REFEREED PAPER

SCOPE FOR VARIETAL IMPROVEMENT TO EXTEND THE HARVEST SEASON IN MAURITIUS

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Abstract

In Mauritius, harvest extends from start-June to mid-December with low juice purity and low sucrose content early in the season. Extension of the harvest season within the centralisation of milling activities is exacerbating the situation. A study was implemented to further understand the physiological basis of ripening with the view of enhancing the breeding of better-performing genotypes for early season. This paper presents the outcome of the first to third ratoon crops of 16 contrasting varieties grown at Reduit (1500 mm rainfall) with supplementary irrigation to contain water stress and its resulting impact on dry matter partitioning.

Based on the proven parameter pol % dry matter of the cane portion (P%CDM) early in the season (April), four variety types were identified, namely Early with a P%CDM above 42%, Intermediate-Early with P%CDM between 40 and 42%, Intermediate-Late P%CDM between 30 and 40% and Late P%CDM below 30%. Compared to the late group, the early group tended to produce fewer tillers with smaller leaf area indices resulting in lower biomass accumulation potential. They, however, exhibited better partitioning efficiencies when allocating total biomass to cane as well as when allocating cane biomass to stored sucrose. The contrast between early and late varieties proves that varieties can be bred for both the early part as well as the late part of the harvest season, such that extension of the season with varieties combining yield and quality can be contemplated.

Keywords: sugarcane, ripening behaviour, early harvest

Introduction

In Mauritius, the harvest period extends from the start of June to mid-December with low juice purity and low sucrose content early in the season. Centralisation of milling activities associated with limits on investments in milling capacity demands that the milling season be extended to earlier than June and later than mid-December. Starting harvesting earlier than June is better than extending the harvest period to after mid-December as, in the latter case, the tillering phase would be delayed such that the duration of the elongation phase will be reduced (Koonjah *et al.*, 2008). Presently, there are very few commercial varieties that exhibit high sucrose contents early in the season (Mamet and Galwey, 1999). Additionally, analysis of long-term records (1947 to 2010) has revealed an increasing trend in the seasonal average of fibre % cane (F%C) and a decreasing trend in the pol % cane (P%C) (Figure 1). Research has shown that artificial ripening can improve sucrose content (Cheeroo-Nayamuth, and Nayamuth, 2008). However, the operation has some logistical challenges.

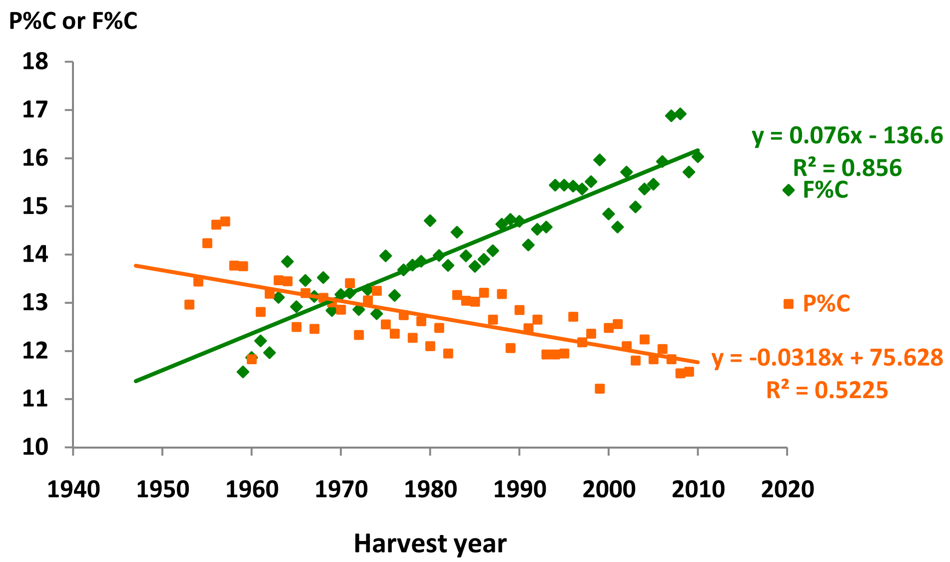

Figure 1. Trend in seasonal sucrose (P%C) and fibre (F%C) contents.

Physiological studies to select early maturing varieties have been reported (Herbert and Rice, 1971; Bond, 1982; Cuenya and Mariotti, 1986; Legendre, 1995; Lo and Chen, 1995; Cox *et al*., 1998). Breeding for earliness was reported to be successful in Argentina (Cuenya and Mariotti, 1986) and Australia (Cox *et al*., 1990; Mc Donald and Wood, 2001). Varieties tend to peak to maximum sucrose at different times of the year with seasonal fluctuations (Gosnell and Koenig, 1972; McDonald and Wood, 2001). In Mauritius, peak sucrose content is normally recorded around October, while the best time to assess earliness would be during the exponential phase of growth around April and May when higher genetic variability is expressed (Cuenya and Mariotti, 1986).

In Mauritius, studies on ripening behavior of a set of contrasting varieties revealed that early varieties tended to produce higher numbers of shorter phytomers, lower LAI and exhibited lower biomass accumulation potential (Cheeroo-Nayamuth *et al.*, 1994). The study also confirmed that the selection for earliness characteristic is optimal if carried out early in the season. Study of the sucrose content of a wider number of parents comprising both the Mauritian and foreign varieties were collected at the start of the harvest period and at mid-season in 2000, using pol % cane dry matter (P%CDM) as the selection criteria. The results revealed four contrasting sucrose accumulation patterns reported as precocious (3.5%), early (14.9%), high sucrose (32.3%) and late types (49.3%) (MSIRI, 2001).

This study was therefore implemented with the main objective of gaining an insight into the physiological basis of ripening with the view to enhancing the breeding and selection of better-performing early varieties and thus ensuring acceptable sucrose contents early in the harvest season.

Materials and Method

The trial was planted in 2002 at Réduit, characterised by a low humic latosol (L2) (Parish and Feillafé, 1965) and with an annual rainfall of 1464 mm (1971 to 2000 average). The trial design adopted was a split plot with three replicates, with harvest date as main plot and variety as sub-plot. The plot size was 16 m^2 (one row 10 m long with row spacing of 1.6 m). Sixteen varieties exhibiting contrasting ripening behaviour (Table 1) were selected for the study. Fertilisation was carried out with compound fertiliser 17:8:25 (N:P:K) at the rate of 1 t/ha. Supplementary irrigation, pending availability, was adopted to eliminate the confounding effect of water stress on ripening.

Table 1. Ripening behaviour of varieties selected for the study.

Precocious	Early	High sucrose	Late
CP 70321	CP 65357	CP 72370	M 937/77
CP 721210	M 33/82	M 1197/77	N 9
M 2597/79	NA 6390	M 2343/77	R 570
M 744/70	Q 96	M 587/70	
	SP 703770		

Agronomy data collection and analysis were carried out on a monthly basis for stalk density, stalk height, phytomer production and leaf size. Leaf area index (LAI) was determined from locally-derived regression analysis (Mongelard (1968). The trial was harvested at three dates, namely mid-May (H1), mid-August (H2) and mid-November (H3) which corresponded to early, mid and late season. Pre-harvest samples were taken at 6 weeks prior to each harvest (at 46 wks of age), i.e. first week of April (PH1), first week of July (PH2) and first week of October (PH3).

At pre-harvest sampling and at harvest, analysis was based on six whole cane stalks per variety from which the number of green leaves, the number of visible internodes and the stalk height were recorded. The stalk was topped at the apex and was separated into stem, green leaves, dry leaves and cabbage (leaf sheath and immature top of stalk). The stem was pulverised in a Jeffco cutter-grinder. The stem portion was then analysed for quality characters, namely pol % cane (P%C), brix % cane (Bx%C) and fibre % cane (F%C) by the method of De Saint Antoine (1968). Juice purity, dry matter % cane (DM%C) and pol % cane on dry matter basis (P%CDM). The remaining plant parts were weighed fresh and a sub-sample was then taken from each plant part for dry weight determination by placing for 48 h in an oven preheated to 80°. After sampling, the plot was harvested. The plot weight and stalk density were used to derive the cane yield and total above-ground biomass yield on a fresh weight basis. The dry matter fraction of the different plant parts were then used to determine the latter parameters on a dry mass basis.

Rainfall, minimum temperature and maximum temperature and total solar radiation were recorded at an on-site meteorological station.

Results and Discussion

The results comprised the cumulative data of the ratoon years 2004, 2005 and 2006. P%DM was used as the selection criteria. Analysis was based on the GenStat statistical software (VSNi, 2008).

Climate

The average seasonal solar radiation recorded was 6718 MJ/m^2 over the H1 crop, 6784 MJ/m^2 over the H2 crop and 6942 MJ/m^2 over the H3 crop (Table 2). The solar radiation was in excess of the 1971-2000 average by 275.4 MJ/m^2, 314.1 MJ/m^2 and 305 MJ/m^2 over the H1, H2 and H3 crop seasons, respectively.

The annual rainfall for the three harvest dates averaged 1442 mm in 2004, 1555 mm in 2005 and 1214 mm in 2006 (Table 2). Thus, it was only in year 2006 that the recorded rainfall was substantially lower than the 1971-2000 average of 1464 mm.

Table 2. Recorded seasonal solar radiation, rainfall and irrigation applied over the period of study.

		2004	**2005**	**2006**	**Average**
H1	Solar radiation (MJ/m^2)	6727	6815	6914	6819
	Rain (mm)	1482	1533	1256	1424
	Irrigation applied (mm)	125	200	200	175
H2	Solar radiation (MJ/m^2)	6550	6604	6848	6667
	Rain (mm)	1407	1553	1261	1407
	Irrigation applied (mm)	150	225	200	192
H3	Solar radiation (MJ/m^2)	6878	6931	7062	6957
	Rain (mm)	1437	1578	1214	1410
	Irrigation applied (mm)	200	200	200	200
Year average	Solar radiation (MJ/m^2)	6718	6784	6942	6815
	Rain (mm)	1442	1555	1244	1413
	Irrigation applied (mm)	158	208	200	189

Monthly rainfall distribution is characterised by a wet season extending from December to April, with the wettest month being February (Figure 2). Rainfall distribution over the three crop years contrasted with that of the 1971 to 2000 average. Peak monthly rainfall was recorded in the month of January in 2004 (464 mm) and in March in 2005 (654 mm). For the year 2006, peak rainfall of 300 mm was recorded in the month of January and March, with a slightly lower amount being recorded in the month of February. The peak monthly rainfall in 2004 and 2005 seasons occurred over short periods of time and a large proportion was lost as surface runoff or subsurface drainage. Additionally, the evapotranspiration demands of the different crops were followed and supplementary irrigation applied to avoid the development of water stress conditions. Pending water availability, the amount of irrigation applied ranged from 125 to 200 mm/season (Table 1).

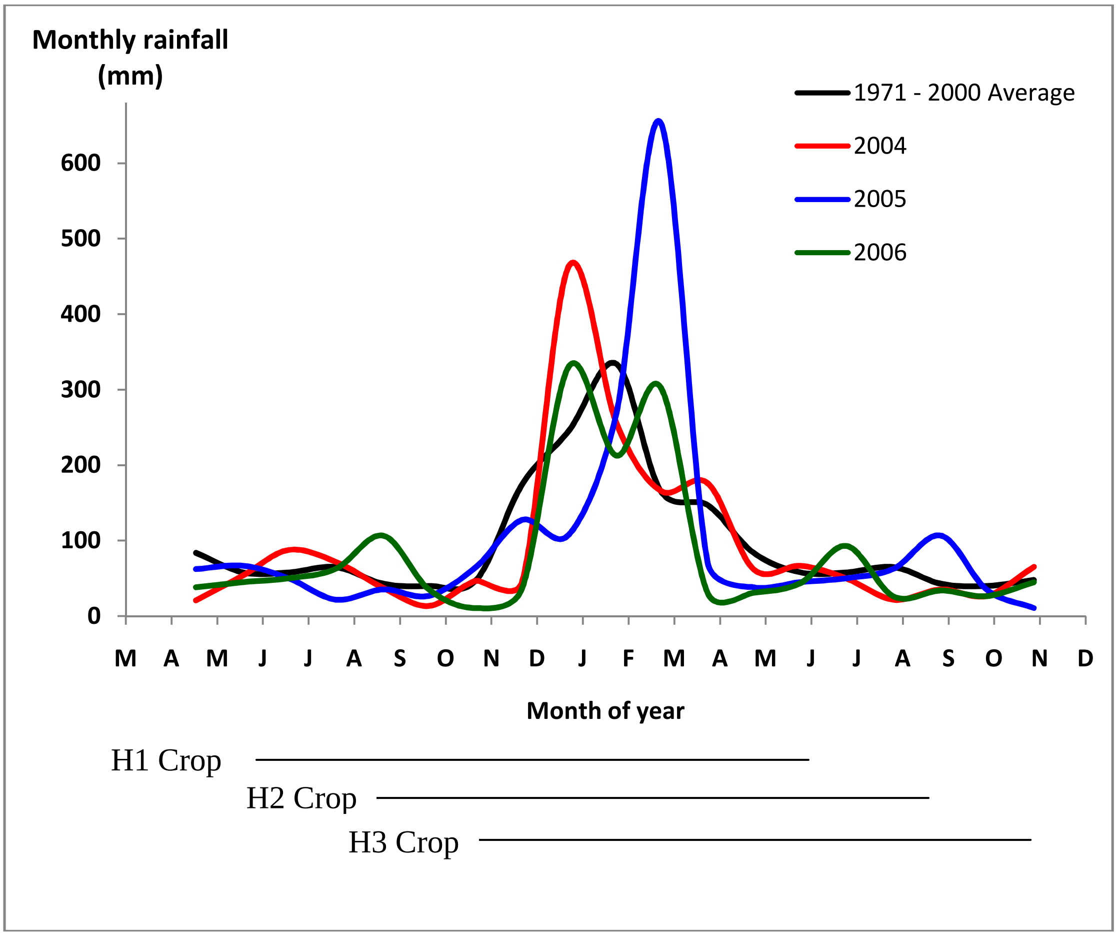

Figure 2. Monthly rainfall across the three experiment years compared to the 1971 to 2000 average.

Thus, the H1 plots, that were ratooned in mid-May, were subjected to high temperatures and large amounts of rainfall conducive to vegetative growth rather than ripening when they were harvested. The H2 plots that were ratooned in mid-August were subjected to ideal conditions for tillering, and warm and wet condition for elongation followed by dry cool conditions conducive to ripening. For the H3 crops, the tillering phase extended into the warm and wet season and it is probable that the onset of the elongation was delayed. The latter was then constrained by the cooler temperatures as from May, such that the crop had a shorter elongation phase.

Monthly minimum and maximum temperatures were close to the 1971 to 2000 average across all three seasons. Compared to the average values, a slight decrease in maximum temperatures (-0.32 and -0.23 °C) was recorded over two crop seasons, while minimum temperatures were slightly higher than average values over a range of 0.06 to 0.55 °C (Table 3). The temperature amplitude was thus lower by 0.38 to 0.55 °C compared to that of the long-term average values. The three crop seasons were therefore considered similar with respect to the temperature parameter.

Table 3. Difference between 1971-2000 average temperature and recorded temperature (°C) over the three harvest dates across the 2004 to 2006 seasons.

Harvest date	2004		2005		2006		Average		
	Max	Min	Max	Min	Max	Min	Max	Min	Decrease in amplitude
H1	-0.03	0.15	-0.32	-0.04	-0.35	0.52	-0.23	0.21	0.44
H2	0.94	0.87	-0.11	0.65	-0.83	0.13	0.00	0.55	0.55
H3	-0.21	-0.49	-0.47	0.39	-0.29	0.27	-0.32	0.06	0.38

Harvest date

Cane yields, on a fresh weight basis, at mid-May harvest (67.3 t/ha) and mid-August harvest (65.1 t/ha) were comparable and were both significantly (P=0.05) higher than at the mid-November harvest (48.2 t/ha) (Figure 3a). The lower cane yield in mid-November was attributed to the fact that the tillering phase of the latter crop extended into the hot and rainy season such that the elongation phase was delayed and then was constrained by the cooler and drier months as from May.

On a dry weight basis, the highest cane yield (19.4 t/ha) was recorded at H2 harvest (Figure 3b). This was explained by the fact that the climatic conditions during the yield accumulation and ripening phases were favourable to these development phases. The slightly lower yield at H1 harvest was attributed to the climatic conditions being non-conducive to ripening. This is confirmed by the comparatively lower dry matter content of the cane (DM%C) at the H1 harvest (Figure 3c). Despite a higher DM%C, a significantly (P=0.005) lower yield (14.3 t/ha) was recorded at the H3 harvest. This was explained by the smaller sink that developed in the restricted elongation phase of H3 crops.

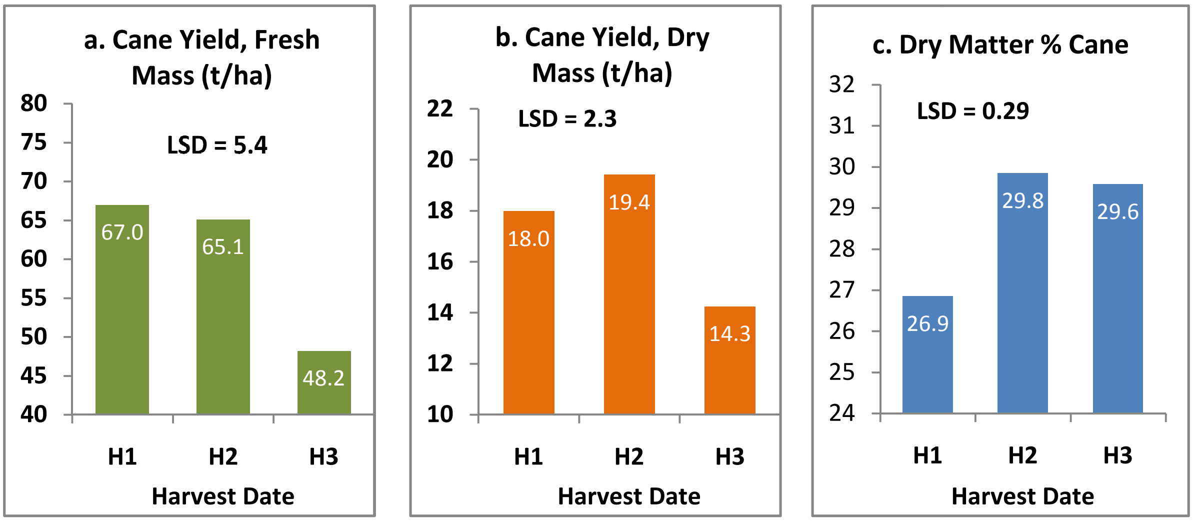

Figure 3. Cane and dry matter content recorded at three harvest dates.

Sugar productivity (Figure 4a) was significantly (P=0.05) higher at H1 harvest and was nearly equivalent at H1 and H2 harvests. Both P%CDM and juice purity followed the same trend. Lower sugar yield at H1 harvest was attributed to cane immaturity due to unfavourable climatic conditions. This is confirmed by the low P%CDM and low juice purity recorded in the H1 crop (Figures 4b and 4c). Low sucrose content early in the season has been reported from various studies in subtropical countries (Herbert and Rice, 1971; Bond, 1982; Cuenya and Mariotti, 1986, Cox *et al.*, 1990; Mc Donald and Wood, 2001).

The lower sugar yield at H3 harvest was attributed to partial remobilisation of stored sucrose for renewed vegetative growth associated with increasing temperatures and onset of the rainy conditions. This is confirmed by the slight decline in both P%CDM and juice purity recorded at the H3 harvest date.

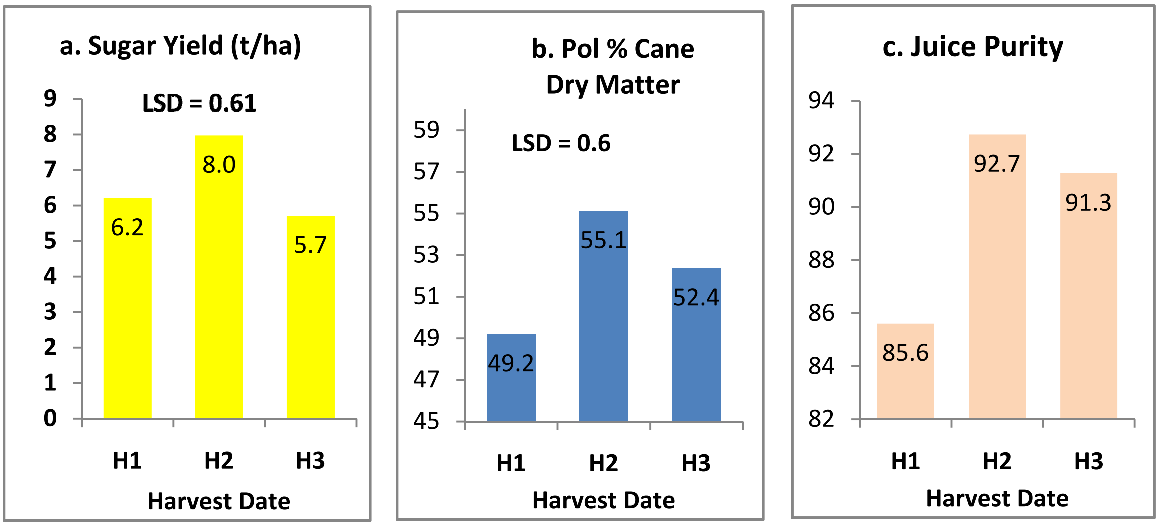

Figure 4. Sugar productivity and cane quality characters recorded at three harvest dates.

Categorisation of ripening behaviour

As the scope of the study was to understand the physiological basis of ripening, varietal behaviour was assessed based on the cane quality parameters. The pol % cane on dry matter basis (P%CDM) was adopted as the character for the assessment of ripening behaviour, because it eliminated the interference from the maturity stage of the crop and water content that would be controlled by the level of water stress that may result from incomplete satisfaction of evapotranspiration demand.

The average P%CDM at PH1 for the three seasons ranged from 28.1 to 43.9% with an average of 36.8%, while the corresponding values at H1 harvest ranged from 41.7 to 54.9% with an average of 49.2% (Table 3). Maximum P%CDM was reached at mid and late pre-harvest and harvest dates. The gap between the minimum and maximum values thus decreased from 16.7% at PH1 to 13.3% at H1. The gap gradually narrowed to 11.6% at PH2, to 9.8% at H2 and finally to an average of 8.8% in the late treatment. The gradual narrowing of the gap between the maximum and minimum values of P%CDM at the different sampling points indicated that the categorisation of varieties would be achieved at the highest level of precision if done early in the season. This confirmed findings reported earlier (Cheeroo-Nayamuth *et al.*, 1994; Nayamuth *et al.*, 2005).

Based on the P%CDM at PH1, varieties were initially categorised in three main groups (Table 4):

1. Those exhibiting values of P%CDM above 40% (8 varieties).
2. Those exhibiting values of P%CDM between 30 and 40% (4 varieties).
3. Those exhibiting values of P%CDM below 30% (4 varieties).

Should the categorisation have been made at the H1 stage, the cutting point would have roughly been above 50% for the first group and below 45% for the last group. This would have then resulted in an interchange of ranking for varieties M 2597/79 and NA 6390.

Table 4. Pol % cane on dry mass basis (P%CDM) at pre-harvest and harvest dates.

Type	Variety	Pre-harvest and Harvest Dates						Change in P%CDM		
		PH1	H1	PH2	H2	PH3	H3	H1-PH1	H2-PH2	H3-PH3
EARLY	CP 65357	43.90	53.28	55.74	55.79	53.39	54.55	9.38	0.06	1.16
	CP 70321	43.46	52.54	59.18	59.28	59.60	55.67	9.08	0.10	-3.93
	SP 703370	43.14	52.77	58.70	58.43	54.21	51.70	9.63	-0.27	-2.51
	CP 72370	42.26	54.94	58.52	57.45	58.00	52.92	12.68	-1.07	-5.08
	Group Mean	***43.19***	***53.39***	***58.03***	***57.74***	***56.30***	***53.71***	***10.20***	***-0.30***	***-2.59***
INTERMEDIATE	M 33/82	41.56	50.80	55.47	54.07	52.97	51.73	9.24	-1.40	-1.24
	CP 721210	40.92	51.59	55.61	55.51	55.83	52.92	10.67	-0.10	-2.91
	M 2597/79	40.55	49.24	55.66	53.71	53.90	53.42	8.70	-1.95	-0.47
	Q 96	40.15	50.54	53.69	53.84	53.52	54.45	10.40	0.16	0.93
	Group Mean	***40.79***	***50.55***	***55.11***	***54.28***	***54.05***	***53.13***	***9.75***	***-0.83***	***-0.92***
	M 587/70	37.35	48.29	52.60	54.26	52.10	52.10	10.94	1.66	0.00
	M 1197/77	35.93	48.25	56.01	55.46	55.38	53.91	12.32	-0.55	-1.47
	NA 6390	35.62	52.40	57.83	57.00	55.59	55.07	16.79	-0.83	-0.52
	M 744/70	30.95	48.41	57.47	57.44	54.11	52.11	17.46	-0.04	-2.00
	Group Mean	***34.96***	***49.34***	***55.98***	***56.04***	***54.29***	***53.30***	***14.38***	***0.06***	***-1.00***
LATE	N 9	29.42	42.62	48.81	51.55	51.14	50.33	13.20	2.73	-0.81
	M 937/77	28.33	41.66	47.56	49.52	52.14	49.25	13.33	1.96	-2.89
	M 2343/77	27.66	45.25	53.46	57.04	56.90	58.36	17.59	3.59	1.47
	R 570	27.18	44.52	50.26	51.54	51.36	51.18	17.34	1.28	-0.17
	Group Mean	***28.15***	***43.51***	***50.02***	***52.41***	***52.88***	***52.28***	***15.37***	***2.39***	***-0.60***
Variety Average		36.77	49.20	54.79	55.12	54.38	53.10			
Minimum		27.18	41.66	47.56	49.52	51.14	49.25			
Maximum		43.90	54.94	59.18	59.28	59.60	58.36			
Range		16.72	13.28	11.62	9.76	8.46	9.11			

In order to avoid such uncertainties in the categorisation, the evolution of the P%CDM across the harvest season (Figure 5) and the magnitude of change in P%CDM from the respective pre-harvest and harvest dates were added as additional categorisation criteria (Table 4).

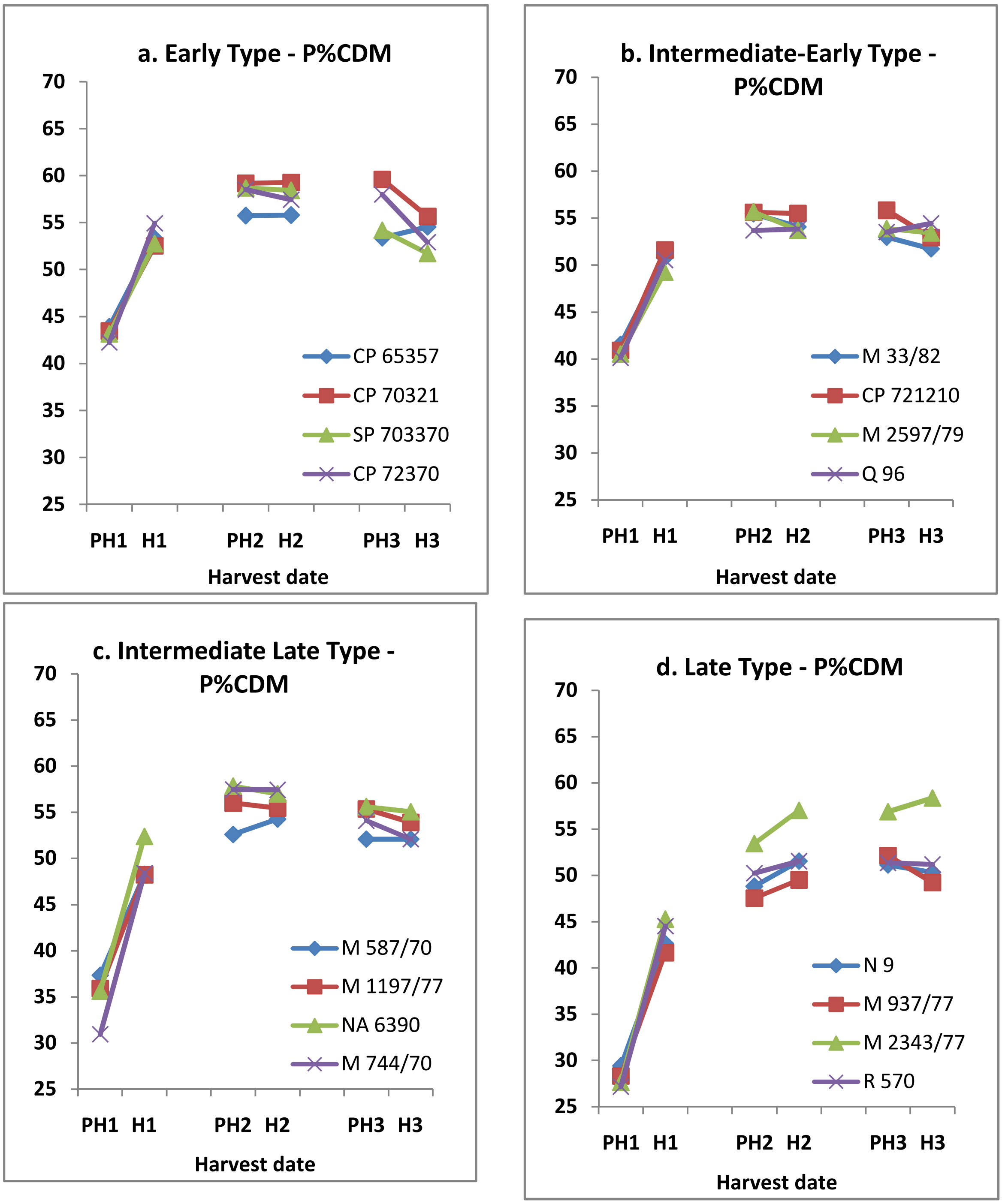

Figure 5. Evolution of pol % cane on dry mass (P%CDM) in variety groups with different ripening behaviour.

Thus, the first group of 8 varieties was segregated into two groups. The remaining two groups maintained their distinctive behaviour even with the inclusion of the additional criteria. The final categorisation was as follows:

Early: P%CDM above 42% at PH1, increase in P%CDM of about 10% from PH1 to H1, high sucrose (>55%) at mid-harvest and large decrease in P%DM of about 2.6% from PH3 to H3.

Intermediate-Early: P%CDM between 40 and 42% at PH1, increase in P%CDM of about 10% from PH1 to H1, relatively small decrease in P%DM of about 0.8 to 0.9% from PH2 to H2 and PH3 to H3.

Intermediate-late: P%CDM between 30 and 40% at PH1, large increase in P%CDM of about 14% from PH1 to H1, relatively small decrease in P%DM of about 1% from PH3 to H3.

Late: P%CDM below 30% at PH1, large increase in P%CDM of about 15% from PH1 to H1, further increase in P%CDM from PH2 to H2 and relatively small decrease in P%DM of about 0.6% from and PH3 to H3.

This categorisation confirmed that variety M 2597/79 exhibits characteristics closer to early varieties, and variety NA 6390 exhibits characteristics closer to the late varieties. Among the late varieties, M2343/77 exhibited a distinct potential for sucrose accumulation early in the season while maintaining its ability to continue to accumulate sucrose at the end of the harvest season.

Agro-physiological characters and ripening behaviour

Agronomic and biomass data collected over the ratoon crops (Table 5) showed that early varieties tended to produce fewer stalks both at peak population and stable stages, the difference between early and late types being 1.84 stalk/m^2 at peak population phase, and 2.61 stalk/m^2 at stable population phase. Early varieties also developed comparatively smaller leaf area per stalk, the difference between early and late types being 956 cm^2 for leaf area per stalk in April. The combined result is that early varieties developed leaf area indices that were smaller by 1.39. This lead to reduced solar radiation interception and lower biomass accumulating potential, the gap being 16.43 t/ha (Table 5). However, although early varieties partitioned a higher proportion of the total biomass produced into cane portion, shorter canes stalks were produced. Early varieties are also more efficient at partitioning the cane biomass into stored sucrose (Table 5). These findings are in line with results reported by Cheeroo-Nayamuth *et al.* (1994). In early maize varieties a lower leaf area index (LAI) of 2 compared to 4.9 in the late ones were reported (Njeru, 1983).

Table 5. Agronomic and biomass characteristics of contrasting variety types.

Variety type	Data at harvest					Stalk population		April data	
	Total dry matter (t/ha)	Cane dry matter (t/ha)	Pol (t/ha)	Cane % total biomass	Stalk height (cm)	Peak (Jan) (No./m^2)	Stable (Apr) (No./m^2)	Leaf area/stalk (cm^2)	Leaf area index
Early	14.68	10.47	5.80	73.27	174.01	9.91	5.55	2437	1.36
Intermediate - Early	25.17	18.14	9.54	73.57	200.17	10.79	7.17	3028	2.11
Intermediate - Late	29.98	21.34	11.33	71.84	212.40	11.85	7.81	3598	2.73
Late	31.11	21.89	10.72	70.50	205.98	11.75	8.15	3393	2.75
Difference between Late and Early types	**16.43**	**11.42**	**4.92**	**-2.77**	**31.97**	**1.84**	**2.61**	**956**	**1.39**

Conclusions

Based on a restricted set of 16 contrasting varieties, the study showed that the best cane and sugar yields for ratoon crops were attainable at mid-season. Similar yield on fresh weight basis can be expected early in the season, but the crop would be immature with low dry matter contents and low sucrose contents. Since the early crops were harvested at the end of the warm and wet season, the crop would still be in a vegetative phase and cane would not have ripened. Late harvests were also associated with lower yields compared to the mid-harvest crop. This was explained by the fact that tillering took place during part of the warm and wet season, resulting in a delay in the onset of the elongation phase. The duration of yield accumulation was then curtailed by the onset of the cool dry winter as from May.

P%CDM of the set of varieties varied across the harvest season, with the magnitude of difference between varieties being widest early in the season. The adoption of the said parameter proved useful in categorising the varieties. Based on the P%CDM in April, i.e. during the fast growing vegetative phase, as well as the evolution of the said character during the harvest season, four distinct groups, namely early, intermediate-early, intermediate-late and late, were identified. Compared to the late group, the early group tended to produce fewer tillers with smaller leaf area indices, resulting in smaller biomass accumulation potential. However, the early group exhibited better partitioning efficiencies when allocating total biomass to cane as well as when allocating cane biomass to stored sucrose. The contrast between early and late varieties proves that varieties can be bred for both the early part as well as the late part of the harvest season, such that extension of the season with varieties combining yield and quality can be contemplated.

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