BUREAU OF SUGAR EXPERIMENT STATIONS

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FINAL REPORT
SRDC PROJECT BS4S
ALTERNATIVE SELECTION STRATEGIES FOR THE BURDEKIN SUGARCANE IMPROVEMENT PROGRAM

by

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SD94007

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1.0 SUMMARY

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. In 1985, BSES began a series of four experiments on the Burdekin Sugar Experiment Station to examine alternative selection strategies for early stage trials, with the objective of improving selection efficiency.

Lodging of cane in selection trials grown on the Burdekin Sugar Experiment Station is recognised as a major factor limiting genetic progress. Mass selection of individual sugarcane clones is difficult in high yielding, lodged trials in the Burdekin district of Queensland, and results are unreliable. In this study, an alternative scheme evaluated for early stage trials utilised family selection based on objective yield measurements, followed by mass selection within selected families.

The project demonstrated the practical utility of family selection for early stage trials in the Burdekin. Family selection, but not individual mass selection, can still be carried out in trials that are heavily lodged and/or adversely affected by cyclones. The results suggest combined family and mass selection within families will be required to optimise genetic progress.

The BSES and CSR selection programs targeting the Burdekin district have been modified progressively to incorporate the findings of this project. The recommended system for early stage trials grown under Burdekin conditions is to select families on weighed family plot data in plant crops, and mass select clones within selected families in ratoon crops. With this system, objective progeny performance data allow more accurate identification of superior families and parents for further exploitation in the breeding and selection programs. Field operations are simpler and less expensive, and genetic progress is expected to be improved for the important production traits of tonnes cane/ha, sugar content and tonnes sugar/ha.

Although the project was plagued by adverse weather conditions, the practical utility of family selection and potential genetic gains was identified.

2.0 BACKGROUND TO RESEARCH

Commercial sugarcane varieties with improved genetic characteristics would provide a major economic advantage to the Australian sugar industry. The Burdekin district, serviced by the Burdekin Sugar Experiment Station, is a major canegrowing area in Australia, and is rapidly becoming more important with the completion of the Burdekin Falls Dam in 1987. In 1985 at the outset of the project, the Burdekin district produced 3.75 M tonnes of cane from about 32 800 ha. In 1993, the Burdekin district produced a record 6.1 M tonnes of cane from about 49 400 ha, at an average CCS of 14.89 units. Clones superior to the existing commercial clones (Q96 and Q117) would be of great value to the industry at present. In future, there will be a need for clones that perform well on the new lands being developed for sugarcane culture in the Burdekin River Irrigation Area.

In the early 1980s, BSES plant breeders recognised that the Burdekin BSES and CSR

selection programs were not producing varieties of a commercial standard. Despite the growing conditions in the Burdekin being markedly different from other canegrowing districts of Queensland, the major commercial varieties grown in the previous 20 years (Q63 and Q96) were selected as seedlings in other districts, not in the Burdekin. The situation has still not improved, and in 1993 the varieties Q96 and Q117 accounted for more than 95% of production in the Burdekin. It is reasonable to assume that direct selection of varieties in the target environment should be more successful than indirect selection in other districts.

The success of the sugarcane selection and breeding program targeting the Burdekin district is highly dependent on an efficient selection system in the early stages of the program. In 1985, BSES began a series of experiments to examine alternative selection strategies for early stage trials, with the objective of improving selection efficiency.

3.0 PROJECT OBJECTIVES

To evaluate alternative selection strategies for the early stages of selection for the Burdekin district sugarcane improvement program, including studies of single-planted seedlings versus bunch-planted seedlings in Stage 1, and family selection versus mass (individual clone) selection in Stages 1 and 2.

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 biased and subject to large errors. Assessment of families and parent clones for breeding purposes is based largely on the performances 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 objectively 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 opportunity of using a method of family selection as an alternative to individual mass selection. The method involves the evaluation and

comparison of samples of individual 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. The acquisition of suitable weighing machines presented an opportunity to investigate the application of family selection, based on objective yield data, to improve selection efficiency in early stage trials.

Four experiments were planned and carried out on the Burdekin Sugar Experiment Station to investigate various aspects of selection in early stage trials.

5.0 RESEARCH METHODOLOGY

5.1 Experiment 1

Objectives:

- Determine if the `best' families selected in Stage 2 trials where crop growth is deliberately restricted are superior to the `worst' families, when evaluated in Stage 3 trials.

- Determine if mass selection within families, as opposed to random sampling of clones, was effective in Stage 2 trials with restricted growth.

Methodology:

Detailed experimental methods and procedures for Experiment 1 are provided by Hogarth *et al* (1990) and Hogarth and Braithwaite (Unpublished, 1990).

In 1984, original seedlings from 200 biparental sugarcane families were planted on the Burdekin Sugar Experiment Station in bunches (Skinner, 1982) of 10 seedlings per bunch. In 1985, selected stalks, each assumed to be a different clone, were planted into Stage 2 in 2 m plot trials. Crop growth in the plant crop was deliberately restricted to avoid lodging and facilitate mass selection. In 1986, each clone was graded using standard methods (Skinner, 1965). This included a visual appraisal of yield and a brix measurement to assess sugar content, relative to a standard commercial clone. Families were assessed on the number of seedlings receiving a grade of a standard sufficient to warrant further testing. This was the selection rate for each family. Based on selection rates, the 20 `best' and the 5 `worst' families were selected from the 200 planted. For each of the 25 families chosen, 10 selected and 10 randomly sampled clones were evaluated in a Stage 3, 10 m plot trial. The Stage 3 trial was planted in 1987, after an initial planting in 1986 failed to germinate and establish satisfactorily.

The Stage 3 trial was a randomised complete block, split-plot design, of two replicates. Whole-plots were families and split-plots were selection classes, that is, selected or random clones. Each subplot of 5 clones was 5 rows x 10 m long. In addition, one 10 m plot of Q96 was included in each main plot for grading purposes. This Stage 3 trial was harvested as a plant crop in 1988 and as a ratoon crop in 1989. Both crops were heavily lodged due to the

influences of cyclone `Charlie' in 1988 and cyclone `Aivu' in 1989. At harvest, a 2-stalk sample was taken from each plot for determination of sugar content (CCS). Cane yield as tonnes cane/ha (TCH) was measured for each clonal plot, and tonnes sugar/ha (TSH) calculated. Net merit grade (NMG) based on sugar yield relative to the standard clone (Skinner, 1965) was used to evaluate the relative performance of clones and families.

Plant and ratoon crop harvest results were analysed to show the realised gains from family and mass selection in Stage 2 trials with restricted growth.

5.2 Experiment 2

Objectives:

- Compare the relative effectiveness of family and individual mass selection in Stage 2, 2 m plot trials.

- Estimate gains from selection by comparing the selected groups of clones with randomly sampled clones in a Stage 3, 10 m plot trial.

Methodology:

Detailed experimental methods and procedures for Experiment 2 are provided by McRae *et al* (1994, in preparation) and Hogarth and Braithwaite (Unpublished, 1990).

Sixty full sib sugarcane families were planted in two adjacent Stage 2 trials on the Burdekin Sugar Experiment Station in April 1986. One trial was for `Family' selection and the other for `Mass' selection purposes. Each trial was a randomised complete block design of four replicates. Family plots of 3 rows by 9.6 m consisted of 15 clones each planted in a 1.92 m subplot. Families were replicated, but clones were not. The commercial variety, Q96, was also planted in six plots of 3 rows by 9.6 m in each replicate for grading purposes. To facilitate individual mass selection in the plant crop of the Mass selection trial, crop growth was deliberately checked by reducing the application of irrigation and fertiliser. Lodging was prevented, and selection was carried out in a relatively erect, but atypical crop. In contrast, crop growth was not deliberately checked in the plant crop of the Family selection trial. In addition to the two replicated trials, 15 clones randomly sampled from each of the 60 families were planted and propagated in a 2 m plot to supply material for planting `Random' clones in a Stage 3 evaluation trial.

The Stage 2 Family selection trial was harvested and families evaluated as a plant crop in August 1987 and as a ratoon crop in September 1988. The Mass selection trial was harvested for family evaluation only as a ratoon crop in September 1988. At harvest, a 9-stalk sample was taken from each family plot for determination of sugar content (CCS). Cane yield as tonnes cane/ha (TCH) was measured for each family plot, and tonnes sugar/ha (TSH) was calculated. Net merit grade (NMG) based on sugar yield relative to the standard clone (Skinner, 1965) was used to evaluate the relative performance of the families.

For the Family trial, the seven best families were selected, based largely on family NMG, on

plant crop performance in the Stage 2 trial. In 1988, and before harvest of the first ratoon crop, it had been planned to mass select clones from within selected families using standard methods (Skinner, 1965). Nine of the 15 clones from each family plot were to be selected, giving a total of 36 full sib selections per family. Unfortunately, within family selection was severely disrupted in 1988 by the influences of cyclone `Charlie' and again in 1989 by cyclone `Aivu'. The first (1988) and second ratoon (1989) crops were heavily lodged, precluding the accurate determination of plot position, visual grading of clones, and removal of planting material. Within family selection was eventually done in the third ratoon crop in 1990. The third ratoon crop was also lodged, delaying selection until July, when clones were selected and planting material cut on a row-by-row basis as the trial was harvested. Clones were not brixed to estimate sugar content as planned, and selection was based solely on a visual estimate of yield.

For the Mass trial, routine mass selection of clones was done in the plant crop (1987) of the Stage 2 trial using standard methods (Skinner, 1965). This included a visual appraisal of yield and a brix measurement relative to the standard clone Q96. In total, 252 clones were selected and propagated in 1987 for planting into a Stage 3 clonal evaluation trial, planned for 1988.

The Stage 3 clonal evaluation trial was eventually planted in July 1990. The trial consisted of 864 test clones each planted in an unreplicated 9.5 m plot. These consisted of 252 selections from the Stage 2 Family trial, 252 clones from the Mass trial, and the 360 Random clones. These clones were evaluated in a randomised complete block, split-plot design of 6 replicates. Whole-plots were treatments nested within a selection group, that is, Family, Mass or Random clones. Each treatment whole-plot was 7 rows by 9.5 m long, and consisted of 6 test clones and one plot of Q96 for grading purposes.

Unfortunately, the Mass group of clones were not allocated to treatments and replicates at random. In an attempt to minimise the influence of competition effects between adjacent clones, clones were ranked on performance in Stage 2 and placed into treatments (whole-plots) with clones of similar grades. This constrained randomisation was not done for the Family group and only partly for the Random group of clones, thus confounding any comparison of alternative selection strategies. Given that broad sense heritability on an individual basis for yield in small plots is usually low (Skinner *et al,* 1987), the bias may not be too serious.

The Stage 3 evaluation trial was harvested as a plant crop in August 1991 and a ratoon crop in October 1992. Each clonal plot was weighed at harvest, and a 2-stalk sample taken for determination of sugar content.

Data for TCH, CCS, TSH and NMG were analysed for the Stage 2 trials. Plant, ratoon and combined crop data for the Family trial, ratoon crop data for the Mass trial, and combined ratoon crop data for both trials were subjected to standard analyses of variance. Data for TCH, CCS, TSH, and NMG were analysed for the Stage 3 trial. Plant, ratoon and combined crop data were also subjected to standard analyses of variance. Realised gains from selection provided an objective method for comparing different selection strategies.

5.3 Experiment 3

Objectives:

- Determine the effectiveness of family selection in Stage 2 trials, where crop growth is not deliberately restricted.
- Determine the effectiveness of mass selection within families.
- Estimate gains from selection by comparing the selected groups of clones with randomly sampled clones in a Stage 3, 10 m plot trial.

Methodology:

Detailed experimental methods and procedures for Experiment 3 are provided by Hogarth and Braithwaite (Unpublished 1990) and McRae, Hogarth, Erquiaga and Foreman (1994, in preparation).

Sixty four full sib sugarcane families were planted on the Burdekin Sugar Experiment Station in April 1986, in a randomised complete block experiment of 4 replicates. Each family single-row plot consisted of 15 full sib clones each planted in a 2 m subplot, with a 1 m gap used to define family plot ends. Families were replicated but clones were not. The commercial variety Q96 was also planted in eight 30 m plots in each replicate for grading purposes.

This Stage 2 trial was grown under commercial conditions, and was harvested as a plant crop in August 1987 and a first ratoon crop in September 1988. At harvest, a 10-stalk sample was taken from each family plot for determination of sugar content (CCS). Cane yield as tonnes cane/ha (TCH) was measured for each family plot, and tonnes of sugar/ha (TSH) was calculated. Net merit grade (NMG), based on sugar yield relative to the standard clone (Skinner, 1965), was used to evaluate the relative performance of the families.

In 1988, and before harvest of the first ratoon crop, it had been planned to mass select clones from within families using standard methods (Skinner, 1965). For 3 replicates, 6 of the 15 clones from each family plot were to be selected, giving a total of 18 full sib selections per family. The fourth replicate was not to be selected, 9 clones being randomly sampled from each family plot for a supply of `random' clones in a Stage 3 evaluation trial. Unfortunately, within family selection was severely disrupted in 1988 by the influences of cyclone `Charlie' and again in 1989 by cyclone `Aivu'. The first (1988) and second (1989) ratoon crops were heavily lodged, thus precluding the accurate determination of plot position, visual grading of clones, and removal of planting material. Selection was eventually done in the third ratoon crop in 1990. The third ratoon crop was also lodged, delaying selection until late July, when clones were selected and planting material cut on a row-by-row basis as the trial was harvested. Clones were not brixed to estimate sugar content as planned, and selection was based solely on a visual estimate of yield.

These mass selected and randomly sampled clones from each family were evaluated in a

Stage 3 trial, planted in early August 1990, using a randomised complete block, split-plot design of 3 replicates. Whole-plots were families and split-plots were selection classes. Each family whole-plot was 9 rows by 9.5 m, and consisted of 3 subplots of 3 contiguous rows. One subplot consisted of 3 random clones, and the other 2 subplots were a random sample of the 6 selected clones from each family plot in Stage 2. Four whole-plots of both Q96 and Q117 were also planted per replicate for grading purposes.

This Stage 3 clonal evaluation trial was harvested as a plant crop in September 1991 and as a ratoon crop in October 1992. Each clonal plot was weighed at harvest, and a 2-stalk sample taken for determination of sugar content.

Data for TCH, CCS, TSH and NMG were analysed for the Stage 2 and Stage 3 trials. Plant, ratoon and combined crop data for both trials were subjected to standard analyses of variance. Realised gains from selection provided an objective method for comparing different selection strategies.

5.4 Experiment 4

Objectives:

- Evaluate the efficiency of family selection based on objective yield measurements, in a population of single-spaced original seedlings.
- Determine the effectiveness of mass selection within families, based on a visual appraisal of yield.
- Estimate gains from selection by comparing the performance of selected clones with randomly sampled clones in a Stage 3, 10 m plot trial.
- Test the practical utility and efficacy of eliminating Stage 2 trials from the selection program.

Methodology:

Detailed experimental methods and procedures for Experiment 4 are provided by Hogarth and Braithwaite (Unpublished 1990) and McRae *et al* (1993).

Seventy five full sib sugarcane families were planted in a Stage 1 seedling trial on the Burdekin Sugar Experiment Station in 1986 using a randomised complete block design of 2 replicates. Each 2-row family plot contained 55 seedlings and a stool of a standard clone Q96. Intra-row plant spacing was 0.6 m. Q96 was also planted in whole plots. This Stage 1 seedling trial was harvested as a plant crop in 1987 and a ratoon crop in 1988. At harvest, an 8-stalk sample was taken from each family plot for determination of sugar content (CCS). Cane yield as tonnes cane/ha (TCH) was also measured for each family plot, and tonnes sugar/ha (TSH) was calculated. Net merit grade (NMG), based on sugar yield relative to the standard clone (Skinner, 1965), was used to evaluate the relative performance of the families.

Before harvest of the plant crop, 8 seedlings were sampled at random from each family plot and the best 8 from the remainder were mass selected using standard methods (Skinner, 1965). Visual selection grades (VSG) were recorded for each random and mass selected seedling. The VSG included a visual appraisal of yield and a brix measurement relative to the standard clone. Families were also assessed on the number of selected seedlings receiving a VSG higher than 9. This was the selection rate for each family.

These randomly sampled and mass selected clones were evaluated in a Stage 3 trial using a randomised complete block, split-plot design, of 4 replicates. Whole-plots were families and split-plots were selection classes. Each subplot of 4 clones was 4 rows x 10 m long. Ten whole-plots of Q96 were also planted per replicate. This Stage 3 evaluation trial was harvested as a plant crop in 1988 and a ratoon crop in 1989. Both crops were heavily lodged, due to the influences of cyclone `Charlie' in 1988 and cyclone `Aivu' in 1989. Each clonal plot was weighed at harvest, and a 2-stalk sample taken for determination of sugar content.

Data for TCH, CCS, TSH and NMG were analysed. Plant, ratoon and combined crop data for both trials were subjected to standard analyses of variance. Realised gains from selection provided an objective method for comparing different selection strategies.

6.0 RESULTS AND DISCUSSION

6.1 Experiment 1

Details of results, statistical methods used, and a discussion of the results for Experiment 1 are provided by Hogarth and Braithwaite (Unpublished 1990) and Hogarth *et al* (1990). The major findings included:

- When crop growth is deliberately restricted in early-stage selection trials, neither family nor mass selection within families is particularly successful, particularly for yield of cane. Family selection was based on subjective yield data, using selection rates from individual mass selection.

- Selection of the `best' families was effective because the `best' families had significantly higher means than the `worst' families for TCH, CCS, TSH, NMG and the proportion of superior clones.

- Mass selection within families was not very effective for yield of cane, as the selected group of clones was not significantly different from the random group in the plant crop, and was significantly different at the 5 % level in the ratoon crop of the Stage 3 trial. For CCS, TSH and NMG, selection was more effective, but the differences were not very large. Mass selection within families did not result in significantly more superior clones than random sampling of clones within families.

- Family selection should be liberal because even poor families produce some superior clones.

- Family means are more useful than within-family variances for selecting families capable of producing superior commercial clones. Family size was probably too small to obtain reliable estimates of within-family variances.

6.2 Experiment 2

Details of results, the statistical methods used, and a discussion of the results for experiment 2 are provided by McRae, Hogarth, Stringer, Erquiaga and Foreman (1994, in preparation). The major findings included:

- Family selection, based on weighed family performance in Stage 2, was not very effective, despite there being significant genetic differentiation among families. The efficiency of family selection was probably reduced as a result of the plant crop in Stage 2 being affected by drought conditions and poor infiltration of irrigation water.

- Plant crop results alone are sufficient to evaluate families in Stage 2 trials.

- The practical utility and cost savings of family selection for early stage, lodged trials in the Burdekin was demonstrated. Family selection, but not individual mass selection, can still be carried out in trials adversely affected by cyclones.

- Variable quality of sett or planting material may have confounded comparisons among selection strategies.

- For family selection to be effective, rates of family selection need to be liberal.

- Individual mass selection was effective in a relatively erect Stage 2 trial where crop growth was deliberately checked, and was more effective than family selection.

- The BSES and CSR sugarcane breeding and selection programs targeting the Burdekin should continue to utilise family selection, despite this one adverse result. Further studies are in progress to test the efficacy of family selection.

6.3 Experiment 3

Details of results, the statistical methods used, and a discussion of the results for Experiment 3 are provided by McRae, Hogarth, Erquiaga and Foreman (1994, in preparation). The major findings included:

- The practical utility of family selection for early stage, lodged trials in the Burdekin was demonstrated. Mass selection of individuals is almost impractical under these conditions.

- Family selection, based on weighed family performance in a Stage 2 trial, was effective, even under heavily lodged conditions. Selected families as a group were superior to the rejected families when evaluated in Stage 3.

- Intensive family selection, that is, selecting the best 8 families from 64, was more effective than using liberal family selection by selecting the best 16 and 24 families.

- Plant crop results alone are adequate for assessing family performance in Stage 2 trials. Eleven of the best 16 families selected in the plant crop on NMG were also in the top 16 based on ratoon crop results for the Stage 2 trial.

- Mass selection within families, based solely on a visual appraisal of yield in the third ratoon crop of a heavily lodged Stage 2 trial, was ineffective. Gains from combined family and mass selection within selected families were no better than gains from pure family selection.

6.4 Experiment 4

Details of results, the statistical methods used, and a discussion of the results for Experiment 4 are provided by McRae *et al.* (1993) and Hogarth and Braithwaite (Unpublished 1990). The major findings included:

- Family selection in Stage 1, based on weighed family performance in a population of single-spaced original seedlings, was effective. Selected families as a group were superior to the rejected families when evaluated in Stage 3. Results were inconclusive for discriminating among the different family selection strategies.

- The practical utility and cost savings of family selection for original seedling populations grown in the Burdekin, was demonstrated.

- Mass selection within families also was effective in a poorly grown plant crop of seedlings. The effectiveness of mass selection within families was consistent across families.

- Gains from combined family and mass selection within families were superior to gains from pure family selection. Further work on the relative importance of means and variances is needed to determine optimum selection rates among and within families.

- Planting seedlings to the field in autumn and growing them under commercial conditions should improve the efficiency of family selection. Heavy lodging, expected in high yielding plant crops of original seedlings, will preclude visual mass selection.

- Plant crop results alone are sufficient to evaluate families in crops which are vegetatively planted and well grown, at least early in the crop cycle, and where plot errors are correlated.

- Single-spaced original seedlings produce enough sett material for selections to be planted directly to Stage 3, 10 m plot trials. Stage 2, 2 m plot trials can be eliminated from the program, as selected clones can be objectively weighed in larger plots of 10 m in Stage 3 trials. Seedlings must be planted as single-spaced individuals, as selected bunch-planted seedlings will not supply enough material for planting a 10 m plot.

7.0 GENERAL CONCLUSIONS

- The practical utility and cost savings of family selection for early stage trials in the Burdekin, was demonstrated. Family selection, but not individual mass selection, can still be carried out in trials heavily lodged and/or adversely affected by cyclones.

- When crop growth is deliberately restricted in early-stage selection trials in the Burdekin, neither family selection, individual mass selection, nor mass selection within families is particularly effective.

- Family means are more useful than within-family variances for selecting families capable of producing superior commercial clones. Family means, based on the mean weighed performance of replicated samples of full sib progeny, are also much cheaper to estimate than are within-family variances. In these studies, family size was probably too small to obtain reliable estimates of within-family variances.

- Combined family and mass selection within families will be required to optimise genetic progress for the important production characters, tonnes cane/ha, sugar content, tonnes sugar/ha, and the selection index, net merit grade. Further work on the relative importance of means and variances is needed to determine optimum selection rates among and within families.

- Plant crop results alone are sufficient to evaluate families in early stage trials, at least early in the crop cycle, and where plot errors are correlated.

- Stage 2 trials in the Burdekin are an inefficient use of resources and can be effectively eliminated from the selection program. Original seedlings can be planted as spaced individuals in Stage 1 trials, and selected clones are planted directly to Stage 3 trials, where clones are objectively weighed in 10 m plots.

- The system currently being tested for Burdekin conditions is to select families on weighed family plot data in the plant crops of Stage 1, original seedling trials. Crop growth is not deliberately restricted, and the crop is fully grown under commercial conditions. Mass selection within selected families is based on a visual estimate of yield, and is conducted in the young ratoon crop. Selected clones are planted directly to Stage 3 trials, in which each clone is objectively evaluated in an unreplicated 10 m plot. With this system, objective progeny performance data will allow for the accurate identification of superior families and parents for further exploitation in the breeding program. Field operations are simpler and less expensive, and genetic progress is expected to be improved.

8.0 DIFFICULTIES

This project was plagued by adverse weather conditions which seriously affected its progress. The experimental program was severely disrupted in 1988 by the influences of cyclone `Charlie' and again in 1989 by cyclone `Aivu'. The first (1988) and second (1989) ratoon crops of the Stage 2 trials of Experiments 2 and 3 were heavily lodged, thus precluding the accurate determination of plot position, visual grading of clones, and removal of planting material. The third ratoon crops of these trials were again heavily lodged in 1990, delaying planned selection and the planting of the Stage 3 clonal evaluation trials.

Undoubtedly, selection efficiency for both mass and family selection was greatly reduced as

a result of the heavily lodged conditions. Although frustrating, it is obvious that growing conditions in the Burdekin are very different from other canegrowing districts of Australia, and that any effective selection program must treat lodging as a normal event.

9.0 IMPLICATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Significant changes have been made to BSES and CSR selection programs targeting the Burdekin district as a result of findings in this Project, with programs modified progressively to incorporate the findings. Effects also extend beyond the Burdekin, eg family selection, based on objective yield measurements, is now routinely used in early-stage selection trials targeting the Northern, Herbert, Central, Southern and New South Wales districts, as well as in original seedling populations in the Burdekin.

SRDC funded Project BS46S, `Optimum family selection strategies in original seedlings, particularly for heavily lodged crops', directly evolved from the findings of Project BS4S. The project is evaluating a new method of family selection in original seedling populations in the Burdekin. Specifically, the project 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.

Lodging is recognised as an important impediment to efficient selection in the Burdekin district. Plot shape and the influences of competition effects from neighbouring plots need investigation in early stage trials, using a population of unselected clones. SRDC Project CSR17S `Optimal plot size and replication for testing clones in early stages of selection', a collaborative CSR/BSES project, will research this aspect.

Family selection allows genetic material to be evaluated across locations. Limited seed or planting material for individual seedlings or clones has limited the evaluation of individual genotypes to single sites in early-stage trials. Project BS57S, `Genotype-environment interaction and selection of sugarcane families for the Burdekin River Irrigation Area', is partly funded by BSES, CSR and SRDC, and is evaluating the importance of family x environment interactions in the Burdekin district, using original seedling populations.

Objective progeny performance data made available with family selection allows for the accurate identification of superior families and parents for further exploitation. In Project BS75S, `Evaluation of methods of estimating breeding value of sugarcane parental clones', techniques were developed that allow highly unbalanced, `messy', and diverse sources of data to be combined to obtain the best linear unbiased prediction (BLUP) of breeding value for each trait and genotype. Estimates and predictions from BLUP must now be compared with current empirical methods used by BSES and CSR in order to efficiently use objective data for prediction in the breeding program. Project BS119S, `Best linear unbiased prediction as a method for predicting cross potential', is funded by SRDC and aims to research this aspect.

One aspect which will need research 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.

10.0 INTELLECTUAL PROPERTY ARISING FROM THE RESEARCH

There are no matters of any description arising from the research in project BS4S, that pertain to intellectual property rights.

11.0 PUBLICATIONS

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APPENDIX 2

FAMILY SELECTION FOR EARLY STAGE TRIALS IN THE BURDEKIN

By

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Abstract

Mass selection of sugarcane clones (*Saccharum* spp. hybrids) in high yielding, lodged trials in the Burdekin district is difficult and results are unreliable. An alternative scheme for early stage trials utilises family selection based on objective yield measurements in plant crops, followed by mass selection within selected families in ratoon crops. The responses of clones selected in Stage 2, 2 m plot trials, using combined family and mass selection were compared with clones selected in an adjacent trial, but using individual mass selection. Selected clones were evaluated in a Stage 3, 10 m plot trial, with clones sampled randomly from the same 60 biparental sugarcane families. Family selection was not very effective, despite significant genetic differentiation among families for yield of cane, sugar content and tonnes sugar per hectare. For family selection to be effective, the rate of family selection needs to be liberal. Individual mass selection was effective in a relatively erect trial, where crop growth was deliberately checked. The practical utility of family selection for Burdekin conditions was demonstrated. The poor performance of family selection in this study was an unexpected result, and further studies are needed.

Introduction

Lodging in high yielding sugarcane trials is a major factor limiting genetic progress in Burdekin selection programs (Pollock, 1982). Until 1986, individual or mass selection of clones in early stage selection trials was based on visual estimates of yield, but estimation in small plots was difficult and imprecise under lodged conditions. To facilitate mass selection, crop growth in trials was deliberately checked by reducing the application of irrigation and fertilisers (Hogarth, Braithwaite and Skinner, 1990). Lodging was usually prevented and selection was carried out in relatively erect, but atypical crops. As a result, clonal assessment was biased and subject to large errors.

Hogarth (1971) found selection based on weighed family plots to be effective in relatively erect seedling crops. The recent development of mobile weighing equipment permits the efficient and objective assessment of families for yield. For Burdekin conditions, Hogarth *et al.* (1990) found family and mass selection were ineffective in an early stage clonal trial with crop growth deliberately checked. McRae, Hogarth, Erquiaga and Foreman (1994, In Preparation) found family selection, based on weighed family performance in an early stage trial, was effective even under heavily lodged conditions. Mass selection within families

was ineffective. McRae, Hogarth, Foreman and Braithwaite (1993) found selection based on weighed family plots of sugarcane seedlings was effective under Burdekin conditions. Mass selection within families was also effective, and combined family and mass selection was expected to optimise genetic progress in early stage trials. Benefits of family selection include simpler and cheaper field operations, and should result in greater genetic progress. Objective progeny performance data also allow for accurate identification of superior families and parents for further exploitation.

This paper presents results of an experiment to compare the efficacy of family versus individual mass selection in early stage trials. Family selection in a Stage 2, 2 m plot trial grown under commercial conditions, was based on weighed family whole-plot data, using replicated samples of full sib progeny. Individual mass selection was carried out in an adjacent Stage 2 trial, but with crop growth deliberately checked by reducing applications of irrigation and fertiliser. Performances of selected clones from both trials were evaluated in a Stage 3, 10 m plot trial.

Materials and Methods

Sixty full sib sugarcane families were planted in two adjacent Stage 2 trials on the Burdekin Sugar Experiment Station in April 1986. One trial was for `Family' selection and the other for `Mass' selection purposes. Each trial was a randomised complete block design of four replicates. Family plots of 3 rows by 9.6 m consisted of 15 clones each planted in a 1.92 m subplot. Families were replicated, but clones were not. The commercial variety, Q96, was also planted in six plots of 3 rows x 9.6 m in each replicate for grading purposes. To facilitate individual mass selection in the plant crop of the Mass selection trial, crop growth was deliberately checked by reducing the application of irrigation and fertiliser. Lodging was prevented, and selection was carried out in a relatively erect, but atypical crop. In contrast, crop growth was not deliberately checked in the plant crop of the Family selection trial. In addition to the two replicated trials, 15 clones randomly sampled from each of the 60 families were each planted and propagated in a 2 m plot to supply material for planting `Random' clones in a Stage 3 evaluation trial.

The Stage 2 Family selection trial was harvested and families evaluated as a plant crop in August 1987 and as ratoon crop in September 1988. The Mass selection trial was harvested for family evaluation only as a ratoon crop in September 1988. At harvest, a 9-stalk sample was taken from each family plot for determination of sugar content (CCS). Cane yield, as tonnes of cane/ha (TCH), was also measured for each family plot, and tonnes of sugar/ha (TSH) was calculated. Net merit grade (NMG), based on sugar yield relative to the standard clone (Skinner, 1965), was used to evaluate the relative performance of the families.

For the Family trial, the seven best families were selected, based largely on family NMG, on plant crop performance in the Stage 2 trial. In 1988, and before harvest of the first ratoon crop, the plan was to mass select clones from within selected families using standard methods (Skinner, 1965). Nine of the 15 clones from each family plot were to be selected, giving a total of 36 full sib selections per family. Unfortunately, within family selection was severely disrupted by the influences of cyclone `Charlie' in 1988 and by cyclone `Aivu' in

1989. The first (1988) and second ratoon (1989) crops were heavily lodged, precluding the accurate determination of plot position, visual grading of clones, and removal of planting material. Within family selection was eventually carried out in the third ratoon crop in 1990. The third ratoon crop was also lodged, delaying selection until July, when clones were selected and planting material cut on a row-by-row basis as the trial was harvested. Clones were not brixed to estimate sugar content as planned, and selection was based solely on a visual estimate of yield.

For the Mass trial, routine mass selection of clones was carried out in the plant crop (1987) of the Stage 2 trial using standard methods (Skinner, 1965). This included a visual appraisal of yield and a brix measurement relative to the standard clone, Q96. In total, 252 clones were selected and propagated in 1987 for planting into a Stage 3 clonal evaluation trial, planned for 1988.

The Stage 3 clonal evaluation trial was eventually planted in July 1990. The trial consisted of 864 test clones, each planted in an unreplicated 9.5 m plot. These consisted of 252 selections from the Stage 2 Family trial, 252 clones from the Mass trial, and the 360 Random clones. These clones were evaluated in a randomised complete block, split-plot design, of six replicates. Whole-plots were treatments nested within a selection group, that is, Family, Mass or Random clones. Each treatment whole-plot was seven rows by 9.5 m long and consisted of six test clones, and one plot of Q96 for grading purposes.

Unfortunately, the clones in the Mass group were not allocated to treatments and replicates at random. In an attempt to minimise the influence of competition effects between adjacent clones, clones were ranked on performance in Stage 2, and placed into treatments (whole-plots) with clones of similar grades. This constrained randomisation was not done for the Family group and only partly for the Random group of clones, thus confounding any comparison of alternative selection strategies. Given that broad sense heritability on an individual basis for yield in small plots is usually low (Skinner, Hogarth and Wu, 1987), the bias may not be too serious.

The Stage 3 evaluation trial was harvested as a plant crop in August 1991 and a ratoon crop in October 1992. Each clonal plot was weighed at harvest, and a 2-stalk sample taken for determination of sugar content.

Statistical Analysis

Data for TCH, CCS, TSH and NMG were analysed for the Stage 2 trials. Plant, ratoon and combined crop data for the Family trial, ratoon crop data for the Mass trial, and combined ratoon crop data for both trials were subjected to standard analyses of variance (ANOVA). In the mixed model analyses, Replicates (R) and Families (F) were considered random effects. Trials (T) and Crops (C) were considered fixed effects.

Data for TCH, CCS, TSH, and NMG were analysed for the Stage 3 trial. Plant, ratoon and combined crop data were also subjected to standard analyses of variance. In the mixed model analyses, Replicates (R), Families (F), Treatments within Groups (T(G)) and Samples (within treatments and groups) were considered random effects. Groups (G), family selected

versus mass selected and randomly sampled clones, and Crops (C) were considered fixed effects. Crop and year effects were completely confounded. 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 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.

Realised gains from selection provided an objective method for comparing different selection strategies. Two methods of pure family selection in the Stage 2 trial were evaluated using the response of random clones in the Stage 3 trial. The methods included selecting the best 7, 14 and 21 families from 60, based on Stage 2 results for plant crop NMG (PNMG) and ratoon crop NMG (RNMG). Response to combined family and mass selection within the seven best selected families was evaluated using the selected group of clones from the Family trial.

Realised heritability was calculated as the ratio of the selection response measured in Stage 3, using random clones, and the selection differential measured in actual units in Stage 2. For the estimates, the top 21 families were selected for each of TCH, CCS, TSH and NMG using data for both crops of the Stage 2 Family trial. Other estimates of broad sense heritability were calculated by correlating Stage 2 family means with family means for random clones in Stage 3.

Results and Discussion

In the plant crop of the Stage 2 Family trial (results not shown), differences among families were significant for TCH ($P<0.01$), CCS and TSH ($P<0.05$). Differences among families for NMG were almost significant ($P=0.06$). The results suggest there is sufficient genetic differentiation among families for family selection to be effective. In the ratoon crops of the Family and Mass selection trials, differences among families were significant ($P<0.01$) for all characters.

Error coefficients of variation for TCH (23.0%), CCS (12.1%), TSH (26.1%) and NMG (33.7%) in the plant crop of the Family trial were much higher than for the respective coefficients in the ratoon crops of either the Family or Mass trials. Coefficients of variation for the Family and Mass trials were respectively 15.8 and 17.7% for TCH, 5.0 and 5.6% for CCS, 16.1 and 16.8% for TSH, and 18.2 and 18.9% for NMG. The plant crop of the Stage 2 Family trial was affected by drought conditions and poor infiltration of irrigation water and this probably contributed to larger error variances, and therefore, higher coefficients of variation.

In the combined mixed model ANOVA fitting a Crop effect (Table I) for the Family trial, the C effect was significant for CCS, but not for TCH, TSH or NMG. The Family x Crop (F x C) interaction was not significant for any character. This suggests plant crop results alone are adequate for assessing family performance in Stage 2 trials. Bull, Hogarth and Basford (1992) and McRae *et al.* (1993) also found family x crop interactions to be relatively

unimportant in early stage trials in the Bundaberg and Burdekin districts, respectively.

In the combined mixed model ANOVA for the ratoon crops of the Stage 2 trials (Table II), the Trial effect was significant for TCH and TSH, but not for CCS or NMG. Crop growth in the plant crop of the Mass trial, but not the Family trial, was deliberately checked by reducing the application of irrigation and fertiliser. Carryover effects from plant crop growth, as well as block effects, probably account for yield differences in the ratoon crop. The Family x Trial (F x T) interaction was not significant for TCH, TSH or NMG. Although the F x T interaction was significant for CCS, the F x T variance component (0.03) was much smaller than the respective Family component (0.29). A lack of any important F x T interactions in the ratoon crops suggests family performance was consistent across trials, despite the plant crops being managed differently. Five of the top 10 families based on NMG in the plant crop of the Family trial, were also in the top 10 for NMG in the ratoon crops of both the Mass and Family trials.

Table I -- Combined mixed model ANOVA fitting a crop effect, for characters measured in the Stage 2 Family selection trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	3	29400**	2.15	526.87**	62.84**
Families, F	59	2092**	4.21**	41.33**	9.34**
Error (1)	177	994	1.74	21.54	5.02
Crops, C	1	581	343.00*	401.68	0.01
Error (2)	3	14486	10.56	343.26	17.71
F x C	59	483	1.21	8.86	2.25
Error (3)	177	368	1.35	9.12	2.62
General mean		131.88	13.98	18.43	7.22
Plant crop mean		132.98	14.83	19.35	7.22
Ratoon crop mean		130.78	13.14	17.52	7.21

Significance levels of appropriate F-ratios, * $P < 0.05$ and ** $P < 0.01$, are given with the mean squares.

Table II -- Combined mixed model ANOVA for characters measured in the ratoon crops of the Stage 2 Mass and Family trials.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Trials, T	1	82063**	8.15	1572.98**	15.24

Replicates, R(T)	6	3421**	2.95**	54.85**	13.79**
Families, F	59	988**	2.90**	23.64**	5.81**
F x T	59	457	0.88*	9.02	2.01
Error	354	386	0.63	8.30	1.89
General mean		117.70	14.96	17.54	7.40
Family trial mean		130.78	14.83	19.35	7.22
Mass trial mean		104.63	15.09	15.73	7.58

Significance levels of appropriate F-ratios, * $P < 0.05$ and ** $P < 0.01$, are given with the mean squares.

In the plant crop of the Stage 3 clonal evaluation trial (Table III) there were significant differences among selection Groups (selected or random clones) for TCH, TSH and NMG, but not for CCS. The Mass selected group of clones performed significantly better ($P<0.01$) than the Family group of clones for TCH, TSH and NMG. There was a response due to alternative selection strategies in Stage 2 trials, and the result was disappointing for family selection. The Mass group of clones was also significantly better ($P<0.05$) than the Random group of clones for CCS, but not for TCH, TSH or NMG. This suggests that brixing of clones for estimating sugar content in the Stage 2 trial was effective, but visual grading of clones for yield in 2 m plots was ineffective. It has been suggested that indirect selection for yielding ability in trials where growth has been deliberately checked may select against varieties with high yield potential under better and possibly lodged conditions, which are typical of the Burdekin district (Hogarth *et al.*, 1990; McRae *et al.*, 1993).

Table III -- Mixed model ANOVA for characters measured in the plant crop of the Stage 3 trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	5	12029**	15.99**	201.33**	22.80
Groups, G	2	12667*	4.75	303.96*	147.59*
Error (1)	10	1683	1.13	38.20	17.82
Treatments, T(G)	21	2072	1.71	52.77*	27.92*
Error (2)	105	1389	1.71	31.69	15.51
Sampling	720	544	0.96	13.51	6.67
General mean		71.71	15.17	10.87	6.86
Family group mean		63.83	15.18	9.68	6.05
Mass group mean		77.69	15.31	11.86	7.58
Random group mean		73.05	15.06	11.01	6.93

Significance levels of appropriate F-ratios, * $P < 0.05$ and ** $P < 0.01$, are given with the mean squares.

Performance of clones selected from within the seven best families, selected on Stage 2 plant crop results, were not significantly different from the random group of clones for any character, when evaluated in the plant crop of the Stage 3 trial. This suggests family selection in Stage 2, and using a high selection intensity, was not effective. Absolute values for TCH, TSH and NMG would suggest combined family and mass selection within selected families was even detrimental. This result was unexpected, and several factors may have contributed to the poor efficiency of family selection. Selection of families was based on plant crop results of a Stage 2 trial affected by drought conditions and poor infiltration of irrigation water, and family means were estimated with low precision. Secondly, germination and establishment of clones was variable in the Stage 3 trial. This was partly due to a late planting in July, and from using planting material cut from different sources for the different treatment Groups. That is, planting material for the Family group of clones was cut from a third ratoon Stage 2 trial, whereas material for the Mass and Random groups was cut from a second ratoon propagation block. Clearly, for an unbiased comparison, seed material should be treated the same and cut from the one source block. Thirdly, liberal visual selection of clones within selected families was done in a heavily lodged trial, and may have been ineffective in the third ratoon crop. Finally, the ranking of clones on performance in Stage 2, and planting clones of similar grades in whole-plots in order to minimise the influence of competition effects in single-row plots, may have confounded the comparison and should be avoided.

In the ratoon crop of the Stage 3 trial, differences among selection Groups in the mixed model ANOVA (Table IV) were significant for CCS, but not for other characters. The superiority of the Mass group of clones relative to the Family group that was evident in the

plant crop of the Stage 3 trial, did not occur in the ratoon crop. The mass and family groups were not significantly different for any character. The variable germination and poor establishment of many clones that was evident in the plant crop was not as marked in the better grown ratoon crop. The Mass group was significantly better ($P<0.05$) than the Random group of clones for CCS and NMG. Again the brixing of clones in the Stage 2 trial was effective. The Family group was significantly better ($P<0.05$) than the Random group of clones for CCS, but not for other characters. Family selection in Stage 2 was effective for sugar content, a character which usually has a high broad sense heritability on both a family and an individual basis (Skinner *et al.* 1987).

Table IV -- Mixed model ANOVA for characters measured in the ratoon crop of the Stage 3 trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	5	5549**	30.96**	104.92**	55.78**
Groups, G	2	647	34.96*	68.31	26.11
Error (1)	10	1159	3.54	23.38	4.45
Treatments, T(G)	21	1211	4.36	35.73	8.18
Error (2)	105	1053	2.91	25.77	5.66
Sampling	720	929	2.02	26.55	5.70
General mean		104.00	15.72	16.35	6.69
Family group mean		102.79	16.02	16.51	6.84
Mass group mean		105.84	15.90	16.83	6.95
Random group mean		103.55	15.39	15.90	6.40

Significance levels of appropriate F-ratios, * $P < 0.05$ and ** $P < 0.01$, are given with the mean squares.

In the combined mixed model ANOVA of the Stage 3 trial fitting a Crop (C) effect (results not shown), the C effect was significant ($P<0.01$) for TCH, CCS and TSH, but not for NMG. The ratoon crop (104.0 t/ha) was much better grown than the late planted plant crop (71.7 t/ha). Crop yields were well below the Pioneer mill average for plant cane in 1991 (96.9 t/ha) and ratoon cane in 1992 (121.2 t/ha). This is not unexpected for a genetically heterogeneous population. Yields for the commercial standard, Q96, were below mill average for plant cane (89.0 t/ha), but above for ratoon cane (134.2 t/ha). The Group x Crop interaction (G x C) was highly significant ($P<0.01$) for TCH, CCS, TSH and NMG. That is, the response of the different Groups of clones was not consistent across crops. This is despite harvest data from consecutive years constituting repeated measurements on the same plot. The interaction for CCS may be due to time of harvest, reflecting differential rates of maturity of clones from the different groups. Other studies in the Burdekin by Hogarth *et al.* (1990) and McRae *et al.* (1993) have shown clones perform consistently in plant and first

ratoon cane, especially where plot errors are correlated. Variable quality planting material and subsequent crop establishment is a possible reason for the interaction on this occasion.

Family selection, based on weighed family whole-plot performance in Stage 2, was not very effective. In general, selected families as a group were not superior to rejected families when evaluated using randomly sampled clones in Stage 3 (Table V). Absolute gains from family selection were not encouraging. The seven best families (out of 60) selected on Stage 2 plant (PNMG) or ratoon (RNMG) crop performance, were not significantly different from the unselected population when evaluated in either crop of the Stage 3 trial. Differences in the quality of sett or planting material cut from the Stage 2 trials, was not a sufficient explanation to account for the poor performance of the Family group of clones in Stage 3 (see Tables III and IV). Planting material for the Random group of clones was all cut from the one propagation block. Therefore, variable quality of planting material was unlikely to have contributed to the poor performance of random clones from the same seven families relative to random clones from unselected families in Stage 3 (Table V).

Table V -- Realised gains for random clones in plant and ratoon crops of the Stage 3 trial, to two methods of pure family selection in Stage 2, and selecting the 7, 14 and 21 best families.

Stage 3 trial response	Character	Stage 2 PNMG			Stage 2 RNMG		
		Number of families selected			Number of families selected		
		Best 7	Best 14	Best 21	Best 7	Best 14	Best 21
Plant	TCH	-1.76	4.68*	1.60	-4.68	-0.73	-0.07
	CCS	-0.16	-0.07	-0.03	-0.03	0.07	0.08
	TSH	-0.44	0.61	0.20	-0.78	-0.06	0.04
	NMG	-0.38	0.40	0.12	-0.50	-0.02	0.05
Ratoon	TCH	-5.26	3.73	2.96	3.85		3.02
	CCS	-0.15	0.01	-0.10	0.20	6.88**	0.23*
	TSH	-1.05	0.53	0.32	0.74	0.17	0.74*
	NMG	-0.45	0.26	0.14	0.41		0.41**
						1.26**	
						0.62**	

Gains are expressed as deviations from the mean of the random group of clones in Stage 3. Significance of lsd, * $P < 0.05$ and ** $P < 0.01$, refers to differences between means of selected and unselected families.

The results also suggest family selection should be liberal. With a higher rate of family selection, or a lower selection intensity, selecting 14 (23%) or 21 (35%) families in Stage 2, gave more favourable results. Selecting the top 14 families, based on Stage 2 RNMG, produced positive and significant gains for TCH, TSH and NMG when evaluated in the ratoon crop of the Stage 3 trial. Selecting the top 21 families, based also on Stage 2 RNMG, realised significant gains for CCS, TSH and NMG.

Family selection, based on ratoon crop data in Stage 2 (RNMG) was superior to family selection based on plant crop data (PNMG). The efficiency of family selection in the plant crop of the Stage 2 trial was probably reduced as a result of the plant crop being affected by drought conditions and poor infiltration of irrigation water. Growing the plant crop of Stage 2 trials under better conditions may improve the efficiency of family selection.

Realised heritability estimates (Table VI) using liberal family selection, appeared realistic and suggest family selection in Stage 2 trials should be effective. For liberal family selection, the top 21 families were selected for each of TCH, CCS, TSH and NMG, in both crops of the Stage 2 trial. Sample sizes are small and standard errors are expected to be large, and variation between generation means (scaling) would influence the accuracy of the estimates.

Table VI -- Estimates of realised heritability, selecting the top 21 families in Stage 2.

Stage 2 crop selected	**Stage 3 crop evaluated**	**TCH**	**CCS**	**TSH**	**NMG**
Plant	Plant	0.19	0.36	0.12	0.08
	Ratoon	0.28	0.22	0.20	0.09
Ratoon	Plant	0.18	0.38	0.17	0.05
	Ratoon	0.45	0.65	0.41	0.41

Estimates of broad sense heritability, calculated by correlating family means in Stages 2 and 3 (Table VII), were similar in magnitude to the realised heritability estimates. Estimates were generally higher for family selection in Stage 2 when realised response was measured in the ratoon crop of Stage 3. A poor correlation of family performance in Stage 2 with mean performance of random clones from each family in Stage 3 for the major selection index, NMG, is disappointing. Variable germination and poor establishment of clones in the plant crop of the Stage 3 trial may have reduced the efficiency of family selection. Family by year interactions, which were not measured, may also have reduced the efficiency of family selection by reducing the correlation between family performance in Stages 2 and 3.

Table VII -- Correlation estimates of broad sense heritability.

Stage 2 crop	Stage 3 crop	TCH	CCS	TSH	NMG
Plant	Plant	0.19	0.33	0.10	0.07
	Ratoon	0.23	0.30	0.13	0.13
Ratoon	Plant	0.10	0.55	0.05	0.06
	Ratoon	0.34	0.51	0.22	0.20

Conclusions

Family selection, based on weighed family performance in Stage 2, was not very effective, despite there being significant genetic differentiation among families. Plant crop results alone are sufficient to evaluate families in Stage 2 trials. The practical utility of family selection for early stage, lodged trials in the Burdekin was demonstrated. Family selection, but not individual mass selection, can still be carried out in trials adversely affected by cyclones. The efficiency of family selection was probably reduced as a result of the plant crop being affected by drought conditions and poor infiltration of irrigation water. Variable quality of sett or planting material, may have confounded comparisons among selection strategies. For family selection to be effective, rates of family selection need to be liberal. Mass selection was effective in a relatively erect Stage 2 trial where crop growth was deliberately checked, and was more effective than family selection. The BSES and CSR sugarcane breeding and selection programs targeting the Burdekin should continue to utilise family selection, despite this one adverse result. Further studies are in progress to test the efficacy of family selection.

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APPENDIX 3

FAMILY AND MASS SELECTION WITHIN SUGARCANE FAMILIES IN THE BURDEKIN

By

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Abstract

Mass selection of sugarcane clones (*Saccharum* spp. hybrids) in high yielding, lodged trials, typical of the Burdekin district, is difficult and results are unreliable. An alternative scheme for early stage selection trials, using family selection based on objective yield measurements followed by mass selection within families, was evaluated. Samples of full sib progeny from 64 biparental sugarcane families were objectively weighed and assessed for sugar content in a replicated Stage 2, 2 m plot trial. Eighteen selected and nine random clones from each of the 64 families were evaluated as individuals in a Stage 3, 10 m plot trial. The practical utility of family selection was demonstrated for early stage, lodged trials in the Burdekin. Family selection, based on weighed family performance in Stage 2, was effective, even under heavily lodged conditions. Selected families as a group were superior to rejected families when evaluated in Stage 3. Intensive family selection, selecting the best eight families, was more effective than more liberal family selection. Plant crop results alone are adequate for assessing family performance in Stage 2 trials. Mass selection within families, based solely on a visual appraisal of yield in the third ratoon crop of a heavily lodged Stage 2 trial, was ineffective. Gains from combined family and mass selection within selected families were no better than gains from pure family selection. Objective progeny performance data also allow accurate identification of superior crosses and parents for further exploitation. The benefits of the system are simpler and cheaper field operations and greater genetic progress.

Introduction

Lodging in high yielding sugarcane trials is a major factor limiting genetic progress in Burdekin selection programs (Pollock, 1982). Until 1986, individual or mass selection of clones in early stage selection trials was based on visual estimates of yield, but estimation in small plots was difficult and imprecise under lodged conditions. To facilitate mass selection, crop growth in trials was deliberately checked by reducing the application of irrigation and fertilisers (Hogarth, Braithwaite and Skinner, 1990). Lodging was usually prevented and selection was carried out in relatively erect, but atypical crops. As a result, clonal assessment was biased and subject to large errors.

Hogarth (1971) found selection based on weighed family plots to be effective in relatively erect seedling crops. The recent development of mobile weighing equipment permits the efficient and objective assessment of families for yield. For Burdekin conditions, Hogarth *et al.* (1990) found family and mass selection were ineffective in an early stage clonal trial with crop growth deliberately checked. McRae, Hogarth, Stringer, Erquiaga and Foreman (1994, In Preparation) also found family selection to be relatively ineffective in an early stage clonal trial. Crop growth was not deliberately checked, but was affected by drought conditions and poor infiltration of irrigation water. In contrast, individual mass selection was effective in a relatively erect trial, where crop growth was deliberately checked. McRae, Hogarth, Foreman and Braithwaite (1993) found selection based on weighed family plots of sugarcane seedlings was effective under Burdekin conditions. Mass selection within families was also effective, and combined family and mass selection was expected to optimise genetic progress in early stage trials. Benefits of family selection include simpler and cheaper field operations, and should result in greater genetic progress. Objective progeny performance data also allow for accurate identification of superior families

This paper presents results of an experiment to evaluate the effectiveness of pure family selection, and combined family and mass selection within families, in early stage trials in the Burdekin. Family selection in a Stage 2, 2 m plot trial was based on weighed family whole-plot data, using replicated samples of full sib progeny. Mass selection of clones within `selected' families was done in a third ratoon crop of the Stage 2 trial. Performances of selected and randomly sampled clones from each of 64 families were evaluated in a Stage 3, 10 m plot trial.

Materials and Methods

Sixty four full sib sugarcane families were planted on the Burdekin Sugar Experiment Station in April 1986, in a randomised complete block experiment of four replicates. Each family single-row plot consisted of 15 full sib clones each planted in a 2 m subplot. Families were replicated, but clones were not. A 1 m gap was used to define family plot ends. The commercial variety, Q96, was also planted in eight 30 m plots in each replicate for grading purposes.

This Stage 2 trial, grown under commercial conditions, was harvested as a plant crop in August 1987, and as a first ratoon crop in September 1988. At harvest, a 10-stalk sample was taken from each family plot for determination of sugar content (CCS). Cane yield, as tonnes of cane/ha (TCH), was also measured for each family plot, and tonnes of sugar/ha (TSH) was calculated. Net merit grade (NMG), based on sugar yield relative to the standard clone (Skinner, 1965), was used to evaluate the relative performance of the families.

In 1988, and before harvest of the first ratoon crop, it had been planned to mass select clones from within families using standard methods (Skinner, 1965). For three replicates, six of the 15 clones from each family plot were to be selected, giving a total of 18 full sib selections per family. The fourth replicate was not to be selected, nine clones being randomly sampled from each family plot for a supply of `random' clones in a Stage 3 evaluation trial. Unfortunately, within family selection was severely disrupted in 1988 by the influences of

cyclone `Charlie' and again in 1989 by cyclone `Aivu'. The first (1988) and second (1989) ratoon crops were heavily lodged, thus precluding the accurate determination of plot position, visual grading of clones, and removal of planting material. Selection was eventually done in the third ratoon crop in 1990. The third ratoon crop was also lodged, delaying selection until late July, when clones were selected and planting material cut on a row-by-row basis as the trial was harvested. Clones were not brixed to estimate sugar content as planned, and selection was based solely on a visual estimate of yield.

These mass selected and randomly sampled clones from each family were evaluated in a Stage 3 trial, planted in early August 1990, using a randomised complete block, split-plot design of three replicates. Whole-plots were families and split-plots were selection classes. Each family whole-plot was nine rows by 9.5 m, and consisted of three subplots of three contiguous rows. One subplot consisted of three random clones, and the other two subplots (B1 and B2) were a random sample of the six selected clones from each family plot in Stage 2. Four whole-plots of both Q96 and Q117 were also planted per replicate for grading purposes.

This Stage 3 clonal evaluation trial was harvested as a plant crop in September 1991 and as a ratoon crop in October 1992. Each clonal plot was weighed at harvest, and a 2-stalk sample taken for determination of sugar content.

Statistical Analysis

Data for TCH, CCS, TSH and NMG were analysed for the Stage 2 and Stage 3 trials. The proportion of superior clones with NMG greater than 10.0 (Clones NMG $\geq$ 10.0) and 7.5 (Clones NMG $\geq$ 7.5) were also analysed for the Stage 3 trial. Plant, ratoon and combined crop data for both trials were subjected to standard analyses of variance (ANOVA). In the mixed model analyses, Replicates (R) and Families (F) were considered random effects. Treatments (T), selected versus randomly sampled clones, and Crop (C) effects were considered fixed. Crop and year effects were completely confounded. 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 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.

Realised gains from selection provide an objective method for comparing different selection strategies. Two methods of family selection in the Stage 2 trial were evaluated using the response of clones from the selected families in the Stage 3 trial. The methods included selecting the best 8, 16 and 24 families from 64, based on Stage 2 results for plant crop NMG (PNMG) and ratoon crop NMG (RNMG). Response to pure family selection, was estimated from the random group of clones in the Stage 3 trial. Response to combined family and mass selection within selected families was evaluated using the mean performance of the mass selected groups (B1 and B2) of clones.

Realised heritability was calculated as the ratio of the selection response measured in Stage 3, using random clones, and the selection differential in actual units in Stage 2. For the

estimates, the top 16 or 24 families were selected for each of TCH, CCS, TSH and NMG using data for both crops of the Stage 2 trial. Other estimates of broad sense heritability on a family basis were calculated by correlating Stage 2 family means with family means for random clones in Stage 3.

Results and Discussion

In both plant and first ratoon crops of the Stage 2 trial (Table I), differences among families for TCH, CCS, TSH and NMG were highly significant. The results suggest there is sufficient genetic differentiation among families for family selection to be effective. Error coefficients of variation are acceptable for Stage 2 family trials in the Burdekin. The plant crop of the Stage 2 trial, which was affected by drought conditions and poor infiltration of irrigation water, yielded less than the better grown ratoon crop, despite the longer growing period, and had less precision than the ratoon crop.

Table I -- ANOVA for characters measured within plant and ratoon crops of the Stage 2 trial.

Source of Variation	df	Mean Squares							
		Plant Crop				Ratoon Crop			
		TCH	CCS	TSH	NMG	TCH	CCS	TSH	NMG
Replicates, R	3	14779**	4.63**	220.97**	1.53	9832**	12.73**	117.88**	3.76*
Families, F	63	1152**	2.33**	23.85**	6.70**	1135**2	1.67**	26.18**	5.23**
Error	189	420	0.54	9.48	2.71	87	0.37	6.14	1.18
General Mean		109.24	14.31	15.59	7.35	114.96	15.18	17.38	6.90
CV (%)		18.77	5.12	19.75	22.43	14.74	3.99	14.25	15.72

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

In the combined mixed model ANOVA (Table II) fitting a Crop effect, the C effect was significant for CCS and TSH, but not for TCH or NMG. The Family x Crop (F x C) interaction was significant for TCH, TSH and NMG. Although the F x C effect was significant for these characters, the F x C variance component for TCH (10.68), TSH (0.30) and NMG (0.07), was much smaller than the respective Family component for TCH (186.85), TSH (4.01) and NMG (0.94). Eleven of the best 16 families selected in the plant crop on NMG were also in the top 16 based on ratoon crop results for the Stage 2 trial. This suggests plant crop results alone are adequate for assessing family performance in Stage 2 trials. Bull, Hogarth and Basford (1992) in Bundaberg, and McRae *et al.* (1993) and McRae *et al.* (1994, In Preparation) in the Burdekin, also found family x crop interactions to be

relatively unimportant in early stage trials.

Table II -- Combined mixed model ANOVA fitting a crop effect, for characters measured in the Stage 2 trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	3	23364**	14.27**	314.12**	1.19
Families, F	63	2019**	3.51**	43.22**	10.16**
Error (1)	189	525	0.50	11.17	2.65
Crops, C	1	4186	98.55**	413.89*	25.87
Error (2)	3	1247	3.09	24.73	4.10
F x C	63	268*	0.49	6.81*	1.78*
Error (3)	189	183	0.41	4.44	1.24
General mean		112.10	14.74	16.49	7.12
Plant crop mean		109.24	14.31	15.59	7.35
Ratoon crop mean		114.96	15.18	17.38	6.90

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

In the plant (Table III) and first ratoon (Table IV) crops of the Stage 3 evaluation trial, differences among families for the primary characters, TCH, CCS, TSH and NMG, were significant. Crop yields of 98.5 and 111.5 t/ha were above the Pioneer mill average for plant cane in 1991 (96.9 t/ha), but below for ratoon cane in 1992 (121.2 t/ha), respectively. Yields were good for a genetically heterogeneous population of clones. Yields in the trial for the commercial standards, Q96 and Q117, were 125.4 and 125.6 t/ha for plant cane, and 135.2 and 128.0 t/ha for ratoon cane, respectively. The trial was planted in August 1990, which is four to five months later than usual, and this would account for low plant crop yields.

Table III -- Mixed model ANOVA for primary characters measured in the plant crop of the Stage 3 trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	2	7279**	16.15*	84.01*	49.90**
Families, F	63	3894**	13.11**	83.89**	22.56**
Error (1)	126	1517	3.77	26.37	5.93
Treatments, T	2	1442	0.23	33.68 17.58**	8.07
F x T	126	672*	1.27	11.88	4.80**
Error (2)	256	480	1.31	20.17	3.26
Sampling	1152	821	1.10		5.30
General mean		98.47	14.74	14.50	6.53
Selected B1 group mean		99.66	14.76	14.71	6.64
Selected B2 group mean		99.08	14.72	14.56	6.56
Random group mean		96.67	14.74	14.24	6.41

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

Table IV -- Mixed model ANOVA for primary characters measured in the ratoon crop of the Stage 3 trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	2	70202**	18.70	1132.78**	51.72*
Families, F	63	4469*	31.52**	101.56**	32.29**
Error (1)	126	2899	10.50	51.04	14.21
Treatments, T	2	716	5.92	3.89 28.68	0.80
F x T	126	993	5.92	25.73	8.65
Error (2)	256	872	5.83	37.86	7.80
Sampling	1152	1623	4.73		10.10
General mean		111.47	13.55	15.14	6.39
Selected B1 group mean		112.22	13.47	15.24	6.43
Selected B2 group mean		112.00	13.51	15.10	6.36
Random group mean		110.19	13.66	15.09	6.39

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

In both the plant and first ratoon crops, differences among treatments were not significantly different for the primary characters, TCH, CCS, TSH or NMG. The performance of either of the selected groups of clones was no better than the random group of clones, when evaluated in the Stage 3 trial. This suggests mass selection within families, based on a visual appraisal of yield in the third ratoon crop of the Stage 2 trial, was ineffective. The Stage 2 trial was very heavily lodged, and this would have reduced the efficiency of visual selection. Given that broad sense heritability on an individual basis for yield in small plots is usually low (Skinner, Hogarth and Wu, 1987) the result is not surprising. Mass selection within families was found to be effective in Stage 2 (Hogarth *et al.*, 1990) and Stage 1 original seedling (McRae *et al.*, 1993) trials in the Burdekin. In both of these studies, mass selection within families was conducted in relatively erect crops, and was based on a visual appraisal of yield and a brix measurement relative to a standard clone. In heavily lodged trials, as in this study, brixing of clones is impractical. Stage 3 trials in the Burdekin are routinely planted in autumn when commercial planting occurs. The brixing of clones at such an early

stage of growth, in an attempt to improve genetic gains, is unlikely to be successful, as clones are immature and sugar content is too low.

The Family x Treatment interaction, F x T, was significant for TCH, TSH and NMG, but not for CCS in the plant crop of the Stage 3 trial (Table III). Although the F x T effect was significant for these characters, the F x T variance component for TCH (21.33), TSH (0.63) and NMG (0.17), was smaller than the respective Family component for TCH (88.03), TSH (2.13) and NMG (0.62). In the ratoon crop, the F x T interaction was not significant for any of the primary characters (Table IV).

Differences among families were significant for selection characters based on NMG, in both crops of the Stage 3 trial (Table V). Differences among treatments were not significant for Clones NMG . 10.0 or Clones NMG . 7.5, in either plant or ratoon crops. Mass selection within families in the third ratoon crop of the Stage 2 trial was ineffective in identifying superior clones, when evaluated in Stage 3. Efficiency of selection in a first ratoon crop may be different to selection in a third ratoon crop. The F x T interaction was significant for Clones NMG . 10.0 in the plant crop of the Stage 3 trial. The F x T variance component (0.0024) was as large as the F component (0.0027), suggesting the interaction is important. Appropriate . (Y + 0.5) transformation of the data did not greatly reduce the magnitude of the F x T component (0.0008) relative to the F component (0.0010).

Table V -- Mixed model ANOVA for selection characters measured in plant and ratoon crops of the Stage 3 trial.

Source of Variation	df	Mean Squares			
		Plant Crop		Ratoon Crop	
		Clones NMG . 10.0	Clones NMG . 7.5	Clones NMG . 10.0	Clones NMG . 7.5
Replicates, R	2	0.034	0.478$^{\cdot\cdot}$	0.105	0.324$^{\cdot}$
Families, F	63	0.048$^{\cdot}$	0.260$^{\cdot\cdot}$	0.109$^{\cdot}$	0.164$^{\cdot}$
Error (1)	126	0.023	0.060	0.046	0.104
Treatments, T	2	0.019	0.053	0.028 0.033	0.028
F x T	126	0.024$^{\cdot\cdot}$	0.067	0.031	0.068
Error (2)	256	0.016	0.054		0.057
General mean		0.073	0.339	0.137	0.358
Selected B1 group mean		0.082	0.354	0.151	0.363
Selected B2 group mean		0.076	0.342	0.132	0.344
Random group mean		0.062	0.321	0.128	0.366

Significance levels of appropriate F-Ratios, $^{\cdot}$ P < 0.05 and $^{\cdot\cdot}$ P < 0.01, are given with the mean squares.

In the combined mixed model ANOVA of the Stage 3 trial fitting a Crop (C) effect (Table VI), the C effect was significant for CCS, but not for the other primary characters. The Family x Crop (F x C) interaction was significant for CCS, TSH and NMG. The performance of families was not consistent across crops in Stage 3. Although the F x C effect was significant, the F x C variance component for CCS (0.11), TSH (0.19) and NMG (0.09), was smaller than the respective Family component for CCS (0.45), TSH (1.81) and

NMG (0.56). This suggests plant crop results alone are probably sufficient to evaluate families, at least early in the crop cycle and where plot errors are correlated. McRae *et al.* (1993) also found F x C interactions were unimportant in a Stage 3 trial in the Burdekin. The Treatment x Crop interaction was not significant for any primary character.

Table VI -- Combined mixed model ANOVA fitting a Crop effect, for primary characters measured in the Stage 3 trial.

Source of Variation	df	Mean Squares			
		TCH	CCS	TSH	NMG
Replicates, R	2	60169$^{\cdot\cdot}$	29.60	870.05$^{\cdot\cdot}$	81.15$^{\cdot\cdot}$
Families, F	63	7246$^{\cdot\cdot}$	34.28$^{\cdot\cdot}$	155.74$^{\cdot\cdot}$	44.62$^{\cdot\cdot}$
Error (1)	126	3436	9.97	57.90	14.60
Treatments, T	2	2092	2.86	27.87	5.59
F x T	126	1253	4.58	34.99$^{\cdot}$	10.08$^{\cdot}$
Error (2)	256	984	4.50	25.77	7.40
Crops, C	1	146065	1226.63$^{\cdot\cdot}$	357.51	17.63
Error (3)	2	17312	5.26	346.74	20.48
F x C	63	1117	10.35$^{\cdot\cdot}$	29.71$^{\cdot}$	10.23$^{\cdot\cdot}$
Error (4)	126	980	4.30	19.50	5.54
T x C	2	67	3.29	9.70	3.28
F x T x C	126	412	2.61	11.28	3.37
Error (5)	256	367	2.64	11.84	3.66
Error (6)	2304	1222	2.92	29.01	7.70

Significance levels of appropriate F-Ratios, $^{\cdot}$ $P < 0.05$ and $^{\cdot\cdot}$ $P < 0.01$, are given with the mean squares.

For selection characters (results not shown), in the combined mixed model ANOVA of the Stage 3 trial fitting a Crop effect, the C effect was significant ($P<0.01$) for Clones NMG . 10.0, but not for Clones NMG . 7.5. Although the Family x Crop (F x C) interaction was significant for Clones NMG . 7.5, the F x C variance component (0.0018) was much smaller than the Family component (0.0127). The Treatment x Crop interaction was not significant for either selection character.

Family selection in Stage 2 was effective, even under heavily lodged conditions. Selected families as a group were superior to the rejected families when evaluated in Stage 3 (Tables VII and VIII). In general, absolute gains from family selection based on weighed plot data were positive.

For pure family selection (Table VII), gains for all characters except for CCS, from selecting the best 8 families in Stage 2, were superior to gains from more liberal family selection, by selecting the best 16 and 24 families. In contrast, Hogarth *et al.* (1990) and McRae *et al.* (1994, In Preparation), suggested rates of family selection in Stage 2 trials in the Burdekin need to be liberal, as superior clones can be found in relatively poor families. The best 8 families in Stage 2, based on plant crop results, produced significantly more superior clones, Clones NMG . 10.0 and Clones NMG . 7.5, in Stage 3. Significantly more clones would be selected in Stage 3 from the better families identified in Stage 2, for further evaluation in later stage trials using clonal replication within and across sites.

Pure family selection, based on weighed family performance in the plant crop (PNMG) of the Stage 2 trial, was better than selection based on ratoon crop results (RNMG), particularly

for higher intensities of family selection. This suggests plant crop results alone are adequate for assessing family performance in Stage 2 trials.

Table VII -- Realised gains in Stage 3 to two methods of pure family selection in Stage 2.

Stage 3 trial response	Character	Stage 2 PNMG			Stage 2 RNMG		
		Number of families selected			Number of families selected		
		Best 8	Best 16	Best 24	Best 8	Best 16	Best 24
Plant	TCH	8.952*	1.408	1.346	3.250	-0.391	1.801
	CCS	0.161	0.210	0.126	0.060	0.091	0.107
	TSH	1.560**	0.450	0.348	0.621	0.068	0.412
	NMG	0.800**	0.270	0.196	0.323	0.055	0.218
	Clones NMG . 10.0	0.076**	0.014	0.026	0.035 0.068	-0.007	0.016
	Clones NMG . 7.5	0.123**	0.019	0.003		0.019	0.035
Ratoon	TCH	10.932	1.542	2.654	8.291	2.180	2.693
	CCS	0.490	0.672**	0.385*	0.376	0.180	0.175
	TSH	2.182**	0.961	0.804*	1.715*	0.538	0.579
	NMG	1.242**	0.675*	0.505*	0.973*	0.317	0.331
	Clones NMG . 10.0	0.135**	0.038	0.034	0.080	0.017	0.015
	Clones NMG . 7.5	0.175**	0.078	0.064*	0.175**	0.057	0.055

Gains are expressed as deviations from the mean of the random group of clones in Stage 3. Significance of lsd, * $P < 0.05$ and ** $P < 0.01$, refers to differences between means of selected and unselected families.

Planting more individuals from the better families in subsequent trials in later years is a common practice (Skinner *et al.*, 1987), and aims to exploit within family variance. In an efficient recurrent selection and breeding program, the numbers of progeny, and the number of years in which progeny from a proven family are tested, will be limited by the effects of inbreeding and an increased generation interval.

In sugarcane, a clonally propagated crop, families have no direct commercial value. A family is valuable for selection purposes, only if it includes superior individuals with commercial potential. Both the mean and variance among full sibs are important in determining the worth of a family. Further work on the relative importance of means and variances is needed to determine optimum selection rates among and within families. In the Burdekin, the efficient conduct of within family selection will depend on the severity of lodging. For breeding purposes, the value of objective progeny performance data for families, although critical, is more difficult to quantify.

In general, gains from combined family and mass selection within selected families (Table VIII) were no better than gains from pure family selection (Table VII). Selected clones within selected families as a group were superior to selected clones from the rejected families, when evaluated in Stage 3 (Table VIII). Most of the gains were due to family selection, and not mass selection within families. Mass selection within families, based solely on a visual appraisal of yield in the third ratoon crop of the Stage 2 trial, was ineffective. The Stage 2 trial was very heavily lodged, and this would have reduced the efficiency of visual selection. The confounding influences of competition effects, are also expected to increase with later ratoons (Berding and Skinner, 1991 Unpublished). Visual

selection for yield may be more efficient if done in earlier ratoons, and in trials which are not as heavily lodged, or damaged by cyclones. For early stage selection trials in the Burdekin, the practice of conducting family selection in the plant crop, followed by visual mass selection within selected families in the first ratoon crop, is being further evaluated.

Table VIII -- Realised gains in Stage 3 to two methods of combined family and mass selection in Stage 2.

Stage 3 trial response	Character	Stage 2 PNMG			Stage 2 RNMG		
		Number of families selected			Number of families selected		
		Best 8	Best 16	Best 24	Best 8	Best 16	Best 24
Plant	TCH	6.058	4.171	3.358	2.208	4.120	3.937
	CCS	0.317*	0.379**	0.192**	0.197	0.315**	0.193**
	TSH	1.220**	0.977*	0.681	0.583	0.939*	0.780
	NMG	0.693**	0.588**	0.388*	0.347	0.552**	0.431**
	Clones NMG . 10.0	0.049	0.049*	0.037*	0.056	0.056**	0.042*
	Clones NMG . 7.5	0.151**	0.102**	0.075**	0.109*	0.123**	0.102**
Ratoon	TCH	11.488*	4.753	3.913	8.534	7.145	4.704
	CCS	-0.014	0.104	0.004	0.284	-0.025	-0.015
	TSH	1.528**	0.767	0.559	1.497*	0.931*	0.596
	NMG	0.737*	0.434*	0.294*	0.828**	0.447*	0.290*
	Clones NMG . 10.0	0.094**	0.042	0.027	0.101**	0.052*	0.031
	Clones NMG . 7.5	0.043	0.033	0.025	0.057	0.030	0.025

Gains are expressed as deviations from the mean of the random group of clones in Stage 3. Gains are averaged for selected groups (B1 and B2). Significance of lsd, * $P < 0.05$ and ** $P < 0.01$, refers to differences between means of selected and unselected families.

In other studies in the Burdekin, mass selection within selected families has been successful (Hogarth *et al.*, 1990; McRae *et al.*, 1993). It is likely, even under Burdekin conditions where mass selection may be limited to a visual appraisal of yield in early stage trials, that combined family and mass selection within families is required to optimise genetic gain. For given resources, there is a tradeoff between rates of family selection and rates of mass selection within selected families.

Realised heritability estimates (Table IX), based on selecting the top 8 (12.5%), 16 (25%) and 24 (37.5%) families for TCH, CCS, TSH and NMG in Stage 2, appeared realistic, given that sample sizes are small and standard errors are expected to be large. Variation between generation means (scaling) would also influence the accuracy of the estimates. Regardless, the estimates were much higher than would be expected for mass selection based on selection of individuals, especially under lodged conditions. For the selection index, NMG, estimates were generally higher with more intensive family selection.

Table IX -- Estimates of realised heritability, selecting the top 8, 16 and 24 families in Stage 2.

Stage 3 trial response	Character	Plant crop Stage 2			Ratoon crop Stage 2		
		Number of families selected			Number of families selected		
		Best 8	Best 16	Best 24	Best 8	Best 16	Best 24
Plant	TCH	0.22	0.27	0.26	0.11	0.22	0.11
	CCS	0.49	0.53	0.42	0.72	0.46	0.37
	TSH	0.37	0.11	0.13	0.14	0.11	0.11
	NMG	0.35	0.16	0.15	0.16	0.04	0.19
Ratoon	TCH	0.47	0.40	0.22	0.33	0.35	0.29
	CCS	0.61	0.94	0.61	0.99	0.59	0.74
	TSH	0.51	0.26	0.30	0.38	0.23	0.20
	NMG	0.55	0.40	0.39	0.49	0.22	0.29

Estimates of broad sense heritability, calculated by correlating family means in Stages 2 and 3 (Table X), were similar in magnitude to the realised heritability estimates. The heritabilities, both realised and correlation estimates, suggest that family selection in Stage 2 for TCH, CCS, TSH and NMG, should be effective, even under heavily lodged conditions which are typical of the Burdekin. Estimates for CCS were higher than for TCH. This is expected, given that broad sense heritability on an individual and family basis for yield in small plots is usually low, but for sugar content is usually high (Skinner *et al.*, 1987).

Table X -- Correlation estimates of broad sense heritability.

Stage 2 crop	Stage 3 crop	TCH	CCS	TSH	NMG
Plant	Plant	0.16	0.57	0.18	0.24
	Ratoon	0.24	0.49	0.35	0.42
Ratoon	Plant	0.07	0.44	0.09	0.13
	Ratoon	0.32	0.34	0.35	0.36

Higher heritabilities for NMG, using both realised and correlation estimates based on plant crop results of the Stage 2 trial, suggests that family selection based on plant crop results in Stage 2 is more effective than selection based on ratoon crop results. Heritability estimates were higher for family selection in Stage 2 for TCH, TSH and NMG when response was measured in the ratoon crop of the Stage 3 trial. Variable germination and poor establishment of clones in the plant crop of the Stage 3 trial may have reduced the efficiency of family selection. Family x year interactions, which were not measured, may also have reduced the efficiency of family selection by reducing the correlation between family performance in Stages 2 and 3.

The practical utility of family selection for early stage, lodged trials in the Burdekin was demonstrated. Mass selection of individuals is difficult under these conditions. Further studies are needed to optimise selection rates among and within selected families.

Conditions for selection, as experienced in the cyclone damaged Stage 2 trial, were not conducive to efficient mass or family selection. The efficiency of family selection is expected to improve under better conditions.

Conclusions

The practical utility of family selection for early stage, lodged trials in the Burdekin was demonstrated. Mass selection of individuals is almost impractical under these conditions. Family selection, based on weighed family performance in a Stage 2 trial, was effective even under heavily lodged conditions. Plant crop results alone are adequate for assessing family performance in Stage 2 trials. Mass selection within families, based solely on a visual appraisal of yield in the third ratoon crop of a heavily lodged Stage 2 trial, was ineffective. Gains from combined family and mass selection within selected families were no better than gains from pure family selection. Plant crop results alone are sufficient to evaluate families, at least early in the crop cycle, and where plot errors are correlated.

The system currently being tested for Burdekin conditions is to select families on weighed plot data in plant crops of Stage 1, original seedling trials. Mass selection within selected families is conducted in young ratoon crops. Selected clones are planted directly to Stage 3 trials. With this system, objective progeny performance data allow accurate identification of superior families and parents for further exploitation. Field operations are simpler and less expensive, and genetic progress is expected to be improved.

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