FINAL REPORT

SRDC PROJECT CSR10S

SELECTING CLONES FOR BETTER RATOONING UNDER WET HARVESTING CONDITIONS

by

Phillip Jackson[1], Mike Braunack[2], John Foreman[1],Tom Peatey[3], Andrew Wood[3],

[1]CSIRO Tropical Agriculture, [2]BSES, [3]CSR Ltd.

Principal investigator:
Phillip Jackson, Senior Research Scientist
CSIRO Tropical Agriculture,
Private Mail Bag, PO Aitkenvale, Qld 4814.

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SUMMARY

Stool damage from harvesting of cane in wet conditions, or waterlogging shortly after harvest, can greatly reduce cane yield in subsequent ratoon crops . This is believed to be due to a combination of direct stool damage from heavy harvesting equipment, soil compaction, and waterlogging of the young stubble. This not only lowers productivity but indirectly contributes to disruption of cane supply to mills in wet weather because of growers' understandable reluctance to harvest under such conditions. Development of cane varieties which ratoon well under unfavourable harvesting conditions would bring significant benefits to the industry.

Present sugarcane varieties are complex hybrids between the species *Saccharum officinarum* and *S. spontaneum*, and in a few cases with other related species, although their genome may be of the order of 90% *S. officinarum* (Daniels and Roach, 1987). *S. officinarum* is regarded as being the principal donor of sucrose, while *S. spontaneum* is the principle donor of stress tolerance and ratooning ability. About 25 to 30% of the resources devoted to sugarcane breeding in the CSR program based at Macknade from the 1960's to 1991 has involved attempts to incorporate a wider diversity of wild germplasm, particularly *S. spontaneum*, into core breeding germplasm.

Before the commencement of this project, it was considered that a separate breeding program involving selection for ratooning under wet conditions, and utilising genetic material recently generated from wild germplasm as a source of parental material might be worthwhile. Clones selected from such a program may be suitable as strong ratooning commercial varieties but would be expected to be of particular value as parental material in core breeding programs.

There were three broad aims of this project:
(i) To develop and evaluate a method for screening genetic material under conditions where there is (a) stool damage from harvesting machinery under wet conditions, and (b) waterlogging shortly after harvest.
(ii) To evaluate a range of genetic material for ratooning under these conditions, including material generated from previous introgression breeding programs by CSR..
(iii) To determine if a breeding program aimed at improving ratooning under wet conditions would be worthwhile, and if so, what sort of methods should be used.

A method was developed for imposing stool damage that resembled conditions experienced under wet harvesting conditions in commercial canefields. This involved firstly harvesting under dry conditions, then evenly spray irrigating with approximately 50mm, and finally driving up and down rows with laden haulout equipment. This resulted in significant reductions in early ratoon growth and final cane yield, but resulted in experimental error variation that was not significantly greater than adjacent control treatments. This procedure therefore proved both practical and effective. A "waterlogging" treatment was also applied to one trial, involving application of the above "traffic" treatment, followed by continued irrigation for a further week to maintain saturated conditions on the soil surface.

Twenty-six clones were evaluated in the experiments. Six of these were commercial varieties, and twenty were experimental clones with differing levels of S. spontaneum or other wild germplasm in their background.

The clones were evaluated across eight trials. Five of the trials were conducted at Macknade experiment station where wet harvesting conditions could be closely regulated. Three of these were established in the same field and managed identically except that different post-harvest treatment were imposed to each trial. Of these three, one trial had the traffic treatment imposed, a second had the waterlogging treatment imposed, while the third received a "control" treatment (harvested under dry conditions only). Analysis of G x E interactions between these three environments allowed an assessment of possible effects due to the traffic and waterlogging effects. The other two trials established at Macknade experiment station had the traffic and control treatments imposed, respectively. The three other trials were conducted at different sites in the Herbert with the assistance of cooperating growers. Each of these trials had the traffic treatment imposed.

Measurements were made in the plant, first ratoon and second ratoon crops for the trials at Macknade experiment station, and in the plant and first ratoon crops for the farm trials. In each crop, final yield was measured. In addition, in the ratoon crops, early ratoon growth was monitored by stalk counts, and by measuring canopy light interception.

The traffic treatment resulted in higher soil bulk densities, reduced early ratoon growth and reduced final yields. In the trials at Macknade, the cane yields in the traffic treatment were up to 40% less than in the adjacent control experiment.

For adjacent trials receiving the traffic impact and control conditions there was large genetic variance for early ratoon growth, and small, although significant ($P<0.05$) genotype x environment (GE) interaction. However for cane yield at harvest, no significant genotype x trial interaction was apparent. This indicated that while the traffic treatments reduced cane yield overall, the genotypes responded in a generally similar way. Examination of responses for the individual commercial varieties verified that they responded in a similar way to that of the population of experimental genotypes.

Analysis of results across plant and ratoon crops of all eight trials showed significant genotype and genotype x trial interaction, but no significant genotype x site x crop interactions. These results indicate that the variation among genotypes in response to specific stresses imposed by the traffic impacts was small compared with other sources of variation. Selection for ratooning after dry harvesting conditions at a particular site should also be effective for improving ratooning after wet harvesting conditions at the same site.

Overall, the results suggest that a breeding or selection program specifically targeting better ratooning after wet harvesting conditions is unlikely to result in more gains in these environments than existing core breeding programs targeting regional adaptation. Therefore it is not recommended that a breeding program specifically targeting better ratooning after wet harvesting conditions be initiated.

1. INTRODUCTION

Sugarcane growers are commonly aware that following mechanical harvesting of sugarcane under wet conditions, growth and yield in the ratoon crop is often poor. The relative contribution of different factors are poorly quantified. However, direct mechanical damage of the stool (Torres and Villegas, 1993) and soil compaction (Braunack et al, 1993; Swinford and Boevey, 1984) are probably major contributing factors. Under very wet conditions, waterlogging of the cut stool may also be involved.

Although harvesting under wet conditions often adversely affects the ratoon crop, the benefits of maintaining a continuous cane supply to sugar mills often means that a significant proportion of cane is harvested under wet conditions. This is obviously most common in regions such as that have wet climates such as the tropical coast of north-east Australia.

Sugarcane growers often report that varieties differ in response to harvesting under wet conditions. However, there are no published studies documenting the magnitude of differences among sugarcane clones.

In addition to perceived differences among presently grown commercial varieties, the noble canes (*Sacharum officinarum*) grown commercially earlier this century have been observed to ratoon more poorly after mechanical harvesting, especially after wet conditions, than current cultivars (which contain components of *S. officinarum* and *S. spontaneum* genomes). Further, some *S. spontaneum* clones are believed to have very vigorous ratoon growth, even under adverse conditions (Berding and Roach, 1987). It has been suggested that some of this genetic material could form the basis for breeding programs aimed specifically at developing sugarcane varieties with superior ratooning after wet harvesting.

Given the economic importance of poor ratooning after wet harvesting conditions in sugarcane industries, and the possibility that genetic variation to this constraint exists, this research project was commenced to determine if selection and breeding for improving performance under these conditions would be an attractive investment. The specific objectives of this project were to:

(i) To develop and evaluate a method for screening genetic material under conditions where there is (a) stool damage from harvesting machinery under wet conditions, and (b) waterlogging shortly after harvest.
(ii) To evaluate a range of genetic material for ratooning under these conditions, including material generated from previous introgression programs by CSR.
(iii) To determine if a breeding program aimed at improving ratooning under wet conditions would be worthwhile, and if so, what sort of methods should be used.

2. MATERIALS AND METHODS

2.1 Genetic material

A list of clones used and their genetic background are given in Table 1. A total of 26 clones were evaluated. Twenty of these were experimental clones derived from previous introgression breeding programs in the sugarcane breeding program

conducted by CSR Ltd at Macknade, Australia (Jackson and Roach, 1992) and six were commercially grown varieties.

Table 1. List of clones used and genetic background. "Commercial" refers to a sugarcane clone that has been commercially grown; F_1 refers to a cross between a S. officinarum clone and another species (specified) or between a commercially grown clone and another species (specified)

Clone	Type/Genetic background
MQ88-1802	F_1 (Erianthus sp.)
MQ88-981	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ88-1068	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ88-833	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ84-29B	Commercial x F_1 (S. spontaneum)
MQ88-841	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ88-1084	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ84-19B	Commercial x F_1 (S. spontaneum)
MQ66-99R	F_1 (S. spontaneum)
MQ88-920	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ79-141	Commercial x F_1 (S. spontaneum)
MQ88-1160	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ88-859	F_1 (S. spontaneum) x F_1 (S. spontaneum)
MQ86-31B	F_1 (S. spontaneum)
MQ84-5B	F_1 (S. spontaneum)
MQ78-858	F_1 (S. spontaneum)
MQ88-846	F_1 (S. spontaneum) x F_1 (S. spontaneum)
LF65-3660	F_1 (Erianthus sp)
MQ88-808	F_1 (S. spontaneum) x F_1 (S. spontaneum)
BN78-8031	Commercial x F_1 (S. spontaneum)
NCo310	Commercial
Triton	Commercial
Q124	Commercial
Q115	Commercial
Q117	Commercial
Q138	Commercial

2.2 Experimental design

The 26 genotypes were grown in eight trials in the Herbert region, North Queensland, Australia. Each trial consisted of a randomised complete block design with two replicates. The unit plots were three rows x 6m with a 1m gap between every second plot.

The eight trials used are listed in Table 2. Three of the trials, designated the M1 trials, were situated adjacent to each other at Macknade experiment station, Macknade, in the lower Herbert. These three trials were managed identically except that different post-harvest conditions were imposed on each. These conditions consisted of a "traffic" treatment, a "waterlogged" treatment, and a "control". These are described below.

Table 2. Planting and harvesting dates, and post-harvest treatments imposed, on each of the eight trials conducted.

Trial	Planting date	Harvest date(s)[1]	Harvesting treatment
M1 - C	12 Aug 1993	4 Oct 1994, 13 Jul 1995, 18 Oct 1996	control
M1 - T	12 Aug 1993	4 Oct 1994, 13 Jul 1995, 18 Oct 1996	traffic
M1 - W	12 Aug 1993	4 Oct 1994, 13 Jul 1995, 18 Oct 1996	waterlogged
M2 - C	10 Aug 1993	7 Sep 1994, 11 Jul 1995, 22 Aug 1996	control
M2 - T	10 Aug 1993	7 Sep 1994, 11 Jul 1995, 22 Aug 1996	traffic
F1(Girgenti)	25 May 1994	28 Sep 1995, 16 Aug 1996	traffic
F2 (Guazzo)	13 Jun 1994	26 Jul 1995, 3 Aug 1996	traffic
F3 (Palmas)	20 Jul 1994	4 Jul 1995, 8 Aug 1996	control

[1]Dates are given for plant, first ratoon, and second ratoon crops, in order. Trials F1, F2 and F3 only had plant and first ratoon crops.

A further two trials, designated the M2 trials, were also situated adjacent to each other at Macknade experiment station and managed identically except for different post-harvest conditions. For the M2 trials, the "control" condition was imposed on one trial and the "traffic" treatment imposed on the other.

The remaining three trials were planted at different farms in the Herbert River district in 1995. These were grown on farms owned by Alf Girgenti, Steve Guazzo, and Tony Palmas and were designated trials F1, F2, and F3, respectively in this report. Some details of each are given in Table 2. In the F1 and F2 trials, the traffic impact described below was imposed immediately following harvest of the plant crop. In the F3 trial, harvesting occurred under relatively dry conditions, and no further artificial treatment was imposed.

The soils are classified locally as a Macknade, Toobanna, Toobanna and Hamleigh for the M1 and M2, F1, F2, and F3 sites respectively (Wilson and Baker, 1990). The dominant soils in each of these associations are described as alluvial soils, grey clays, and solodic soils (Northcote, 1971).

The M1 and M2 trials were monitored until the second ratoon crop. In the first ratoon crop, immediately following harvest of the plant crop, the different post-harvest conditions were imposed in both the M1 and M2 sets of trials. Immediately after the harvest of the first ratoon crop (ie. at the commencement of the second ratoon), the traffic impact was imposed on the previous traffic and waterlogged areas in the M1 trials only. In the F1, F2 and F3 trials, measurements were made up to the end of the first ratoon crop.

The times of planting and harvest of each trial is given in Table 2. Cultivation and fertiliser application followed normal commercial practices carried out on the farms on which the trials were grown.

A pot trial was also conducted to impose waterlogging in the same genotypes used in the field trials. The aim was to determine whether similar responses to those observed in the field waterlogging trial could be obtained in a pot trial. If this were the case it may enable cheaper evaluation of genotypes in further trials. The 26 genotypes were grown in 30cm high x 25cm diameter pots filled with soil from the field at Macknade. The pots were placed in four "waterlogging bays" at Macknade experiment station, which could be filled with water to a level of about 40cm. These bays had been built for previous research on waterlogging described by Roach and Mullins (1985). The cane was grown in the plant crop for 12 months without any waterlogging, and then harvested at ground level in the pots. Immediately after harvesting of the plant crop, the water level was raised to about 5cm above the pot level in two bays and kept at that level for one week. The other two bays were not waterlogged. After harvesting of the first ratoon crop, the water level in the two waterlogged bays was raised again, this time for two weeks. In neither year was any adverse affect of the waterlogging apparent, either in early growth or in final cane yields. The results from the pot trial are therefore not considered further in this report.

2.3 Post-harvest treatments

Traffic impact

The traffic impact was designed with the aim of evenly applying stool damage similar to that which would occur during commercial mechanical harvesting under wet conditions. First, the crop was harvested under dry conditions with a commercial harvester and hauling out equipment. The trial was immediately spray irrigated with approximately 50mm water, with sprinklers arranged to achieve an even ground coverage. Within 24 hours of irrigation, a four wheel drive tractor and trailer were driven along the rows of cane to simulate damage from harvesting equipment under wet conditions. In 1994, the trailer used was a single axle, dual wheel rollon-rolloff haulout bin with dual tyres (0.85m diameter) laden with a 1.5 tonne weight. In 1995, high flotation equipment was used with a four tonne load. In imposing the impact, the left hand wheel of the tractor and trailer were driven along the top of each row, with this being done for each individual row. In this way, each row received a direct impact (from the left wheels) and an impact slightly to the side (from the right hand wheels).

Waterlogging

This involved all actions described for the traffic impact, plus continued irrigation following the impact from the tractor and trailer. Irrigation was continued for one week following harvest, and about 20mm was applied twice per day, such that free water was always visible in puddles on the ground surface. Prior to establishment of the trial, the ground used was laser levelled to obtain a zero slope so that waterlogging occurred evenly across all plots.

Control
Trials grown under "control" conditions were harvested under dry conditions and then irrigated, in exactly the same way as applied for the traffic impact. However, unlike the previous two conditions, the crop was then allowed to ratoon without further interference.

2.4 Measurements

Soil measurements:
Measurements of several soil properties before and following the traffic impact were made in the plots of Q117 to document effects of the different post harvest treatments. These are detailed in Braunack and Peatey (1998). Only measurements on bulk density are given in this report. Undisturbed soil cores (7.5cm diameter x 5cm high) were collected to a depth of 30cm from the middle of the row before harvest and again after traffic imposition. These cores were used to determine the soil bulk density (oven drying). .

The following plant measurements were made in each trial:
Stalk number (m^{-2}): This was measured in each plot by counts of stalks along a four metre section of each of two rows, including one middle row. Stalk counts were made in the ratoon crops at approximately one month and three months after harvest and then about four months prior to harvesting. For the first two counts, all tillers were counted, regardless of size. For the last count, the aim was to obtain an estimate of final stalk numbers, and stalks less than 1 m high were excluded since these would be either dead at harvest or would contribute little to final yield.
Canopy light interception (%): This was measured using a Licor linear light interception probe (Licor inc., Lincoln, Nebraska). Measurements were made in the ratoon crops at approximately three months after harvest. The relative canopy light interception in each plot was estimated on a clear day between 10.00am and 2.00pm from the mean of six measurements made from ground level at six randomly chosen points within two rows. These measurements were compared with readings taken in full sun within 10 minutes, and the light intercepted by the canopy calculated from the mean of the six measurements divided by the full sunlight measurement.
Stalk weight (kg/stalk): This was determined from weights of six or eight stalks, sampled at random from two rows at final harvest.
Cane yield (t/ha): Calculated from the last count of stalk number x stalk weight at final harvest x 10.

2.5 Data analyses

Cane yield at harvest was analysed for each individual trial and crop-year combination, using a model partitioning variation due to blocks and genotypes. Heritability was

calculated from the ratio of genetic variance to phenotypic variance. Phenotypic variance (σ_p^2) was determined from:

$\sigma_p^2 = \sigma_g^2 + \sigma_e^2 / n$

where:

σ_g^2 = genetic variance

σ_e^2 = error variance.

n = number of replicates within trial

Analyses of variance were done across the trials within each of the M1 and M2 sets of trials. Analyses were firstly done within each of the first ratoon and second ratoon crops to assess whether the different post-harvest conditions may have induced significant genotype x environment interactions in the adjacent trials. In these analyses, genotypes were assumed to be random effects, and the following linear model was assumed for partitioning of variance:

$y_{ijm} = \mu + t_j + b_{mj} + g_i + (gt)_{ij} + (gb)_{ijm}$

where y_{ijm} = observed yield of the *i*th genotype in the *j*th trial in the *m*th block.

μ = mean of all observations;

t_j = effect of the *j*th trial, $j = 1..n_t$

b_{mj} = effect of the *m*th block withing the *j*th trial, $m = 1..n_b$ (error 1)

g_i = effect of the *i*th genotype, $i = 1..n_g$

$(gt)_{ij}$ = interaction effect between the *i*th genotype and the *j*th trial;

$(gb)_{ijm}$ = interaction effect between the *i*th genotype and the *m*th block within the *j*th trial (error 2);

where n_t, n_b, n_g are the number of trials, blocks, and genotypes respectively. For estimation of variance components, genotypes and blocks within trials were considered to be random effects while trials were regarded as fixed effects. Variance components were estimated for genotypes and genotype x trial interaction using the following expectations for mean squares:

Source of variation	Expected mean square
Genotypes	$\sigma_e^2 + n_b\, n_t\, \sigma_g^2$
Genotype x trial interaction	$\sigma_e^2 + n_b\, \sigma_{gt}^2$
Error 2	σ_e^2

An analysis of variance across all trials and crop cycles was also done. Of particular interest in these analyses was to determine if the genotype x crop x trial interaction was large; this would be the case if ratooning response across trials varied significantly. The following model was used for this analysis:

$y_{ijkm} = \mu + t_j + b_{mj} + g_i + (gt)_{ij} + (gb)_{imj} + c_k + (tc)_{jk} + (cb)_{kmj} + (gc)_{ik} + (gtc)_{ijk} + (gcb)_{ijkm}$

where y_{ijkm} = observed yield of the *i*th genotype at the *j*th trial in the *k*th crop-year in the *m*th block;

μ = mean of all observations;

t_j = effect of the *j*th trial, $j = 1..n_t$

b_{mj} = effect of the *m*th block withing the *j*th trial, $m = 1..n_b$

g_i = effect of the *i*th genotype, $i = 1..n_g$

$(gt)_{ij}$ = interaction effect between the *i*th genotype and the *j*th site;

$(gb)_{imj}$ = interaction effect between the *i*th genotype and the *m*th block within the *j*th trial (error 2);

c_k = effect of the *k*th crop-year, k = 1..n_c

$(tc)_{jk}$ = interaction effect between the *j*th trial and the *k*th crop-year;

$(cb)_{kmj}$ = interaction effect between the *k*th crop-year and the *m*th block within the *j*th trial (error 3);

$(gc)_{ik}$ = interaction effect between the *i*th genotype and the *k*th crop-year;

$(gtc)_{ijk}$ = interaction effect between the *i*th genotype, *j*th site and *k*th crop-year;

$(gcb)_{ijkm}$ = interaction effect between the *i*th genotype, the *m*th block and the *k*th crop-year within the *j*th site;

where n_t, n_b, n_g and n_c are the number of sites, blocks, genotypes and crop-years respectively. For estimation of variance components, genotypes, crop-years and blocks within trials were considered to be random effects while trials were considered to be fixed effects. Variance components were estimated for all effects involving genotypes using the following expectations for mean squares:

Source of variation	Expected mean square
Genotypes	$\sigma_e^2 + n_c \sigma_y^2 + n_b n_t n_c \sigma_g^2$
Genotype x trial interaction	$\sigma_e^2 + n_c \sigma_y^2 + n_b n_c \sigma_{gt}^2$
Error 2	$\sigma_e^2 + n_c \sigma_y^2$
Genotype x crop-year interaction	$\sigma_e^2 + n_b n_t \sigma_{gc}^2$
Genotype x trial x crop-year interaction	$\sigma_e^2 + n_b \sigma_{gtc}^2$
Error 4	σ_e^2

3. RESULTS

3.1 Trial effects

3.1.1 Soil measurements

Bulk densities at each site before and after the traffic treatments imposed at the beginning of the first ratoon crops are shown in Appendix 1. Results for the two Macknade traffic trials were similar and are averaged in this Figure, as are the results for the two Macknade control trials. Traffic resulted in a significant increase in soil bulk density of the row at all sites except for the F3 (Palmas) site to a depth of 15 to 20cm. The maximum bulk density for the Macknade soil was 1.53 gcm^{-3}, which was achieved on the traffic and waterlogged soil at 10cm depth. The control plots at Macknade showed no significant difference in soil bulk density of the row before and after harvest since there was no traffic over this position. There was little or no difference in soil bulk density at depths below 20cm at all sites.

3.1.1 Ratoon growth and cane yield

Mean stalk numbers for the M1 and M2 trials are shown in Figures 1a and 1b. In the first ratoon crop, the M1 trials produced more stalks on average than those in M2 (Figure 1a). This may in part reflect the later harvest date (and warmer weather) in M1 (Table 2), and possibly higher soil fertility in M1.

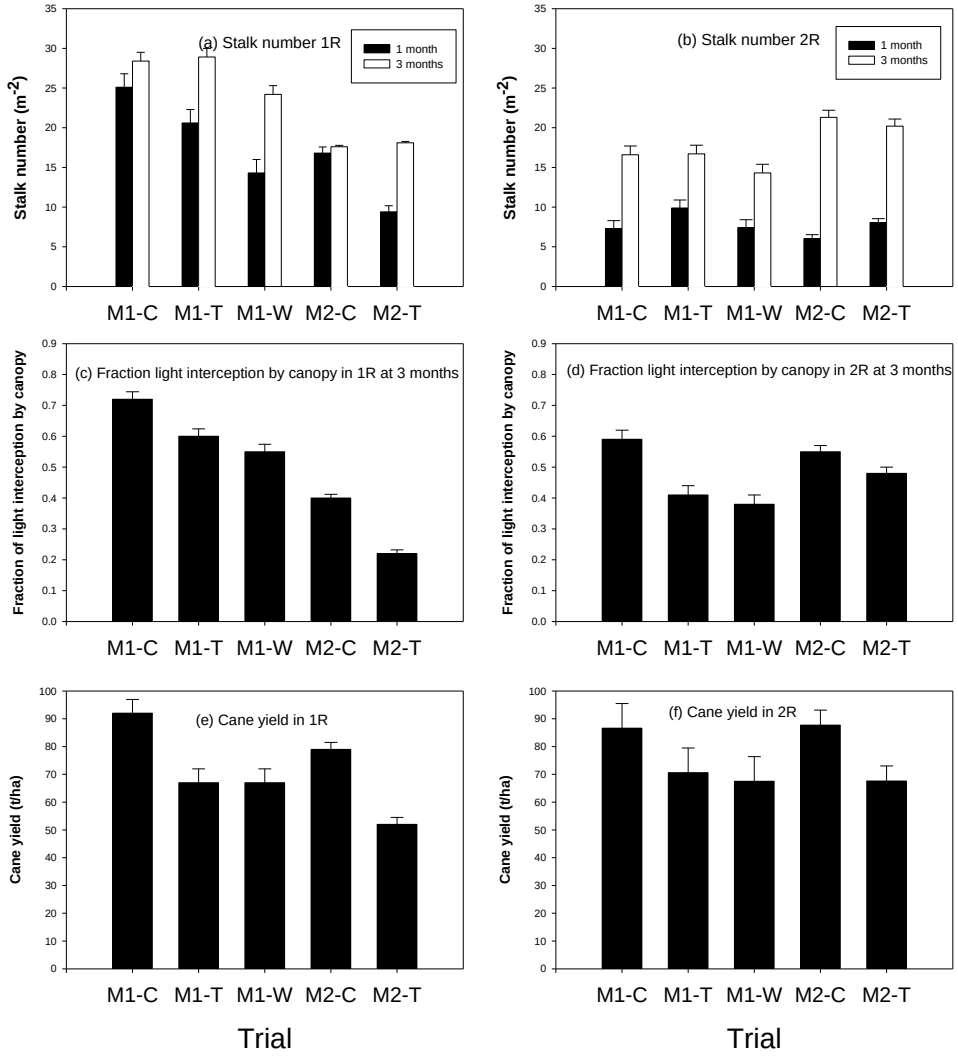

Figure 1. Stalk numbers, canopy light interception, and cane yield in first ratoon (1R) and second ratoon (2R) crops in trials in blocks M1 and M2. Codes used for trials are given in Table 2. Vertical bars indicate standard errors of differences.

In the first ratoon crop within both the M1 and M2 sets of trials, stalk numbers at about one month after harvest were significantly less in the trials receiving the traffic impact compared with the adjacent trials growing under the control conditions (Figure 1a). In the M1 trials, the trial receiving the waterlogging condition also had lower stalk numbers at one month after harvest. By 3 months after harvest, stalk numbers across the different trials within the M1 and M2 sets were similar (Figure 1a). However, canopy light interception at around this time remained different between the trials within the M1 and M2 sets, with the traffic and waterlogging trials having less developed canopies than the control treatments in both trials (Figure 1c). This difference was most marked in M2, where canopy light interception in the trial growing under the control conditions was nearly double that of the traffic trial. These

results indicate that while stalk numbers had become similar in the traffic and waterlogging trials three months after harvest, stalks were smaller, in terms of light intercepted per stalk. This smaller stalk size was also clearly obvious from visual observation.

Final cane yields in the first ratoon crop were also significantly less in the trials receiving the traffic impact and waterlogged conditions within both M1 and M2 sets of trials compared with the control trials (Figure 1e). In the M1 trials, the cane yield shown for the control trial in first ratoon crop (Figure 1e) represented an amount that was 80% of the plant crop yield, while both the trials receiving the traffic impact and waterlogged condition both had first ratoon crop cane yields that were 61% of the plant crop yields. In the M2 trials, the control trial in the first ratoon crop yielded 83% of the plant crop, while the trial receiving the traffic impact had first ratoon yields that were 64% of the plant crop.

In the second ratoon crop, there was no effect of the traffic impact in the M1 trials on stalk numbers (Figure 1b) but a significant effect on canopy light interception was clear (Figure 1d). For the two M2 trials (where different post-harvest conditions had not been imposed at commencement of the second ratoon crop) there was no difference in stalk numbers (Figure 1b), but a small difference remained for canopy light interception (Figure 1d). For final cane yields in the second ratoon crop, the trials receiving the traffic impact and waterlogged conditions had lower yields than in the adjacent control trials for both the M1 and M2 trials (Figure 1f). However, the difference between the two M2 trials was not as marked as in the first ratoon crop.

Mean cane yields in all trials and in all crops are shown in Appendix 1. For the farm trials, the separate effect of the traffic impact is not possible to estimate due to lack of a control trial at the same site.

3.2 Genetic variation

Within both the M1 and M2 trials, there was significant variation due to genotypes and genotype x trial interaction for stalk numbers in the first ratoon crop at about 1 month after harvesting (Table 3). However, the variance component for genotype x trial interaction was much smaller than for genotypes. At three months, significant genotype x trial interaction remained for stalk number across the M1 trials, but not for the M2 trials. At this time, significant genotype x trial interaction existed for canopy light interaction in the M1 trials but not for the M2 trials, despite the large difference in main effects between the latter trials (Figure 1c).

In the second ratoon crop, there was no significant genotype x trial interaction across the M1 trials for stalk number or light interception (Table 3). Significant genotype x trial interaction occurred for stalk number at one month after harvest in the M2 trials, but no such interaction was evident for stalk number or canopy light interception at three months.

Genetic variance components, heritabilities, and error coefficients of variation for cane yield at harvest in the ratoon crops for each individual trial x crop-year combination are shown in Table 4. For all except the M1-C trial in the second ratoon crop, there

was significant (P<0.05) variation due to genotypes. For the M1-C trial, there was high error variance in the second ratoon crop (Table 4) for reasons that were not clear, and this probably contributed to the statistical non-significance of the genetic effects. There were no clear differences in genetic or error variances, or in heritabilities, between trials receiving the control conditions versus those receiving the traffic impact or waterlogged conditions. Thus it would appear that the traffic impact or waterlogging conditions did not introduce an additional or problematic source of experimental error.

Table 3. Genotypic variance components, genotype x trial variance component, and error variance component for analyses of the M1 and M2 sets of trials, for stalk number (SN, m^{-2}) and canopy light interception (LI).

Set of trials	Crop	Attribute	Genotypic variance component	G x trial variance component	Error variance component
M1	1R	SN - 1 month	192**	11.1*	15.8
		SN - 3 months	195.1**	5.13*	23.2
		LI - 3 months	0.0136**	0.0041**	0.0089
	2R	SN - 1 month	19.9**	-0.64(NS)	8.84
		SN - 3 months	18.9**	-1.02(NS)	14.6
		LI - 3 months	0.0023**	-0.0002(NS)	0.014
M2	1R	SN - 1 month	27.2**	4.7*	8.80
		SN - 3 months	26.4**	-0.81(NS)	9.32
		LI - 3 months	0.0046**	0.001(NS)	0.0044
	2R	SN - 1 month	15.01**	2.59*	6.16
		SN - 3 months	39.5**	1.08(NS)	9.75
		LI - 3 months	0.0021**	0.000(NS)	0.0058

Table 4. Genetic variance component, error coefficient of variation (cv, %), and heritability for cane yield (t/ha) in the ratoon crops for each trial.

Trial	Genetic variance	cv	Heritability
1st ratoon crop			
M1-C	172.0**	19.6	0.51
M1-T	98.0**	21.0	0.49
M1-W	150.5**	16.7	0.78
M2-C	107.1**	15.6	0.58
M2-T	77.2**	17.7	0.64
F1	300.0**	18.6	0.63
F2	281.0**	27.5	0.38
F3	253.5**	15.7	0.81
2nd ratoon crop			
M1-C	-14.1	31.9	0.0
M1-T	124.2*	30.3	0.35
M1-W	251.1**	21.3	0.71
M2-C	289.5**	18.3	0.69
M2-T	113.5**	25.9	0.42

Analyses of variance were done separately for cane yield at harvest in the M1 and M2 sets of trials. For both sets, and in both first and second ratoon crops, genotypic variance was highly significant ($P<0.01$, Table 5). However, genotype x trial variance was not significant in either the M1 or M2 trials, in either the first or second ratoon crops. This indicates that the traffic impact and waterlogging did not cause substantially different responses among the varieties to those expressed under the control conditions. Similar responses were observed for both the six commercial varieties and the other experimental material (Appendix 1). For example, in the M2 trials, the six commercial varieties had an average cane yield in the traffic trial that was 64% of that in the control trial, while the comparative figure for the other experimental material was 67%. Clearly, the significant genotype x trial interactions observed for early growth in some cases (Table 3) did not translate to significant effects on final cane yields.

Table 5. Genotypic and GE interaction variance components from analyses of variance of cane yield (t/ha) within crops for the M1 and M2 sets of trials.

Trial	Crop	Genotypic variance component	G x trial variance component	Error variance component
M1	First ratoon	121.7**	19.3 (NS)	190.0
	Second ratoon	62.7**	40.6 (NS)	396.4
M2	First ratoon	88.6**	7.25 (NS)	118.6
	Second ratoon	198.7**	14.5 (NS)	282.0

Results from analyses of variance across trials and crop-years within each of M1 and M2 trials are shown in Table 6. In both sets of trials there was highly significant variation due to genotype main effects and to genotype x crop interaction. For the M1 trials, there was significant variation due to genotype x trial interaction, although the variance component was small relative to the other sources of variation. However, of particular significance for both the M1 and M2 trials was the absence of significant variation due to genotype x trial x crop interaction. This shows that differences among genotypes between trials did not differ between the plant crop (before treatments were imposed) and ratoon crops. In the M1 set of trials, the significant genotype x trial interaction was probably therefore due to genotype x site effects.

Table 6. Variance components from analyses of variance of cane yield (t/ha) across trials and plant and first ratoon crop-years within the M1 and M2 sets of trials, and across all trials (M1 + M2 + farm trials).

Variance component	M1 trials	M2 trials	All trials
σ_g^2	125.0**	151.2**	155.0**
σ_{gt}^2	33.7**	5.2 (NS)	61.2**
σ_{gc}^2	98.0**	33.3**	42.0**
σ_{gtc}^2	40.4 (NS)	-3.5 (NS)	10.5 (NS)
σ_e^2	336.0	241	355.1

A similar result was apparent from a pooled analysis of cane yield in the plant and first ratoon crops across all eight trials (Table 6). While significant variety x trial interaction was evident, there was no significant ($P<0.05$) genotype x trial x crop-year interaction. This again indicates that responses specific to particular trials did not vary significantly between crop cycles. The different post-harvest conditions therefore appeared to have little or no effect on affecting yield responses among genotypes in the ratoon crops.

4. DISCUSSION

A key finding of this research was that there was a high genetic correlation between ratoon performance after harvesting under dry conditions compared with conditions where severe traffic impact was imposed. This was indicated by the absence of GE interaction between adjacent trials with contrasting conditions at harvest. This was despite the apparently large detrimental effects of the traffic treatments on ratoon growth generally and was contrary to expectations at the outset of the research. These findings indicate that indirect selection for ratooning performance after dry harvesting conditions would be effective for improving performance after much wetter harvesting conditions at the same site.

These results further imply that in screening diverse sugarcane clones for superior ratooning under adverse and wet conditions, it is unnecessary to incorporate environments involving wet harvesting conditions to make good selection gains. With the genetic and genotype x site interaction components being of greatest importance in the analysis of variance across all trials and crop cycles, it would appear that selection for broad or specific adaptation to sites is the key pathway to improved ratoon performance for ratooning after adverse harvesting conditions at those sites.

These results also indicate that there is probably limited genetic variation in response to specific stresses imposed by mechanical harvesting under wet conditions among a diverse set of sugarcane germplasm. Genetic variation to responses to other factors, such as site-specific constraints is probably larger and could offer easier pathways to genetic improvements in ratoon performance. This is consistent with other research on GE interactions in sugarcane in Australia (eg. Jackson and Hogarth, 1992; Mirzawan et al, 1993). At the commencement of this research we expected that some of the material closely related to *S. spontaneum* may have exhibited superior performance after the adverse harvesting treatments. Further, it had been suggested that such material could form the basis of a focused breeding program aiming to develop varieties more suitable than existing cultivars for mechanical harvesting under wet conditions. However based on results obtained in this research it would appear that progress in a breeding program with this specific aim would be difficult to achieve.

Despite the absence of significant GE interaction between control and traffic treatments at final harvest, there was some GE interaction for early tillering and canopy development. The fact that these early differences did not translate to final yield suggests that compensatory mechanisms probably operated between early growth

and final harvest. For example, clones that did not produce as many tillers under the traffic treatment early on may have lost fewer stalks than other more profuse tillering clones, or may have produced larger stalks by final harvest.

The absence of general genetic variation in response to wet harvesting conditions found in this study does not preclude the possibility that differences among some individual sugarcane cultivars may exist, as is sometimes reported by canegrowers. Differences among commercial cultivars, where they exist, would be important to recognise; this information being useful in assisting optimal use and harvesting of those cultivars. Clearly, some degree of genetic variation is feasible and likely, given the diversity of genotypes that may be generated from breeding programs. The techniques developed and tested in the work reported here demonstrate an effective method for screening varieties in trials. The traffic and waterlogging treatments did not generate increased error variances, which suggested that the stresses imposed were able to be generated in a uniform way across the experimental plots using the techniques employed. The techniques used were also practical in that they were relatively easy and cheap to apply. In sugarcane breeding programs it may be useful to use such methods in one trial in the last stage of selection before release of varieties. This would allow ratooning performance of varieties under wet harvesting conditions to be evaluated against existing cultivars, and identification of varieties exhibiting exceptionally good or poor performance.

5. IMPLICATIONS AND RECOMMENDATIONS

The results obtained suggest that it would not be worthwhile conducting a breeding and selection program specifically targeting better ratooning after wet harvesting conditions. Similar results to those obtained in wet harvested trials are likely to be obtained from trials conducted under normal or dry conditions. Selection for superior performance at a particular site within existing core breeding programs is likely to offer similar selection gains. Material closely related to Saccharum spontaneum did not appear to offer significantly better responses to unfavourable ratooning conditions than more commercial type germplasm.

6. INTELLECTUAL PROPERTY ARISING FROM THE RESEARCH

There is no information or products arising from this research that relate to intellectual property rights.

7. LIST OF PUBLICATIONS ARISING FROM PROJECT

Jackson, P. Braunack, M., Peatey, T. and Foreman, J. 1996. Selecting varieties for better ratoon performance after wet harvesting. Proc. Aust. Soc. Sugar Cane Tech. Conf: 399-400.

Jackson, P., Braunack, M., Foreman, J. and Peatey, T. Genetic variation in sugarcane for ratooning after harvester damage (compaction) in wet soil. Submitted to Crop Science.

Braunack, M. and Peatey, T. Changes in soil physical properties after one pass of a sugarcane haulout unit. (in preparation).

8. ACKNOWLEDGMENTS

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Appendix 1. Bulk density changes after traffic impacts.

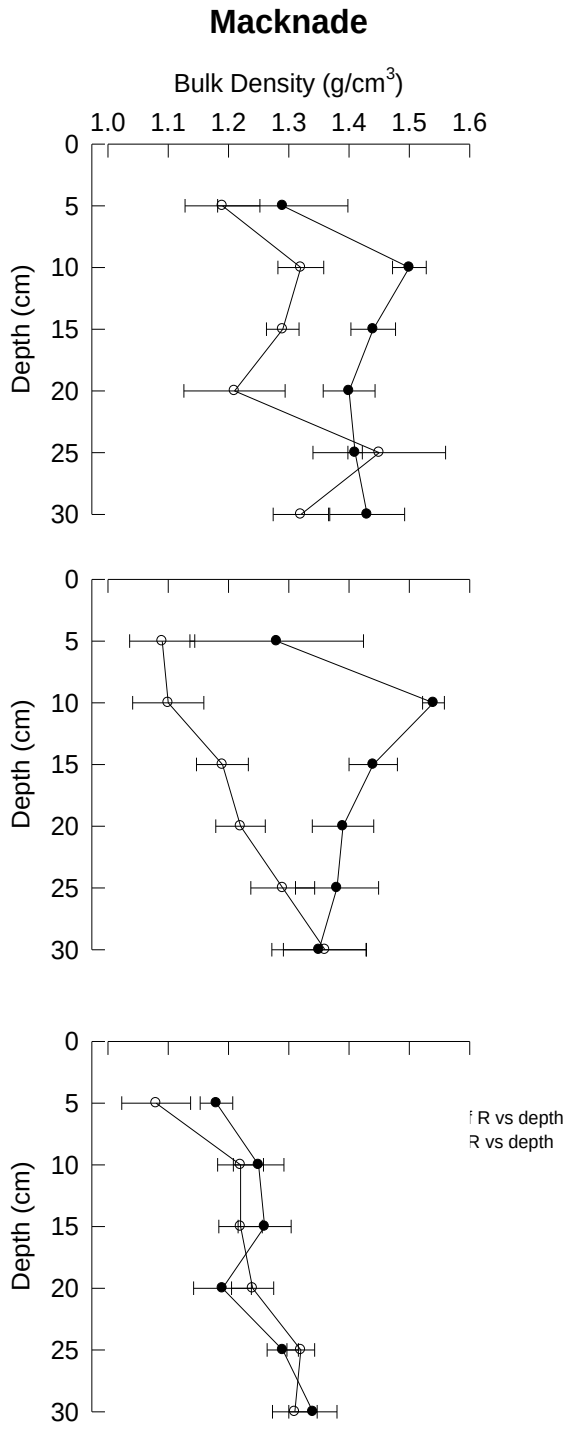

Figure A1.1. Bulk densities at the Macknade trials before (clear markers) and after (filled markers) traffic impact for the waterlogged trial (top), the two traffic trials (middle), and the two control trials (bottom). Horizontal bars indicate standard errors.

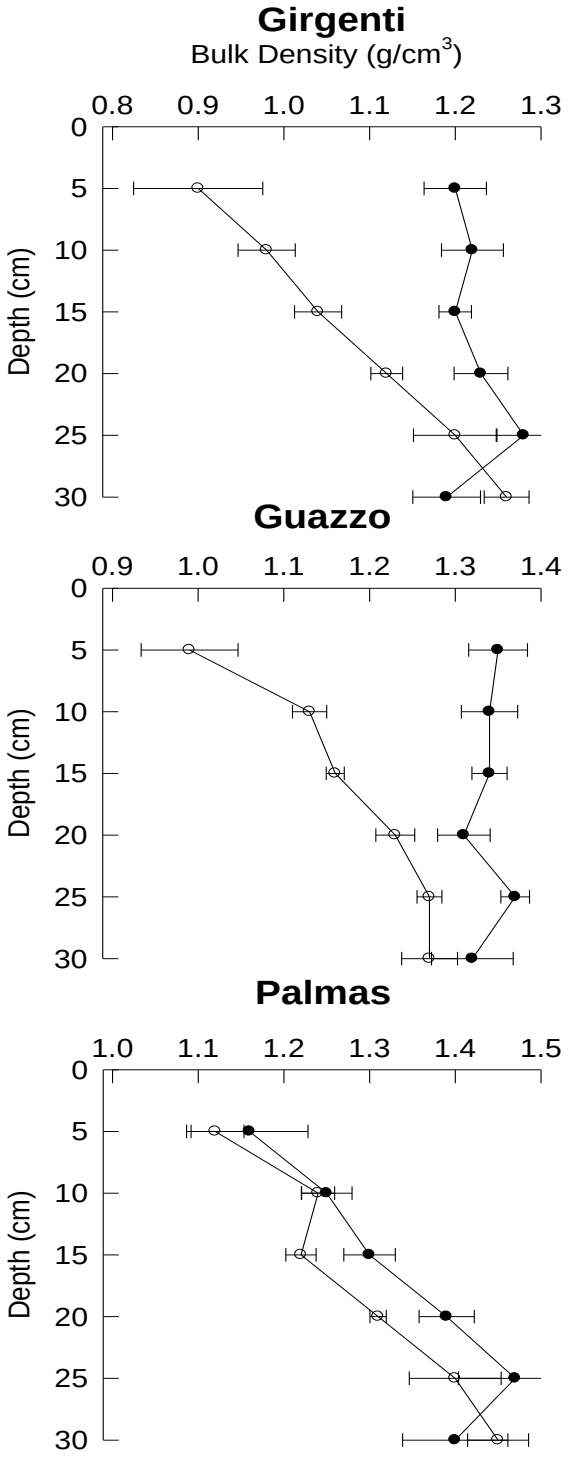

Figure A1.2 Bulk densities before (clear markers) and after (filled markers) traffic impact at the three farm trials. Horizontal bars indicate standard errors.

Appendix 2. Mean cane yield (t/ha) of each variety in each trial x crop-year. Least significant differences (P<0.05) are shown for each trial x crop-year. Codes for trials and crop years were shown in Table 2. Averages are given for all experimental varieties (experimental), commercial varieties (commercials) and for the whole set of varieties.

Table A2.1 Cane yields for entries in the M1 trials. P, 1R and 2R refer to plant, first ratoon and second ratoon crops, respectively.

Entry	M1C-P	M1T- P	M1W-P	M1C-1R	M1T-1R	M1W-1R	M1C-2R	M1T-2R	M1W-2R
BN78-8031	122.4	132.1	159.4	77.6	67.3	75.5	62.3	49.8	51.1
LF65-3660	97.0	74.5	93.9	42.4	32.1	32.4	93.0	34.6	28.0
MQ66-99R	101.2	74.6	95.8	66.4	61.2	64.0	77.7	81.3	83.8
MQ78-858	100.0	142.4	119.4	71.5	67.9	65.2	103.0	68.3	52.7
MQ79-141	107.0	84.3	97.3	90.6	70.9	83.4	73.6	95.0	75.7
MQ84-19B	163.3	112.4	146.1	131.3	87.6	88.7	88.9	72.9	81.9
MQ84-29B	160.0	114.6	114.5	79.1	77.3	55.2	92.0	77.5	86.7
MQ84-5B	107.3	121.2	107.3	90.9	60.7	79.4	85.2	82.7	61.3
MQ86-31B	80.0	94.9	128.2	68.5	44.6	60.9	64.8	55.4	52.4
MQ88-1068	151.5	82.7	84.7	113.1	72.7	57.8	76.9	54.8	59.2
MQ88-1084	87.3	67.6	68.7	74.6	42.5	49.1	91.9	50.5	41.7
MQ88-1160	162.1	114.5	111.9	114.3	70.9	74.5	95.8	50.7	55.3
MQ88-1802	70.9	78.5	88.7	70.0	66.1	58.0	113.5	93.5	68.0
MQ88-808	153.3	140.6	143.0	84.2	61.2	66.1	73.5	73.5	55.2
MQ88-833	168.2	134.6	148.3	86.4	60.9	76.3	62.9	84.8	69.2
MQ88-841	126.7	87.9	99.0	96.1	67.5	74.7	93.1	78.2	76.7
MQ88-846	68.5	164.2	130.9	71.5	100.0	81.8	101.5	93.5	74.6
MQ88-859	92.1	104.6	66.7	84.8	65.5	65.8	77.9	64.1	80.8
MQ88-920	93.3	96.7	87.0	69.1	49.7	62.2	77.2	64.9	74.5
MQ88-981	97.8	74.6	82.4	85.2	51.2	50.9	74.8	60.5	51.9
EXP'S	115.5	104.9	108.7	83.4	63.9	66.1	84.0	69.3	64.0
NCO-310	112.1	137.6	108.5	85.8	84.2	73.3	64.2	103.1	81.9
Q115	46.0	108.2	109.3	85.5	69.1	52.9	70.3	52.9	80.9
Q117	113.8	140.3	128.7	109.3	86.1	62.2	93.2	50.4	58.9
Q124	122.8	92.1	137.0	105.5	56.4	78.2	88.8	40.3	65.1
Q138	153.1	141.2	150.7	104.6	77.3	78.4	101.0	77.1	108.3
TRITON	117.6	126.0	131.6	118.6	87.9	70.2	109.1	110.8	63.7
COMMCLS	110.9	124.2	127.6	101.5	76.8	69.2	87.8	72.4	76.5
AVERAGE	114.4	109.3	113.0	87.6	66.9	66.8	84.8	70.0	66.9
lsd	40.7	40.5	47.5	29.3	22.9	18.2	44.9	34.8	23.4

Table A2.2. Cane yields (t/ha) for entries in the M2 trials.

Entry	M2C-P	M2T-P	M2C-1R	M2T-1R	M2C-2R	M2T-2R
BN78-8031	114.0	82.5	76.7	47.4	81.0	50.2
LF65-3660	57.5	53.0	49.4	32.4	60.6	60.5
MQ66-99R	59.5	53.0	60.4	50.3	93.7	69.6
MQ78-858	76.5	69.5	71.7	47.4	82.8	56.4
MQ79-141	95.5	76.0	77.7	45.0	78.7	59.2
MQ84-19B	73.0	91.5	76.7	52.0	81.3	57.5
MQ84-29B	114.5	100.5	96.0	59.0	98.0	88.6
MQ84-5B	74.5	68.5	68.3	53.0	68.3	56.4
MQ86-31B	65.5	47.5	65.7	45.4	65.3	50.8
MQ88-1068	99.0	94.5	73.7	59.0	119.1	56.0
MQ88-1084	84.0	67.5	70.0	51.7	75.7	59.8
MQ88-1160	99.0	91.0	79.0	61.0	66.6	51.6
MQ88-1802	76.5	67.5	72.3	65.4	62.7	51.9
MQ88-808	86.0	68.0	77.3	48.7	83.1	73.9
MQ88-833	123.5	97.0	64.0	32.4	87.4	49.0
MQ88-841	101.0	88.5	96.0	60.0	86.9	109.3
MQ88-846	106.5	75.0	82.0	40.7	66.9	68.1
MQ88-859	97.0	88.5	90.4	57.0	108.8	69.4
MQ88-920	107.0	71.5	81.4	56.4	80.2	65.9
MQ88-981	56.5	83.0	53.4	31.0	58.8	42.9
EXP'S	88.3	76.7	74.1	49.7	80.3	62.3
NCO-310	108.5	70.5	93.0	47.3	88.2	89.5
Q115	106.5	99.0	89.0	60.0	128.4	87.1
Q117	113.8	85.8	93.3	65.0	86.0	71.8
Q124	108.5	79.5	80.7	66.0	118.4	83.3
Q138	111.0	85.0	89.7	69.4	113.3	88.2
TRITON	115.5	109.3	93.4	44.3	115.0	76.8
COMMERCIALS	110.6	88.2	89.8	58.7	108.2	82.8
AVERAGE	93.5	79.3	77.7	51.8	86.7	67.0
lsd	37.4	27.9	20.0	15.0	26.1	28.5

Table A2.3. Cane yield (t/ha) for entries in the farm trials.

Entry	GIR-P	GIR-1R	PAL-P	PAL-1R	GUA-P	GUA-1R
BN78-8031	85.3	106.0	46.9	80.1	101.3	90.2
LF65-3660	39.5	71.0	25.9	35.3	49.0	65.4
MQ66-99R	45.0	97.0	32.6	79.3	47.7	98.1
MQ78-858	81.0	96.0	32.2	56.6	93.0	105.1
MQ79-141	73.3	62.3	41.5	52.3	68.7	103.5
MQ84-19B	114.7	137.0	60.7	97.0	106.3	161.4
MQ84-29B	82.0	110.3	36.9	72.4	98.7	127.8
MQ84-5B	69.0	91.7	38.3	61.5	73.3	108.6
MQ86-31B	56.7	76.0	24.3	63.9	59.3	87.4
MQ88-1068	97.3	115.0	27.4	75.1	87.7	98.3
MQ88-1084	52.7	87.0	37.6	79.7	88.0	112.0
MQ88-1160	81.7	97.0	53.0	59.4	77.7	84.0
MQ88-1802	56.0	94.3	42.4	55.7	64.3	90.2
MQ88-808	88.0	107.3	31.5	70.0	77.7	128.0
MQ88-833	98.3	75.7	46.9	80.1	94.7	95.3
MQ88-841	91.7	97.3	46.5	68.0	96.0	95.3
MQ88-846	88.0	107.7	40.6	83.5	103.7	146.7
MQ88-859	93.7	99.0	54.5	87.6	113.3	128.2
MQ88-920	85.0	97.0	28.9	51.4	83.7	96.7
MQ88-981	59.3	101.7	40.5	56.7	66.7	74.5
EXP'S	76.9	96.3	39.4	68.3	82.5	104.8
NCO-310	84.3	102.7	28.2	54.4	80.0	105.5
Q115	89.0	94.0	24.8	44.9	92.7	115.1
Q117	116.5	106.3	48.1	64.1	87.7	128.8
Q124	111.2	135.2	57.6	76.6	119.3	127.1
Q138	134.7	102.0	54.5	68.6	115.7	94.0
TRITON	78.7	116.0	49.6	87.2	102.3	124.3
COMMERCIALS	102.4	109.4	43.8	66.0	99.6	115.8
AVERAGE	82.8	99.3	40.5	67.8	86.5	107.4
lsd	32.4	30.4	17.8	17.3	19.7	43.2