whilst many clones are virtually non-responsive (<20% yield increase) all populations display a distribution of responsive clones in plant and ratoon crops. Analysis shows that clonal distribution between these classes is different in plant and ratoon crops. This observation is not unexpected or particularly meaningful given the well-documented difficulty, routinely experienced by breeders, of predicting ratoon performance from the plant crop performance. A comparison of yield in 1.5m rows with yield in 0.5m rows (Fig. 5) shows that, in general terms, superior yielding clones at 0.5m tend to be superior at 1.5m spacing. However, the relation is less clear cut for increase in yield from 0.5m rows compared with yield in 1.5m rows. In this case several of the lower yielding clones at 1.5m have provided very large responses to 0.5m. Hence, capacity exists to select clones better suited to the closer row spacing. Relevant breeding and selection programs should be started immediately. It would appear that a double pronged approach to selecting responsive cultivars is merited. In the immediate future significant benefit can be obtained from screening existing and promising new cultivars from the current breeding program for responsiveness to HDP. In the longer term family selection in close rows followed by clonal selection in close rows will be required to generate varieties best suited to HDP. Given the time required to breed and select new varieties (>12 years) the new breeding program should be initiated immediately if it is to match the expected commercial adoption of HDP.

An assessment of morphological traits failed to detect any direct relation between a specific trait and the capacity of a clone to respond to close rows (Fig. 6). The magnitude of yield response to 0.5m rows appears to have been largely unrelated to stalk number per ha, height class, habit class, leaf length or width or to average weight per stalk. In order to see whether a combination of traits might be more indicative the trait measurements were aggregated into six classes for each trait and a trait index for each clone calculated as the product of each trait class. However, there was little relation between this trait index and the yield response to 0.5m rows (Fig. 7). At this stage there appears to be no reliable method for detecting HDP responsive clones from their morphological appearance.

4.5 Ratooning response

Comparison of the effects of hand harvesting and mechanical harvesting in the plant crop on subsequent ratoon performance of two cultivars in 0.5m rows demonstrated both the inherent robustness of the close row configuration and its capacity to recover from stool damage incurred by mechanical harvesting (Table 15). A conventional harvesting machine was used so that traffic over the rows was unavoidable in the close rows. Hand harvesting of the ratoon crops showed no significant impact of plant crop harvesting method on ratoon yields in 1.5m or 0.5m rows. In both row spacings the mechanical harvesting caused a significant reduction of stalk numbers but this was compensated by an increase in stalk weight in both cases.

This result is also borne out by ratoon yields in the previously reported field trials that, of necessity, were all finally harvested by conventional machine to prepare for ratooning. In all cases the yield increment from close rows was sustained in subsequent ratoon crops despite observations of often quite severe stool damage at harvest.

4.6 Economic assessment

The assessment of economic benefits from HDP has been conducted as a simple gross margin analysis within the project. In addition an external economic consultant (McLeod, 1997) and an external review commissioned by SRDC (Munro *et al*, 1999) have conducted economic analyses on the cost/benefits of HDP. Each assessment concluded that the 50% yield increase from HDP provided a significant economic benefit to growers and estimated that a yield increase of about 10 to 20% (depending upon assumptions made) was required to cover the additional production costs incurred by HDP.

Details of the cost assumptions used to compute gross margins for 1.5m and 0.5m row crops are shown in Table 16. An example of a cost/benefit comparison of 1.5m and 0.5m rows for a hypothetical farm is given in Table 17. This table illustrates the appreciable increase in gross margin which can be expected from 0.5m rows and also demonstrates the significant reduction in production costs per tonne of cane (viz. 22% in plant cane and up to 28% in ratoon crops). The economic benefit to growers from high density planting is readily evident with the increased gross margins from 0.5m crops remaining positive down to a CCS of 11 and a sugar price of \$280/tonne (Fig 8). Hence, HDP is an attractive strategy to help counter the current economic downturn in the industry due to low sugar prices. HDP crops become economically viable when the yield increase exceeds 10% for a sugar price of \$280/tonne and about 7% when sugar is \$320/tonne (Fig. 9). A comparison of gross margins for plant and ratoon crops shows that plant crops of 100 TCH and 13 CCS at 1.5m are unprofitable for a sugar price of \$320/tonne and below. However, 0.5m plant crops at 13 CCS break-even at \$280/tonne and each ratoon crop gives roughly a three fold increase in gross margin (Fig. 10).

Sensitivity analysis shows that 0.5m rows remain profitable under economic conditions which are unsuitable for 1.5m rows (Fig. 11). At 13 CCS 0.5m rows remain profitable until the sugar price drops to \$220 versus about \$260 for 1.5m rows. If the sugar price is \$300/tonne 0.5m rows remain profitable down to a CCS of 10.5 versus 12 CCS for 1.5m rows. Close rows at 13 CCS are economically superior to 1.5m rows for any yield increase over 8 to 10% if the sugar price is \$300. In addition, 0.5m rows are economically viable under conditions when the yield from 1.5m rows is only 70 TCH. The return from 0.5m increases as the yields in 1.5m rows are optimalised and achieve near maximum production levels.

The above analyses do not include provision for additional capital expense to procure multi-row equipment for HDP production. Such costs are not expected to be significant since HDP will probably rely upon contract planting and harvesting so that new equipment will only be procured as replacement for existing planters and harvesters at the normal changeover time. The multi-row harvester will be compatible with most row spacings but the planter will be an HDP dedicated machine. Growers will only be required to modify existing tractors, fertiliser applicators and spray gear to suit multi-row beds and track widths of 2.1m and again this will be a negligible cost.

The additional costs for milling capacity, transport systems and sugar storage facilities incurred by HDP will depend upon the production strategy adopted in a given mill area.

Should adoption be based purely on increasing crop production then adoption of HDP by 50% of growers could increase total industry production by 25% (ca. 10 million tonnes cane). Additional capacity and facilities will be required unless a greatly extended season can be adopted. In this case the rate of adoption of HDP can be expected to bring provisional plans for routine capital and infrastructure expansion forward by about 10 to 15 years. This could impose severe constraints during a period of economic fragility. However, in many cases growers will adopt HDP against a background of reducing production costs, reversing the decline in CCS, increasing the size and duration of fallow or rotation areas or of extending production of alternative crops. If these strategies are adopted then total cane production in a district may increase only marginally or not at all. Production efficiency will rise appreciably, soil health should recover and long term sustainability will be enhanced but no additional investment in capacity and infrastructure will be required.

Hence adoption of HDP makes sound economic and environmental success.

4.7 Technology transfer

The potentially great value of high density planting to the Australian sugar industry and the difficulties likely to arise from the need to introduce an entirely new farming system to exploit it was recognised from the beginning of this project. In addition, the adverse mind-set present in the industry from the historical performance of “pineapple rows” was also recognised as a severe constraint to acceptance of any new attempt to promote HDP. Consequently the project included a very active public relations component to counter these trends and to inform growers and other researchers of the value of HDP to the industry once proper management techniques were employed.

Whilst HDP is a very important concept it is only part of a thrust to dramatically improve sugarcane production methodology by moving to more precise, more sustainable and more cost effective farming systems. Hence, the extension component was kept to the forefront from project conception. The primary objective of the public relations and information activities was to keep the HDP concept before the industry, to rapidly communicate the results and progress being achieved and to promote a ground swell of interest in adopting HDP. To this end motivated growers were actively involved in planning and implementing demonstrations of HDP and were requested to solve local management problems involved with dual rows and multiple close rows.

The HDP concepts and results were conveyed to the industry:

- through the formal BSES information meetings conducted in southern, central and northern regions;
- by presentations at BSES station field days in Rocky Point, Nambour, Bundaberg, Mackay, Ayr, Ingham and Meringa;
- by field walks and other activities related to HDP demonstrations;
- by articles in the BSES Bulletin, Australian Sugarcane and newspapers;
- by radio and TV interviews.

The success of this technology transfer process can be judged by the number of growers who have elected to try dual row planting on their farms. No detailed survey of the areas now under dual rows has been conducted but it is estimated to be in excess of 3,000 ha and rapidly increasing as growers move to totally dual row operations. Pressure from growers to establish production areas of 0.5m crops is also increasing and currently greatly exceeds the BSES capacity to respond. This pressure is highlighting the need to design and develop specific multi-row planting and harvesting equipment to service and maintain the momentum established by this project.

4.8 Conclusions

There are several conclusions which can be drawn from this project ranging from the impact of the results obtained, the procedures adopted to obtain meaningful results for growers to the manner in which the extension component was melded with the project from the beginning.

4.8.1 Results

- Compared with 1.5m rows high density planting can increase cane (and sugar) yields by 50% in close rows (0.5m) and about 20% in dual rows.

- The increased yields from HDP relate directly to an increase in light interception (about 50%) in the period prior to canopy closure by 1.5m rows.

- HDP returns a more effective use of available nutrients and soil water when compared with 1.5m rows.

- The response to HDP is obtained at all latitudes, under rainfed and irrigated conditions, in plant, first and second ratoon crops but maximum benefit is dependent on the use of a responsive variety.

- The magnitude of genetic variance is unaltered by row spacing so there is considerable opportunity for specific selection for responsiveness to HDP.

- No reliable method for detecting responsive clones from their morphological traits was detected.

- The benefits of HDP can only be exploited by adopting a new farming system based on multiple rows, precision farming and specifically developed planting and harvesting equipment.

- An economic assessment shows that HDP is commercially attractive under most conditions. It allows a 22 to 28% reduction in costs of production, provides a net increase in operating profit of roughly $1,000/ha/year over a cycle of plant and three ratoon crops and remains profitable at lower sugar prices and CCS values than 1.5m rows.

- HDP provides growers with the opportunity to increase production from their farm or to maintain current crop production from a smaller area, thereby releasing land for crop rotation, fallow, alternative cropping etc.

- The maximum economic benefits from HDP are obtained when all other production procedures have been optimised and “best practices” adopted.

- Soil fumigation (Vapam) brought yields in 1.5m rows to near potential and optimised the response to HDP.

4.8.2 Procedures

- This project reflects the benefit of involving growers in all stages of project development and implementation. Ownership of project procedures and results was transferred rapidly to growers and extension staff thereby facilitating adoption.

- The objective of this project was to establish and extend the principle of potential benefits from HDP. Practical solutions to exploiting this benefit under commercial conditions have largely been left to the growers since no one solution will meet all conditions, constraints and growers’ agendas.

- Grower inputs have been assessed and included in trial design and treatment definition in order to answer the most commonly raised queries or suggestions.

- Trial design has been kept as simple as possible for trials run off-station in order to promote grower interest, involvement and acceptance.

4.8.3 Extension

- If extension or technology transfer is to be effective it must be included as a primary component of any R&D project and involved at all stages of the project. Attempts to subsequently transfer a technology developed in isolation by R&D personnel are rarely successful.

- Extension staff and growers must be a part of the technology development process, not only to encourage ownership but also to provide valuable inputs on project formulation and implementation.

5.0 DIFFICULTIES ENCOUNTERED

Few difficulties were encountered in the implementation of this project. In order to achieve the objectives it became necessary to extend the scope of the project and to secure additional funds to fabricate an early prototype multi-row planter. SRDC assisted with both of these requests after presentation of an HDP workshop. All project objectives were achieved or surpassed.

Most difficulty was associated with convincing industry and researchers of the potential benefits available from HDP. The simple physiological basis for the yield response was, and still is, difficult for many to accept. The mind set established from the past industry experience with 'pineapple rows' has delayed acceptance of the very significant advantages available from HDP. Recognition of this fact during project planning and a strong focus on PR and extension activities is beginning to reverse this trend.

Budgetary restrictions prevented trials being continued beyond the first ratoons. This was disappointing given the investment involved in establishing and monitoring the trials to that time and the need to establish the commercial duration of the HDP response.

6.0 RECOMMENDATIONS FOR FURTHER RESEARCH

Many of the key areas for research into HDP in sugarcane have been or are being addressed. However, the fine detail requires further study in order to cover all eventualities and verify the duration of response through 3rd and later ratoons. The SRDC commissioned Review of the BSES high density program considered those avenues of HDP requiring further R&D and assigned priorities for investment. The topics were discussed with the BSES HDP team and the resultant recommendations reflected a consensus approach based on limited funds.

Key HDP topics for further R&D include:

6.1 Multi-row equipment for HDP – to develop specific equipment to facilitate adoption of HDP.
Design, fabrication and testing of precise, high performance equipment to support an HDP based farming system for increased profitability and sustainability:
- multi-row billet planter and quality billet production
- multi-row harvester and haulout
- multi-row bed-former.

6.2 Limits to high density planting – to optimise planting density, fertiliser and irrigation strategies.
Replicated trials to:
- examine alternative inter and intra-row spacings
- assess water use efficiencies under HDP
- assess nutrient use efficiencies under HDP.

This project is being funded by SRDC.

6.3 Factors influencing response to HDP – to extend the database and facilitate industry adoption of HDP.
Replicated strip trials throughout the industry to evaluate:
- responses from a range of varieties
- responses under a range of production conditions
- responses from a range of planting times.

This project has subsequently been funded by SRDC.

6.4 Economical insecticide rates for grub control in HDP – to explore alternative pesticide application technologies suited to HDP.
Replicated trials to:
- determine the economical rate for each of three pesticides under HDP
- obtain NRA approval
- solve application techniques and equipment design.

6.5 Breeding and selection for HDP – to investigate the programs required to produce and select cultivars responsive to HDP.
Dual program to:
- evaluate families under HDP and 1.5m rows
- select clones under HDP and 1.5m rows
- design optimal program for HDP.

6.6 HDP to alleviate the declining CCS problem in north Queensland – a practical application of HDP to address (in part) a specific industry problem.
Replicated trials to:
- use more upright, less vigorous, high CCS cultivars to alleviate low CCS.

6.7 HDP and precision farming systems – to conceive and develop new cane farming systems to optimise production and minimise costs.
Review of current best farming practices and their integration into HDP based farming systems suited to different regions and constraints within the industry. Formulation of options for HDP based production systems and specific equipment required.

6.8 Furrow irrigation under HDP – to investigate techniques for the successful furrow irrigation of HDP crops.
Review of practices in other industries to identify possible methodologies. Whilst furrow irrigation is common in the industry it is likely that water conservation requirements will force the adoption of more efficient spray or trickle based practices in the near future. In this case the irrigation of multi-row beds will be managed easily.

7.0 APPLICATION TO INDUSTRY

The results from this project are clearly of immediate application and of great significance to the sugar industry. Every effort has been made to make all sectors of the industry aware of this fact. Ready and widespread adoption of dual rows is evidence that growers see HDP as a way to improve production technologies and reduce costs. Even though many growers are not fully aware of all the implications of dual rows they will address and solve these for themselves under their own conditions.

Close rows are the ultimate target for HDP but will require specific multi-row equipment for their proper adoption. Growers are already anxious to access suitable equipment so that they can examine close rows for themselves and modify them to suit their own concepts and constraints. This project has taken the viewpoint that RD&E can only demonstrate the potential for HDP, inform growers of the benefits, provide practical demonstrations of HDP and offer some preliminary recommendations on how it might be implemented. Individual growers will then move this technology into the commercial arena.

8.0 PUBLICATIONS

Publications associated with this project are as follows.

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Table 1. Location of trial sites with water management regime and the method used for yield estimation.

Trial Site	Latitude (^oS)	Water Status	Yield estimation*
Meringa	17^o 06"	Rainfed	Stalk sampling
Tully	17^o 56"	Rainfed	Mechanical harvester
Ayr	19^o 34"	Full irrigation	Mechanical harvester
Mackay	21^o 09"	Supplementary irrigation	Stalk sampling
Bundaberg	25^o 00"	Full irrigation	Stalk sampling
Harwood	29^o 26"	Rainfed	Stalk sampling

* stalk sampling: stalk counted in replicated quadrats and stalk weights obtained from replicated samples of 20 contiguous stalks

mechanical harvester: plots harvested by a conventional harvester and yield measured in a weighing truck. Harvesters cannot manage 0.5m rows without significant stalk damage and loss in adjacent unharvested rows.

Table 2. Yield parameters for plant crops of sugarcane cultivars grown at three row spacings and six latitudes.

Site	Cultivar	Stalk No./ ha (,000)			Weight per stalk (kg)			Tonnes cane/ha			Sugar content (CCS)			Tonnes sugar/ha		
		1.5m	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**
Meringa	Q113	78.9	87.1	141.0	1.333	1.370	1.237	106	119	174	12.8	12.5	13.5	13.4	15	23.6
	Q120	60.7	77.6	109.7	1.500	1.357	1.260	91	105	139	13.6	13.7	14.5	12.4	14.4	20
	Q124	61.6	73.8	86.7	1.983	2.017	1.717	123	149	149	13.8	13.6	13.6	17	20.2	20.4
	Mean	**67.0**	**79.5**	**112.5**	**1.606**	**1.581**	**1.404**	**107**	**125**	**164**	**13.4**	**13.3**	**13.9**	**14.3**	**16.5**	**21.3**
	lsd@5%*	9.1			0.136			20			1.3			3.3		
Tully	Q117							86	93	103	12.8	13.6	12.8	11	12.7	13.2
	Q120							85	94	110	12.2	12.3	13.8	10.4	11.5	15.2
	Q152							96	101	119	12	12.9	12.6	12.6	13	15
	Mean							**90**	**96**	**111**	**13.1**	**12.6**	**12.9**	**11.3**	**12.4**	**14.5**
	lsd@5%							9.6			1.1			2		
Ayr	Q96							142	185	201	16.5	16.3	16.4	23.4	30.2	33.3
	Q117							152	192	187	15.3	15.9	15.8	23.2	30.5	29.2
	Q124							135	184	201	13.3	13.9	14.5	18.1	25.7	29.2
	Mean							**143**	**187**	**196**	**15.1**	**15.4**	**15.6**	**21.6**	**28.8**	**30.6**
	lsd@5%							21.9			0.6			3.4		
Mackay	Q121	90.3	118.8	151.5	1.299	1.164	1.094	117	139	165	17.3	17.5	17.1	20.3	24.2	28.1
	Q124	85.3	110.0	150.5	1.501	1.376	1.354	128	151	205	17.4	17.7	15.8	22.2	26.7	32.2
	Q135	85.3	113.7	156.8	1.501	1.256	1.224	128	143	190	17.4	17.5	16.9	22.2	24.9	32.1
	Mean	**91.5**	**114.2**	**152.9**	**1.364**	**1.265**	**1.224**	**124**	**144**	**187**	**17.4**	**17.6**	**16.6**	**21.6**	**25.3**	**30.8**
	lsd@5%	9.6			0.072			12.1			1.4			2.9		

Table 2. cont.

Site	Cultivar	Stalk No./ ha (,000)			Weight per stalk (kg)			Tonnes cane/ha			Sugar content (CCS)			Tonnes sugar/ha		
		1.5m	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**
Bundaberg	Q124	91.1	84.4	94.4	1.577	1.689	1.666	142	191	278	15.8	15	16.7	21.5	31.9	46.5
	Q141	129.6	98.1	107.4	1.673	1.713	1.747	158	157	234	15.3	15.1	14.9	22.1	24.9	35.1
	Q150	166.7	143.3	163.3	1.682	1.456	1.433	141	168	250	15.6	14.7	14.1	24.2	25.4	35.2
	Mean	**129.1**	**108.6**	**121.7**	**1.644**	**1.619**	**1.615**	**147**	**182**	**245**	**15.6**	**14.9**	**15.2**	**22.6**	**27.4**	**38.9**
	lsd@5%	8.4			0.071			16.2			0.8			3.7		
Harwood	Q124	81.9	106.1	126.0	1.406	1.456	1.319	115	142	166	13.2	13.5	14.1	15.1	19.1	23.4
	Q155	70.9	123.6	142.2	1.332	1.082	1.006	94	119	143	12.1	13.3	13.6	11.4	15.8	19.5
	Q159	81.5	110.6	141.6	1.446	1.333	1.282	118	130	181	12	11.5	10.5	14.2	15	18.9
	TS65-28	74.3	94.6	108.3	1.558	1.458	1.495	116	140	162	12.4	12.2	11.9	14.4	17.1	19.1
	Mean	**77.1**	**108.7**	**129.5**	**1.435**	**1.332**	**1.275**	**111**	**133**	**163**	**12.4**	**12.6**	**12.5**	**13.8**	**16.8**	**20.2**
	lsd@5%	5.7			0.096			11.5			0.8			2.7		
OVERALL MEANS		**89.1**	**103.2**	**129.2**	**1.522**	**1.441**	**1.372**	**120**	**142**	**177**	**14.3**	**14.4**	**14.4**	**17.3**	**21.0**	**25.7**

* lsd - least significant difference between means for each row spacing

Table 3. Yield parameters for first ratoon crops of sugarcane cultivars grown at three row spacings and three latitudes.

Site	Cultivar	Stalk No./ ha (,000)			Weight per stalk (kg)			Tonnes cane/ha			Sugar content (CCS)			Tonnes sugar/ha		
		1.5m	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**
Mackay	Q121	119.1	129.1	150.8	0.878	0.866	1.039	104	111	156	13.4	12.3	13.1	13.9	13.7	20.4
	Q124	111.7	121.4	157.5	1.014	0.991	1.044	113	119	165	12.7	13.4	13.5	14.3	16.3	22.1
	Q135	108.6	124.9	140.1	1.080	1.024	1.119	118	128	156	13.2	13.0	13.5	15.5	16.4	21.0
	Mean	**113.1**	**125.1**	**149.5**	**0.991**	**0.960**	**1.067**	**112**	**119**	**159**	**13.1**	**12.9**	**13.4**	**14.6**	**15.5**	**21.2**
	lsd@5%	6.9			0.082			12.1			1.1			2.1		
Bundaberg	Q124	109.3	136.4	185.6	1.376	1.452	1.328	149	199	246	16.7	15.9	15.9	25.0	31.7	39.0
	Q141	110.4	121.6	191.1	1.370	1.547	1.458	150	188	276	16.1	15.8	15.6	24.1	29.9	43.0
	Q150	116.3	131.5	176.7	1.401	1.301	1.265	162	171	224	16.6	15.4	15.5	26.9	26.4	35.2
	Mean	**112.0**	**129.8**	**184.4**	**1.382**	**1.433**	**1.350**	**154**	**186**	**249**	**16.5**	**15.7**	**15.7**	**25.3**	**29.3**	**39.1**
	lsd@5%	9.5			0.060			11.9			0.3			1.9		
Harwood	Q124	99.8	102.9	149.8	1.165	1.349	1.211	115	139	181	15.5	15.4	15.3	17.7	21.4	27.9
	Q155	113.4	114.0	169.5	1.051	1.290	1.234	117	145	208	16.3	15.6	15.9	19.0	22.7	32.8
	Q159	116.8	107.9	163.8	1.054	1.261	1.289	123	136	211	15.4	15.7	14.9	18.9	21.4	31.8
	TS65-28	78.6	83.0	111.4	1.278	1.333	1.236	100	110	137	15.6	16.0	15.8	15.5	17.7	21.5
	Mean	101.3	102.1	145.3	1.161	1.306	1.230	**116**	**133**	**178**	15.8	15.6	15.3	18.3	20.7	27.4
	lsd@5%	9.0			0.122			15.0			0.8			2.7		
OVERALL MEANS		**108.4**	**117.3**	**159.6**	**1.167**	**1.241**	**1.222**	**125**	**145**	**196**	**15.1**	**14.9**	**14.9**	**19.1**	**21.8**	**29.5**

Table 4. Yield parameters for second ratoon crops of sugarcane cultivars grown at three row spacings and one latitude.

Site	Cultivar	Stalk No./ ha (,000)			Weight per stalk (kg)			Tonnes cane/ha			Sugar content (CCS)			Tonnes sugar/ha		
		1.5m	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**	**1.5m**	**Dual**	**0.5m**
Bundaberg	Q124	121.4	133.3	180.0	1.103	1.078	1.123	133	142	198	16.0	16.1	16.0	21.2	22.9	31.7
	Q141	118.1	134.7	153.3	1.123	1.107	1.223	132	149	187	14.6	14.7	14.2	19.2	22.0	26.4
	Q150	133.3	139.8	172.5	0.992	1.073	1.107	132	150	190	15.3	14.8	15.7	20.2	22.2	29.9
	Mean	**124.3**	**136.0**	**168.6**	**1.073**	**1.086**	**1.151**	**132**	**147**	**192**	**15.3**	**15.2**	**15.3**	**20.2**	**22.4**	**29.3**
	lsd@5%	7.6			0.063			12.2			0.4			1.7		
OVERALL MEANS		**124.3**	**136.0**	**168.6**	**1.073**	**1.086**	**1.151**	**132**	**147**	**192**	**15.3**	**15.2**	**15.3**	**20.2**	**22.4**	**29.3**

Table 5. Yield response against four row spacings at two locations.

Location	Crop	Cultivar	Row Spacing 1.5m	Dual	Triple	0.5m
Mackay	Plant	Q124	95	152	126	184
	1st Ratoon	Q124	100	114	132	189
Harwood	Plant	Q124	115	142	154	166
		Q155	94	119	134	143
		Q159	118	130	148	181
		TS 62-28	116	140	138	162
	1st Ratoon	Q124	115	139	151	181
		Q155	117	145	161	208
		Q159	123	136	144	211
		TS 62-28	100	110	112	137
		Mean	**109**	**133**	**140**	**176**

Table 6. Average yield response to various row spacings. Data aggregated from trials at Harwood, Bundaberg and Mackay.

	Row Spacing				
	1.5m	**1.0m**	**Duals**	**Triples**	**0.5m**
Setts/ha (approx)	20,000	30,000	33,000	45,000	60,000
Tonnes Cane/ha	115	123	141	140	168
Number of samples	507	333	195	30	507
Transformed Yield	115	130	135	148	169

Duals	2 rows at 0.5m spacing and 1.8m centres
Triples	3 rows at 0.5m spacing and 2.0m centres
Setts/ha	calculated number of setts planted based on 3 setts per m of row
Transformed Yield	sample yields transformed on a pro rata basis against a standard yield of 115 TCH at 1.5m

Table 7. Yield response of some commercial cultivars to row spacing.

Cultivar	No. of Trials	Method of Yield Estimation	Tonnes cane/ha			% Increase vs 1.5m rows	
			1.5m rows	Dual rows	0.5m rows	Dual rows	0.5m rows
Q96	1	Harvester	142	185	201	30	42
Q113	1	Sampling	106	119	174	12	64
Q117	2	Harvester	119	143	145	20	22
Q120	2	Harvester	88	100	125	13	41
Q121	1	Sampling	125	148	173	18	38
Q124	4	Harvester	127	164	200	30	57
Q135	1	Sampling	129	167	210	29	63
Q141	1	Sampling	158	157	234	-1	48
Q150	1	Sampling	141	168	250	19	77
Q152	1	Harvester	96	101	119	5	24
Q155	1	Sampling	117	145	208	24	78
Q159	1	Sampling	123	136	211	11	72
TS65-28	1	Sampling	100	110	137	10	37
Means			**121**	**142**	**184**	**17**	**51**

Table 8. Impact of nitrogen application on cane yields in 1.5m and 0.5m rows at three sites. Data transformed to provide uniformity across trial sites.

Trial	Applied Nitrogen (kg/ha)	Cane Yield (TCH) Row Spacing 1.5m	Cane Yield (TCH) Row Spacing 0.5m	Transformed Yield* Row Spacing 1.5m	Transformed Yield* Row Spacing 0.5m
1	108	60	106	100	177
	168	62	97	103	162
	228	55	101	92	168
	288	59	108	98	179
2	24	90		86	
	74	112	180	107	164
	124	111	191	106	174
	174	111	181	105	165
	224	112	179	106	163
	271		186		169
3	10	45	63	49	69
	20	65	85	71	94
	60	91	118	100	129
	100	95	141	104	155
	300	100	144	110	158

- refer to text for transformation procedure

Table 9. Effect of row spacing on water use effectiveness.

Row Spacing	Trickle Tapes	Effective Rainfall (Ml/ha)	Irrigation ML/ha	Cane Yield TCH	Tonnes Cane per Ml
1.5m	1 per row	4	3.0	84	12.0
Duals at 1.8m	1 per 2 rows	4	2.5	82	12.7
0.5m	1 per 2 rows	4	4.5	145	16.9

Table 10. Average impact of row spacing on yield components for plant and ratoon crops of 26 sugarcane clones grown under high or low management regimes at Bundaberg.

Crop	Management †	Row spacing	Stalk No. per ha	Weight per stalk (kg)	Tonnes cane/ha	Sugar content CCS	Tonnes sugar/ha
Plant (1996/7)	High	1.5m	96,197	1.443	135	17.26	23.4
		1.0m	110,774	1.351	146	17.45	25.5
		0.5m	137,410	1.380	187	17.50	32.7
	Low	1.5m	79,009	1.226	95	17.41	16.5
		1.0m	91,893	1.239	112	17.56	19.5
		0.5m	118,089	1.164	135	17.55	23.6
	lsd@5%		5,782	0.068	10.2	0.42	1.88
1st Ratoon (1997/8)	High	1.5m	99,607	1.337	132	12.69	16.6
		1.0m	109,667	1.272	137	12.81	17.7
		0.5m	147,156	1.338	197	12.83	25.1
	Low	1.5m	82,086	1.033	84	13.17	11.0
		1.0m	98,436	0.992	97	13.36	12.9
		0.5m	105,769	1.012	107	13.43	14.2
	lsd@5%		9,150	0.082	15.3	0.43	2.06

† High management – 500 litres of water and 28 kg of nitrogen per metre of row
Low management – 75 litres of water and 2.8 kg of nitrogen per metre of row

Table 11. Mean squares from the analysis of variance of the impact of row spacing and management on key yield components of the plant and ratoon crop of 26 sugarcane clones grown at Bundaberg in 1996-97.

a) Plant crop

Sources of variation	Stalk No. per ha	Weight per stalk		Tonnes cane/ha	Sugar content CCS	Tonnes sugar/ha
Blocks	5,340	0.338		4,151	46.291	411.03
Management (M)	3,988,308 ***	3.849	***	205,963 ***	1.226	6,284.68 ***
Error a	60,912	0.080		2,905	1.233	78.18
Row spacing (R)	6,495,296 ***	0.156		85,782 ***	1.701	2,743.76 ***
RxM	4,943	0.143		3,283	0.088	104.36
Error b	89,346	0.078		2,646	1.317	74.49
Clones (C)	388,928 ***	1.150	***	4,885 ***	39.609 ***	231.77 ***
CxR	27,044	0.020		641	1.432	22.15
CxM	31,401	0.058		926	1.459	34.14
CxRxM	14,515	0.024		457	0.661	15.23
Error c	20,967	0.030		651	1.214	22.68

*,**,*** Significant at the 0.05, 0.01 and 0.001 levels respectively

b) Ratoon crop

Sources of variation	Stalk No. per ha	Weight per stalk		Tonnes cane/ha	Sugar content CCS	Tonnes sugar/ha
Blocks	683,251	0.814		35,688	15.839	461.99
Management (M)	6,395,303 ***	11.063	***	422,107 ***	34.216	5,922.46 ***
Error a	16,386	0.001		1,332	3.067	20.45
Row Spacing (R)	5,057,454 ***	0.116		81,894 **	1.760	1,426.00 ***
RxM	987,032	0.033		30,162	0.143	429.92
Error b	403,585	0.177		9,886	2.269	146.32
Clones (C)	230,526 ***	0.758	***	5,798 ***	31.489 ***	102.22 ***
CxR	49,683	0.042		1,243	1.494	22.37
CxM	65,049	0.058		1,098	1.650	17.79
CxRxM	57,867	0.029		1,338	0.844	22.03
Error c	48,628	0.043		1,380	1.216	26.17

Table 12. Response of key yield components to row spacing in plant and 1st ratoon crops of 78 sugarcane clones grown at Bundaberg.

Crop	Row spacing	Stalk No. per ha	Weight per stalk (kg)	Tonnes cane/ha	Sugar content CCS	Tonnes sugar/ha
Plant (1996/7)	**1.5m**	97,714	1.301	123	14.0	17.2
	0.5m	154,987	1.301	195	14.1	27.6
	lsd @5%	13,853	0.126	13.8	0.67	2.1
1st Ratoon (1997/8)	**1.5m**	99,573	1.366	134	13.8	18.5
	0.5m	162,603	1.346	214	13.7	29.4
	lsd @5%	13,850	0.128	19.2	0.62	2.9

Table 13. Mean squares from the analysis of variance of yield components for plant and 1st ratoon crops of 78 sugarcane clones grown at Bundaberg.

Crop	Source of Variation	Stalk No. per ha	Weight per stalk	Tonnes cane/ha	Sugar content CCS	Tonnes sugar/ha
Plant (1996/7)	**Blocks**	54,405	0.179304	1,132	0.785	28
	Row Space (R)	25,585,983 ***	0.000008	407,150 ***	2.359 ***	8,464 ***
	Error a	158,851	0.004131	572	0.003	15
	Clones (C)	319,764 ***	0.283435 ***	2,957 ***	6.446 ***	67 ***
	R x C	76,342 **	0.022511 *	1,309 **	0.932	32 **
	Error b	30,179	0.014647	423	1.224	10
1st Ratoon (1997/8)	**Blocks**	54,935	0.004528	16	2.050	15
	Row Space (R)	30,987,607 ***	0.029408	504,556 ***	0.346	9,211 ***
	Error a	20,678	0.021602	2	10.801	37
	Clones (C)	183,704 ***	0.268812 ***	3,387 ***	5.383 ***	79 ***
	R x C	115,115 ***	0.031337 **	2,150 **	1.109	49 **
	Error b	99,011	0.027696	2,001	1.115	41

*,**,*** Significant at the 0.05, 0.01 and 0.001 levels respectively

Table 14. Clonal variance for key yield parameters as a function of row spacing in plant and ratoon crops of two trials.

Trial	Crop	Row Spacing	CLONAL VARIANCE Stalk No. per ha	Weight per stalk	Cane yield (tonnes/ha)	CCS	Sugar yield (tonnes/ha)
16 Clones	Plant	0.5m	200,050,598	0.058	354.80	1.91	18.41
		1.0m	236,878,538	0.060	224.72	2.28	10.37
		1.5m	200,712,327	0.063	141.74	2.27	6.47
	1st Ratoon	0.5m	54,883,362	0.033	339.34	1.39	5.38
		1.0m	86,088,889	0.043	220.64	2.00	4.92
		1.5m	107,543,096	0.045	191.72	1.75	3.89
78 Clones	Plant	0.5m	1,339,563,557	0.069	1,482.66	1.12	34.16
		1.5m	491,048,621	0.077	440.11	1.96	10.52
	1st Ratoon	0.5m	734,874,467	0.062	1,378.62	1.28	32.96
		1.5m	267,360,123	0.074	395.52	1.42	10.57

Table 15. Impact of hand or machine harvest of the plant crop on yield parameters measured in the subsequent 1st ratoon crop.

Cultivar	Row Spacing	Stalk No/ha Hand	Stalk No/ha Machine	Weight/stalk (kg) Hand	Weight/stalk (kg) Machine	Tonnes cane/ha Hand	Tonnes cane/ha Machine
Q170	**1.5m**	89,944	93,667	0.805	0.907	73	87
	0.5m	138,750	121,750	0.768	0.820	100	100
Q141	**1.5m**	96,556	97,222	0.610	0.563	59	56
	0.5m	149,875	137,875	0.524	0.574	75	79
	lsd @5%	12,832		0.116		15.7	

Hand plots totally harvested by hand
Machine plots harvested by conventional harvester

Table 16. Costs used in economic analysis of the cost/benefits available from high density planting.

	Costs ($/ha)	
	1.5m Rows	**0.5m Rows**
Plant crop		
Land Preparation	100	100
Contract Planting	100	200
Seed	100	300
Herbicides	50	50
Pesticides	263	395
Cultivation	100	25
Fertiliser	450	450
Fuel	100	100
Irrigation	300	300
Fixed costs	600	600
Total Plant Crop	**2,163**	**2,520**
Ratoon crops		
Chemicals	50	50
Cultivation	50	0
Fertiliser	300	450
Fuel	75	75
Irrigation	300	300
Fixed costs	600	600
Total Ratoon Crops	**1,375**	**1,475**
Harvesting (& Levies)		
Cost ($/tonne)	6.50	6.50

Table 17. Example of cost benefit analysis for a hypothetical farm with a plant and three ratoon crops under 1.5m or 0.5m rows.

Assumptions

Farm Size	100	ha
Plant cane yield	100	TCH
Sugar price	300	$/tonne
CCS	14	
Price of cane	27.58	$/tonne
Harvesting & Levies	6.50	$/tonne
Close Row Increase	50	%

		Unit	Plant	1st Ratoon	Crop 2nd Ratoon	3rd Ratoon	Total
1.5m Rows	Cropped Area	ha	20	20	20	20	80
	Cane Production	TCH	2,000	2,200	2,000	1,800	8,000
	Production Costs	$	43,260	27,500	27,500	27,500	125,760
	Harvest Costs	$	13,000	14,300	13,000	11,700	52,000
	Total Costs	$	56,260	41,800	40,500	39,200	177,760
	Gross Income	$	55,156	60,672	55,156	49,640	220,624
	Gross margin	$	**-1,104**	**18,872**	**14,656**	**10,440**	**42,864**
0.5m Rows	Area	ha	20	20	20	20	80
	Cane Production	TCH	3,000	3,300	3,000	2,700	12,000
	Production Costs	$	50,390	29,500	29,500	29,500	138,890
	Harvest Costs	$	19,500	21,450	19,500	17,550	78,000
	Total Costs	$	69,890	50,950	49,000	47,050	216,890
	Gross Income	$	82,734	91,007	82,734	74,461	330,936
	Gross margin	$	**12,844**	**40,057**	**33,734**	**27,411**	**114,046**
	Increase in GM	**$**	**13,948**	**21,186**	**19,078**	**16,970**	**71,182**
1.5m Rows	Cost/tonne cane		21.6	12.5	13.8	15.3	15.7
0.5m Rows	Cost/tonne cane		16.8	8.9	9.8	10.9	11.6

Figure 1. Average response of cane yield to planting density.

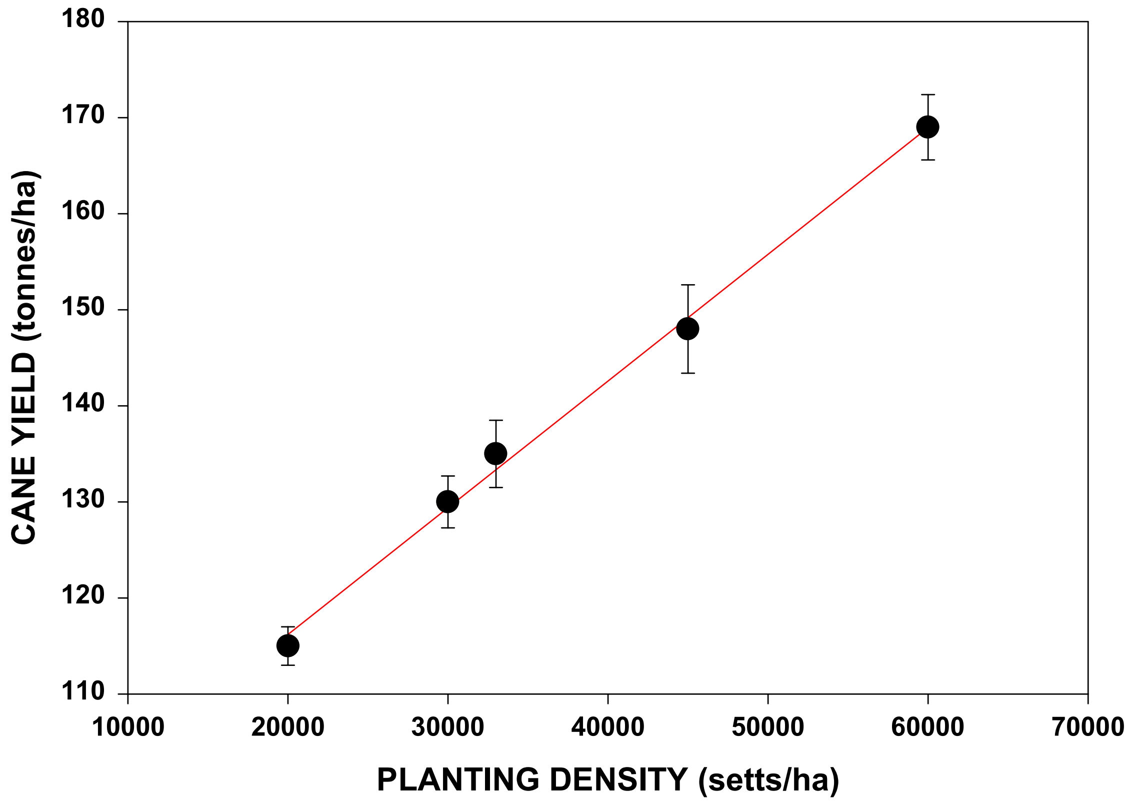


Figure 2. Light interception by plant and ratoon crops grown in 1.5m and 0.5m rows under a high water/high nitrogen regime.

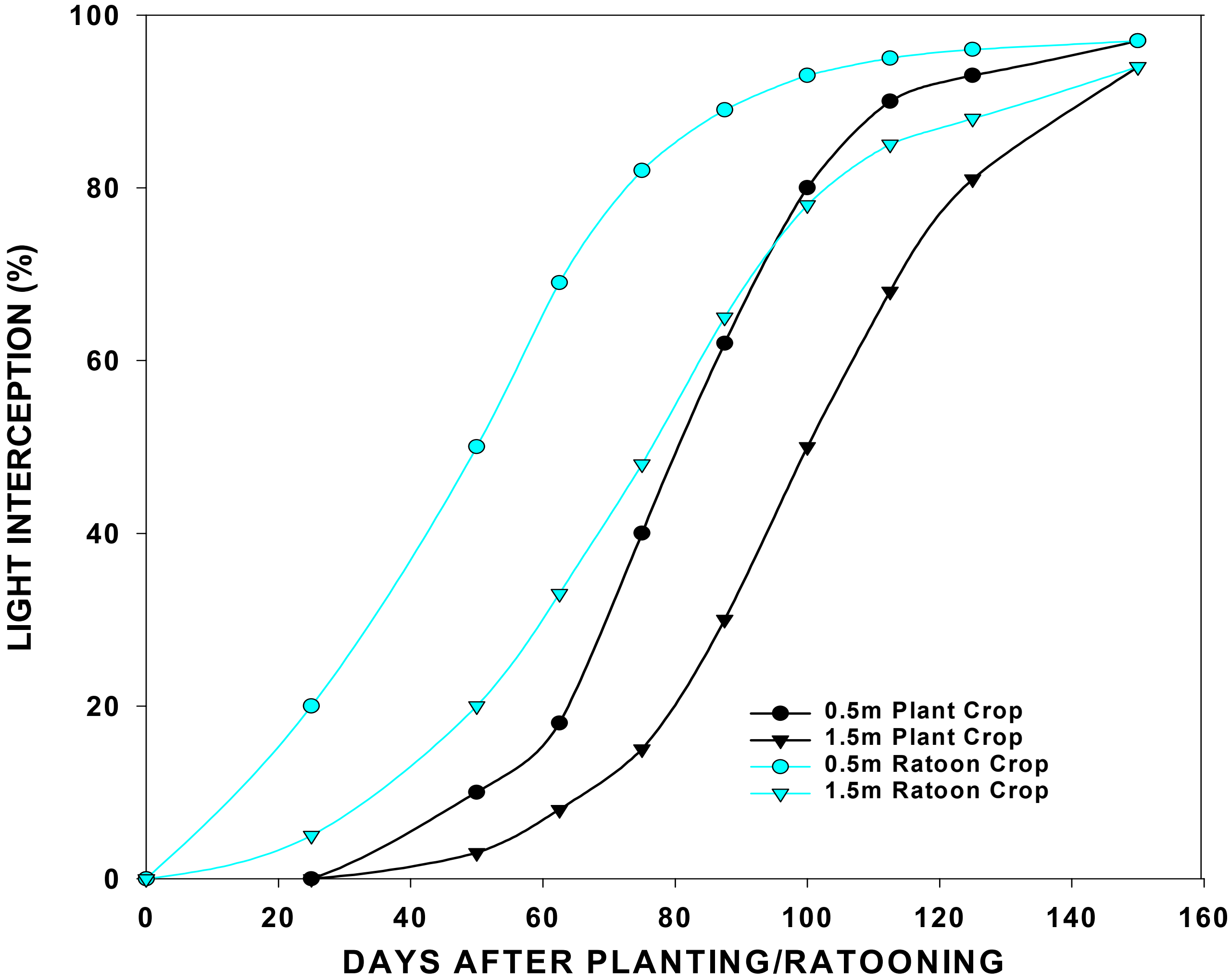


Figure 3. Effect of row spacing on yield response to applied nitrogen.

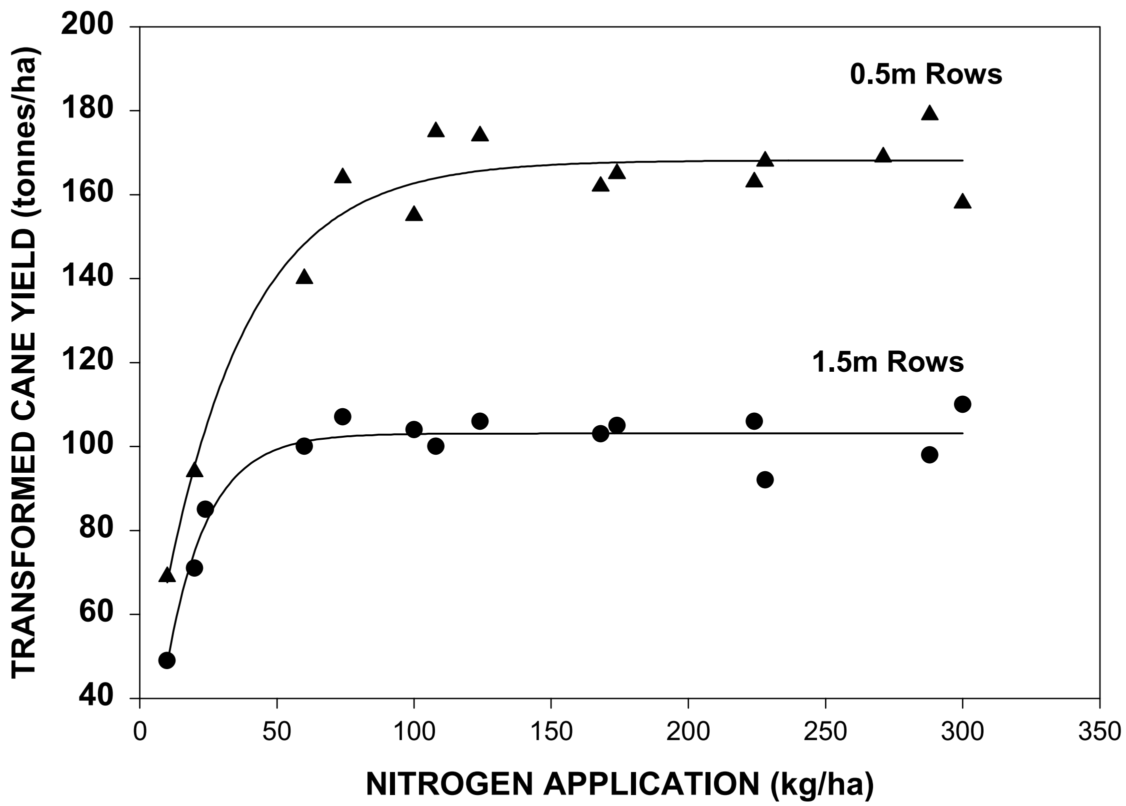


Figure 4. **Relative frequency (% of population) of yield response classes to high density in plant and ratoon crops for three different populations of clones and cultivars and an overall average from all trials.**

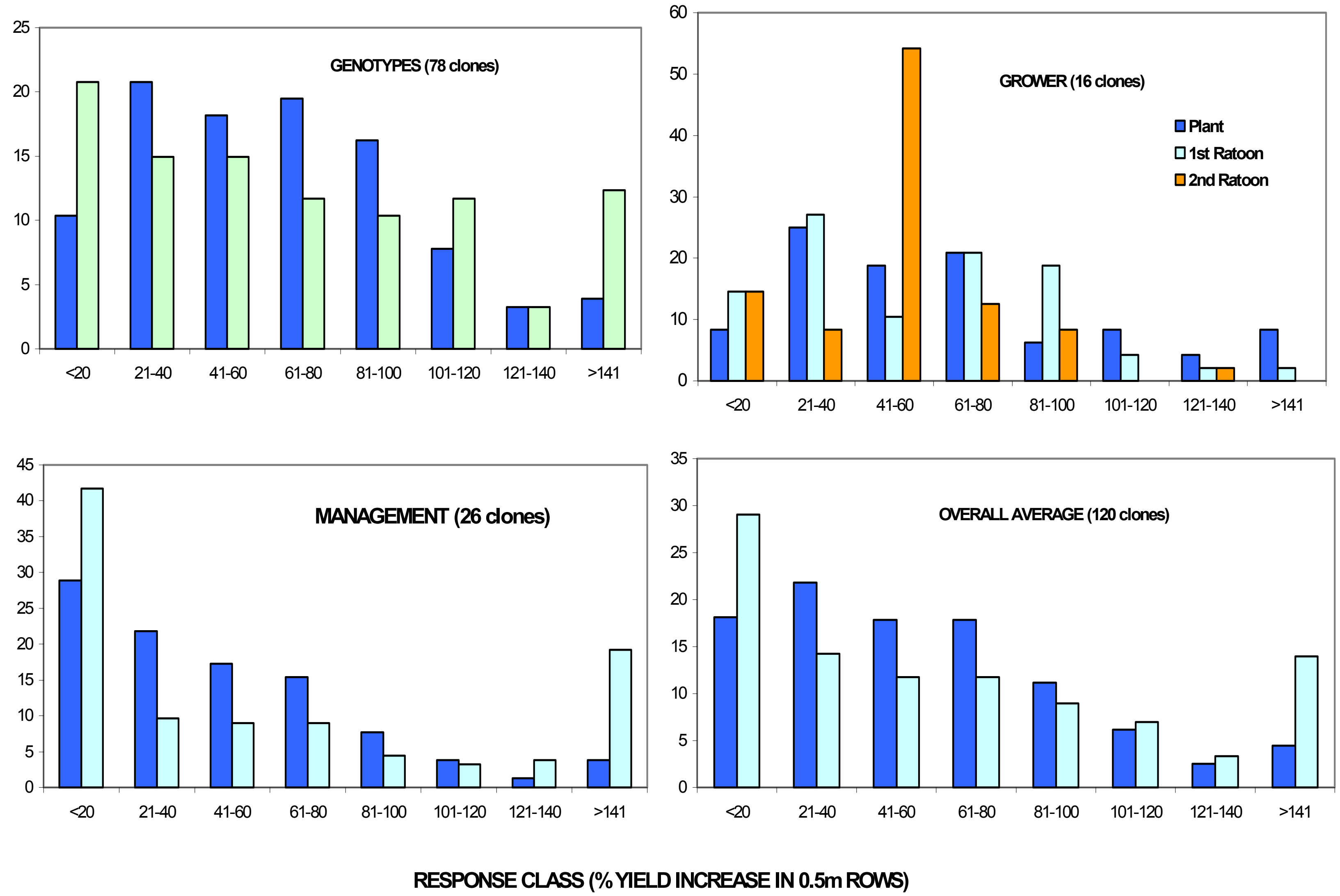
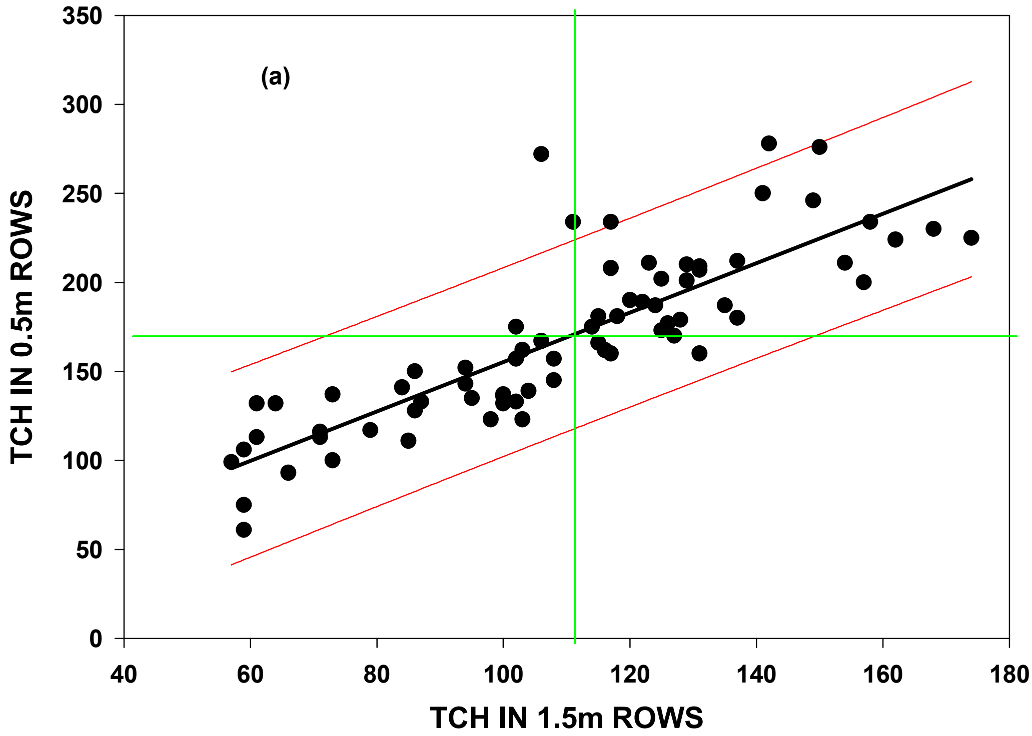


Figure 5. Relation between (a) cane yields in 1.5m rows and yields in 0.5m rows and (b) yield response in 0.5m rows and yield in 1.5m rows.



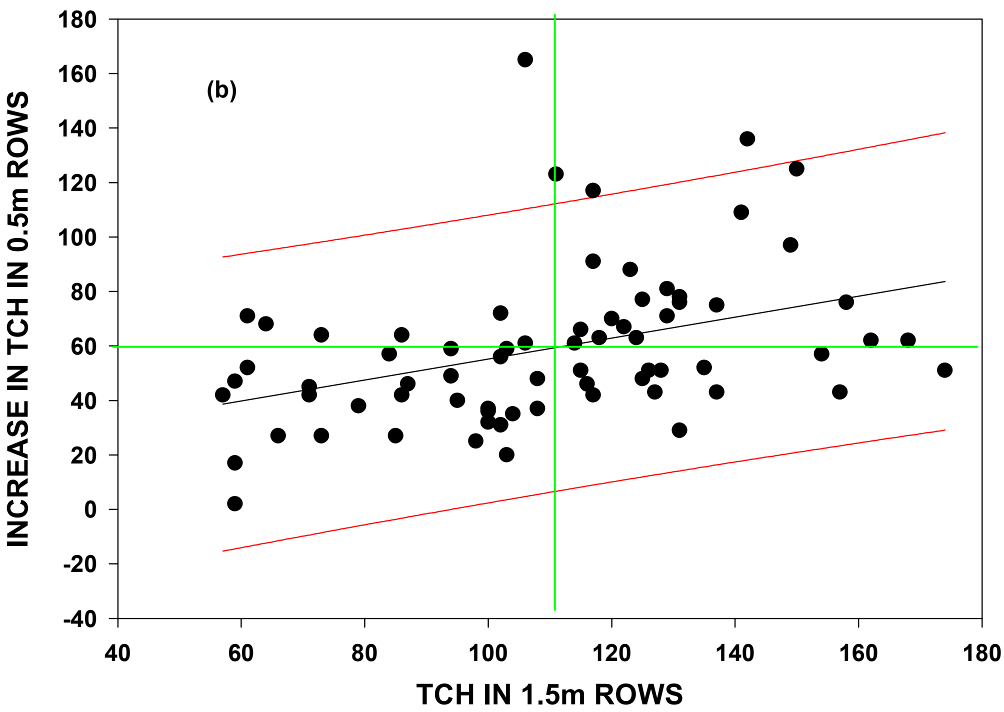


Figure 6. Relations between yield response to 0.5m rows and clonal stalk number, height class, habit class, leaf length, leaf width and weight per stalk.

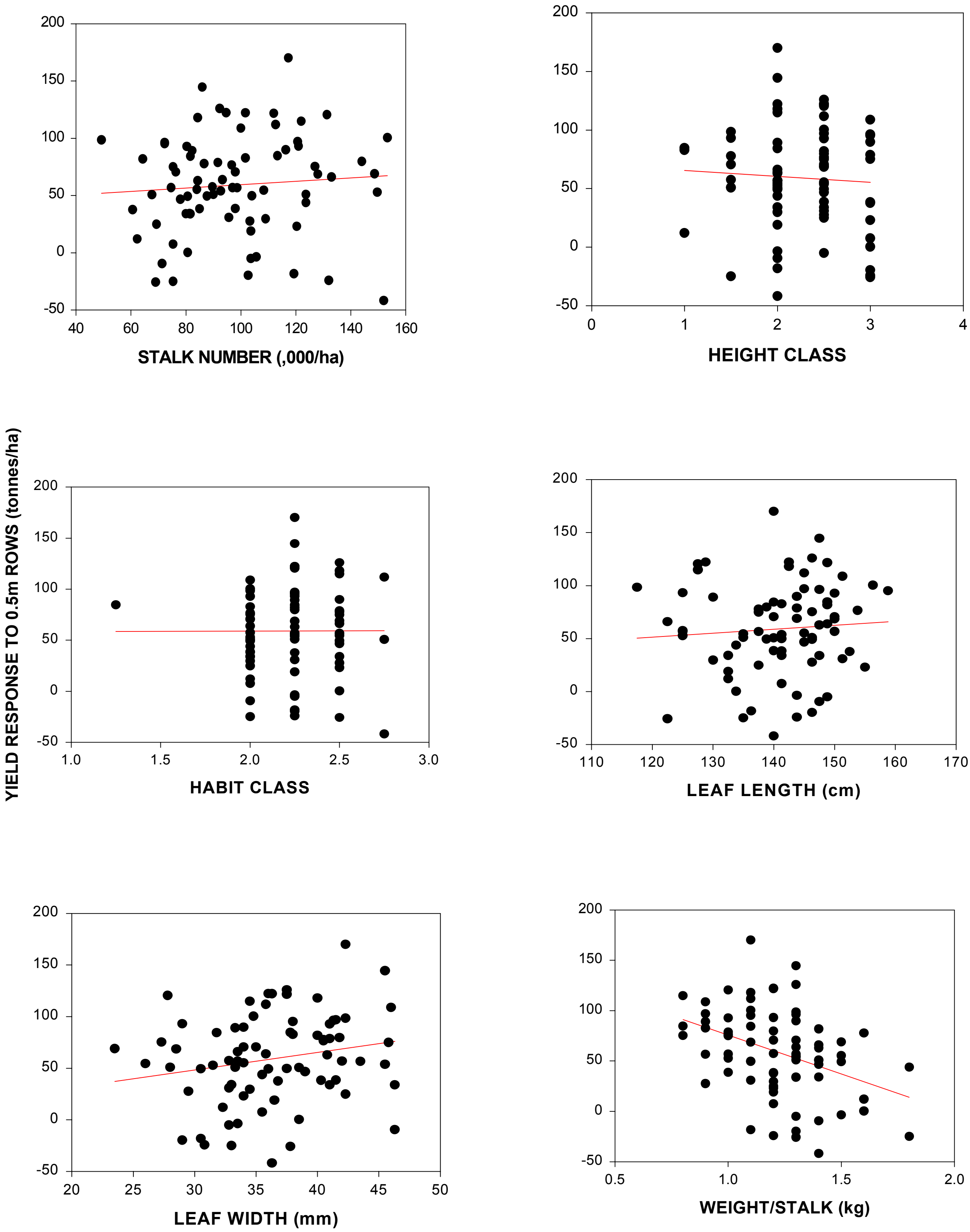


Figure 7. **Relationship between yield response to 0.5m rows and the trait Index, calculated as the product of class numbers for stalk number, height class, habit class, leaf length, leaf width and weight per stalk.**

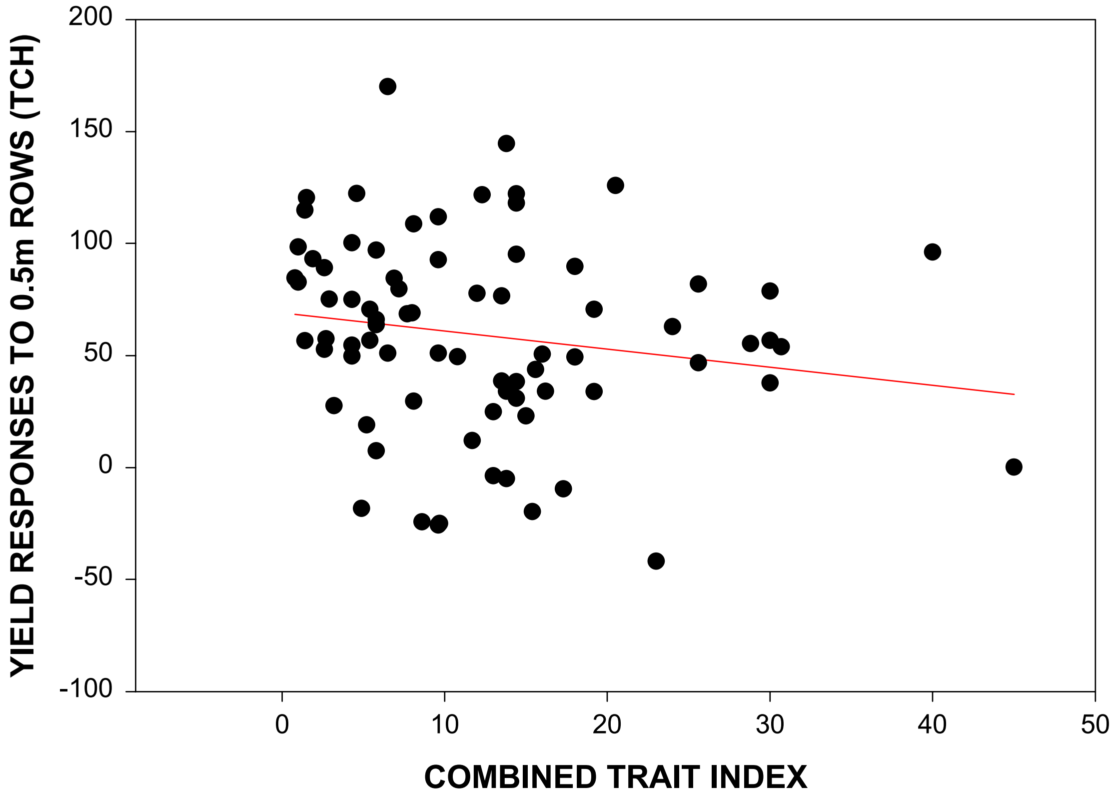


Figure 8. Influence of sugar price and CCS level on gross margins for 1.5m rows and 0.5m rows.

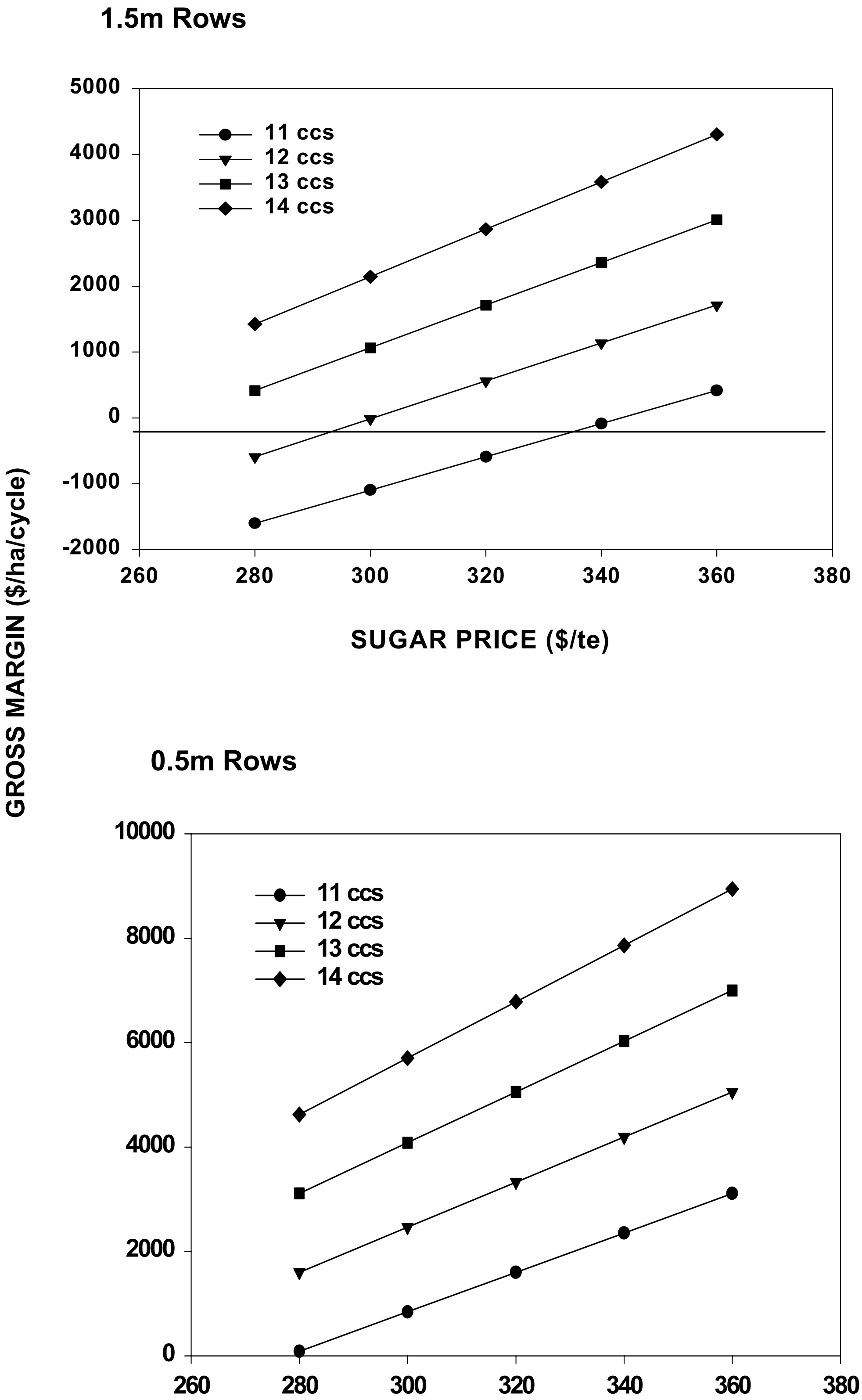


Figure 9. **Effect of magnitude of response to 0.5m rows on gross margins for sugar prices of $280 and $320/tonne. Based on a yield of 100TCH in 1.5m rows and 13 CCS.**

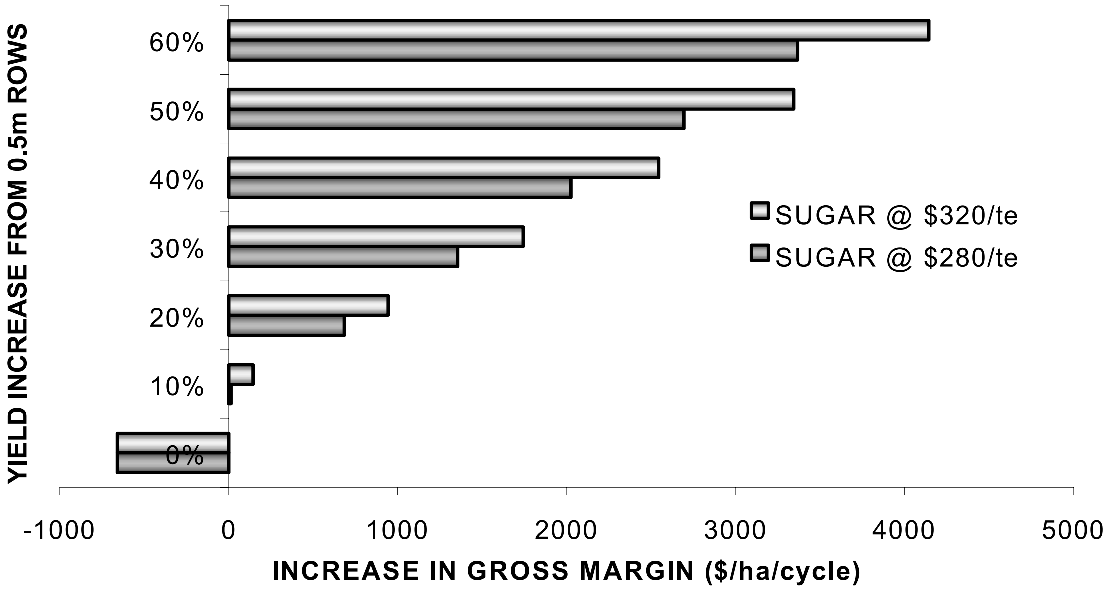


Figure 10. **Effect of row spacing on gross margins for plant and ratoon crops for sugar prices of $280 and $320/tonne. Based on a yield of 100TCH in 1.5m rows and 13 CCS.**

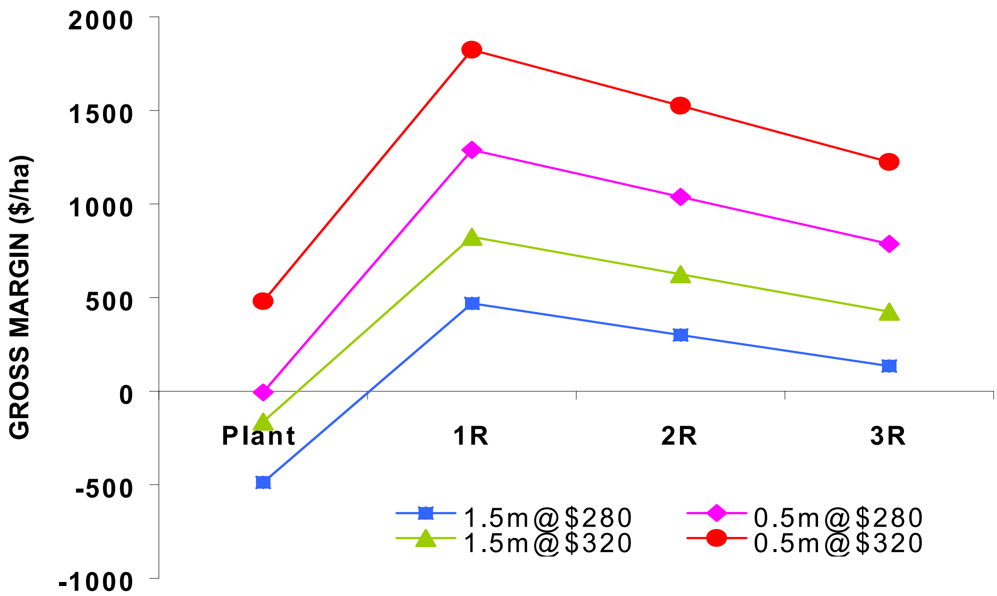


Figure 11. Sensitivity of gross margins to key cost determining parameters
a) sugar price, based on a yield of 100 TCH and 13 CCS at 1.5m
b) CCS, based on a yield of 100 TCH at 1.5m and $300/te sugar
c) yield increase from 0.5m rows, based on 100 TCH and 13 CCS in 1.5m rows and $300/te sugar
d) yield at 1.5m rows, based on 13 CCS and $300/te sugar.