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GENOTYPE X ENVIRONMENT INTERACTION AND SELECTION OF SUGARCANE FAMILIES FOR THE BURDEKIN RIVER IRRIGATION AREA

by

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SD95005

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1.0 SUMMARY

The arable lands being developed for sugarcane production in the Burdekin River Irrigation Area (BRIA) are on markedly different soil types and, as a consequence, may present environmental challenges different to those influencing sugarcane production on the more established alluvial soils of the Burdekin delta and levee areas.

The success of a sugarcane selection and breeding program targeting the BRIA is highly dependent on an efficient selection system in the early stages. Although the relative performance of sugarcane genotypes may differ in different environments, current BSES and CSR selection programs targeting the Burdekin district do not include multi-environment testing until the final stages of clonal evaluation. Selection of sugarcane families only in the Burdekin delta on the Burdekin Sugar Experiment Station (BSES) or Kalamia Estate (CSR) may not be desirable, particularly when the BRIA consists of markedly different soil types. In this study, the importance of family by environment interactions was evaluated for the first stage of selection of original seedling populations. The aim was to determine if the BSES and CSR selection programs for evaluation of sugarcane families in the Burdekin district need to be expanded to encompass the lands being developed in the Burdekin River Irrigation Area.

In 1991, original seedlings from full sib sugarcane families were planted in two trials on each of the three major soil types of the Burdekin district. The trials were harvested as plant crops in 1992, and as ratoon crops in 1993. Cane yield, sugar content and sugar yield were measured on family plots. The evaluation of families on each of the alluvial, Barratta clay and sodic duplex soil types typical of the Burdekin district is unnecessary as the relative performance of families was independent of soil type. However, there was weak evidence to suggest factors other than soil type, such as management practices, may differentially influence the responses of sugarcane families. The results also suggested plant crop results alone were sufficient for evaluating seedling families. BSES and CSR should continue to evaluate sugarcane seedling families in the Burdekin at one site on a regional experiment station. Seedling trials conducted on the alluvial soils of the Burdekin Sugar Experiment Station or Kalamia Estate should adequately service the developing lands of the BRIA.

2.0 BACKGROUND TO RESEARCH

The area of irrigated arable land available for sugarcane production in the Lower Burdekin Valley, Queensland, Australia, is increasing due to the completion of the Burdekin Falls Dam on Lake Dalrymple in 1987, and the development of the BRIA. The BRIA adjoins the present irrigated lands of the Burdekin delta and, when fully developed, the scheme is expected to provide an additional 50 000 ha for irrigation (Noonan and McNee, 1990).

The lands being developed in the BRIA are on markedly different soil types and as a consequence may present environmental challenges different to those influencing sugarcane production on the more established alluvial soils of the Burdekin delta and levee areas. Farming practices suited to the soils of the BRIA differ from those familiar to

most canegrowers in the Burdekin district (Freshwater, 1993). In contrast to the Burdekin delta, soil fertility of the BRIA soils is also generally low.

The different soil types suitable for agriculture in the BRIA can be divided into broad groups based on similarities of morphology, chemical and physical attributes, and management requirements (Donnollan, 1991). The broad soil groups include the cracking clays, sodic duplex soils, non sodic duplex soils, and gradational and uniform non cracking soils. The majority (78%) of soils suitable for cane production in the BRIA are cracking clays and sodic duplex soils.

In 1990, at the outset of the project, the Burdekin district produced 4.44m tonnes of cane from about 40 670 ha, at an average CCS of 14.48 units. In 1994, the district will produce a record 6.64m tonnes of cane from about 53 500 ha, at an average CCS of 15.5 units. Clones superior to the existing commercial clones (mainly Q96 and Q117) would be of great value to the industry at present. Now and increasingly so in the future, there will be a need for clones that perform well on the new lands being developed for sugarcane culture in the BRIA.

The success of a sugarcane selection and breeding program targeting the Burdekin district is highly dependent on an efficient selection system in the early stages of the program. Although the relative performance of sugarcane genotypes may differ in different environments, current BSES and CSR selection programs targeting the Burdekin district do not include multi-environment testing until the final stages of clonal evaluation. It is reasonable for plant breeders to suggest that direct selection of varieties in the target environment (BRIA) should be more successful than indirect selection in other areas (Burdekin delta). Selection of sugarcane families (and other early stages of selection) only on the regional experiment stations (Burdekin Sugar Experiment Station and Kalamia Estate) may not be desirable, particularly when the BRIA consists of markedly different soil types. In this study, the importance of family by environment interactions was evaluated for the first stage of selection of original seedling populations.

3.0 OBJECTIVES

- To determine the magnitude and nature of family x environment interaction within the Burdekin district.

- To identify the important environmental factors that influence adaptation of families of sugarcane in the Burdekin district.

4.0 INTRODUCTION

Lodging of cane in selection trials grown on the Burdekin Sugar Experiment Station was recognised as a major factor limiting genetic progress in the Burdekin selection program (Pollock, 1982). Up until 1986, selection of clones in early stage trials was based on

visual estimates of yield, but visual estimation in small plots was difficult and imprecise under lodged Burdekin conditions. To facilitate visual mass selection (Skinner, 1965), crop growth in trials was deliberately restricted by reducing the application of irrigation and fertilisers (Hogarth *et al.*, 1990). Lodging was usually prevented and selection carried out in relatively erect crops. Unfortunately, crop growth was atypical for the target environment and, as a result, clonal assessment was potentially biased and subject to large errors. Assessment of families and parent clones for breeding purposes is based largely on the performance of progeny in the early stages of selection (Skinner *et al.*, 1987). With unreliable information, it is likely that the selection of elite families for further exploitation was not optimum, and elite parent clones were not identified for use in the breeding program.

With the acquisition of mobile weighing equipment in the early 1980s (Hogarth and Mullins, 1989), the opportunity arose to weigh more stages of selection, rather than persisting with subjective visual selection. In early stage trials, where clones are grown as single stools or in small 2 m plots, it was still impractical to use weighing units to weigh individual clones. Clones are planted in small plots due to limited availability of planting material, and because of the large numbers evaluated.

Hogarth (1971) recognised the value of family selection as an alternative to individual mass selection. In 1985, BSES began researching alternative selection strategies involving family selection for early stage trials conducted in the Burdekin, with the objective of improving selection efficiency (Hogarth *et al.*, 1990; McRae *et al.*, 1993; McRae and Hogarth, 1994). In essence, the alternative methods involved the evaluation and comparison of samples of full sib progeny or clones from different families or biparental crosses. Individual clones from the best families are subsequently selected and evaluated in the later stages of selection.

Based on this research, the recommended system for early stage trials grown under Burdekin conditions was to select families on weighed family plot data in plant crops, and mass select clones within selected families in the regrowth or ratoon crops. The results also suggested that combined family and mass selection within families was required to optimise genetic progress. The practical benefits of the system and the potential for genetic gain were so promising that BSES elected to adopt family selection for routine purposes in 1986, in anticipation of positive findings in Project BS4S.

A major practical benefit of family selection is that it allows genetic material to be evaluated across locations. This is important if there is the potential for genotype x environment interaction. Limited seed or planting material for individual sugarcane seedlings or clones has previously limited the evaluation of individual genotypes to single sites in early-stage trials. The inclusion of a propagation stage in order to build up quantities of planting material is undesirable as it is costly in terms of resources, and also lengthens the generation interval for selection. With family selection samples of seed representing full sib progeny or clones from the same families can be planted and evaluated objectively as families across a range of environments.

Family x environment interactions have been shown to be important for sugarcane in southern Queensland (Bull *et al.*, 1992) and more recently in the Herbert River district of north Queensland (Jackson, *et al.*, 1994). This project evaluated the importance of family x environment interactions in the Burdekin district, using populations of original seedlings. The aim was to determine if the BSES and CSR selection programs for evaluation of sugarcane families in the Burdekin district need to be expanded to encompass the lands being developed in the Burdekin River Irrigation Area.

5.0 RESEARCH METHODOLOGY

In 1991, original seedlings from full sib sugarcane families were planted in two trials on each of the three major soil types of the Burdekin district. The families were sampled randomly from the population of families or crosses routinely planted by BSES or CSR in the Burdekin, and included both experimental and proven or progeny-tested crosses. The soil types included the alluvials of the Burdekin delta, and the sodic duplex and Barratta clay soils of the BRIA. Details for the six test locations are given in Table I.

Table I

Location of trials, listing soil types, planting dates, harvesting dates, and number of families tested

Soil type	Alluvial		Barratta clay		Sodic duplex	
Site	BSES	KAL	CALT	BAC-BC	PASQ	BAC-SD
Location	Brandon, delta	Kalamia, delta	Clare, BRIA	Clare, BRIA	Clare, BRIA	Clare, BRIA
QDPI soil type[#]			2Ugd	2Uge	2Dbb	2Dyb
Planting date	12-5-91	6-6-91	15-5-91	29/30-5-91	21-5-91	29/30-5-91
Method of planting	furrow	ridge	furrow	ridge	furrow	ridge
Number of families	119	30	119	30	79	30
Plot Length (m)	10.3	12.7	10.5	12.7	10.4	12.7
Seedling spacing (m)	0.64	0.67	0.66	0.67	0.65	0.67
Harvest date Plant crop	1/2-9-92 (burnt)	29-9-92 (burnt)	22-9-92 (burnt)	27-8-92 (burnt)	7-7-92 (burnt)	26-8-92 (burnt)
Harvest date Ratoon crop	12-10-93 (green)	1-9-93 (burnt)	9-9-93 (green)	8-10-93 (burnt)	15-6-93 (burnt)	7-10-93 (burnt)

[#] Queensland Department of Primary Industries (QDPI) soil type after Donnollan (1991)

BSES and CSR germinated seed or 'fuzz' for crosses (biparental families) in January 1991 on the Burdekin Sugar Experiment Station, Brandon. Seedlings from up to 120 families (90 BSES and 30 CSR) were transplanted to the field as spaced single seedlings in May/June 1991. One hundred and twenty families were planted by BSES on the Burdekin Sugar Experiment Station (BSES, delta alluvial) and Caltabiano's farm (CALT, Barratta clay, 2Ugd) near Clare in the Mulgrave Section of the BRIA. Of these 120 families, 90 were planted on Pasquale's farm (PASQ, sodic duplex, Oakey 2Dbb) also in the Mulgrave Section of the BRIA. Thirty families common to the three BSES sites were also planted by CSR on Kalamia Estate (KAL, delta alluvial), and two sites located on the Burdekin Agricultural College in the Clare Section of the BRIA, representing the Barratta clay (BAC-BC, 2Uge) and sodic duplex (BAC-SD, 2Dyb) soil types.

A randomised complete block design of three replicates was used for each trial. Depending on the trial, each single row family plot contained 15 or 18 seedlings with an intrarow plant spacing of about 0.6 m. The commercial varieties, Q96 and Q117, were germinated from single-eye setts and were planted in each trial for comparative purposes. Each trial was grown using normal commercial cultural practices. Seedlings were planted into ridges (McMahon and Ham, 1994) as opposed to conventional furrow planting on the Barratta clay and sodic duplex sites located on the Burdekin Agricultural College, and the alluvial site on Kalamia Estate. The trials were harvested as plant crops in 1992 and as ratoon or regrowth crops in 1993. At harvest, an 8-stalk sample was taken from each family plot for determination of sugar content (Commercial Cane Sugar, CCS). Each stalk at sampling was taken from a different seedling. To extract juice, samples were crushed through a small laboratory two roller mill. Each family plot was harvested and cane yield t/ha (TCH) was determined, and tonnes of sugar/ha (TSH) was calculated.

The six test sites were characterised. Several key environmental parameters were measured at the trial sites to identify environmental factors influencing responses of the sugarcane families. Four extra plots of each standard clone, Q96 and Q117, were planted adjacent to the seedling trials at each site. These plots were sampled for yield and sugar content at approximately three to four monthly intervals. The data allowed general conditions for growth over time to be quantified and compared for the different trials. At each sampling, two adjacent plants from each plot were destructively harvested, and the material used to determine CCS and total dry matter production. At least two plants were left as a buffer between successive samplings. Growth curves for biomass accumulation were plotted for each location, for plant and ratoon crops.

Temperature, rainfall, solar radiation and wind movement were monitored with automatic weather stations, located at Clare (BRIA) and Kalamia Estate (Burdekin delta). Soil was sampled from each site in August 1991 from surface (0-25 cm) and sub-surface (25-50 cm) depths. The samples were analysed for pH, electrical conductivity and for a range of nutrient levels (Organic C, N, S, P, K, Ca, Mg, Al, Na, Cl, Cu, Zn, Mn, Fe and Bo). Results of soil analyses are given in Table II. The analyses indicate that the sites adequately represented the targeted soil types.

Table II

Results of soil analyses for surface (0-25 cm) and sub-surface (25-50 cm) samples for six test locations

Soil type	Alluvial				Barratta clay				Sodic duplex			
Location	BSES		KAL		CALT		BAC-BC		PASQ		BAC-SD	
Sampling depth (cm)	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50
pH (1:5 water)	6.9	7.4	6.7	7.2	7.3	7.1	7.1	7.5	5.9	6.9	6.6	7.8
Buffer pH	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	5.8	6.6	6.6	6.6
Organic carbon %C	1.6	0.8	1.8	1.3	0.8	0.4	0.8	0.5	1.2	0.5	1.0	0.7
Nitrate nitrogen mg/kg	6.6	2.6	21.8	8.1	4.9	2.4	9.3	2.8	34.1	5.3	60.0	38.9
Sulfur mg/kg	5	6	8	7	9	16	50	63	20	8	72	54
Phosphorus (BSES) mg/kg	200	200	105	94	24	10	41	16	44	8	84	37
Phosphorus (Colwell) mg/kg	100	100	38	28	21	8	16	6	58	10	68	30
Potassium meq/100g	0.23	0.24	0.44	0.43	0.69	0.53	0.53	0.46	0.55	0.35	0.38	0.28
Calcium meq/100g	9.79	10.73	15.28	16.17	14.06	14.49	17.35	18.84	7.85	9.08	10.50	8.71
Magnesium meq/100g	2.96	2.87	7.94	8.43	10.79	11.56	9.60	11.22	7.30	9.46	5.67	7.75
Aluminium meq/100g	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Sodium meq/100g	0.20	0.31	0.43	0.50	0.74	1.20	0.77	1.37	0.91	1.59	0.90	3.10
Chloride mg/kg	15	10	15	15	40	55	30	25	40	40	75	85
Electrical conductivity dS/m	0.05	0.04	0.08	0.06	0.08	0.09	0.14	0.16	0.12	0.07	0.49	0.24
Copper mg/kg	1.5	1.3	2.1	2.4	1.9	1.9	1.6	1.6	1.8	1.7	1.3	1.2
Zinc mg/kg	2.7	0.8	1.4	1.1	0.6	0.5	0.4	0.4	0.4	0.4	0.7	0.4
Manganese mg/kg	42.0	14.0	27.0	14.0	19.0	8.0	11.0	7.0	51.0	20.0	16.0	6.0
Iron mg/kg	48.0	49.0	46.0	53.0	42.0	40.0	26.0	26.0	67.0	40.0	34.0	23.0
Boron mg/kg	<0.02	<0.02	0.30	0.19	0.06	0.02	0.10	0.12	0.05	<0.02	0.18	0.40
Calcium/magnesium ratio	3.31	3.74	1.92	1.92	1.30	1.25	1.81	1.68	1.08	0.96	1.85	1.12
Sodium % of cations (ESP)	1.52	2.19	1.78	1.96	2.82	4.32	2.73	4.30	5.48	7.76	5.16	15.6
Cation exch. capacity meq/100g	13.19	14.16	24.10	25.54	26.29	27.79	28.26	31.90	16.62	20.49	17.46	19.85

5.1 Statistical analysis

Data for TCH, CCS and TSH were subjected to standard analyses of variance (ANOVA). Detailed results will be presented for the analyses of a balanced data set of 24 families, each represented in all replicates at the six test locations. The SAS software package (SAS Institute, 1990) was used for statistical analyses. Expected mean squares and appropriate F-tests for the mixed model analyses were based on 'Scheffés' model (Scheffé, 1959), rather than the 'SAS' model. Variance components were estimated for random effects. Standard errors for the components were estimated using the method of Anderson and Bancroft (1952).

For the analysis of variance within locations and crops, the following linear statistical model was assumed:

$$Y_{ij} = \mu + R_i + F_j + E_{ij}$$

For each observation, μ is a term for the general mean; R_i is the random effect of the ith replicate; F_j is the random effect of the jth family; and E_{ij} is a random error term.

For the mixed model analysis of variance across crops and locations, the following linear statistical model was assumed:

$$Y_{ijkn} = \mu + L_k + R(L)_{i(k)} + F_j + FL_{jk} + FR(L)_{ji(k)} + C_n + CL_{nk} + CR(L)_{ni(k)} + CF_{nj} + CFL_{njk} + Error_{ijkn}$$

For each observation, μ is a term for the general mean; L_k is the fixed effect of the kth location; $R(L)_{i(k)}$ is the random effect of the ith replicate nested within the kth location; F_j is the random effect of the jth family; C_n is the fixed effect of the nth crop-year; FL_{jk}, CL_{nk}, CF_{nj} and CFL_{njk} are the interaction effects; and $FR(L)_{ji(k)}$, $CR(L)_{ni(k)}$ and $Error_{ijkn}$ are random error terms.

For the mixed model analysis of variance within crops and across locations, separating locations into soil types and trials (nested within soil types), the following linear statistical model was assumed:

$$Y_{ijlm} = \mu + S_l + T(S)_{m(l)} + R(ST)_{i(ml)} + F_j + FS_{jl} + FT(S)_{jm(l)} + E_{ijlm}$$

For each observation, μ is a term for the general mean; S_l is the fixed effect of the lth soil type; $T(S)_{m(l)}$ is the random effect of the mth trial nested within the lth soil type; $R(ST)_{i(ml)}$ is the random effect of the ith replicate nested within the mth trial and lth soil type; F_j is the random effect of the jth family; FS_{jl} and $FT(S)_{jm(l)}$ are the interaction effects; and E_{ijlm} is a random error term.

For the mixed model analysis of variance across crops and locations, separating locations into soil types and trials nested within soil types, the following linear statistical model was assumed:

$$Y_{ijlmn} = \mu + S_l + T(S)_{m(l)} + R(ST)_{i(ml)} + F_j + FS_{jl} + FT(S)_{jm(l)} + FR(ST)_{ji(ml)} + C_n + CS_{nl} + CT(S)_{nm(l)} + CR(ST)_{ni(lm)} + CF_{nj} + CFS_{njl} + CFT(S)_{njm(l)} + Error_{ijlmn}$$

For each observation, μ, S_l, $T(S)_{m(l)}$, $R(ST)_{i(ml)}$, F_j, FS_{jl}, and $FT(S)_{jm(l)}$ are as above; C_n is the fixed effect of the *n*th crop-year; CS_{nl}, $CT(S)_{nm(l)}$, CF_{nj}, CFS_{njl} and $CFT(S)_{njm(l)}$ are the interaction effects; and $FR(ST)_{ji(ml)}$, $CR(ST)_{ni(lm)}$ and $Error_{ijlmn}$ are random error terms.

In the experiments, crop and year effects were completely confounded. Therefore, the crop effect constitutes a split-block design (Steel and Torrie, 1980) as harvest data from consecutive years are repeated measurements on the same plot.

The genetic correlation (r_g) for a character measured in different environments was calculated after Falconer (1981) as:

$$r_g = \frac{r_p - r_e.(1-h_X^2)^{0.5} \,.\, (1-h_Y^2)^{0.5}}{(h_X^2 \,.\, h_Y^2)^{0.5}}$$

where h_X^2 and h_Y^2 are the broad sense heritabilities for family means measured in environments X and Y; r_p is the phenotypic correlation for family means for environments X and Y; and r_e is the correlation between error effects for the two environments. For independent environments involving different locations, r_e was assumed to equal zero. Crop-years at the same location were not independent environments and r_e was estimated. Standard errors for the genetic correlations were estimated using the method of Tallis (1959).

The relationships among environments for the relative responses of families for TCH, CCS and TSH were examined using principal component analysis (PCA). The phenotypic correlation matrix, consisting of all correlations between environments for mean performance of the families, was used as input for this analysis. The environments were plotted according to their loadings on the first two components from PCA. In these plots, environments that were most similar in terms of the relative response of families were in close proximity, while those which were dissimilar were far apart. This allows for an easy appraisal of relationships between environments.

Analyses of covariance between each pairwise combination of TCH, CCS and TSH were done. For the mixed model analysis of covariance, the fixed effect of locations was not partitioned into effects of soil type and trials (soil types), but treated as six environments. For the analysis of variance for individual characters, the linear statistical model given for the mixed model analysis of variance across crops and locations, was assumed. In an analogous manner, for the analysis of covariance, the same model was assumed, but mean cross products replaced mean squares, and respective components of covariance were calculated.

To evaluate the relative merits of different methods of family selection, predicted responses to selection were estimated using the following formula (Falconer, 1981):

$$R = i\sigma_p h^2$$

where R is the predicted response to family selection; i is the intensity of selection or standardised selection differential; σ_P is the observed standard deviation of family means; and h^2 is the broad sense heritability of family means.

The phenotypic standard deviation (σ_p) was calculated as $\sqrt{\sigma_P^2}$ where:

$$\sigma_P^2 = \sigma_f^2 + \sigma_{fl}^2/l + \sigma_{fc}^2/c + \sigma_{flc}^2/lc + \sigma_{rf(l)}^2/rl + \sigma_e^2/rlc$$

where, σ_f^2, σ_{fl}^2, σ_{fc}^2, σ_{flc}^2, $\sigma_{rf(l)}^2$ and σ_e^2 are variance components for families, family x location interaction, family x crop-year interaction, family x location x crop-year interaction, family x replicate (location) interaction and error, respectively. The terms l, c and r are the number of locations, crop-years and replicates, respectively for the population of inference. The variance components were determined using the linear statistical model for the mixed model analysis of variance across crops and locations.

Response to family selection was predicted for different combinations of number of locations (1-3), replicates per location (1-6), and number of families evaluated for a given resource input in terms of total number of test plots. Number of plots was based on numbers routinely used by CSR (500) and BSES (1000) for seedling trials in selection programs in the Burdekin. It was also assumed, as is similar to current practices, that 50 families would be selected for the larger BSES program and 20 families selected for the smaller CSR program. Clones for evaluation in later stage selection trials would be selected from within these selected families.

6.0 RESULTS AND DISCUSSION

For family selection to be effective, there needs to be genetic differentiation among families. In the plant crops of the six seedling trials (Table III), differences among families were significant for TCH, CCS and TSH in all trials, except for CCS at Pasquale's and the Barratta clay site located on the Burdekin Agricultural College. In the ratoon crops, differences among families were significant for TCH, CCS and TSH in all trials, except for TSH at the Barratta clay site located on the Burdekin Agricultural College. The results suggest there was sufficient genetic differentiation among families for family selection to be effective in the Burdekin.

Error coefficients of variation (CV%) for plant crops ranged from 11.06% to 21.40% for TCH, 6.12% to 11.39% for CCS, and 16.90% to 22.70% for TSH. For the ratoon crops, error CV's ranged from 15.14% to 26.32% for TCH, 4.67% to 12.16% for CCS, and 19.24% to 27.57% for TSH. Although the error CV's appear to be high, they are acceptable for these characters measured in original seedling trials grown under Burdekin conditions, using single row plots. At all sites, plant crop yields (TCH) were higher than for the respective ratoon crops. Seasonal conditions and a longer growing period for the plant crops would account for these differences.

Table III

Analysis of variance within locations and within plant (P) and ratoon (R) crops for TCH, CCS and TSH. Family (σ_f^2) and error (σ_e^2) variance components are given with standard errors (±SE), and the general mean and coefficient of variation (CV%) are also presented.

Character crop	Statistic	Soil type					
		Alluvial		Barratta clay		Sodic duplex	
		BSES	KAL	CALT	BAC-BC	PASQ	BAC-SD
TCH P	σ_f^2	476.00**	358.63**	465.16**	300.04**	501.61**	148.43**
	(±SE)	(173.41)	(180.55)	(209.97)	(128.60)	(165.64)	(71.57)
	σ_e^2	399.88	795.56	794.36	444.92	247.48	298.42
	(±SE)	(81.63)	(162.39)	(162.15)	(90.82)	(50.52)	(60.91)
	Mean	146.27	131.79	131.67	113.57	142.27	98.29
	CV%	13.67	21.40	21.40	18.57	11.06	17.57
TCH R	σ_f^2	684.84**	247.42*	141.81*	189.46**	539.90**	195.94**
	(±SE)	(267.57)	(136.52)	(76.13)	(96.48)	(189.89)	(94.29)
	σ_e^2	757.02	665.41	360.80	430.97	384.76	392.02
	(±SE)	(154.53)	(135.83)	(73.65)	(87.97)	(78.54)	(80.02)
	Mean	137.72	98.01	92.77	98.34	129.57	95.95
	CV%	19.98	26.32	20.47	21.11	15.14	20.64
CCS P	σ_f^2	0.836**	0.569**	0.589**	0.374	0.080	0.726**
	(±SE)	(0.407)	(0.235)	(0.261)	(0.303)	(0.233)	(0.308)
	σ_e^2	1.722	0.755	0.955	1.934	2.004	1.049
	(±SE)	(0.351)	(0.154)	(0.195)	(0.395)	(0.409)	(0.214)
	Mean	12.930	14.206	13.342	12.781	12.424	12.360
	CV%	10.15	6.12	7.32	10.88	11.39	8.29
CCS R	σ_f^2	0.858*	0.300**	0.741**	0.407**	1.198**	0.413*
	(±SE)	(0.501)	(0.147)	(0.256)	(0.208)	(0.453)	(0.232)
	σ_e^2	2.573	0.626	0.482	0.937	1.174	1.153
	(±SE)	(0.525)	(0.128)	(0.098)	(0.191)	(0.240)	(0.235)
	Mean	13.192	14.390	14.873	14.974	11.607	14.007
	CV%	12.16	5.50	4.67	6.46	9.34	7.66
TSH P	σ_f^2	12.250**	8.041**	8.631**	7.340**	5.197**	1.973*
	(±SE)	(4.688)	(4.039)	(4.019)	(2.890)	(2.346)	(1.225)
	σ_e^2	12.561	17.742	15.947	8.335	8.879	6.630
	(±SE)	(2.564)	(3.622)	(3.255)	(1.701)	(1.812)	(1.353)
	Mean	19.054	18.754	17.595	14.559	17.631	12.156
	CV%	18.60	22.46	22.70	19.83	16.90	21.18
TSH R	σ_f^2	15.885**	5.036*	2.518*	2.498	8.018**	4.108**
	(±SE)	(6.470)	(2.943)	1.530	(1.845)	(3.081)	(2.040)
	σ_e^2	20.190	15.137	8.133	11.220	8.342	8.834
	(±SE)	(4.121)	(3.090)	1.660	(2.290)	(1.703)	(1.803)
	Mean	18.372	14.113	13.736	14.688	15.014	13.450
	CV%	24.46	27.57	20.76	22.80	19.24	22.10

Significance levels of the F-Ratios, * $P < 0.05$ and ** $P < 0.01$, are for the family component of variance.

In the mixed model ANOVA (Table IV) fitting the effects of soil types and trials (soil types), the main effect of families was highly significant for TCH, CCS and TSH, in both plant and first ratoon crops. For selection purposes, the variance components for families (σ_f^2) suggest family selection should be effective in either plant or ratoon crops. The family x soil type interaction was not significant for any character in either crop, and the respective σ_{fs}^2 variance components were either small or negative. This suggests that the evaluation of families on each of the alluvial, Barratta clay and sodic duplex soils is unnecessary as the relative performance of families was independent of soil type. This was an unexpected result as farming practices suited to the soils of the BRIA differ from those familiar to most canegrowers on the alluvial soils of the Burdekin delta and levee areas.

Table IV

Mixed model ANOVA across soil types and trials (soil types), within crop-years. Family (σ_f^2), family x soil type (σ_{fs}^2), family x trial (soil type) ($\sigma_{ft(s)}^2$), and error (σ_e^2) variance components (± standard errors) are given for TCH, CCS and TSH.

Crop	Variance component	Character		
		TCH	CCS	TSH
Plant	σ_f^2	322.71 ± 99.12**	0.345 ± 0.120**	5.738 ± 1.807**
	σ_{fs}^2	−8.47 ± 19.70	−0.003 ± 0.061	−0.082 ± 0.498
	$\sigma_{ft(s)}^2$	72.88 ± 42.41*	0.224 ± 0.123*	1.900 ± 1.027*
	σ_e^2	496.77 ± 42.14	1.403 ± 0.119	11.682 ± 0.991
Ratoon	σ_f^2	279.37 ± 86.89**	0.522 ± 0.166**	5.000 ± 1.604**
	σ_{fs}^2	−18.67 ± 19.51	0.015 ± 0.049	−0.213 ± 0.483
	$\sigma_{ft(s)}^2$	87.04 ± 44.77**	0.139 ± 0.094*	1.866 ± 1.040*
	σ_e^2	498.50 ± 42.28	1.158 ± 0.098	11.976 ± 1.016

Significance levels of appropriate F-Ratios, * $P < 0.05$ and ** $P < 0.01$, are given with the respective variance components.

For each character in both crops, the family x trial (soil type) interaction was significant, and the $\sigma_{ft(s)}^2$ variance component was more important than the σ_{fs}^2 variance component. This suggests factors other than soil type, such as management practices including time of harvest and planting method, may differentially influence the responses of sugarcane families in the Burdekin district. The six trials were harvested as plant crops over a 12 week period and as ratoon crops over 17 weeks. The trial at Pasquale's was planted on land not previously planted to sugarcane. The trials at Kalamia Estate and the Burdekin Agricultural College were planted to ridges as opposed to conventional furrow planting, and these factors may have contributed to the interactions. Although the interaction was significant in the mixed model ANOVA, the variance components for family x trial (soil

type) interactions were smaller than the respective components for the main effect of families for both plant and ratoon crops.

In the mixed model ANOVA (Table V) fitting a crop-year effect, the main effect of families was highly significant for TCH, CCS and TSH. The family x soil type interaction effect was not significant for any character, suggesting that soil type is not important in affecting the relative performance of families. The family x trial (soil type) interaction effect was significant for TCH, CCS and TSH, but the variance components for the interaction $\sigma_{ft(s)}^2$ were much smaller than the respective components for the main effect of families.

Table V

Mixed model ANOVA across soil types and trials (soil types), and crop-years. Family (σ_f^2), family x soil type (σ_{fs}^2), family x trial (soil type) ($\sigma_{ft(s)}^2$), family x crop-year (σ_{fc}^2), family x crop-year x soil type (σ_{fcs}^2), family x crop-year x trial (soil type) ($\sigma_{fct(s)}^2$), and error (σ_e^2) variance components (± standard errors) are given for TCH, CCS and TSH.

Variance component	Character		
	TCH	CCS	TSH
σ_f^2	285.22 ± 89.99**	0.408 ± 0.132**	5.006 ± 1.630**
σ_{fs}^2	−16.74 ± 14.52	0.024 ± 0.033	−0.221 ± 0.356
$\sigma_{ft(s)}^2$	75.34 ± 33.86**	0.092 ± 0.059*	1.660 ± 0.778**
σ_{fc}^2	2.50 ± 3.54	−0.005 ± 0.014	0.050 ± 0.090
σ_{fcs}^2	3.17 ± 5.19	−0.018 ± 0.022	0.073 ± 0.136
$\sigma_{fct(s)}^2$	4.62 ± 9.81	0.090 ± 0.049*	0.223 ± 0.257
σ_e^2	290.61 ± 24.65	1.119 ± 0.095	7.113 ± 0.603

Significance of appropriate F-Ratios, * $P < 0.05$ and ** $P < 0.01$, are given with the respective variance components.

The family x crop-year interaction (σ_{fc}^2) was not significant for TCH, CCS or TSH. This suggests plant crop results alone are sufficient for evaluating seedling families in the Burdekin district. In the experiments, crop and year effects were completely confounded as harvest data from consecutive years are repeated measurements on the same plot. That is, plot errors were correlated for plant and ratoon crop harvests. To avoid this confounding and to obtain unbiased estimates of family x crop interactions, families should be planted in independent trials in consecutive years at the same location, and evaluated in both plant and ratoon crops in the same year. Similarly, unbiased estimates of family x year interactions can be obtained by planting the same families in different years. This often occurs in practice for promising families grown in the Burdekin.

The family x crop-year x soil type interaction was not significant for any character. This suggests families can be reliably selected in plant crops alone, and independently of soil type. The family x crop-year x trial (soil type) interaction was significant for CCS, but not for TCH or TSH. The significant interaction for CCS may be due to different harvest times for the different trials in different crop-years (see Table I), and may reflect differential maturity of families. Although the family x crop-year x trial (soil type) interaction was significant in the mixed model ANOVA, the $\sigma_{fct(s)}^2$ variance component was much smaller than the variance component for families (σ_f^2). Harvesting all trials, in both plant and ratoon crops, at approximately the same time of year would be expected to further reduce the size and importance of this interaction.

Falconer (1952) first noted that a character expressed in two environments could be regarded as two characters which are genetically correlated. On this basis, the genetic correlation between the trait measured in two environments indicates whether or not genotype x environment interaction is present, and the degree to which the phenotypes have the same genetic basis. A genetic correlation of unity or nearly one implies that genotype x environment interaction variance is negligible, and that the same alleles or sets of alleles influence the 'character states' in the same way in the two environments. In contrast, a genetic correlation across environments less than unity would imply the presence of genotype x environment interaction and indicate that the phenotypes in each environment are influenced either by some different alleles or differently by the same alleles (Via and Lande, 1987).

Genetic correlations between all pairs of environments are given in Table VI for sugar yield (TSH). Environments included the six test locations and two crop-years. As expected, large standard errors are associated with the estimates. In general, correlations between the same character (TSH) but measured at different locations in the same crop-year, were positive and moderately high. This is consistent with the finding of a lack of important family x location interactions in the analyses of variance within crops.

The correlations between the same character (TSH) measured at the same location, but in different crop-years, were generally high. This suggests family x crop-year interactions are not important, and that plant crop results alone are sufficient for evaluating seedling families. Genetic correlations between plant crop performance at each location with ratoon crop performance at other locations were generally positive and moderate to high. This suggests family x crop-year x location interactions are not important in the Burdekin.

The performance of the standard commercial varieties, Q96 and Q117, planted at each location and adjacent to each of the seedling trials provided an indication of the general conditions for growth at the different locations in plant (1991/92) and first ratoon (1992/93) crops. The general profile for growth over time was similar for most environments. Differences in the accumulation of biomass over time indicates differences in growing conditions across locations. For example, in the plant crops, the sodic sites (PASQ and BAC-SD) were more conducive for early growth compared with the Barratta clay site at Caltabiano's and the alluvial site at Kalamia Estate.

Biomass readings taken close to the time of harvest of the seedling trials differed in magnitude. There were differences among trials for total biomass near time of harvest, but the relativity of these differences was not always consistent with cane yields of the standard clones planted and evaluated within the seedling trials. Possible reasons for this include the relative positions of the plots for the standards adjacent to and within the seedling trials at the different sites varied. Secondly, competitive ability of the standard clones grown within seedling trials may have differed among locations. Thirdly, the family trial was machine harvested and, thus, cane harvester losses may have varied differentially. The rate of biomass accumulation decreased markedly after May. This decrease in growth is probably associated with environmental conditions of temperature, solar radiation and physiological maturity.

Although accumulation of biomass over time indicated differences in growing conditions across locations, family x environment interactions were still not important in seedling populations grown in the Burdekin. Family x soil type interactions were not significant for TCH, CCS or TSH, despite there being marked physical and chemical differences among the targeted soil types studied. In general, soil fertility for the different test locations was probably adequate, and with a sufficient supply of irrigation water, growing conditions were favourable, and seedlings were not severely stressed.

In the plant crops of the seedling trials, the $\sigma_{ft(s)}^2$ interaction component for CCS was potentially more important for selection purposes than for TCH and TSH (Table IV). The $\sigma_{fct(s)}^2$ interaction component for CCS was also significant in the mixed model ANOVA, fitting a crop-year effect (Table V). The trials were not all harvested at the same time, and differential maturity of families may have contributed to the interactions. Principal component analysis was used to summarise the relationships among environments for discriminating among families for CCS. For CCS, the eigenvalues from PCA indicate that the first two principal components account for 62.6 % of the standardised variance. The relationships among environments, similarities or dissimilarities, depicted by PCA, were not obviously associated with any known factor, such as rainfall, temperature, time of harvest, ridge versus conventional furrow planting, mean CCS or soil type. Further studies would be required in order to clearly identify important environmental factors that influence adaptation of families of sugarcane in the Burdekin district. Given that the interactions were not important relative to the main effect of families, resources needed to elucidate putative relationships may be better utilised studying other aspects of selection methodology.

Table VI

Genetic correlations (± standard error) between environments for the performances of families for TSH. Environments include six locations and two crops (P = plant and R = ratoon).

	KAL P	CALT P	BAC-BC P	PASQ P	BAC-SD P	BSES R	KAL R	CALT R	BAC-BC R	PASQ R	BAC-SD R
BSES P	0.66 (0.19)	1.08 (0.10)	0.92 (0.11)	1.04 (0.10)	0.90 (0.17)	0.94 (0.07)	0.73 (0.16)	1.05 (0.15)	0.82 (0.21)	0.64 (0.17)	0.94 (0.13)
KAL P		0.58 (0.22)	0.44 (0.22)	0.79 (0.18)	0.70 (0.23)	0.58 (0.21)	0.80 (0.11)	0.80 (0.22)	1.17 (0.22)	0.78 (0.17)	0.81 (0.19)
CALT P			0.60 (0.19)	0.76 (0.18)	0.55 (0.24)	1.06 (0.12)	0.38 (0.23)	0.97 (0.12)	0.49 (0.26)	0.46 (0.21)	0.74 (0.19)
BAC-BC P				1.02 (0.11)	0.85 (0.18)	0.58 (0.19)	0.73 (0.16)	0.42 (0.24)	0.85 (0.14)	0.60 (0.18)	0.96 (0.13)
PASQ P					1.47 (0.20)	0.99 (0.12)	0.82 (0.16)	0.84 (0.20)	1.57 (0.25)	0.82 (0.12)	1.32 (0.14)
BAC-SD P						0.73 (0.20)	0.70 (0.21)	0.82 (0.24)	1.48 (0.28)	1.15 (0.15)	1.30 (0.13)
BSES R							0.60 (0.19)	1.01 (0.16)	0.83 (0.21)	0.71 (0.16)	0.75 (0.18)
KAL R								0.42 (0.24)	1.17 (0.19)	0.97 (0.11)	0.61 (0.20)
CALT R									0.76 (0.27)	0.66 (0.21)	0.87 (0.21)
BAC-BC R										1.02 (0.19)	1.38 (0.23)
PASQ R											0.91 (0.14)

Family and family x location interaction correlations (Table VII) were calculated from the components of variance and covariance. Although the correlation between TCH and CCS for family effects was small and negative (−0.12), it was not significantly different from zero. Thus, at least in the short-term, independent selection for CCS should not result in greatly reduced cane yields (TCH). Similarly, directional selection for TCH should not result in reduced yields for sugar content. Sugar yield (TSH) was positively correlated (part-whole) with both TCH and CCS, but more highly correlated with TCH. This probably reflects the higher family coefficient of variation for TCH than for CCS.

Table VII

Partial correlations (± standard errors) between combinations of TCH, CCS and TSH for family and family x location effects, for pooled analysis of covariance.

Source of covariation	Correlated characters		
	TCH and CCS	TCH and TSH	CCS and TSH
Families	−0.12 ± 0.21	0.95 ± 0.02	0.20 ± 0.20
Family x location	0.33 ± 0.12	0.89 ± 0.02	0.72 ± 0.08

The family x location interaction correlation between TCH and CCS was positive (0.33) and significantly different from zero. This suggests that a favourable response for cane yield at specific locations was associated with favourable specific response for CCS at the respective locations. The partial correlations between TCH and TSH, and CCS and TSH were highly positive. This suggests that responses for sugar yield at specific sites were associated with responses for both cane yield and sugar content.

Predicted responses to family selection were estimated using different selection strategies. The small size of the family x crop-year interaction variance components (Table V) suggests that it is sufficient to evaluate original seedling families in plant crops alone. McRae *et al.* (1993) also found plant crop results alone were sufficient for evaluation of sugarcane families in the Burdekin. Evaluating families in ratoon crops only lengthens the generation interval for selection, for little gain in information. For calculating predicted responses to family selection for TCH, CCS and TSH (Table VIII), it was assumed that families would be evaluated in plant cane only. Various selection strategies involving different combinations of number of locations, replicates per location, and number of families evaluated were compared. These options were chosen to represent similar levels of resource input currently used by BSES (1000 plots) and CSR (500 plots) for seedling trials targeting the Burdekin district.

Table VIII

Predicted response to family selection for TCH, CCS and TSH for a large (1000 plots) and a smaller (500 plots) program using different combinations of number of test locations, replicates per location and number of families evaluated and selected.

Test plots	Number families evaluated	Test locations	Replicates per location	Number families selected	Predicted gains from selection		
					TCH	CCS	TSH
500	500	1	1	20	21.98	0.32	2.64
500	250	1	2	20	22.39	0.41	2.74
500	167	1	3	20	21.59	0.45	2.67
500	125	1	4	20	20.51	0.46	2.55
500	100	1	5	20	19.38	0.45	2.42
500	83	1	6	20	18.20	0.44	2.28
500	250	2	1	20	22.90	0.44	2.82
500	125	2	2	20	21.11	0.50	2.65
500	83	2	3	20	18.78	0.49	2.38
500	63	2	4	20	16.70	0.45	2.13
500	50	2	5	20	14.58	0.41	1.86
500	42	2	6	20	12.73	0.37	1.63
500	167	3	1	20	22.36	0.50	2.79
500	83	3	2	20	18.99	0.50	2.42
500	56	3	3	20	15.84	0.45	2.03
500	42	3	4	20	12.88	0.38	1.66
500	33	3	5	20	9.84	0.30	1.27
500	28	3	6	20	7.38	0.23	0.96
1000	1000	1	1	50	21.05	0.30	2.53
1000	500	1	2	50	21.28	0.39	2.60
1000	333	1	3	50	20.20	0.42	2.50
1000	250	1	4	50	18.98	0.42	2.36
1000	200	1	5	50	17.69	0.41	2.21
1000	167	1	6	50	16.41	0.39	2.06
1000	500	2	1	50	21.77	0.42	2.68
1000	250	2	2	50	19.52	0.46	2.45
1000	167	2	3	50	16.93	0.44	2.15
1000	125	2	4	50	14.48	0.39	1.85
1000	100	2	5	50	12.14	0.34	1.55
1000	83	2	6	50	9.81	0.28	1.26
1000	333	3	1	50	20.93	0.47	2.61
1000	167	3	2	50	17.12	0.45	2.18
1000	111	3	3	50	13.33	0.38	1.71
1000	83	3	4	50	9.93	0.29	1.28
1000	67	3	5	50	6.70	0.20	0.87
1000	56	3	6	50	3.18	0.10	0.41

Predicted gains from selection for TCH, CCS and TSH for the different selection strategies varied as expected. Predicted gains for TSH ranged from 0.96 to 2.82 t/ha for the CSR program, and from 0.41 to 2.68 t/ha for the BSES program. For the larger

BSES program, the best option in terms of gain for TSH was 500 families evaluated at two locations with one replicate/location. Similarly for the CSR program, evaluating 250 families at two locations with one replicate/location appeared to be the best option.

Predicted response to selection for each program was based on a fixed number of test plots and assumed an equal unit cost per test plot. However, it is much more efficient in terms of resource input per family tested to evaluate families on a single site. The current practice for BSES of evaluating 250 families in four replicates on the Burdekin Sugar Experiment Station, and for CSR to evaluate 125 families in four replicates on Kalamia Estate, are efficient options in terms of genetic gain. By testing families at a single site, gains for TCH, CCS and TSH are comparable with evaluating families across locations, and the resources saved per family tested could be used to evaluate more families. That is, the extra resources needed to evaluate families across locations cannot be justified in terms of genetic gain.

There were practical difficulties experienced in establishing original seedling populations on local farms, and this is also justification for testing seedling families only on regional experiment stations, given a lack of important family x location interactions in the Burdekin district. On regional experiment stations, trials can be harvested and planted at the desired time. On local farms, the farmer and cooperating harvesting contractor can constrain the timing of activities due to commercial commitments. For optimising long-term gains from selection, other aspects to be considered include family size necessary for exploiting within family variance, value of progeny test data for evaluating the worth of parent clones, and effective population size of parent clones for minimising inbreeding depression.

7.0 GENERAL CONCLUSIONS

- Family selection should be effective in original seedling populations of sugarcane grown in the Burdekin district. For family selection to be effective, there needs to be genetic differentiation among families. In plant and ratoon crops at six locations, differences among families were mostly significant for TCH, CCS and TSH.

- The evaluation of families on each of the alluvial, Barratta clay and sodic duplex soil types typical of the Burdekin district is unnecessary as the relative performance of families was independent of soil type. Family x soil type interactions were not important for TCH, CCS or TSH, in either plant or ratoon crops.

- Factors other than soil type, such as management practices, may differentially influence the responses of sugarcane families in the Burdekin district. Family x trial (soil type) interactions were significant for TCH, CCS and TSH in plant and ratoon crops. The relative size of the interaction variance components relative to the main effect of families suggests the interactions are of minor importance for selection purposes.

- Plant crop results alone are sufficient for evaluating seedling families in the Burdekin district. Family x crop-year interactions were not significant for TCH, CCS or TSH. Family x crop-year x soil type and family x crop-year x trial (soil type) interactions also were not important.

- There are practical difficulties in establishing and maintaining original seedling populations on local farms in the Burdekin. Seedling raising requires greater care and different cultivation techniques from commercial cane growing.

- BSES and CSR should continue to evaluate sugarcane seedling families in the Burdekin at one site on a regional experiment station. Predicted responses to selection suggest the current practices for BSES of evaluating 250 families in four replicates on the Burdekin Sugar Experiment Station, and for CSR of evaluating 125 families in four replicates on Kalamia Estate, are efficient options in terms of genetic gain. Extra resources needed to evaluate families across locations in the Burdekin cannot be justified in terms of genetic gain.

8.0 DIFFICULTIES

There were practical difficulties in establishing and maintaining original seedling populations on local farms in the Burdekin, particularly on the Barratta clay soils. Seedling raising requires greater care and different cultivation techniques from commercial cane growing. Pests caused minor damage to two trials. The plant crop of the trial at Pasquale's suffered early stage damage by the Eastern swamphen (*Porphyrio porphyrio*). Installation of a gas operated scare gun and vigilant shooting minimised the damage to the trial. The Sulphur-crested cockatoo (*Cacatua galerita*) and Black field cricket (*Teleogryllus* spp) caused some damage to the plant crop of the trial at Caltabiano's. The risk of damage to trials by pests was greater in the developing lands of the BRIA due to the presence of the rice industry.

9.0 IMPLICATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The evaluation of seedling families on each of the alluvial, Barratta clay and sodic duplex soil types typical of the Burdekin district is unnecessary as the relative performance of families is independent of soil type. BSES and CSR should continue to evaluate sugarcane seedling families in the Burdekin at one site on a regional experiment station. Seedling trials conducted on the Burdekin Sugar Experiment Station or Kalamia Estate should adequately service the developing lands of the BRIA. The outcome of the research includes cost efficiencies for evaluating seedling populations. Resources saved by not having to evaluate seedling families on multiple locations will be made available for testing more families or for evaluating clones in later stage trials.

Objective progeny performance data made available with family selection allows for accurate identification of superior families and parents for further exploitation. SRDC

Project BS119S, 'Best linear unbiased prediction as a method for predicting cross potential', aims to increase the rate of population improvement by optimising the method for selecting parents in the breeding program. This work is critical for sugarcane improvement, and BSES has elected to fund this work in the Burdekin.

Lodging is recognised as an important impediment to efficient selection in the Burdekin district. SRDC funded Project CSR17S, 'Optimal plot size and replication for testing clones in early stages of selection', is investigating the influences of competition effects from neighbouring plots in early stage trials. Seedling families are currently evaluated using single-row plots, and this should be reviewed when results of CSR17S are available.

SRDC Project BS46S, 'Optimum family selection strategies in original seedlings, particularly for heavily lodged crops', aims to determine what level of family performance in seedling populations is required for a family to be selected, and to evaluate the effectiveness of visual mass selection within families in young ratoon crops of original seedlings. One aspect which may need to be investigated in the future is the need to optimise rates of family selection, and rates and methods of clonal selection within selected families. A BSES project, 'Improved selection strategies for original seedlings in northern and central districts', aims to optimise selection rates among and within seedling families. Research on this aspect should not be initiated in the Burdekin until the results of this project and Project BS46S are known.

The results for Project BS57S suggested factors other than soil type, such as management practices, may differentially influence the responses of sugarcane families in the Burdekin district. This aspect may need investigation, particularly for the clonal stages of selection. For example, specific genotypes may be suited to ridge, as opposed to conventional furrow planting.

The Burdekin district, being a relatively dry tropical environment, is dependent on irrigation for growing sugarcane. Available moisture and timing of irrigation applications can dramatically influence CCS of milled cane. The relatively predictable nature of the Burdekin environment may allow for field manipulation and optimism of CCS at harvest time. Suitability of genotypes for manipulation, especially in the early part of the season, would impact on this area. Project BS93S, 'Breeding clones with high early sugar content', should address this aspect as part of the objective to assess potential limitations to further genetic gain in early CCS.

10.0 INTELLECTUAL PROPERTY ARISING FROM THE RESEARCH

There are no matters of any description, arising from the research in project BS57S, that pertain to intellectual property rights.

11.0 ACKNOWLEDGMENTS

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12.0 PUBLICATIONS

McRae, T A, Jackson, P A, Foreman, J W, Erquiaga, D L and Morgan, T E (1993). Genotype-environment interaction and selection of sugarcane families for the Burdekin River Irrigation Area. *In*: 'Focussed Plant Improvement'. Proc. Tenth Australian Plant Breeding Conf., pp 33-34.

McRae, T A and Jackson, P A (1995). Selection of sugarcane families for the Burdekin River Irrigation Area. (Submitted ASSCT).

13.0 REFERENCES

Anderson, R L and Bancroft, T A (1952). Statistical theory in research. McGraw-Hill Book Co., New York.

Bull, J K, Hogarth, D M and Basford, K E (1992). Impact of genotype x environment interaction on response to selection in sugarcane. *Aust. J. Exp. Agric.*, 32:731-737.

Donnollan, T E (1991). Understanding and managing Burdekin (BRIA) soils. Queensland Department of Primary Industries Publication.

Falconer, D S (1952). The problem of environment and selection. *Am. Nat.*, 86:293-298.

Falconer, D S (1981). Introduction to quantitative genetics. Second Edition, Longman, London.

Freshwater, I (1993). A guide to canegrowing in the Burdekin River Irrigation Area. Second Edition. Bureau of Sugar Experiment Stations, Australia.

Hogarth, D M (1971). Quantitative inheritance studies in sugar-cane. II. Correlations and predicted responses to selection. *Aust. J. Agric. Res.*, 22:103-109.

Hogarth, D M, Braithwaite, M J and Skinner, J C (1990). Selection of sugarcane families in the Burdekin district. *Proc. Aust. Soc. Sugar Cane Technol.* 1990 Conf., pp 99-104.

Hogarth, D M, and Mullins, R T (1989). Changes in the BSES plant improvement program. *Proceedings of the International Society of Sugar Cane Technologists.* 20:956-961.

Jackson, P A, McRae, T A and Hogarth, D M (1994). Selecting superior sugarcane crosses for the Herbert River district. *Proc. Aust. Soc. Sugar Cane Technol.* 1994 Conf., pp 47-54.

McMahon, G G and Ham, G J (1994). Ridge planting sugarcane on heavy clay soils in the Burdekin. *Proc. Aust. Soc. Sugar Cane Technol.* 1994 Conf., pp 70-74.

McRae, T A and Hogarth, D M (1994). Alternative selection strategies for the Burdekin sugarcane improvement program. Bureau of Sugar Experiment Stations Publication, SRDC Final Report Project BS4S SD94007.

McRae, T A, Hogarth, D M, Foreman, J W and Braithwaite, M J (1993). Selection of sugarcane seedling families in the Burdekin district. *In:* 'Focussed Plant Improvement' Proc. Tenth Australian Plant Breeding Conf., pp 77-82.

Noonan, P J and McNee, D A K (1990). Development strategies for the Burdekin River irrigation area. Queensland Department of Primary Industries Project Report QO90037.

Pollock, J S (1982). Variety selection in the Burdekin. *Proc. Aust. Soc. Sugar Cane Technol.* 1982 Conf., pp 121-129.

SAS Institute (1990). SAS/STAT User's Guide, Release 6.08, Fourth Edition. SAS Institute, Cary, NC, USA.

Scheffé, H (1959). The Analysis of Variance. Wiley NY, USA.

Skinner, J C (1965). Grading varieties for selection. *Proc. Int. Soc. Sugar Cane Technol.*, 12:938-949.

Skinner, J C, Hogarth, D M and Wu, K K (1987). Selection methods, criteria and indices, pp 409-453 *In:* D.J. Heinz (Ed) Sugarcane Improvement Through Breeding. Elsevier, Amsterdam.

Steel, R G D and Torrie, J H (1981). Principles and Procedures of Statistics. 2nd Edn. McGraw-Hill, Singapore.

Tallis, G M (1959). Sampling error of genetic correlation coefficients calculated from analyses of variance and covariance. *Aust. J. Statist.* 1:35-43.

Via, S and Lande, R (1987). Evolution of genetic variability in a spatially heterogeneous environment: effects of genotype-environment interaction. *Genet. Res.*, 49:147-156.

Appendix I

Plant and ratoon crop means for tonnes cane/ha (TCH) of 24 families evaluated. Families are ranked on mean performance across six locations.

Crop	Family	Female parent	Male parent	Location						
				BSES	KAL	CALT	BAC-BC	PASQ	BAC-SD	MEAN
Plant	CSR47	MQ65-698	BN79-9301	192.54	154.97	190.33	150.50	162.39	116.63	161.23
	CSR89	CP70-1547	MQ74-396	187.42	150.97	185.21	132.70	175.21	86.17	152.95
	CSR102	MQ71-1438	TS66-440	169.43	134.80	178.35	130.37	176.07	118.30	151.22
	BSES179	Q135	61N1232	169.77	166.13	149.90	126.43	163.67	127.33	150.54
	CSR74	MQ65-698	MQ79-212	152.49	134.20	122.52	144.30	177.35	115.60	141.08
	CSR40	MQ84-30B	BN73-3304	165.50	151.67	170.08	124.63	137.18	91.60	140.11
	CSR56	MQ81-664	CO-1148	163.71	135.00	126.71	125.80	163.46	103.47	136.36
	CSR75	CO-961	BN61-1123	130.70	156.60	136.42	115.47	157.48	117.00	135.61
	BSES61	79C116	Q142	162.63	156.37	159.53	81.17	140.17	107.70	134.59
	CSR53	CP52-68	CO-1148	159.87	124.27	122.62	126.60	155.98	114.93	134.04
	BSES63	CO740	72C159	141.38	132.83	124.38	120.97	160.69	114.47	132.45
	BSES113	77N1233	61N1232	155.73	117.40	132.17	134.57	144.23	96.63	130.12
	CSR61	W68-1055	MQ79-212	129.97	184.37	102.18	123.70	135.68	89.23	127.52
	CSR78	CP65-357	MQ69-1160	170.98	147.67	103.62	108.40	137.39	91.70	126.63
	BSES35	73C214	72C494	135.47	141.67	116.82	117.03	142.31	94.87	124.69
	CSR7	CP71-1240	POLYCROSS	156.63	103.70	125.63	103.30	149.79	99.37	123.07
	BSES40	74C439	Q96	131.54	105.53	125.33	107.67	139.53	97.57	117.86
	CSR32	BN60-9671	POLYCROSS	131.39	110.70	125.44	102.13	129.70	96.70	116.01
	BSES18	79A457	71C998	122.35	145.43	105.52	90.67	136.11	87.60	114.61
	CSR58	CP65-357	KQ87-7209	131.35	113.33	114.03	109.60	122.22	83.90	112.41
	BSES75	F161	72C494	119.76	113.50	128.30	95.70	114.53	79.83	108.60
	CSR39	L62-96	MQ82-505	119.44	103.17	115.89	99.47	102.56	76.23	102.79
	BSES53	75C151	76S1464	120.00	94.10	91.05	100.47	109.62	89.30	100.76
	CSR87	TS66-440	CP57-526	90.38	84.67	108.10	53.93	81.20	62.90	80.20
Ratoon	BSES179	Q135	61N1232	160.26	155.87	98.78	109.20	195.68	114.83	139.10
	CSR89	CP70-1547	MQ74-396	183.85	131.40	120.17	110.77	168.81	97.63	135.44
	CSR47	MQ65-698	BN79-9301	162.68	124.13	106.61	112.20	145.98	120.60	128.70
	CSR53	CP52-68	CO-1148	189.54	100.07	103.22	120.07	137.29	109.77	126.66
	CSR40	MQ84-30B	BN73-3304	205.24	95.70	112.26	95.50	137.59	91.67	122.99
	CSR102	MQ71-1438	TS66-440	159.60	91.03	106.90	110.53	119.48	126.43	119.00
	CSR75	CO-961	BN61-1123	120.57	98.70	116.68	129.97	141.47	104.43	118.64
	CSR56	MQ81-664	CO-1148	150.24	98.57	88.00	109.70	141.59	104.03	115.36
	BSES63	CO740	72C159	139.97	73.67	97.61	102.27	152.54	120.90	114.49
	CSR74	MQ65-698	MQ79-212	118.79	106.13	97.83	112.07	136.91	112.60	114.06
	BSES61	79C116	Q142	156.13	92.60	123.22	78.53	135.19	97.73	113.90
	CSR78	CP65-357	MQ69-1160	149.91	116.37	88.77	109.50	121.65	92.63	113.14
	BSES35	73C214	72C494	137.55	103.53	84.71	110.13	123.41	102.03	110.23
	CSR32	BN60-9671	POLYCROSS	140.31	90.37	93.84	91.07	130.38	102.43	108.07
	BSES113	77N1233	61N1232	125.42	97.03	95.12	96.30	131.14	90.03	105.84
	CSR61	W68-1055	MQ79-212	98.23	119.47	84.13	110.13	122.30	88.37	103.77
	CSR7	CP71-1240	POLYCROSS	144.92	75.33	81.03	85.70	126.92	97.87	101.96
	BSES18	79A457	71C998	121.50	112.53	63.35	95.13	135.27	76.27	100.67
	CSR58	CP65-357	KQ87-7209	134.25	93.77	77.17	88.07	118.97	86.63	99.81
	BSES40	74C439	Q96	106.59	82.23	79.72	91.30	115.53	89.63	94.17
	BSES53	75C151	76S1464	117.48	74.87	75.44	96.10	100.08	79.07	90.51
	CSR39	L62-96	MQ82-505	103.21	76.03	88.71	81.30	109.35	62.53	86.86
	BSES75	F161	72C494	92.07	88.57	71.76	71.60	109.07	85.03	86.35
	CSR87	TS66-440	CP57-526	86.99	54.27	71.49	43.13	53.03	49.63	59.76

Appendix II

Plant and ratoon crop means for sugar content (CCS) of 24 families evaluated. Families are ranked on mean performance across six locations.

Crop	Family	Female parent	Male parent	Location						
				BSES	KAL	CALT	BAC-BC	PASQ	BAC-SD	MEAN
Plant	CSR7	CP71-1240	POLYCROSS	13.92	16.43	14.46	14.03	13.40	14.70	14.49
	BSES35	73C214	72C494	13.41	15.57	15.58	11.23	13.45	13.50	13.79
	CSR32	BN60-9671	POLYCROSS	14.41	14.17	13.94	13.43	13.46	13.07	13.75
	BSES40	74C439	Q96	13.77	14.80	13.79	12.97	12.97	13.93	13.70
	BSES75	F161	72C494	13.84	15.17	13.71	13.53	12.80	13.07	13.69
	BSES179	Q135	61N1232	12.96	14.07	13.53	14.20	13.43	13.30	13.58
	CSR58	CP65-357	KQ87-7209	13.71	13.73	14.39	13.23	12.57	13.03	13.44
	BSES18	79A457	71C998	13.25	15.33	13.32	13.83	12.52	11.83	13.35
	CSR53	CP52-68	CO-1148	14.25	13.43	13.44	12.67	13.22	12.77	13.30
	BSES113	77N1233	61N1232	14.14	13.60	13.03	12.87	13.21	12.53	13.23
	CSR78	CP65-357	MQ69-1160	11.51	14.33	12.85	13.40	13.25	13.17	13.09
	BSES63	CO740	72C159	11.87	15.03	14.08	12.57	12.51	11.90	12.99
	BSES61	79C116	Q142	13.98	15.23	13.07	11.83	11.86	12.00	12.99
	CSR89	CP70-1547	MQ74-396	13.77	14.27	13.26	13.40	11.77	11.27	12.96
	CSR102	MQ71-1438	TS66-440	13.41	13.83	13.84	13.10	10.78	11.63	12.76
	CSR56	MQ81-664	CO-1148	12.28	13.17	13.79	11.93	12.19	12.63	12.66
	CSR47	MQ65-698	BN79-9301	14.06	13.57	11.86	14.17	11.74	10.57	12.66
	CSR40	MQ84-30B	BN73-3304	12.11	14.30	14.06	11.37	12.00	11.80	12.61
	CSR87	TS66-440	CP57-526	12.48	13.67	13.03	10.40	12.45	12.27	12.38
	CSR75	CO-961	BN61-1123	11.65	14.03	13.37	11.97	12.28	10.77	12.34
	CSR74	MQ65-698	MQ79-212	12.68	13.70	11.95	13.63	10.39	11.00	12.22
	CSR61	W68-1055	MQ79-212	12.16	13.73	11.45	11.70	11.07	12.83	12.16
	CSR39	L62-96	MQ82-505	10.28	12.33	12.72	13.07	11.88	11.97	12.04
	BSES53	75C151	76S1464	10.39	13.43	11.72	12.20	12.98	11.10	11.97
Ratoon	CSR7	CP71-1240	POLYCROSS	14.65	15.10	16.11	16.70	12.39	15.97	15.15
	BSES40	74C439	Q96	14.71	15.87	16.29	16.43	13.01	13.77	15.01
	BSES35	73C214	72C494	14.61	15.53	15.25	15.30	13.12	15.30	14.85
	CSR32	BN60-9671	POLYCROSS	14.93	14.73	15.97	15.20	12.78	14.77	14.73
	BSES179	Q135	61N1232	13.92	14.70	15.42	16.20	12.76	14.87	14.65
	CSR58	CP65-357	KQ87-7209	12.86	15.07	15.93	16.17	13.37	14.30	14.62
	BSES61	79C116	Q142	13.16	15.23	16.05	15.60	12.56	14.83	14.57
	BSES18	79A457	71C998	13.33	15.30	15.41	15.37	12.08	15.57	14.51
	BSES75	F161	72C494	13.49	15.00	16.04	14.90	12.89	13.67	14.33
	CSR78	CP65-357	MQ69-1160	14.13	14.77	15.27	14.20	12.12	13.67	14.03
	BSES63	CO740	72C159	13.44	14.20	14.89	15.30	11.84	13.77	13.91
	CSR53	CP52-68	CO-1148	12.93	14.23	14.54	14.43	12.72	13.20	13.68
	CSR87	TS66-440	CP57-526	12.85	13.97	15.35	14.87	11.73	13.23	13.67
	CSR102	MQ71-1438	TS66-440	13.18	13.77	14.74	15.00	10.04	14.27	13.50
	CSR89	CP70-1547	MQ74-396	15.01	13.97	14.90	14.83	9.74	12.07	13.42
	CSR39	L62-96	MQ82-505	9.78	13.87	14.71	15.20	12.64	13.87	13.35
	BSES53	75C151	76S1464	12.53	14.00	13.98	14.83	10.50	13.50	13.22
	BSES113	77N1233	61N1232	14.11	13.50	13.49	14.00	9.88	14.17	13.19
	CSR56	MQ81-664	CO-1148	12.00	14.00	14.18	14.10	10.51	13.83	13.10
	CSR61	W68-1055	MQ79-212	10.87	14.07	13.96	14.93	10.60	13.93	13.06
	CSR40	MQ84-30B	BN73-3304	12.80	13.67	13.02	14.67	10.87	13.17	13.03
	CSR47	MQ65-698	BN79-9301	13.90	13.33	13.58	13.87	10.20	12.73	12.94
	CSR74	MQ65-698	MQ79-212	11.65	13.40	14.04	13.43	10.87	14.17	12.93
	CSR75	CO-961	BN61-1123	11.75	14.10	13.86	13.83	9.36	13.57	12.74

Appendix III

Plant and ratoon crop means for sugar yield t/ha (TSH) of 24 families evaluated. Families are ranked on mean performance across six locations.

Crop	Family	Female parent	Male parent	Location						
				BSES	KAL	CALT	BAC-BC	PASQ	BAC-SD	MEAN
Plant	CSR47	MQ65-698	BN79-9301	27.09	21.01	22.53	21.23	19.08	12.43	20.56
	BSES179	Q135	61N1232	22.30	23.47	20.25	17.95	21.96	17.02	20.49
	CSR89	CP70-1547	MQ74-396	25.87	21.54	24.56	17.66	20.65	9.73	20.00
	CSR102	MQ71-1438	TS66-440	22.85	18.57	24.66	17.14	18.96	13.94	19.35
	CSR53	CP52-68	CO-1148	22.78	16.71	16.70	16.02	20.54	14.71	17.91
	CSR40	MQ84-30B	BN73-3304	20.16	21.68	23.89	14.18	16.48	10.86	17.88
	BSES61	79C116	Q142	23.32	23.92	20.77	9.69	16.53	12.90	17.86
	CSR7	CP71-1240	POLYCROSS	21.79	16.94	18.12	14.57	20.09	14.70	17.70
	BSES113	77N1233	61N1232	22.02	16.03	17.24	17.50	19.07	12.15	17.33
	BSES35	73C214	72C494	18.16	22.07	18.22	13.02	19.28	12.85	17.27
	CSR56	MQ81-664	CO-1148	20.04	17.92	17.45	15.07	19.96	13.05	17.25
	CSR74	MQ65-698	MQ79-212	19.30	18.27	14.65	19.52	18.63	12.74	17.18
	BSES63	CO740	72C159	16.96	19.96	17.10	15.20	20.11	13.69	17.17
	CSR75	CO-961	BN61-1123	15.27	21.68	18.19	13.67	19.38	12.56	16.79
	CSR78	CP65-357	MQ69-1160	19.59	21.13	13.34	14.32	17.91	12.05	16.39
	BSES40	74C439	Q96	18.12	15.69	17.49	14.05	18.33	13.63	16.22
	CSR32	BN60-9671	POLYCROSS	18.77	15.81	17.50	13.73	17.53	12.60	15.99
	CSR61	W68-1055	MQ79-212	15.69	25.32	12.09	14.38	15.13	11.60	15.70
	BSES18	79A457	71C998	16.14	22.38	13.86	12.40	16.92	10.38	15.35
	CSR58	CP65-357	KQ87-7209	17.96	15.57	16.38	14.44	15.38	10.94	15.11
	BSES75	F161	72C494	16.68	17.14	17.64	13.10	14.65	10.46	14.95
	CSR39	L62-96	MQ82-505	12.56	12.94	14.83	13.08	12.14	9.08	12.44
	BSES53	75C151	76S1464	12.62	12.70	10.84	11.91	14.24	9.96	12.04
	CSR87	TS66-440	CP57-526	11.27	11.64	13.96	5.60	10.19	7.72	10.06
Ratoon	BSES179	Q135	61N1232	22.70	22.86	15.21	17.69	24.99	17.14	20.10
	CSR89	CP70-1547	MQ74-396	27.63	18.48	17.76	16.55	16.47	11.77	18.11
	CSR53	CP52-68	CO-1148	24.61	14.24	15.09	17.34	17.46	14.48	17.20
	CSR47	MQ65-698	BN79-9301	22.61	16.93	14.38	15.55	14.76	15.55	16.63
	BSES61	79C116	Q142	20.45	14.09	19.83	12.55	17.00	14.50	16.40
	BSES35	73C214	72C494	20.17	16.09	12.93	16.92	16.17	15.55	16.31
	CSR102	MQ71-1438	TS66-440	20.64	12.31	15.78	16.62	11.94	18.00	15.88
	CSR32	BN60-9671	POLYCROSS	21.19	13.36	15.00	13.84	16.66	15.26	15.88
	CSR78	CP65-357	MQ69-1160	21.18	17.21	13.55	15.70	14.71	12.75	15.85
	CSR40	MQ84-30B	BN73-3304	26.14	13.06	14.60	13.87	14.97	12.09	15.79
	BSES63	CO740	72C159	19.08	10.46	14.54	15.63	18.19	16.56	15.74
	CSR7	CP71-1240	POLYCROSS	21.15	11.38	13.09	14.31	15.62	15.63	15.20
	CSR56	MQ81-664	CO-1148	18.05	13.83	12.52	15.43	14.92	14.35	14.85
	CSR75	CO-961	BN61-1123	14.41	13.67	16.13	17.85	13.22	13.72	14.83
	CSR74	MQ65-698	MQ79-212	13.87	14.30	13.70	15.01	14.86	15.98	14.62
	BSES18	79A457	71C998	16.26	17.23	9.69	14.65	16.48	11.85	14.36
	CSR58	CP65-357	KQ87-7209	17.01	14.18	12.28	14.25	15.87	12.40	14.33
	BSES40	74C439	Q96	15.67	13.09	12.94	15.03	15.16	12.27	14.03
	BSES113	77N1233	61N1232	17.82	13.06	12.86	13.68	12.93	12.81	13.86
	CSR61	W68-1055	MQ79-212	10.93	16.81	11.74	16.45	13.10	12.38	13.57
	BSES75	F161	72C494	12.58	13.45	11.61	10.50	14.08	11.78	12.33
	BSES53	75C151	76S1464	14.81	10.48	10.54	14.25	10.50	10.60	11.86
	CSR39	L62-96	MQ82-505	10.25	10.65	12.97	12.47	13.97	8.80	11.52
	CSR87	TS66-440	CP57-526	11.73	7.48	10.94	6.39	6.29	6.55	8.23