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SHORTENING THE SELECTION PROCESS FOR SUGARCANE

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SUMMARY

There is a need to shorten the selection process for sugarcane (*Saccharum* hybrids) in Mauritius in order to improve the efficiency of the varietal improvement programme. On average six to seven ratoon crops are grown in Mauritius and selection for ratooning ability is of major importance. The current selection cycle lasts around 15 years and ratooning ability is tested on five occasions. Data (estimates of sucrose content, cane and sugar yields) from the Mauritius Sugar Industry Research Institute's selection trials planted in 1986–90, representing 85 trials (9680 genotypes) in Stage 3 (one-line stage) and 141 trials (2620 genotypes) in Stage 4 (two-line stage) were analysed. It was hypothesized that 1st ratoon (1R) data in Stage 3 and 2nd ratoon (2R) in Stage 4 were effectively redundant and that the cycle could be shortened by two years without loss of precision. Repeatability estimates, between plant cane (P) and the mean of P and 1R (P + 1R) in Stage 3, and between (P + 1R) and the mean of plant cane, 1st and 2nd ratoon (P + 1R + 2R) in Stage 4, were found to be positive and highly significant for all characters indicating that the extra ratoon data were unnecessary.

Present and proposed selection scenarios were studied further using differential-selection methodology. The coincidence indices (CI) obtained with the two scenarios were extremely high (63–82% in Stage 3 and 91–96% in Stage 4) again indicating that the additional ratoon data were not cost effective. Realized gains from selection in Stage 4 based on (P + 1R + 2R) as opposed to (P + 1R) were shown to be small or even negative. The results concur extremely well with published data from Australia and the USA. It was therefore recommended that the cycle be reduced by two years and that the resources be more usefully allocated to test genotypes over more sites and more replicates.

INTRODUCTION

The current selection cycle for sugarcane at the Mauritius Sugar Industry Research Institute (MSIRI) lasts around fifteen years (from crossing to commercial release) and some varieties have been released after much lengthier testing periods. There is a necessity to shorten the time required for the development of varieties, without loss of information and without any decrease in precision, in order to improve the efficiency of the programme and to increase the productivity of growers. Traditional breeding methods have probably done more to improve productivity in sugarcane agriculture than any other discipline and the cost of investment in these procedures has given enormous returns. However, conflicting economic factors are now exerting pressure on breeding programmes to become more efficient and produce better varieties while reducing costs (Irvine, 1994).

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The difficulty of selecting superior genotypes from sugarcane progenies is well established (McIntosh, 1935). Selection efficiency is affected by numerous factors including: the genetic variability in the base population, environmental effects, genotype × environment (G × E), genotype × year (G × Y), genotype × environment × year (G × E × Y) interactions, competition effects, heritabilities of traits involved, the intensity of selection as well as the relationship between the character measured and commercial sugar yield. Many breeding programmes are inefficient with methodologies based strongly upon tradition, with little review of efficiencies (S. B. Milligan, personal communication). There is a propensity to be unnecessarily cautious and the decision to release a variety is ultimately one of comparing relative risks. The tendency in the Louisiana programme is to over-test varieties prior to release. Varieties are released based on 180–190 yield observations among at least ten locations and three years. In other crops, for example wheat, maize, soyabean, rice and cotton it is customary to use a quarter to a half this number of test plots (Milligan, 1994).

Evaluation across ratoon crops in a multi-stage selection programme significantly increases the time and resources needed for selection. It also contributes to a lengthy generation interval between crossing and selection of elite progeny for use as new parental lines (Jackson, 1992). The number of ratoon crops harvested commercially varies from none in parts of Java and Hawaii to fifteen or more in parts of Africa. In Mauritius six to seven ratoons are grown and about 85% of the cane crushed each year is ratoon cane. There are considerable varietal differences in ratoon performance, and selection for this character is a major objective in any programme where ratoon crops are important commercially. A cane yield decline of 10–15% in ratoons is a common phenomenon throughout the world. In the subtropics this decline is often of the order of 40% (Sundara *et al.*, 1992). This character is selected for indirectly through a limited sample of crop-years (crops and years are confounded and the combination of crops and years is referred to as crop-years) and the efficiency of this process is fundamental for the improvement of ratooning potential.

Limited resources are conserved whenever a phase of selection, location, generation or trait is removed from a plant breeding programme. Several sugarcane breeding stations have recently shortened their programmes. In Brazil (Copersucar) the time has been decreased from 16 to 13 years; Thailand already has an extremely short programme (7–8 years) and still seeks to shorten this further. In Queensland the programme has been cut down to 8–9 years by de-emphasizing evaluation in ratoons (Cox and Hogarth, 1993). The Florida (Canal Point) sugarcane programme averages 9–10 years and its philosophy is to shorten the generation time as much as feasible by returning promising selections to the breeding programme as rapidly as possible (Miller, 1994). The Louisiana Agricultural Experiment Station programme was shortened recently from 14 to 12 years from cross to release. The programme could be shortened further with no loss of information or additional resource demands. It could be shortened even further if resources were increased or additional risks were assumed (S. B.

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Milligan, personal communication). The cost to an industry associated with a longer evaluation programme should also be considered. This evaluation should include not only the direct costs of the programme but also the costs to the industry of delaying the release of superior varieties.

In Mauritius ratooning ability is currently studied on five separate occasions in the selection cycle (Fig. 1) namely at the single-line stage (Stage 3), the double-line stage (Stage 4), and in three different series of variety trials, T1, T2, and T3. It was hypothesized that this amount of testing was excessive and that ratooning ability should be studied in detail only in the final phase of selection when increased precision is obtained through larger plot sizes and higher numbers of replicates. The possibility of shortening the duration of these variety trials is also under consideration but is beyond the scope of this paper. This study aimed to determine whether testing for ratooning ability could be reduced to a minimum in the preliminary stages of selection without undue loss of information.

MATERIALS AND METHODS

Trial designs and procedures

Data were used from MSIRI selection trials (planted 1986–90). These represented 85 trials and 9680 genotypes in Stage 3 and 141 trials and 2620 genotypes in Stage 4. Details of trial designs and procedures for selection at MSIRI were described by Lalouette (1968). Around 2000 genotypes are normally planted each year in Stage 3 trials. Genotypes are tested in up to three environments at this stage depending upon the availability of planting materials. Superior genotypes are identified on the basis of their kilobrix (an estimate of sugar yield) values in the plant cane (P) and 1st ratoon (1R) crops and around 500–750 genotypes are promoted to Stage 4 each year. From Stage 4 around forty genotypes are selected for promotion to variety trials on the basis of kilobrix performance in plant cane, 1st and 2nd ratoon crops (2R).

In Stage 3 genotypes are planted over one line of 5 m and are compared with a single commercial control variety in an unreplicated rows-and-columns design. In Stage 4 genotypes are planted over two lines of 5 m together with several commercial controls in classical lattice designs or randomized complete blocks with two or three replicates.

Description of data

Field Brix (an estimate of sucrose content) was measured using a hand refractometer in either June–July or September. All plots were harvested manually sometime between July and October (Table 1) and the cane yield (t ha^{-1}) was measured on a field balance. Kilobrix (an estimate of sugar yield) was calculated as the product of field Brix and cane yield (t ha^{-1}).

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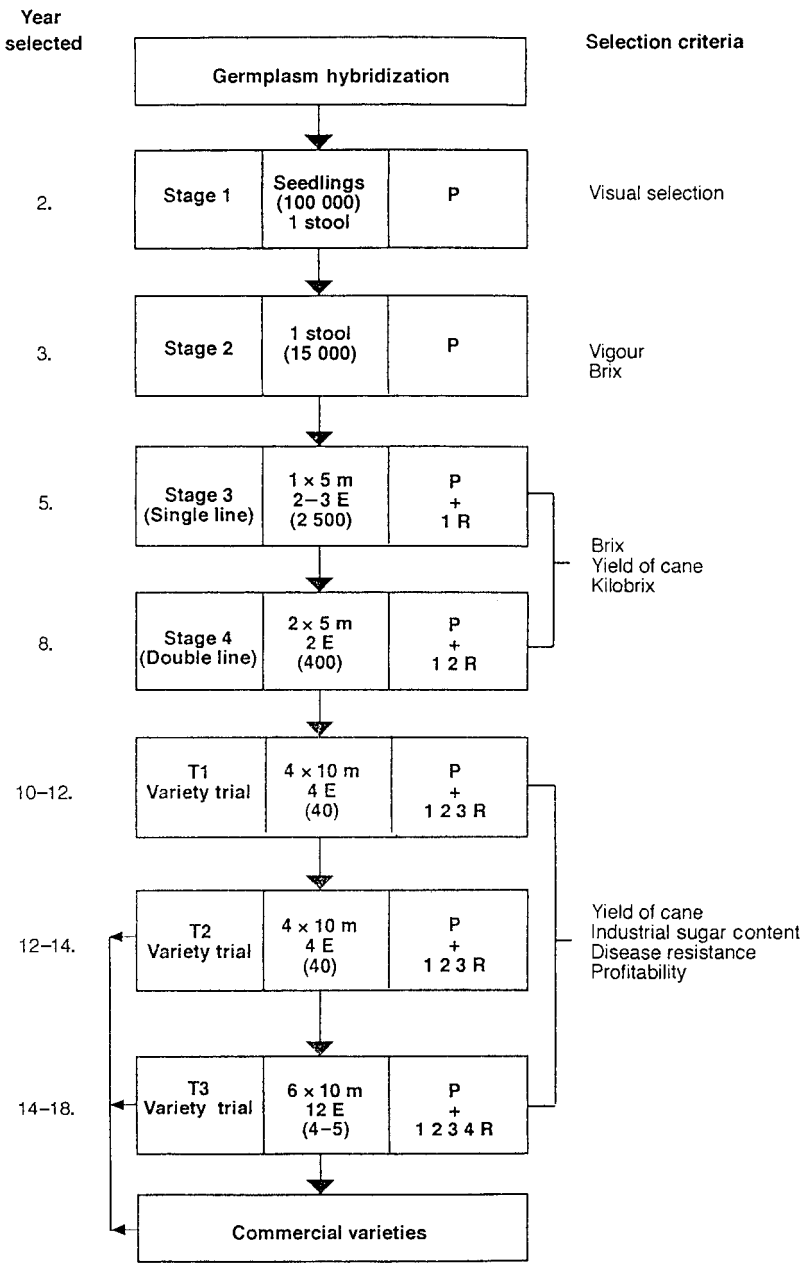


Fig. 1. The selection programme at the Mauritius Sugar Industry Research Institute. Figures in parentheses are number of genotypes tested; plot sizes are given as number of rows × length of row (m); P = plant cane; R = ratoon; E = environment.

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Table 1. Dates of sampling for field Brix and yield of cane in Stages 3 and 4 of selection.

Stage	Crop	Brix 1986–89	Brix 1990–	Yield of cane 1986–
3	Plant cane (P)	September	June–July	September
3	1st ratoon (1R)	June–July	June–July	August
4	Plant cane (P)	September	June–July	September–October
4	1st ratoon (1R)	September	June–July	September–October
4	2nd ratoon (2R)	June–July	June–July	July

Statistical methods

In the Stage 3 trials only the values of control varieties are used in an analysis of variance. Following this analysis of the controls the experimental genotypes are assessed by comparison with an appropriate mean value of the controls depending upon the significances of the rows and columns. The significance of the difference between the genotype under consideration and the mean of the controls (t) is calculated for each genotype for each character according to the methodology of Lalouette (1968). This method was developed for use with a large number of genotypes. The probability associated with the t value is related to an l.s.d. value such that a 75% selection probability is equivalent to an l.s.d.$_{0.25}$. For each genotype in each individual crop-year and in various combinations of crop-years (cumulative crop cycles) the values (mean value across replicates in Stage 4) of field Brix, cane yield and kilobrix, together with the selection probabilities associated with each of these three characters were studied.

Phenotypic correlation coefficients when measured on the same plots on different occasions are referred to as individual repeatability estimates (Mariotti, 1980). Repeatability estimates were calculated using GENSTAT for all combinations of crop-years, for Brix, cane yield and kilobrix values and probabilities for both selection stages, pooled over trials within years (for example, Table 3, Brix 1R *vs*. P + 1R, the value of 0.83 is obtained by pooling all six trials from the year 1986) and then pooled over trials and years (for example, Table 3, 0.81 is the mean of the pooled values from 1986 to 1990).

A differential-selection analysis was used to show the differences between two selection scenarios. This analysis divides the population into four quadrants depending upon selection or rejection in two different situations; in this instance different crop-years are shown in Table 2. This analysis is similar to the coincidence index (CI) of Mariotti (1980). The CI is calculated as the sum of the RR and SS quadrant percentages (Table 2). Differential selection was studied, using kilobrix probabilities of either 50% or 75% as the selection criterion, pooled over trials within years and pooled over trials and years for various combinations of crop-years for Stages 3 and 4.

Elite genotypes in Stage 4 were studied by ranking the genotypes on the basis of their mean kilobrix values in plant cane and 1st ratoon (P + 1R) and in plant

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Table 2. Differential selection quadrants.

	Selection in one crop-year	
	Reject	Select
Selection in another crop-year		
Reject	RR	RS
Select	SR	SS

Coincidence index (CI) = RR + SS.

cane, 1st and 2nd ratoon (P + 1R + 2R). The selected group in each case consisted of the top fifteen genotypes.

Realized responses to selection were calculated according to the methodology of Jackson (1992). The difference between the mean of the selected genotypes and the grand mean (kilobrix t ha^{-1}) was taken to be the gain due to selection. Realized responses to selection were calculated as the difference between the gain obtained for the current practice (P + 1R + 2R) and that of the proposed practice (P + 1R). As forty genotypes are generally promoted to variety trials from Stage 4 each year the performance of the top forty genotypes was used to calculate the gain.

RESULTS

Repeatability at Stage 3

All the repeatability estimates for Stage 3 (Table 3) were positive and highly significant. The repeatability estimates pooled over trials within years for Brix and Brix probability (P *vs.* 1R) were, however, rather low. The weak relationship between the Brix values in these crop-years is likely to be due to differences in the dates of sampling for Brix (Mamet *et al.*, 1996) as prior to 1990 the sampling date for plant cane was September whereas the 1R was sampled either in June or July (Table 1). Post 1990 both crop-years were sampled either in June or July and this change is reflected in the higher repeatability found for 1990. The estimates for cane yields were higher than those for Brix which reflects the fact that differences in sampling dates (in the different crop-years) have more influence on sucrose content than on yields of cane.

It was hypothesized that selecting on the basis of plant cane instead of on the cumulative P + 1R results would be more efficient and it was important therefore to establish that the repeatability between P and P + 1R crop-years was sufficiently high. Although autocorrelation effects were likely to have inflated the correlation coefficients somewhat, the relationships between these crop-years were all positive and highly significant. The repeatability values obtained for the 1R *vs.* P + 1R comparison were generally slightly higher than the corresponding P *vs.* P + 1R values but were not sufficiently different to merit consideration of selection on the basis of 1R alone. These results indicate that the gains from

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Table 3. Repeatability estimates between crop-years, Stage 3, 1986–90.

Year	Number of trials	d.f.	Field Brix			Cane yield			Kilobrix		
			P *vs.* 1R	P *vs.* P + 1R	1R *vs.* P + 1R	P *vs.* 1R	P *vs.* P + 1R	1R *vs.* P + 1R	P *vs.* 1R	P *vs.* P + 1R	1R *vs.* P + 1R
1986	6	656	0.51	0.89	0.83	0.51	0.79	0.93	0.49	0.80	0.92
1987	24	1993	0.26	0.84	0.71	0.64	0.88	0.93	0.66	0.91	0.92
1988	20	2379	0.37	0.74	0.84	0.42	0.80	0.88	0.40	0.82	0.85
1989	15	1719	0.22	0.71	0.80	0.55	0.83	0.93	0.52	0.82	0.92
1990	20	2517	0.61	0.92	0.86	0.53	0.85	0.90	0.53	0.85	0.90
Pooled 1986–90	85		0.39	0.82	0.81	0.53	0.83	0.91	0.52	0.84	0.90
Year	Number of trials	d.f.	Brix probability			Cane-yield probability			Kilobrix probability		
			P *vs.* 1R	P *vs.* P + 1R	1R *vs.* P + 1R	P *vs.* 1R	P *vs.* P + 1R	1R *vs.* P + 1R	P *vs.* 1R	P *vs.* P + 1R	1R *vs.* P + 1R
1986	6	656	0.23	0.63	0.70	0.41	0.61	0.86	0.44	0.64	0.87
1987	24	1993	0.27	0.75	0.65	0.36	0.76	0.81	0.34	0.78	0.76
1988	20	2379	0.21	0.60	0.72	0.42	0.77	0.81	0.41	0.79	0.79
1989	15	1719	0.33	0.66	0.77	0.45	0.75	0.87	0.44	0.75	0.84
1990	20	2517	0.37	0.83	0.71	0.49	0.78	0.85	0.46	0.78	0.85
Pooled 1986–90	85		0.28	0.70	0.71	0.43	0.73	0.84	0.42	0.75	0.82

Table 4. Differential selection, Stage 3 (pooled 1986–90).

Selection criterion Kilobrix probability ⩾50%							Selection criterion Kilobrix probability ⩾75%						
Plant cane \ 1st ratoon	Reject		Select				Plant cane \ 1st ratoon	Reject		Select			
	No.	%	No.	%	Total	CI		No.	%	No.	%	Total	CI
Reject	3049	32.8	831	9.0	3880	62.3	Reject	4681	50.4	736	7.9	5417	66.0
Select	2669	28.8	2734	29.5	5403		Select	2416	26.0	1450	15.6	3866	
Total	5718		3565		9283		Total	7097		2186		9283	
Plant cane \ P + 1R	Reject		Select				Plant cane \ P + 1R	Reject		Select			
	No.	%	No.	%	Total	CI		No.	%	No.	%	Total	CI
Reject	3407	36.5	503	5.4	3910	78.3	Reject	4981	53.4	474	5.1	5455	80.6
Select	1521	16.3	3902	41.8	5423		Select	1338	14.3	2540	27.2	3878	
Total	4928		4405		9333		Total	6319		3014		9333	

CI = Coincidence index.

selecting in P + 1R as opposed to plant cane are likely to be minor but further analyses were required to validate this assertion.

Differential selection at Stage 3

The results of the differential selection analysis based on different selection scenarios are given in Table 4. The coincidence indices (CI) for the pooled analysis were similar for both selection pressures. The P *vs.* P + 1R analysis showed that this index was consistently around 80%. The CI for individual years (not presented) ranged from 70.2% to 81.1% for the analyses which used the 50% kilobrix probability and from 79.2% to 81.6% for the analyses using 75% probability. The genotypes falling in the quadrant RS merited closer study as these were the potentially good varieties that would be lost if genotypes were selected on the basis of plant cane data instead of P + 1R data. The progress of these varieties was traced in the variety trials but none of the genotypes was found to be outstanding; hence no potential commercial varieties were lost.

Repeatability at Stage 4

The results of the repeatability analysis for all the crop-years were again positive and highly significant (Table 5). The P + 1R *vs.* P + 1R + 2R results were very

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Table 5. Repeatability estimates between crop-years, Stage 4, 1986–90.

Year	Number of trials	d.f.	Brix					
			P *vs.* 1R	1R *vs.* 2R	P *vs.* 2R	P *vs.* P + 1R	P *vs.* P + 1R + 2R	P + 1R *vs.* P + 1R + 2R
1986	23	382	0.82	0.24	0.12	0.94	0.87	0.94
1987	30	583	0.63	0.41	0.21	0.92	0.79	0.90
1988	16	283	0.41	0.43	0.07	0.78	0.45	0.78
1989	42	711	0.71	0.63	0.56	0.91	0.86	0.97
1990	30	613	0.78	0.10	0.17	0.97	0.93	0.95
Pooled 1986–90	141		0.67	0.36	0.23	0.91	0.78	0.91
Year	Number of trials	d.f.	Cane yield					
			P *vs.* 1R	1R *vs.* 2R	P *vs.* 2R	P *vs.* P + 1R	P *vs.* P + 1R + 2R	P + 1R *vs.* P + 1R + 2R
1986	23	382	0.43	0.63	0.39	0.76	0.67	0.93
1987	30	583	0.66	0.77	0.65	0.89	0.85	0.98
1988	16	283	0.55	0.68	0.36	0.84	0.68	0.90
1989	42	711	0.47	0.68	0.49	0.86	0.79	0.95
1990	30	613	0.41	0.52	0.45	0.88	0.80	0.94
Pooled 1986–90	141		0.50	0.66	0.47	0.85	0.76	0.94
Year	Number of trials	d.f.	Kilobrix					
			P *vs.* 1R	1R *vs.* 2R	P *vs.* 2R	P *vs.* P + 1R	P *vs.* P + 1R + 2R	P + 1R *vs.* P + 1R + 2R
1986	23	382	0.38	0.68	0.32	0.77	0.64	0.93
1987	30	583	0.67	0.78	0.66	0.89	0.86	0.98
1988	16	283	0.53	0.68	0.41	0.84	0.71	0.92
1989	42	711	0.39	0.64	0.46	0.87	0.79	0.95
1990	30	613	0.40	0.38	0.37	0.87	0.81	0.93
Pooled 1986–90	141		0.47	0.63	0.44	0.85	0.76	0.94

highly related for all three characters. The results for the probabilities of the characters are not shown but for the P *vs.* P + 1R + 2R comparison the values ranged from 0.45 to 0.74 for Brix, from 0.63 to 0.73 for cane yield and from 0.63 to 0.73 for kilobrix whereas for the P + 1R *vs.* P + 1R + 2R comparison the values ranged from 0.83 to 0.91 for Brix, from 0.89 to 0.93 for cane yield and from 0.87 to 0.93 for kilobrix. These results indicate that the P + 1R and P + 1R + 2R data are highly similar and that even the plant cane data are highly correlated with the P + 1R + 2R data. Thus there is definitely little advantage in terms of information to be gained from 2nd ratoon results.

Differential selection at Stage 4

The results of the differential-selection analysis, based on the kilobrix results at 50% and 75% selection probabilities for the P + 1R and P + 1R + 2R crop-years are given in Table 6 for two individual crop-years (1989 and 1990) and the pooled results over years (1986–90). The other individual crop-years gave similar results. The CI for individual crop-years ranged from 88.4 to 91.4 at 50% and from 91.0 to 96.1 at 75%. Again the genotypes that occurred in the RS quadrant were studied in detail (genotypes which would be lost if the new practice were adopted). These genotypes represented between 2.4% and 4.2% of the genotypes planted in Stage 4 when the selection probability was 50% and between 1.8% and 3.1% when the selection probability was 75%. These genotypes were traced through the selection process but very few showed any promise in the later stages of selection. This further suggests that a large number of elite varieties would not be lost if selection at Stage 4 were based on P + 1R results.

Comparisons of selected genotypes

Elite genotypes were studied by ranking the genotypes on the basis of sugar yield (kilobrix) in P + 1R and P + 1R + 2R. Of the fifteen genotypes selected in P + 1R across all trials within years, between ten and twelve genotypes were also in the top fifteen in P + 1R + 2R.

Realized responses to selection

The results of this analysis are given in Table 7. In three of the five years studied the gain from planting the extra ratoon crop was negative. In the years where the gain was positive the values obtained were minor (less than one unit of kilobrix). These results are influenced by year effects and yield decline over ratoons.

DISCUSSION

As early as 1969 sugarcane breeders were interested in the repeatability between crop-years. Smith and James (1969) studied plant cane and 1R values of seedlings and obtained repeatability values of 0.61 for number of stalks, 0.55 for stalk diameter and 0.39 for Brix. Tai *et al.* (1980) estimated individual repeatability by the correlations between crop-years in Florida. They obtained the following

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Table 6. Differential selection, Stage 4 (1989, 1990 and pooled 1986–90).

Selection criterion Kilobrix probability ⩾50%							Selection criterion Kilobrix probability ⩾75%						
1989													
P + 1R \ P + 1R + 2R	Reject		Select				P + 1R \ P + 1R + 2R	Reject		Select			
	No.	%	No.	%	Total	CI		No.	%	No.	%	Total	CI
Reject	414	58.0	18	2.5	432		Reject	514	72.0	22	3.1	536	
Select	53	7.4	229	32.1	282		Select	42	5.9	136	19.0	178	
						90.1							91.0
Total	467		247		714		Total	556		158		714	
1990													
P + 1R \ P + 1R + 2R	Reject		Select				P + 1R \ P + 1R + 2R	Reject		Select			
	No.	%	No.	%	Total	CI		No.	%	No.	%	Total	CI
Reject	415	67.5	24	3.9	439		Reject	478	77.7	18	2.9	496	
Select	30	4.9	146	23.7	176		Select	31	5.0	88	14.3	119	
						91.2							92.0
Total	445		170		615		Total	509		106		615	
Pooled 1986–90													
P + 1R \ P + 1R + 2R	Reject		Select				P + 1R \ P + 1R + 2R	Reject		Select			
	No.	%	No.	%	Total	CI		No.	%	No.	%	Total	CI
Reject	1723	66.7	83	3.2	1806		Reject	2017	78.1	63	2.4	2080	
Select	175	6.8	603	23.3	778		Select	129	5.0	375	14.5	504	
						90.0							92.6
Total	1898		686		2584		Total	2146		438		2584	

CI = Coincidence Index.

highly significant repeatability values between plant cane and 1st ratoon values of Stage 3 (first replicated trial): these were 0.82 for stalk number, 0.88 for stalk cane yield, 0.84 for Brix, 0.70 for cane yield and 0.62 for sugar yield. They also stated that plant cane performance of Stage 3 gave very high predictability for the 1R crop of the same stage for all the characters measured. The present results confirm the close correlations between crop-years and indicate that the repeatability estimates are higher when cumulative crop-years are used. These results indicate

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Table 7. Realized gains from selection (kilobrix t ha^{-1}) based on gain P + 1R + 2R minus gain P + 1R.

Year	Mean P + 1R selected	Grand mean P + 1R	Gain P + 1R	Mean P + 1R + 2R selected	Grand mean P + 1R + 2R	Gain P + 1R + 2R	Realized response
1986	21.94	15.72	6.22	21.41	14.84	6.58	0.36
1987	28.74	16.53	12.21	27.03	15.49	11.54	−0.67
1988	15.50	11.13	4.37	16.89	11.82	5.07	0.70
1989	24.88	15.71	9.17	23.73	14.84	8.89	−0.29
1990	24.58	16.67	7.91	21.50	14.41	7.09	−0.82

clearly that the gains from including the 1R crop in Stage 3 and the 2R crop in Stage 4 in Mauritius are likely to be minor.

Jackson (1992) used two series of trials planted in two different years in Queensland, Australia and obtained moderate to high (>0.65) genetic correlations between sugar yield in plant cane and 1R and 2R (at the one-line stage) for most locations indicating a high degree of similarity between the crop-years. He also estimated the relative efficiency of selection (E) by using the following formula:

$$E = \left(\sqrt{(H_p/H_r)}\right) \times r_g$$

where H_p = Broad-sense heritability in plant cane
H_r = Broad-sense heritability in ratoon crop
r_g = genetic correlation between sugar yield in plant cane and ratoon crops.

He obtained an average relative efficiency of selection for yield in ratoon-crop years of 0.67 via indirect selection in the plant-crop year; this indicated that most ratoon information is redundant. The current differential-selection analyses indicated an extremely high degree of similarity between plant cane and P + 1R in Stage 3 (CI = 81%) and between P + 1R and P + 1R + 2R in Stage 4 (CI = 91%). In addition only a small percentage of genotypes fell in the RS quadrant which again indicates that the additional ratoon data are superfluous and that the proposed change in selection strategy would not cause the loss of many elite genotypes.

In the comparison of selected genotypes in the five sets of Stage 4 trials the coincidence of the performance ranks between P + 1R and P + 1R + 2R was very high (10–12 of the 15 genotypes). Similarly Jackson (1992) obtained a coincidence ranging from 11 to 12 genotypes in two series of trials between plant cane and the mean of P + 1R + 2R. These results concur extremely well and further indicate that ratoon crops provide similar information to that of plant cane.

Realized gains from selection based on the mean of P + 1R + 2R compared with selection on P + 1R in Mauritius were small or even negative and similar results were obtained by Jackson (1992). The three types of analysis used by

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Jackson (1992) all indicated that there would only be diminishing gains to be made by evaluating material beyond plant cane. Therefore he suggested that the testing of genotypes in plant cane alone may be appropriate in the early stages of selection in Australia.

This strategy may not be appropriate for highly selected populations (for example, variety trials), where genetic variance and genetic correlations between crop-years would be expected to be smaller. Ramdoyal *et al.* (1986) used data from 12 variety trials in Mauritius to look at the interrelationships between crop cycles. They found that plant cane was poorly correlated with individual ratoon crops (range of correlation coefficients: 0.30–0.44) compared with the relationships amongst ratoon crops (0.42–0.66) and that plant cane was least similar to the mean values across ratoons (cumulative results). Unfortunately all the trials were planted in the same year and crop cycles were confounded with years. Therefore these results must be viewed with caution.

Hogarth (1977) showed that competition for yield was particularly important in ratoon crops in Australia. He concluded that in the early stages of selection where small plots are generally used, increased competition in ratoon crops further reduces the advantage of evaluating material in ratoon crops. Most studies in Australia have shown clearly that G × E interactions are of major importance (approaching the magnitude of the main effects of genotypes), while genotype × crop (G × C) or G × Y interactions are of relatively minor importance (Jackson *et al.*, 1995). Thus there is a need to test varieties over sites not crop-years in order to maximize gains from selection. In Louisiana, Milligan *et al.* (1990) aimed to determine the relative importance of years, environments and crops in order to optimize resource allocation. Within a crop G × E variances tended to be larger than G × Y. Estimates of genetic advance potential of plant cane sucrose yields over years and environments implied that testing over environments could substitute for years, effectively reducing the time to identify elite clones. Analysis across crops showed G × C, G × E and G × Y × E interaction variances were usually larger than G × Y. Estimates of genetic advance showed no difference in potential from replicating across years or across crops.

Jackson and Hogarth (1992) used cluster analysis and principal component analysis in order to design efficient selection methods and to evaluate the relative importance of testing across locations and crop-years. Crop-years within sites were generally more similar for genotypic responses than environments from different sites. They therefore concluded that there is limited gain in testing across multiple crops or years within a particular site. They also suggested that the characterization of ratooning performance on the basis of evaluation at one or a few randomly chosen sites is therefore probably ineffective. They further suggested that selection for ratooning response should involve careful consideration (or even manipulation) of the environmental factors that are important in causing differences among genotypes in ratooning response (for example, wet conditions at harvest). In addition they showed that G × E interactions were due mainly to differences in

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soil nutrient levels rather than to factors such as moisture deficits that vary between years.

CONCLUSIONS

The results of this study suggest that the selection cycle in Mauritius could be shortened by two years and that the preliminary stages of selection could be completed after six years of testing. Stage 3 could be selected on the basis of plant cane instead of P + 1R results whereas Stage 4 could be selected on the basis of P + 1R instead of P + 1R + 2R. The recycling of genotypes as parents could also be done two years earlier which would improve considerably the additive genetic gain per year. The resources released could be more usefully allocated to test varieties in more environments with more replicates which would improve considerably the efficiency and precision.

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REFERENCES

Cox, M. C. & Hogarth, D. M. (1993). Progress and changes in the South Queensland variety selection program. *Proceedings Australian Society of Sugar Cane Technologists* 15:251–255.

Hogarth, D. M. (1977). Quantitative inheritance studies in sugar cane. 1. Estimation of variance components. *Australian Journal of Agricultural Research* 22:93–102.

Irvine, J. E. (1994). Changes in sugarcane breeding. *Sugar Journal* December.

Jackson, P. A. (1992). Genotype × environment interactions in sugarcane. II. Use of performance in plant cane as an indirect selection criterion for performance in ratoon crops. *Australian Journal of Agricultural Research* 43:1461–1470.

Jackson, P. A. & Hogarth, D. M. (1992). Genotype × environment interactions in sugarcane. I. Patterns of response across sites and crop-years in North Queensland. *Australian Journal of Agricultural Research* 43:1447–1459.

Jackson, P., McRae, T. & Hogarth, M. (1995). Selection of sugarcane families across variable environments. II. Patterns of response and association with environmental factors. *Field Crops Research* 43:119–130.

Lalouette, J. A. (1968). Breeding of sugar cane varieties in Mauritius. *Proceedings of the International Society of Sugar Cane Technologists* 13:1062–1067.

Mamet, L. D., Julien, M. H. R. & Galwey, N. W. (1996). Earliness of ripening in sugar cane (*Saccharum* spp. L.) in Mauritius: variation and inheritance studies. *Sugar Cane* 4 July/August.

Mariotti, J. A. (1980). Clonal selection across environments on sugar cane. *Proceedings of the International Society of Sugar Cane Technologists* 17:1142–1150.

McIntosh, A. E. S. (1935). *An Account of the Methods Employed in Testing and Selecting Sugarcane Seedlings for Thick-cane Areas in the British West Indies. Department of Science and Agriculture Barbados, Bulletin* 9. Bridgetown: Department of Science and Agriculture.

Miller, J. D. (1994). The philosophy of the Canal Point breeding program: major issues in the establishment of new breeding programs. *Sugar Journal* October.

Milligan, S. B. (1994). Test site allocation within and among stages of a sugar cane breeding program. *Crop Science* 34:1184–1190.

Milligan, S. B., Gravois, K. A., Bischoff, K. P. & Martin, F. A. (1990). Crop effects on broad-sense heritabilities and genetic variances of sugarcane yield components. *Crop Science* 30:344–349.

Ramdoyal, K., Domaingue, R., Fong San Pin, G. & Julien, M. H. R. (1986). Inter-relationships between

https://doi.org/10.1017/S0014479799354028 Published online by Cambridge University Press

different crops of a cane cycle and their impact on selection strategies in sugarcane. *Proceedings of the International Society of Sugar Cane Technologists* 19:447–453.

Smith, G. A. & James, N. I. (1969). Association of characters within and repeatability between years in progenies of four sugarcane crosses. *Crop Science* 9:819–821.

Sundara, B., Sankaranarayanan, P. & Batcha, M. B. G. R. (1992). Varietal characteristics affecting ratooning potential of sugar cane. *Sugar Cane* 6:1–4.

Tai, P. V. P., Miller, J. D., Gill, B. S. & Chew, V. (1980). Correlations among characters of sugarcane in two intermediate selection stages. *Proceedings of the International Society of Sugar Cane Technologists* 17:1119–1128.

https://doi.org/10.1017/S0014479799354028 Published online by Cambridge University Press