

**BUREAU OF SUGAR EXPERIMENT STATIONS
QUEENSLAND, AUSTRALIA**

**FINAL REPORT
SRDC PROJECT BS5S
SEASONAL DISTRIBUTION OF GROWTH AND
SUGAR ACCUMULATION IN SUGARCANE**

**by
M C Cox
SD95002**

Principal Investigator: Dr M C Cox
Senior Research Officer
BSES
P O Box 651
BUNDABERG Q 4670

Phone: (071) 59 3228

This project was funded by the Sugar Research Council/Sugar Research and Development Corporation during the 1988/89, 1989/90, 1990/91, 1991/92, and 1992/93 financial years.

**BSES Publication
SRDC Final Report SD95002**

January 1995

CONTENTS

	Page No
1.0 SUMMARY	1
2.0 BACKGROUND	1
3.0 PROJECT OBJECTIVES	2
4.0 INTRODUCTION	2
5.0 METHODOLOGY	3
5.1 General	3
5.2 Trials and locations	3
5.2.1 Meringa	3
5.2.2 Bundaberg	3
5.2.3 Harwood	3
5.3 Environmental data	4
5.4 Sampling and measurements	4
5.5 Analyses	4
6.0 RESULTS AND DISCUSSION	5
6.1 Crop growth and weather conditions	5
6.2 Analyses of variance	6
6.3 Effect of selection for high early CCS	7
6.3.1 Predicted response to selection	7
6.3.2 Genotypic correlations	7
6.3.3 Effect on growth and sugar accumulation	8
6.3.4 Association between flowering and high CCS	9
6.4 Path coefficient analyses	9
6.4.1 Cane yield and its components	9
6.4.2 Sugar yield and its components	10
6.5 Characterising clonal differences	10
6.5.1 Grouping analyses and CCS response	10
6.5.2 Other characteristics of groups	11
6.6 Comparison of one- and two-year crops in New South Wales	12
6.7 HPLC analyses	12
7.0 DIFFICULTIES	13
8.0 RECOMMENDATIONS FOR FUTURE RESEARCH	14
8.1 Investigate the potential of two-year cropping cycles as part of the Queensland production system	14
8.2 Investigate the contribution of time of harvest to clone x environment interaction	14

CONTENTS (Continued)

	Page No
9.0 PUBLICATIONS	15
10.0 REFERENCES	15
11.0 ACKNOWLEDGMENTS	16
APPENDIX A Origin of 50 clones	17
APPENDIX B Total nitrogen (N), phosphorus (P), and potassium (K) applied	18
APPENDIX C Sampling times at each location	19
APPENDIX D Traits measured or calculated in trials at Meringa, Bundaberg, and Harwood	20
APPENDIX E1 Rainfall and soil moisture in relation to crop growth and sugar accumulation at Meringa	21
APPENDIX E2 Rainfall and soil moisture in relation to crop growth and sugar accumulation at Bundaberg	22
APPENDIX E3 Rainfall and soil moisture in relation to crop growth and sugar accumulation at Harwood (one-year crop)	23
APPENDIX E4 Rainfall and soil moisture in relation to crop growth and sugar accumulation at Harwood (two-year crop)	24
APPENDIX F1 Analyses of variance over clones (C), locations (L), years (Y), and sampling times (T)	25
APPENDIX F2 Variance components from analyses of variance over clones (C), locations (L) and years (Y) for each sampling time (T), using random models (RM) and mixed models (MM - C random; L and Y fixed)	26

CONTENTS (Continued)

	Page No
APPENDIX G Predicted response to selection for CCS at three locations over two crop-years	27
APPENDIX H Genotypic correlations between CCS and cane yield (TCH), conductivity and fibre	28
APPENDIX I Cane yield (TCH) and sugar yield (TSH) response for the top five early CCS clones (!) and remaining clones (#) at Meringa, Bundaberg and Harwood	29
APPENDIX J1 Genetic path coefficient analysis of cane yield (1) and its components stalk weight (2) and stalk number (3)	30
APPENDIX J2 Genetic path coefficient analysis of sugar yield (1) and its components cane yield (2) and CCS (3)	31
APPENDIX J3 Ratio of the direct effects of (a) stalk weight and stalk number on cane yield (P_{21}/P_{31}) and (b) cane yield and CCS on sugar yield (P_{21}/P_{31})	32
APPENDIX K Six clonal groups based on CCS response over thirty environments (3 locations x 5 sampling times x 2 replications)	33
APPENDIX L CCS of six clonal groups over five sampling times	35
APPENDIX M Relationship between HPLC juice measurements (sucrose and adjusted sucrose) and pol % juice	36

1.0 SUMMARY

Fifty clones, which were representative of the BSES breeding collection, were assessed for growth and sugar accumulation at Meringa, Bundaberg, and Harwood in plant and first ratoon crops. A two-year cropping cycle trial was also grown at Harwood. Crop growth (cane yield increase) from May to October was influenced by rainfall and soil moisture, with moisture stress evident in both crops at Meringa and the first ratoon crops at Bundaberg and Harwood. Analyses of variance showed that the data were of acceptable precision. A key finding was that, despite the diversity of the three locations, the clone x location interaction (C x L) was not significant for cane yield in the overall analysis which partitioned out the harvest time effect. Analyses involving randomly selected harvests at each location did generate significant C x L interactions, indicating that at least part of the C x L interaction generally found for cane yield may be due to harvest time differences.

Clonal variation and predicted response to selection for CCS were greatest early in the crushing season and decreased throughout the season. At Meringa, selection for high early CCS resulted in considerably lower cane yield and, while sugar yields were similar very early in the season, reductions of up to 1.8 t/ha later in the season were found. At Bundaberg, slightly lower cane yields resulted from selection for high early CCS, but sugar yields were higher except at the final harvest time. At Harwood, selection for high early CCS resulted in similar (plant crop) or higher (first ratoon crop) cane yields, and thus these clones maintained higher sugar yield throughout the season. These results were consistent with genotypic correlations between cane yield and CCS at Meringa which were strongly negative early in the season. Flowering data indicated that high early CCS clones tended to flower profusely in comparison to other clones. Since flowering is known to reduce cane yield more in the tropical regions than the sub-tropical or temperate regions, this may explain the generally poorer yield of high early CCS clones at Meringa.

Grouping analyses for clones, using CCS data over 30 environments (3 locations x 5 harvests x 2 crop-years), produced clonal groups that fitted well with origin or parentage. The highest early CCS group consisted of four 'CP' clones, while another group of 13 clones, with moderate early and high mid-to late season CCS, consisted of eight current commercial varieties, and six of the 13 clones had the same parentage.

Comparison of one- and two-year crops confirmed that the two-year cropping cycle, which accounts for 80% of the Broadwater and Harwood crop, is a productive system. The best two-year clones outperformed the best one-year clones in cane and sugar yields up until September. A feature of productive two-year clones was the high contribution of one-year stalks to total cane and sugar yield, up to 36% of the total.

2.0 BACKGROUND

Selection for high early sugar content has the potential to increase sugar production and to extend the crushing season through an earlier start. However, selection for high early sugar may change the seasonal pattern of yield accumulation and affect regional adaptation. For example, clones from Louisiana which have been selected for high sugar content, appear to have higher growth rates early in the season. Many of them also flower freely and tend to be better adapted to southern than northern regions of Australia.

A significant proportion of cane in New South Wales is produced from two-year crops. Availability of suitable clones may allow production of such crops in southern Queensland. The relationship between high early sugar content and clones suitable for one- and two-year production has not been established.

The potential for genetic manipulation of seasonal patterns of yield and sugar accumulation is not known. Its significance for clonal adaptation to different regions has not been examined. It is not known whether high early sugar content can be maintained throughout the season. Information about these aspects of clonal adaptation is required for developing breeding strategies aimed at improving early sugar content.

3.0 PROJECT OBJECTIVES

- ! Examine the effect of selection for high early sugar content on the seasonal distribution of yield and sugar accumulation in sugarcane.
- ! Characterise clonal differences in the seasonal distribution of growth and sugar accumulation.
- ! Determine the extent of genetic determination of such differences and the potential for their genetic manipulation.
- ! Examine the relationship between patterns of growth and regional adaptation

4.0 INTRODUCTION

At existing levels of cane yield, an extra unit of sugar content during May, June and July represented 47 600 tonnes of sugar worth \$13.3m at 1987 prices when this project was initiated. The situation now, with annual crops of greater than 30m tonnes and higher sugar prices, would provide greater returns. The potential for increasing early sugar content through breeding and selection has been demonstrated (see BS25S Final Report). Selection for high early sugar content may change the seasonal pattern of yield accumulation and affect regional adaptation. This project will provide information necessary for developing and evaluating strategies for breeding clones with high early sugar content.

5.0 METHODOLOGY

5.1 General

Trials involving 50 clones were planted in three diverse environments - Meringa (northern region), Bundaberg (southern region), and Harwood (New South Wales). One trial was planted in each region except at Harwood where two trials were planted to investigate both one- and two-year cropping cycles. The 50 clones were a representative sample from the

BSES breeding and clonal selection population with some resistance to Fiji disease virus. The clones and their origin are listed in Appendix A. Trials used a randomised complete block design with two replications. Each plot consisted of four rows, each 10 m in length with 1.5 m row spacing at Meringa and Harwood, and 1.42 m row spacing at Bundaberg. Clones were long-hot-water treated and propagated at each location in 1988. The trial at Bundaberg was planted in 1989, but the trials at Meringa and Harwood were planted in 1990 because of poor germination in 1988 and the need to repropagate. Further details of the Harwood trials are provided in Cox *et al.* (1994).

5.2 Trials and locations

5.2.1 Meringa

The trial at Meringa was planted on July 24 and 25, 1990 on a gley podzolic soil of white schist origin, locally known as a Clifton soil. Fertiliser applied in the plant crop was DAP18 (100 kg/ha) and urea (233 kg/ha) while, in the first ratoon crop, Nitraking (520 kg/ha) was applied. Rates of N, P and K for all trials are given in Appendix B. SuSCon (14 kg/ha) was applied in the plant crop to control cane grubs. Weeds were controlled with normal cultivation.

5.2.2 Bundaberg

The trial at Bundaberg was planted on April 24, 1989 on kraznozem soil of basaltic origin, locally known as a red volcanic. Fertiliser applied in the plant crop was Crop King 33 (300 kg/ha) and urea (200 kg/ha). Similar fertiliser was applied in the first ratoon except that 300 kg/ha of urea was used. Weeds were controlled with normal cultivation. Flood irrigation was applied as required in the plant crop (4 irrigations, 608 mm total) and first ratoon crop (7 irrigations, 920 mm total).

5.2.3 Harwood

The two trials at Harwood were planted on September 27, 1990 on a grey clay loam recently classified as a humic gley. The land was laser levelled prior to planting. Fertiliser in the plant crop was Crop King 44 (220 kg/ha) and urea (333 kg/ha). No further fertiliser was applied to the two-year trial while, in the first ratoon crop of the one-year trial, Crop King 44 (320 kg/ha) and urea (333 kg/ha) were applied. Lorsban (1.5 L/ha) was used to control black beetle. Weeds were controlled using Stomp (3 L/ha in plant and first ratoon crops) and atrazine (6 L/ha and 3.3 L/ha in plant and first ratoon crops).

5.3 Environmental data

Weather data were recorded by Monitor Sensor Automatic Weather Station systems. Because of equipment problems at Meringa, data were also taken from the station weather tower and the Cairns weather Bureau. Tain data loggers with gypsum block sensors were used to measure soil moisture (kPa) at all locations. The gypsum blocks were placed at 25, 50, 75, and 100 cm depths, in two adjacent plots in each trial. As these were not put in place until 1990, soil moisture was not measured in the plant crop at Bundaberg.

5.4 Sampling and measurements

Each trial was sampled five times between May and October (March and September for the two-year trial at Harwood). Sampling times are given in Appendix C. A large number of characters was measured (both destructively and non-destructively). The major traits and the method of measurement are similar to those detailed by Cox *et al.* (1994) for the Harwood trials. A list of traits measured is given in Appendix D. (Not all traits are able to be discussed in the Results and Discussion section). Apart from normal juice measurements (BSES, 1984), juice samples at Bundaberg were frozen for later analysis of sucrose, glucose and fructose using HPLC (Abeydeera, 1983). Ten clones were selected for HPLC analysis at Meringa and Harwood for the first two samplings in the plant and first ratoon crop. Duplicate samples were taken to test the precision of the HPLC analysis.

5.5 Analyses

Statistical analyses were conducted using SAS (SAS, 1989). Pattern analyses were performed on the data to investigate the similarity among clones based on their discrimination across environments, as described by Bull *et al.* (1994). In these analyses, the 50 clones were grouped across 30 environments (3 locations x 2 crops x 5 times of harvest) and the seasonal response in growth and sugar accumulation of the clonal groups was investigated. Quantitative genetic estimates (heritability, genotypic correlation, predicted response to selection etc) follow Falconer (1981). Path coefficient analyses (Dewey and Lu, 1959; Li, 1956) were conducted for cane yield and sugar yield and their components. The use of genotypic correlations in the path coefficient analyses was proposed by Kang *et al.* (1991) to circumvent the spurious associations that occur when a trait is derived from the product of two components. For comparison of standard laboratory juice analyses and sucrose measured by HPLC, Pol % juice was calculated as follows (BSES, 1991):

$$\text{Pol\% Juice} = \frac{1}{(\text{Brix}/227) + 0.991} * 0.26 * \text{Pol}$$

As the pol reading in the CCS analysis is confounded by the positive rotation due to glucose (52.5^N) and the negative rotation due to fructose (92.5^N), an adjusted sucrose was calculated as follows (BSES, 1991):

$$[\text{Adj Sucrose}] = [\text{Sucrose}] + [\text{Glucose}] * \frac{52.5}{66.5} - [\text{Fructose}] * \frac{92.5}{66.5}$$

This allowed the comparison of Pol % Juice with sucrose (no confounding due to reducing sugars) and an apparent sucrose adjusted for the concentrations of glucose and fructose.

6.0 RESULTS AND DISCUSSION

6.1 Crop growth and weather conditions

Average crop growth (cane yield) and sugar accumulation (CCS, sugar yield) over the period are shown graphically in Appendices E1 to E4 for Meringa, Bundaberg, Harwood one-year, and Harwood two-year crops. Daily rainfall (plus irrigation) and soil moisture data are included in the plots. The mean cane yield and CCS of the trial samplings within the crushing period were compared with those for the closest mill to Meringa and Bundaberg (Table 1).

Table 1
Comparison of trial and mill average cane yield (TCH) and CCS

Location	Year	Trial/Mill	TCH	CCS
Meringa	1991	Trial	67.2	14.9
		Mulgrave	72.8	14.3
	1992	Trial	66.3	13.9
		Mulgrave	90.1	13.8
Bundaberg	1990	Trial	123.0	13.7
		Millaquin	82.7	13.6
	1991	Trial	97.0	14.3
		Millaquin	70.0	14.2

At Meringa, plant crop yields were similar to those for Mulgrave Mill while first ratoon yields were considerably lower. Good rainfall was experienced in the January-March period in 1991 (1 553 mm), but only 236 mm fell between April and September. Very dry conditions occurred during the young ratoon growth (October to December 106 mm), rainfall in the January to March 1992 period was well below average (370 mm), and the April to September period was also dry. The soil moisture data (Appendix E1) showed that there were substantial periods when the soil moisture deficit was above 300 kPa. Minimal growth is likely to occur under these conditions (Kingston and Ham, 1975), and this probably explains the lack of growth during the sampling period. The poorer soil type on which the trial was grown may explain its lower productivity compared with Mulgrave Mill

under water limiting conditions. The CCS in the plant crop was high due to the very dry period from April to September. In the ratoon crop, reasonable rainfall up till May resulted in a lower early CCS than in the plant crop, but this was followed by extremely dry conditions which caused a rapid rise in CCS, with similar levels to the plant crop being attained by the end of the season.

At Bundaberg, cane yields in the trial were substantially higher than those for Millaquin. This was because the trial was grown on very good red volcanic soil and irrigated when necessary. In the plant crop, reasonable growth occurred during the sampling period because April to October rain plus irrigation totalled 355 mm. In contrast, little growth occurred in the ratoon crop during the sampling period because only 93 mm of rain fell and no irrigation was applied. Soil moisture data were not available for the plant crop, but were probably not limiting to any degree. Soil moisture deficit in the ratoon crop was above 300 kPa for much of July and from September onwards, so there were periods when growth was minimal. The CCS was higher in the first ratoon, again probably because of the very dry April to October period in 1991. There was also a close agreement between trial and mill CCS.

The comparison of trial and mill data at Harwood was confounded by the fact that one- and two-year statistics are not separated out for the mill, thus cannot be presented. The relationship between cane yield and CCS, and rainfall and soil moisture were discussed by Cox *et al.* (1994).

6.2 Analyses of variance

Analyses of variance were conducted over clones (C), locations (L), years (Y) and sampling times (T) for each trait, assuming a random model. Appendix F1 shows probabilities that mean squares for all effects and interactions involving C are different from the appropriate error mean squares. In all cases, main effects were highly significant. The interaction C x L was significant for all traits except cane yield (TCH) and stalk number (STPH). This was most surprising, particularly in a situation where three widely diverse locations were involved, as generally C x L interactions for TCH have been found to be significant and very important. The C x Y interactions were all significant, as were the C x L x Y interactions (except STPH).

Analyses of variance over C, L and Y for each T were conducted to further examine the environmental interactions. These analyses were run assuming a random model (RM) and also assuming a mixed model (MM) with C random, and L and Y fixed effects. Variance components (σ^2) from these analyses are presented in Appendix F2. There was very close agreement between variance components calculated using the two models.

For σ^2 CCS,
 σ^2 c was highest at sampling 1 and decreased throughout the season, as has been reported numerous times (Cox *et al.*, 1990; Cox *et al.*, 1994; Tai, 1985). Both σ^2 cl and

σ^2
 σ^2_{CLY} were significant but generally much less than σ^2_c , while σ^2_{CY} was effectively zero. For TCH, σ^2_{CL} was effectively zero at each T (confirming non-significance of the C x L interaction in the overall analysis), σ^2_{CY} was also very small, while σ^2_{CLY} was by far the most important component, in general being of similar magnitude to σ^2_c . Variance components for TSH showed that σ^2_c increased with T, while σ^2_{CLY} was the most important interaction, though generally smaller in magnitude than σ^2_c (except at the earliest sampling).

Many previous analyses of clone x location experiments would have involved harvests of different locations at different times, and it is likely that there has been some confounding of C x L interactions with C x T interactions. Ten further analyses of variance across C, L and Y, randomly selecting one T at each location were conducted. All C x L interactions were significant when the mixed model was used, while four out of ten were significant when the random model was used. This demonstrates that C x L interactions were able to be generated from these data when different harvest times were involved.

6.3 Effect of selection for high early CCS

6.3.1 Predicted response to selection

Predicted response to selection (Falconer, 1981) for CCS was calculated for each L, Y and T, assuming 10% of the population was selected (Appendix G). Previous studies in Bundaberg (Cox *et al.*, 1990) have shown that predicted gains were higher early in the season. This was confirmed here with gains of about 2-2.5 units in the first two samplings compared with 1.7-1.8 units at the last sampling. In Harwood, where CCS levels were lower, even greater predicted gains were evident early (2.4-2.9 units) compared to late (1.4-1.8 units). In Meringa, the predicted gains were reasonable early (1.8-2.2 units), were lower in mid-season (1.2-1.7 units), but tended to increase again at the end of the season (1.7-2.2 units). This may indicate some potential for selecting for late season CCS, although 1991 and 1992 were particularly dry years in the north and may have been somewhat atypical.

6.3.2 Genotypic correlations

Genotypic correlations (r_G) among traits were estimated (Falconer, 1981) and those between CCS and TCH, CCS and conductivity (CON), and CCS and fibre (FIB) are presented in Appendix H. Genotypic correlations between traits are often variable, but in this study reasonably consistent trends over sampling times were evident. Estimates of r_G between CCS and TCH at Meringa were negative and moderate in early samplings, tending towards small, positive values in late samplings. At Bundaberg, there was very little genetic association between CCS and TCH, although moderate to low, negative estimates of r_G were found in the first two samplings of the plant crop. At Harwood, estimates of r_G were generally small, indicating little genetic association between CCS and TCH.

These results may indicate some limitations in combining high early CCS with reasonable cane yield in clones selected at Meringa. In fact, this fits the experience of breeding for high early sugar (see BS25S Final Report), where elite selections from Bundaberg are performing well in the core program (including TCH) while those selected at Meringa have not performed as well. If the positive values of r_G between CCS and TCH at times 4 and 5 were repeatable, it may be worth exploiting this by selecting for CCS late in the season. This would be aided by the relatively larger genetic variance for late CCS found at Meringa and higher predicted response to selection.

In general, estimates of r_G between CCS and CON indicated little genetic association early in the season at all locations, tending towards a strong, negative association late in the season. This has no implications for early CCS selection but indicates that clones selected with high mid to late season CCS are unlikely to have high ash levels. The genetic association between CCS and FIB also tended to be low in early samplings, with strong, negative values in later samplings. Again this has little implication for early CCS selection, but does mean fibre levels need to be watched in clones selected with high late season CCS. The variety Q141 combines very high late season CCS and very low fibre, and this caused some problems in milling when it was first released.

6.3.3 Effect on growth and sugar accumulation

The top five clones for CCS, averaged over samplings 1 and 2 and over plant and first ratoon crops (ie high early sugar), were identified at each location and are shown in Table 2. Four out of five varieties were common between Meringa and Bundaberg, three out of five between Bundaberg and Harwood and two out five between Meringa and Harwood.

The cane and sugar yield responses over time for the top five clones (T5) were compared with those for the remaining 45 clones, and these are shown graphically in Appendix I.

Table 2

Top five clones for early CCS at Meringa, Bundaberg and Harwood

Rank	Meringa	Bundaberg	Harwood
1	CP75-1553	CP75-1322	CP75-1322

2	CP73-351	CP73-351	Q121
3	CP78-1628	CP75-1553	CP73-351
4	CP75-1322	Q121	Q146
5	Q117	Q117	Q141

The difference between the two groups for TCH was most pronounced at Meringa, with the T5 group averaging 11-13 t/ha lower in the plant crop and 16-20 t/ha lower in the first ratoon crop. The higher early CCS resulted in similar sugar yields in the first two samplings of plant and first ratoon crops, but the T5 were 0.8-1.8 t/ha lower in later samplings. At Bundaberg, TCH was only slightly lower for the T5 group of clones while TSH tended to be higher except at the final sampling. At Harwood, TCH of the T5 group was similar in the plant crop and actually higher in the first ratoon crop. Consequently, the T5 group maintained higher TSH throughout the season.

These results support the conclusions based on genotypic correlations that, in this group of clones at least, it may be difficult to combine high early CCS with high productivity at Meringa. For Bundaberg, selection for high early CCS appears to be about neutral in terms of increasing sugar yield while, at Harwood, there appear to be genuine gains in sugar yield through selection for early CCS.

6.3.4 Association between flowering and high CCS

Percent flowering for each clone was recorded at each sampling. Table 3 shows the percent of clones that flowered overall and the percent of clones that flowered in the top five for early (mean of samplings 1 and 2, plant and first ratoon crops) and late (mean of sampling 5, plant and first ratoon crops) CCS.

Table 3
Percent of clones that flowered

Location	Crop	Overall Flowering (%)	% of clones in top 5 for CCS	
			Early ¹	Late ²
Meringa	P	94	100	80
	1R	44	80	0
Bundaberg	P	52	80	20
	1R	6	0	0
Harwood	P	0	0	0
	1R	14	40	40

¹ Mean of samplings 1 and 2 over plant and first ratoon crops (see section 6.3.3)

² Mean of sampling 5 over plant and first ratoon crops

Flowering was profuse at Meringa in the plant crop, moderate at Meringa in the first ratoon and at Bundaberg in the plant crop, light at Bundaberg and Harwood in the first ratoon crop, and zero at Harwood in the plant crop. In general the results showed that a higher percentage of clones with high early CCS flowered, while clones with high late CCS tended to be less prone to flower.

6.4 Path coefficient analyses

6.4.1 Cane yield and its components

Analyses of the contribution of yield components (stalk weight and stalk number) to cane yield using correlations should be viewed with caution as both of these components were used in the calculation of cane yield. Genotypic correlations and path coefficients are shown in Appendix J1. Genotypic correlations between stalk weight and cane yield (r_{21}) were

consistently and strongly positive across locations, years, and sampling times, while those between stalk number and cane yield (r_{31}) were very variable, from weakly positive to strongly negative. There were very strong negative genotypic correlations between stalk weight and stalk number, ranging from -0.22 to -0.99. Because the path coefficients are unit-free, some measure of the relative importance of each causal factor can be made (Fraser and Eaton, 1983). Thus the relative importance of these components on cane yield was further examined by calculating the ratio of the direct effects (P_{21}/P_{31}) and these are shown in Appendix J3.

These data showed a consistent trend across locations and sampling times, with the ratio well above 1.0 in the plant crop (average 1.3-1.5) and just above 1.0 in the first ratoon crop (1.1-1.3). The interpretation of these results was that stalk weight was the dominant determinant of cane yield in the plant crop. In the first ratoon, stalk weight and stalk number contributed almost equally at Meringa and Bundaberg, but stalk weight was slightly more important in determining cane yield at Harwood. Because these data apply to a highly selected, though representative sample of clones, it may not be wise to extrapolate the results to unselected populations.

6.4.2 Sugar yield and its components

Genotypic correlations and path coefficients in the analysis of the contribution of cane yield and CCS to sugar yield are shown in Appendix J2. Genotypic correlations between cane yield and sugar yield (r_{21}) tended to be low at the start of the season, increasing to strongly positive as the season progressed. Moderate to strong genotypic correlations were found between CCS and sugar yield. The relative importance of these components on sugar yield was further examined by calculating the ratio of the direct effects (P_{21}/P_{31}) and these are shown in Appendix J3.

These data showed that cane yield was a very strong determinant of sugar yield from mid to late season while CCS was dominant from early to mid season. This observation was consistent with the greater degree of genetic variation among clones for CCS at the beginning of the season.

6.5 Characterising clonal differences

6.5.1 Grouping analyses and CCS response

Characterising differences in CCS over the season among 50 clones was simplified by the use of cluster analysis to examine seasonal patterns of sugar accumulation of clonal groups. The partition of variation after reduction of the original 50 clones x 30 environments by cluster analysis (CCS data) indicated that six clonal groups could adequately describe the response of CCS over environments. The six groups retained 97.6% of the sum of squares of clones among groups and 28.6% of the sum of squares of clone x environment.

The clonal composition of each of the six groups is shown in Appendix K. Many of the clonal groups are meaningful in terms of their origin. For example, of the 13 clones in group 90, eight are current commercial varieties in Queensland (7 'Q' canes and CP51-21) while two were considered for release but rejected. Six of the clones in this group have the same parentage (NCo310 x 54N7096). Group 92 included only four clones, all from the southern

United States (CP). Of the nine clones in group 93, four were Hawaiian and three originated in New South Wales; both places grow two-year crops. The 13 clones in group 94 included nine originating from the central, Burdekin or northern selection programs (including one commercial, Q138). Group 84 included two foreign clones and four of the remaining five clones originated from crosses between BSES clones and foreign clones.

Since

σ^2

CL

was

σ^2

significant

and

σ^2_{CY} was close to zero for CCS (see 6.1), the mean response of groups over crop years for CCS was plotted for each location (Appendix L). In all locations, group 92 (4 'CP' clones) was superior for early CCS. This group is very similar to the 'top 5 clones referred to in Table 1 and Appendix I. The CCS of this group plateaued early at Meringa (July), later at Bundaberg (August-September) and did not appear to plateau at all at Harwood. Group 90 (the group containing a majority of the commercial varieties), had intermediate early CCS which continued to increase throughout the season, producing the highest late season CCS. Group 93 (mainly two-year canes) tended to be low throughout the season at all locations. Group 76 had very low early CCS which increased quite steeply throughout the season, producing intermediate late CCS. Groups 84 and 94 were intermediate in CCS throughout the season and showed a similar response at Meringa and Bundaberg but differed somewhat in their early CCS characteristics at Harwood.

6.5.2 Other characteristics of groups

The seasonal response of these groups (based on CCS) for other characteristics, such as cane yield, sugar yield, stalk weight, and stalk number per hectare, was also examined (data not shown). Because there was considerable variation within groups for these characters, only large differences in the group means are discussed.

For cane yield, the mean response of groups over the season was similar within each location, although group 92 tended to have a flatter response curve at each location. This group of four high early CCS clones (CP) also had the lowest cane yield of any group, this being particularly evident at Meringa. Again, the conclusions for this group for cane and sugar yield is similar to those for the 'top 5' clones (see Section 6.2.3). Another characteristic of this group was its low stalk weight, again particularly evident at Meringa where it was 28% lower than other groups. The highest cane yielding clonal group was group 76, which had very low CCS early but good CCS later in the season. The superiority of this group was most evident at Meringa, less evident at Bundaberg and least at Harwood. Two of the clones in this group have never flowered at Meringa while the other two have only flowered once in four to five years. Groups 84 and 94, which were reasonably similar in their CCS response, were also similar in cane yield response. However, group 84 tended to be characterised by high stalk weight and low stalk number (overall mean of 1.3 kg/stalk, 73 000 stalks/ha), while group 94 was characterised by low stalk weight and high stalk number (1.0 kg/stalk, 89 000 stalks/ha).

6.6 Comparison of one- and two-year crops in New South Wales

Details on the growth and sugar accumulation in one- and two-year crop cycles in New South Wales are given by Cox *et al.*, 1994 (attached). Average cane and sugar yield responses during the second year were similar for the one-year (plant plus first ratoon crops) and two-year trials, but total cane and sugar yield was marginally higher in the two-year trial. In both cases, the major growth was from October 1991 to May 1992, with little increase from May to September 1992, due to dry conditions. The best five clones were chosen for each of the two crops, based on total sugar production at optimum harvest. Cane and sugar yields in the first year were considerably higher for the best one-year trial clones, but the best two-year clones gave higher total production over the two years up until September. A notable feature of the best clones in the two-year trial was their lack of growth from June to September in the first year. Another feature of the best two-year clones was the high contribution of one-year stalks to total cane and sugar yields. One-year stalks of the best two two-year clones contributed cane yields of 120 t/ha and sugar yields of 16 t/ha, representing 36% of the total.

6.7 HPLC analyses

Juice purity in May can be quite low, and the presence of the reducing sugars glucose and fructose can cause incorrect sucrose estimation by pol (Atherton, pers. comm.; DeStefano, 1985). Depending on the relative amounts of glucose and fructose, pol will precisely estimate, over-estimate or under-estimate sucrose, and may result in quite large errors in the estimation of early sucrose content of individual clones.

At Bundaberg, all 1 000 samples of juice (50 clones x 2 reps x 5 samplings x 2 crops) were analysed for sucrose, glucose and fructose by HPLC. Some samples from the first two samplings at Meringa and Harwood were also analysed. Duplicate samples were taken and random samples of these were analysed to examine the precision of the HPLC analysis. Correlations between duplicates were calculated for each year and the results were:

1990	(30 samples)	0.975 (sucrose)	0.995 (glucose)	0.996 (fructose)
1991	(56 samples)	0.883 (sucrose)	0.901 (glucose)	0.923 (fructose)

The samples covered a wide range in maturity from pre-season to late season. The HPLC analyses were generally quite precise, but a small number of samples showed large deviations between duplicates, particularly in 1991. Berding (pers. comm.) also found that the precision of estimation of pol was higher than for HPLC sucrose, with correlations between duplicates of 0.999 vs 0.966.

Regressions of clonal means for Pol % Juice on sucrose and adjusted sucrose were calculated using all Bundaberg data (Table 4). Plots are shown in Appendix M.

Table 4

**Regression statistics for Pol % Juice on sucrose and adjusted sucrose
at Bundaberg**

Year	Statistic	Pol % Juice vs Sucrose	Pol % Juice vs Adj Sucrose
All	b . se	0.912 . 0.007	0.957 . 0.007
	a	1.369	0.313
	r	0.984**	0.985**
1990	b . se	0.922 . 0.010	0.967 . 0.010
	a	1.158	0.095
	r	0.986**	0.987**
1991	b . se	0.873 . 0.013	0.917 . 0.013
	a	2.164	1.121
	r	0.975**	0.975**

The data showed that a strong relationship existed between normal juice measurements and HPLC, with correlations between pol % juice and HPLC sucrose from 0.98 to 0.99. The most notable feature of the data was that the slope of the regression was much closer to one for the adjusted sucrose data than the sucrose data. This indicated that normal pol measurements were significantly biased by the glucose and fructose in the samples, the overall effect being to underestimate actual sucrose. This effect was larger in early samplings when concentrations of glucose and fructose were higher. For example, in the May sampling, the adjustment (sucrose - adjusted sucrose) averaged 0.57 in the plant crop and 0.40 in the first ratoon crop. However, for individual clones, adjustments of up to 0.79 or as little as 0.19 sucrose in juice would apply. In October, the average adjustment was only about 0.09 in both crops, with individual adjustments of 0.03 to 0.23. In June and July (the early part of the main crushing season), adjustments for individual clones varied from 0.09 to 0.63 in the plant crop, and from 0.06 to 0.46 in the first ratoon crop. Although this may appear to be causing some bias, it should be remembered that, generally, varieties harvested early in the season will be ones with higher sugar content (ie more mature) and, thus have a lower concentration of reducing sugars. However, from a variety comparison point of view, there would be a significant differential effect on the estimation of sugar content (and thus sugar yield) by normal juice methods early in the season.

7.0 DIFFICULTIES

Initially difficulties were encountered when germination failures of propagation material occurred at Meringa and Harwood. This resulted in a delay of one year in planting these trials. Intensively measuring and sampling three locations (four trials) at five times during each growing season was demanding in terms of resources and this was mainly underestimated in the project proposal. The work has resulted in the generation of a huge

amount of data. For the purposes of this Final Report, it has been difficult to balance conciseness with completeness. Publications from this work will involve expansion of many of the sections in the report.

8.0 RECOMMENDATIONS FOR FUTURE RESEARCH

8.1 Investigate the potential of two-year cropping cycles as part of the Queensland production system

Two-year cropping cycles are a major part of the production system in New South Wales (80% in Harwood and Broadwater and 20% in Condong). Studies of the growth and sugar accumulation of a wide range of varieties at Harwood (Cox *et al.*, 1994) showed that production (both cane and sugar) was higher under a two-year than a one-year cropping system. The best two-year varieties outperformed the best one-year varieties in sugar production per hectare over the two years, except in late harvested ratoon crops. The incorporation of two-year crops as a planned part of the production system in Queensland has not been investigated. In NSW, the ability to harvest (one-year cycle) or standover (two-year cycle) provides growers with flexibility, and factors such as cash flow, variety, crop lodging, frosting, and farm quota all contribute to the decision. The main disadvantage is the cost of waiting an extra year for the income from the crop.

Potential cost savings associated with two-year crops mainly involve cultural/chemical weed control in the young ratoon (\$100-150/ha), although there could be some saving in nitrogen fertiliser, labour costs and harvesting costs. Other advantages may include: less land to sacrifice in ploughout, the ability to farm a larger area, and the potential for an earlier start to the harvest. While the impact on productivity over a full crop cycle of implementing some two-year cropping as part of the production system in Queensland is unknown, the potential for greater profitability exists with lower production costs (at least \$6.5m for 10% of the Queensland crop). Opportunities to utilise such a system to increase productivity also exist.

8.2 Investigate the contribution of time of harvest to clone x environment interaction

Analyses of variance of 50 clones over three very diverse locations with five different sampling times indicated that, once the effect of time of harvest was taken out, clone x location interaction was not significant for cane yield. Many multi-location sugarcane variety trials show significant clone x location interactions. It would be useful to know how much clone x location interaction in cane selection trials was confounded with different times of harvest and perhaps time of planting.

9.0 PUBLICATIONS

Cox, M C, Hansen, P B, and Halili, E R (1994). Growth and sugar accumulation in one- and two-year crop cycles in New South Wales. Proc. Aust. Soc. Sugar Cane Technol. 16:38-46.

10.0 REFERENCES

Abeydeera, W P P (1983). High performance liquid chromatographic determination of sugars on cation exchange resins. Proc. Aust. Soc. Sugar Cane Technol., 5:171-186.

BSES (1984). Laboratory manual for Australian Sugar Mills, Vol. 1, BSES, Brisbane.

BSES (1991). Laboratory manual for Australian Sugar Mills, Vol. 2, BSES, Brisbane.

Bull, J K, Basford, K E, Cooper, M, and DeLacy, I H (1994). Enhanced interpretation of pattern analyses of environments: the use of blocks. Field Crops Res., 37:25-32.

Cox, M C, Hogarth, D M and Mullins, R T (1990). Clonal evaluation of early sugar content. Proc. Aust. Soc. Sugar Cane Technol., 12:90-98.

Cox, M C, Hogarth, D M and Hansen, P B (1994). Breeding and selection for high early season sugar content on a sugarcane (*Saccharum* spp. hybrids) improvement program. Aust. J. Agric. Res., 45:1569-1575.

DeStefano, R P (1985). False pol in sugarcane juice - causes and detection. J. Am. Soc. Sugar Cane Technol., 4:80-85.

Dewey, D R and Lu, K H (1959). A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agron. J., 51:515-518.

Falconer, D S (1981). Introduction to quantitative genetics. 2nd Edn. (Longman: London)

Fraser, J and Eaton, G W (1983). Applications of yield component analysis to crop research. Field Crop Abstracts, 36:787-797.

Kang, M S, Tai, P, and Miller, J (1991). Genetic and phenotypic path analyses in sugarcane: artificially created relationships. Crop Sci., 31:1684-1686.

Kingston, G and Ham, G J (1975). Water requirements and irrigation scheduling of sugarcane in Queensland. I. Water requirements of sugarcane in Queensland. Proc. Qld. Soc. Sugar Cane Technol., 42:57-67.

Li, C C (1956). The concept of path coefficient and its impact on population genetics. Biometrics, 12:190-210.

May, K K and Middleton, F H (1972). Age of harvest. A historical review. Hawaiian Planters' Record, 58 (18):241-263.

SAS Institute Inc. (1989). SAS/STAT User's Guide, Version 6, Fourth Edition, Volumes 1 and 2, Cary, NC: SAS Institute Inc., 1989.

Skinner, J C (1974). Rind hardness and fibre content. Proc. Int. Soc. Sugar Cane Technol., 15:153-167.

Tew, Thomas L (1986). Effect of age at harvest: recent test results. Hawaiian Sugar Technol., 45th Annual Conf. Reports A30-33.

Tai, P Y P (1985). Maturity differences among non-flowering clones of sugarcane. Proc. Am. Soc. Sugar Cane Technol., 4:119.

11.0 ACKNOWLEDGMENTS

The following staff contributed to this project:

Mr P B Hansen, who organised the field work at Meringa, Bundaberg and Harwood, was involved in the data analysis, and produced many of the graphs.

Mr E R Halili, who was closely involved in the field and laboratory work in New South Wales.

Messrs D Parsons and R Farlow (NSW Sugar Milling Cooperative, Harwood Mill), and Mr P Castle (Harwood Cane Protection and Productivity Board).

Ms J K Stringer, who generously assisted with the many analyses of variance and grouping analyses.

Mr D Sanders and Dr G J Leonard who assisted with HPLC analyses.

Dr R T Mullins, who initiated the work.

Staff at Meringa (particularly Mr G Park) and Bundaberg Sugar Experiment Stations

APPENDIX A

Origin of 50 clones

Clone	Origin	Region
78A379	BSES	Burdekin
78A383	BSES	Burdekin
79A245	BSES	Burdekin
79A357	BSES	Burdekin
79A362	BSES	Burdekin
79A504	BSES	Burdekin
79A528	BSES	Burdekin
BN77-7193	CSR, NSW	
BN78-8031	CSR, NSW	
BN78-8032	CSR, NSW	
74C256 ¹	BSES	Central
75C326	BSES	Central
75C802	BSES	Central
76C212	BSES	Central
76C682	BSES	Central
76C741	BSES	Central
76C890	BSES	Central
CP44-101	Canal Point, USA	
CP51-21	Canal Point, USA	
CP73-351	Canal Point, USA	
CP75-1322	Canal Point, USA	
CP75-1553	Canal Point, USA	
CP78-1628	Canal Point, USA	
H56-752	Hawaii, USA	
H60-3802	Hawaii, USA	
H69-9103	Hawaii, USA	
H70-0144	Hawaii, USA	
H71-0505	Hawaii, USA	
LEANDER	CSR	
77N557	BSES	Northern
77N561 ¹	BSES	Northern
78N175	BSES	Northern
78N713	BSES	Northern
79N819	BSES	Northern
Q110	BSES, Commercial	
Q117	BSES, Commercial	
Q121	BSES, Commercial	
Q124	BSES, Commercial	
Q138	BSES, Commercial	
Q141	BSES, Commercial	
Q144	BSES, Commercial	
Q145	BSES, Commercial	
Q146	BSES, Commercial	
75S2497	BSES	Southern
76S1464	BSES	Southern
77S1199	BSES	Southern
SP70-3370	Brazil	
SP71-1406	Brazil	
SP71-3149	Brazil	
SP71-6163	Brazil	

¹ Since released as Q159² Since released as Q161

APPENDIX B

Total nitrogen (N), phosphorus (P), and potassium (K) applied

Trial	Crop	Element kg/ha		
		N	P	K
Meringa	P	125.2	20.0	0.0
	1R	152.4		89.4
Bundaberg	P	110.9	19.8	97.5
	1R	156.9	19.8	97.5
Harwood (One-year)	P	171.2	20.0	57.6
	1R	179.4	29.1	83.8
Harwood (two-year)	P	171.2	20.0	57.6

APPENDIX C

Sampling times at each location

Trial	Crop	Sampling date
Meringa	Plant	10/05/91
		17/06/91
		02/07/91
		03/09/91
		30/09/91
	1st Ratoon	06/05/92
		09/06/92
		23/07/92
		10/09/92
		14/10/92
Bundaberg	Plant	26/04/90
		28/05/90
		04/07/90
		17/08/90
		04/10/90
	1st Ratoon	27/05/91
		01/07/91
		05/08/91
		10/09/91
		14/10/91
Harwood (one-year)	Plant	20/05/91
		25/06/91
		30/07/91
		17/09/91
		22/10/91
	1st Ratoon	25/05/92
		09/07/92
		12/08/92
		16/09/92
		26/10/92
Harwood (two-year)	Plant	04/03/92
		27/05/92
		06/07/92
		10/08/92
		14/09/92

APPENDIX D

Traits measured or calculated in trials at Meringa, Bundaberg, and Harwood

Trait	Abbreviation
Stalk height (cm)	STHT
Stalk number (/ha)	STPH
Sucker number	SU
Weight of tops (t/ha)	TWPH
Total leaf number	TLN
Green leaf number	GLN
Stalk diameter (cm)	STDI
Flowering (%)	FL
Stalk weight (kg, average)	STWT
Stalk brix (lower third)	LOBX
Stalk brix (upper third)	HIBX
Brix (laboratory)	BX
Pol (laboratory)	POL
Conductivity (laboratory)	CON
Fibre (% , laboratory)	FIB
Sucrose (HPLC, DNPRC)	SUC
Glucose (HPLC, DNPRC)	GLU
Fructose (HPLC, DNPRC)	FRU

APPENDIX F1

**Analyses of variance over clones (C), locations (L), years (Y),
and sampling times (T)**

Source	df	Probability of F test					
		CCS	TCH	TSH	STWT	STPH	STDIA
C	49	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CxL	98	0.0001	0.1864	0.0142	0.0001	0.1058	0.0001
CxY	49	0.0295	0.0003	0.0069	0.0001	0.0003	0.0041
CxLxY	98	0.0001	0.0001	0.0011	0.0001	0.0670	0.0003
CxT	196	0.0001	0.0054	0.0001	0.0001	0.0027	0.0100
CxLxT	392	0.0001	0.1229	0.0251	0.6973	0.0156	0.0811
CxYxT	196	0.0655	0.2399	0.0038	0.2628	0.0002	0.2479
CxLxYxT	392	0.0001	0.3301	0.0581	0.0513	0.0061	0.0128
CV (%)		5.9	12.7	15.3	10.5	6.5	2.5

APPENDIX F2

Variance components from analyses of variance over clones (C), locations (L) and years (Y) for each sampling time (T), using random models (RM) and mixed models (MM - C random; L and Y fixed)

Time	Effect	Variance component					
		CCS		TCH		TSH	
		RM	MM	RM	MM	RM	MM
1	C	1.70	1.62 .038	36.1	34.8 .16.2	0.89	0.87 .0.27
	CxL	0.21	0.29 .0.13	-5.5	0.0	0.28	0.30 .0.22
	CxY	-0.16	0.00	6.8	7.7 .13.0	-0.04	0.00
	CxLxY	0.61	0.44 .0.11	62.2	58.7 .19.4	0.84	0.79 .0.23
2	C	1.48	1.45 .0.34	79.5	70.3 .22.5	1.52	1.46 .0.43
	CxL	0.23	0.26 .0.11	-16.3	0.0	0.35	0.42 .0.35
	CxY	-0.06	0.00	-15.5	0.0	-0.12	0.00
	CxLxY	0.41	0.36 .0.07	79.0	58.6 .21.1	0.98	0.86 .0.34
3	C	1.06	1.04 .0.24	63.8	59.6 .19.5	1.53	1.49 .0.44
	CxL	0.09	0.11 .0.07	-9.0	0.0	0.20	0.27 .0.37
	CxY	-0.05	0.00	-6.7	0.0	-0.09	0.00
	CxLxY	0.22	0.17 .0.07	55.5	46.3 .16.9	0.73	0.62 .0.35
4	C	0.87	0.86 .0.20	59.0	54.3 .20.7	2.13	2.13 .0.64
	CxL	0.30	0.29 .0.06	-21.1	0.0	0.15	0.16 .0.52
	CxY	-0.04	0.00	3.1	6.5 .14.6	0.15	0.15 .0.32
	CxLxY	0.05	0.04 .0.04	52.6	37.8 .23.4	0.53	0.52 .0.63
5	C	0.97	0.96 .0.22	52.9	46.0 .23.0	2.90	2.85 .0.86
	CxL	0.17	0.17 .0.05	-30.1	0.0	-0.22	0.00
	CxY	-0.02	0.00	21.9	26.0 .18.4	0.43	0.45 .0.41
	CxLxY	0.15	0.12 .0.04	64.2	47.2 .24.4	1.30	1.18 .0.58

APPENDIX G

Predicted response to selection for CCS at three locations over two crop-years

Location	Sampling time	Predicted response (absolute)		Predicted response (% of mean)	
		P	1R	P	1R
Meringa	1	2.10	2.10	20.5	29.8
	2	1.80	2.20	14.6	20.9
	3	1.24	1.73	9.1	12.7
	4	1.79	1.85	12.0	12.2
	5	1.68	2.16	10.5	13.3
Bundaberg	1	2.36	2.05	38.4	19.4
	2	2.48	2.04	26.6	16.5
	3	2.12	1.68	18.1	12.3
	4	1.91	1.70	13.7	11.4
	5	1.82	1.70	11.8	10.6
Harwood	1	2.90	2.72	58.8	46.5
	2	2.44	2.52	35.3	23.6
	3	1.93	1.52	22.4	13.0
	4	1.81	1.05	15.1	7.9
	5	1.80	1.44	14.0	9.4

APPENDIX H

Genotypic correlations between CCS and cane yield (TCH), conductivity and fibre

Location	Sample	TCH		Conductivity		Fibre	
		P	1R	P	1R	P	1R
Meringa	1	-.77 .12	-.59 .17	.11 .20	-	-.37 .16	.00 .24
	2	-1.3 .33	-.44 .17	-.27 .16	-.10 .27	-.53 .15	-.09 .20
	3	-.03 .39	-.41 .20	-.49 .17	-.12 .18	-.58 .15	-.46 .14
	4	.03 .14	.25 .20	-.82 .07	-.77 .07	-.69 .09	-.62 .10
	5	.35 .22	.44 .19	-.80 .10	-.72 .08	-.71 .10	-.69 .10
Bundaberg	1	-.47 .19	.18 .49	.08 .18	-.35 .19	.19 .16	-.54 .17
	2	-.40 .24	-.10 .22	-.27 .16	-.45 .14	-.20 .15	-.65 .11
	3	-.28 .27	-.11 .23	-.49 .15	-.54 .12	-.31 .15	-.72 .10
	4	.01 .22	-.20 .29	-.49 .14	-.58 .11	-.51 .12	-.83 .07
	5	-.04 .18	.08 .24	-.67 .12	-.60 .11	-.65 .10	-.83 .06
Harwood	1	-.13 .18	.31 .26	-.01 .23	-	.59 .12	-
	2	.30 .21	.22 .20	-.27 .18	-.72 .21	.38 .15	-
	3	.06 .22	.03 .30	-.30 .19	-.49 .15	-.03 .18	-
	4	-.30 .26	-	-.55 .25	-.51 .20	-.39 .15	-
	5	-.47 .17	.58 .39	-.57 .14	-.67 .14	-.63 .13	-

APPENDIX J1

Genetic path coefficient analysis of cane yield (1) and its components stalk weight (2) and stalk number (3)

Pathway	Crop	Path coefficient														
		Meringa					Bundaberg					Harwood				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Stalk wt □ Cane yield Direct effect, P ₂₁	P	2.98	12.6	1.52	1.86	1.35	1.74	1.78	1.91	1.95	1.64	0.93	1.70	1.38	1.68	5.99
	1R	1.24	8	1.15	1.27	1.21	2.60	1.28	1.90	2.25	1.85	2.19	1.71	2.20	-	2.43
Indirect effect via: Stalk no., r ₂₃ P ₃₁	P	-2.14	12.0	-0.95	-0.99	-0.52	-1.10	-1.23	-1.31	-1.36	-0.96	-0.13	-0.80	-0.54	-1.15	-5.45
	1R	-0.83	-	-0.65	-0.77	-0.71	-2.27	-0.86	-1.40	-1.85	-1.61	-1.49	-1.12	-1.46	-	-2.23
Correlation, r ₂₁	P	0.84	8	0.56	0.87	0.83	0.63	0.55	0.60	0.60	0.67	0.80	0.90	0.84	0.53	0.55
	1R	0.42	-0.68	0.50	0.51	0.49	0.34	0.43	0.50	0.40	0.24	0.70	0.59	0.74	-	0.20
Stalk no. □ Cane Yield Direct effect, P ₃₁	P	2.18	0.60	1.25	1.07	0.74	1.31	1.44	1.45	1.53	1.16	0.59	0.89	0.75	1.40	5.79
	1R	1.24	0.56	1.12	1.16	1.12	2.43	1.23	1.64	2.06	1.86	1.61	1.35	1.59	-	2.36
Indirect effect via: Stalk wt., r ₂₃ P ₂₁	P	-2.92	12.1	-1.16	-1.74	-0.94	-1.47	-1.52	-1.73	-1.72	-1.36	-0.21	-1.53	-0.99	-1.38	-5.63
	1R	-0.83	5	-0.67	-0.85	-0.77	-2.43	-0.89	-1.62	-2.03	-1.61	-2.02	-1.41	-2.02	-	-2.29
Correlation, r ₃₁	P	-0.74	1.07	0.09	-0.67	-0.20	-0.16	-0.08	-0.28	-0.19	-0.21	0.39	-0.65	-0.24	0.02	0.16
	1R	0.41	-	0.45	0.31	0.35	0.00	0.34	0.02	0.03	0.25	-0.41	-0.06	-0.43	-	0.07

APPENDIX J2

Genetic path coefficient analysis of sugar yield (1) and its components cane yield (2) and CCS (3)

Pathway	Crop	Path coefficient														
		Meringa					Bundaberg					Harwood				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cane yield \square Sugar yield Direct effect, P_{21}	P	0.92	2.91	0.86	0.73	0.77	0.50	0.69	0.67	0.80	0.89	0.60	0.57	0.72	0.96	1.11
	1R	0.72	0.99	1.08	0.83	0.80	0.30	0.78	0.82	0.82	0.75	0.23	0.58	0.63	-	0.61
Indirect effect via: CCS, $r_{23} P_{31}$	P	-1.07	-3.03	-0.02	0.10	0.15	-0.53	-0.42	-0.26	0.00	-0.02	-0.11	0.20	0.04	-0.20	-0.33
	1R	-0.71	-0.32	-0.23	0.10	0.15	0.16	-0.07	-0.07	-0.16	0.05	0.28	0.15	0.03	-	0.30
Correlation, r_{21}	P	-0.15	-0.13	0.84	0.83	0.92	-0.03	0.26	0.41	0.80	0.87	0.49	0.77	0.76	0.76	0.78
	1R	0.01	0.68	0.85	0.93	0.95	0.46	0.70	0.75	0.66	0.80	0.51	0.73	0.66	-	0.91
CCS \square Sugar yield Direct effect, P_{31}	P	1.45	3.37	0.61	0.56	0.43	1.13	1.05	0.95	0.60	0.49	0.85	0.67	0.64	0.68	0.71
	1R	1.20	0.76	0.57	0.38	0.35	0.91	0.71	0.66	0.77	0.61	0.90	0.70	0.75	-	0.52
Indirect effect via: Cane yield, $r_{23} P_{21}$	P	-0.68	-2.62	-0.03	0.13	0.27	-0.23	-0.28	-0.18	0.00	-0.04	-0.08	0.17	0.05	-0.29	-0.52
	1R	-0.42	-0.41	-0.45	0.21	0.35	0.05	-0.08	-0.09	-0.17	0.06	0.07	0.13	0.02	-	0.35
Correlation, r_{31}	P	0.78	0.75	0.58	0.69	0.70	0.90	0.78	0.77	0.60	0.46	0.78	0.84	0.69	0.39	0.19
	1R	0.77	0.35	0.12	0.59	0.69	0.96	0.63	0.57	0.61	0.67	0.97	0.82	0.77	-	0.87

APPENDIX J3

Ratio of the direct effects of (a) stalk weight and stalk number on cane yield (P_{21}/P_{31}) and (b) cane yield and CCS on sugar yield (P_{21}/P_{31})

Location	Sampling	(a) P_{21}/P_{31}		(b) P_{21}/P_{31}	
		P	1R	P	1R
Meringa	1	1.364	1.002	0.632	0.599
	2	1.044	1.165	0.863	1.303
	3	1.216	1.026	1.419	1.902
	4	1.750	1.101	1.297	2.167
	5	1.823 (1.439)	1.076 (1.074)	1.784	2.301
Bundaberg	1	1.328	1.071	0.439	0.327
	2	1.238	1.041	0.651	1.089
	3	1.320	1.157	0.704	1.240
	4	1.272	1.097	1.345	1.063
	5	1.417 (1.315)	0.996 (1.072)	1.811	1.234
Harwood	1	1.571	1.359	0.702	0.251
	2	1.923	1.260	0.857	0.839
	3	1.837	1.380	1.126	0.842
	4	1.204	-	1.420	-
	5	1.034 (1.514)	1.028 (1.257)	1.568	1.176

APPENDIX K

**Six clonal groups based on CCS response over thirty environments
(3 locations x 5 sampling times x 2 replications)**

Group No.	Clone	Parentage
76	79A528 75C326 Q145 SP71-1406	Q128 x 61N1232 54N7096 x CP50-11 Co1007 x 54N7096 NA56-79 x ?

Group No.	Clone	Parentage
84	79A357 79A504 76C890 H56-752 76S1464 77S1199 SP70-3370	Q96 x CP50-11 67N2254 x H49-3666 60N1853 x R397 H49-118 x ? 62N1659 x L62-96 CP51-21 x 66B15 CP53-19 x ?

Group No.	Clone	Parentage
90	79A362 76C682 CP51-21 78N713 79N819 Q117 Q121 Q124 Q141 Q144 Q146 Q159 75S2497	Q96 x CP50-11 Q117 x CP50-11 F36-819 x CP33-372 Q89 x H49-104 NCo310 x 54N7096 Q77 x 58N829 NCo310 x 54N7096 NCo310 x 54N7096 NCo310 x 54N7096 F144 x CP44-101 62N1659 x 66C807 NCo310 x 54N7096 NCo310 x 54N7096

APPENDIX K (Continued)

Group No.	Clone	Parentage
92	CP78-1628 CP75-1553 CP75-1322 CP73-351	CP65-357 x CP68-1026 73P2 x CP68-1026 CP69-1059 x CP57-614 CP65-357 x L65-69

Group No.	Clone	Parentage
93	BN77-7193 BN78-8031 BN78-8032 75C802 H60-3802 H69-9103 H70-0144 H71-0505 SP71-3149	APOLLO x BN53-2029 APOLLO x MQ72-5089 APOLLO x MQ72-5089 60N1853 x CP50-11 H51-8194 x ? H49-134 x ? H50-723 x ? H58-6297 x ? NA56-79 x ?

Group No.	Clone	Parentage
94	78A379 78A383 79A245 76C212 76C741 CP44-101 LEANDER 77N557 77N561 78N175 Q110 Q138 SP71-6163	67A189 x 58N978 67A189 x 58N978 CP50-11 x MQ33-371 60N2111 x CP53-19 L56-7 x 63B46 Co281 x CP1165 LF46-1902 x CP50-11 Q117 x 65A17 57R3289 x CP43-47 58N829 x 66N2008 NCo310 x CP44-101 58N829 x 66N2008 NA56-79 x ?