BUREAU OF SUGAR EXPERIMENT STATIONS

BRISBANE, AUSTRALIA

BIOMASS ACCUMULATION IN SUGARCANE

NERDD&D PROJECT 79/9028

FINAL REPORT

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ABSTRACT

Growth analysis experiments were conducted at Ayr and Bundaberg from 1979 to 1982 to study biomass accumulation in plant and ratoon crops of sugarcane. Crops were planted and ratooned in March, June, September and December, and harvested at 6, 9, 12 and 15 months of age.

Data were acquired for yields of total fresh and dry matter, in addition to yields of the following vegetative components: dry leaf, green leaf, tops and stalks. Fibre analyses were determined on all components, while glucose, fructose and sucrose % were also determined in the latter three components.

It was shown that yield of total dry matter increased with age at harvest for all months of crop initiation. Potential for dry matter accumulation was closely associated with intercepted solar radiation. Growth for three months was ranked December-March > March-June > September-December > June-September. These rankings represented the interaction of crop growth stage with solar radition.

The proportion of total dry matter allocated to soluble and structural carbohydrate was shown to be dependent on variety as well as an interaction between age at harvest and month of harvest. Canes older than nine months of age, harvested between June and December, had established a plateau type equilibrium between the proportion of total dry matter in soluble and structural carbohydrate.

Good prospects existed for forward extension of the crushing season to March for ethanol production based on 15 month old cane.

Models were developed to describe the growth of yield components of the biomass in relation to intercepted solar radition, month of crop initiation, age at harvest and crop class.

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1. SUMMARY

1.1 Project objectives

Sugarcane research and growing activities within the Queensland sugar industry have been directed towards production and growth of varieties for optimisation of sucrose yields in the period July to December. Canes harvested within the 20 to 26 week harvesting season usually vary from 12 to 18 months in age.

If for political and economic reasons the end use of sugarcane dry matter production needed to be re-optimised from manufacture of sucrose alone to production of sucrose and other energy products, current cultural and varietal philosophies may not pertain. Because of the need to acquire preliminary data to develop possible new plant breeding and cultural philosophies it was considered necessary to document the biomass production characteristics of current varietal 'types' of sugarcane. This included the study of growth on a year-round basis and measurement of leafy residues.

The project objectives were therefore defined as:

1. Study growth and accumulation patterns for total dry matter, dry plant fibre, sucrose and total C_6 sugars throughout the complete growth period for canes of different ages and planted at different times of the year. This work was required to obtain a better understanding of the growth process.

2. Study the division of total dry matter in varieties with high fibre characteristics in comparison with canes of lower fibre, but higher sucrose percentages.

3. Study the effect of production environment on yields of biomass components, because of the geographical extent of the Queensland sugar industry.

4. Study effects of re-optimising current concepts of harvestable material on yield of sucrose, fermentable sugars and fibre.

1.2 Work program

Field experiments were established on the Sugar Experiment Stations at Ayr and Bundaberg for tropical and subtropical growth environments respectively. Each experiment incorporated 16 treatments which comprised four months of planting/ratooning and four ages at harvest. Months of initiation/harvest were March, June, September and December, while ages at harvest were 6, 9, 12 and 15 months. Each experiment included two varieties, and all treatments were replicated twice. Varieties at Ayr were Q92 and Q96, while Q108 and Q111 were planted at Bundaberg.

At each harvest date total fresh weight yields were determined in the field. Samples were taken to the laboratory for determination of proportions of dry leaf, green leaf, top and stalk in the fresh sample. Sub-samples of each component (except dry leaf) were then analysed for moisture, fibre, glucose, fructose and sucrose. Dry leaves were assayed for moisture and fibre only.

Treatments were planted from March to December 1979 and yields were assessed in plant cane, first ratoon and second ratoon cane. Final harvests took place in December 1982.

Data were then subjected to modelling studies to summarise the mass of information and to facilitate its use in estimating yield parameters.

1.3 Main project results

1.3.1 Total dry matter

Detailed data for total dry matter production at both sites are shown in Annex I. On average, yields of dry biomass at Bundaberg were greater than those at Ayr because of moisture stress at the latter centre. Average dry matter yields of 12 month old cane at Ayr and Bundaberg were 38.6 and 43.6 t/ha respectively, while for 15 month old cane the values were 45.8 and 54.5 at Ayr and Bundaberg respectively.

It was shown that crop class, month of crop initiation and age at harvest were statistically significant variables in total dry matter production at both sites, however only at Ayr were varietal differences in total dry matter production significant. Total dry matter yields were ranked first ratoon > plant cane > second ratoon crops.

Examination of dry matter accumulation rates between quarterly harvest dates showed that growth rates per quarter were ranked in the order December-March > March-June > September-December > June-September for each crop class at Bundaberg. These patterns of growth conformed to expectations from prevailing climatic conditions.

Data for 12 month old crops in all crop classes showed that March initiations gave lowest dry matter accumulation rates, and that ratoon cane was not as susceptible to depression in growth rate as was plant cane for crops initiated in December at both Ayr and Bundaberg.

Regression analyses confirmed the value of intercepted solar radiation for estimating total dry matter yields.

Evaluation of photosynthetic efficiency in converting radiant energy to dry matter revealed that canes of at least nine months of age at Ayr and Bundaberg converted 0.9 and 1.2% of incident shortwave solar radiation to dry matter equivalents. A peak efficiency of 2.0% was achieved during a six month period from September to March in second ratoon cane at Bundaberg.

1.3.1.1 Vegetative components of biomass

For both plant and ratoon crops it was apparent that crops initiated in March and June generally supported higher proportions of green leaf and tops in the biomass up to the age of nine months than did crops planted or ratooned in September and December. From 12 to 15 months of age, crop class and month of initiation appeared to have little effect on the proportion of total dry matter represented by green leaf and top, with values stabilising between 7 and 10%.

Proportions of trash (dead leaf) in the biomass increased with age of crop to stabilise at approximately 20% of total dry matter at 12 to 15 months of age.

Stalk proportions in the biomass were heavily dependent on month of initiation and age at harvest. Crops initiated from September to December developed rapidly with stalks comprising 33 to 47% of dry biomass at six months of age, as opposed to much slower stalk development from March and June initiations.

1.3.1.2 Fibre and soluble carbohydrate

Variety, month of crop initiation and age at harvest had significant effects on the proportion of total dry matter found as C_6 sugars or fibre at Ayr and Bundaberg. The data showed that Q108 at Bundaberg directed more dry matter to fibre production than did Q111, while the converse applied for the C_6 sugar values.

It was shown for both varieties at Bundaberg that while total dry matter production continued to increase up to 15 months of age at harvest, canes older than nine months of age harvested between June and December appeared to establish a plateau equilibrium between dry matter division to soluble and structural carbohydrate (Figure 5).

1.3.2 Stalk yields

At Ayr the variety Q96 generally produced superior stalk yields to Q92, while a similar situation prevailed at Bundaberg for Q111 over Q108.

Stalk yields increased from 6 to 15 months of age in all instances, except 15 month old second ratoon cane at Ayr for crops initiated in March, June and September. Both Ayr and Bundaberg data showed that rates of stalk growth in the 12 to 15 month period were lower than for 6 to 9 to 12 month intervals.

On average, stalk yields from 9 and 12 month old crops initiated in March and December were lower than for similarly aged crops initiated in June and September. Month of initiation was less important for yield 15 month old stalks.

It was shown that stalk yields at Ayr were generally greater than those at Bundaberg, even though greater yields of total dry matter were achieved at Bundaberg. The data revealed that Bundaberg varieties supported a higher proportion of total dry matter in top material than did canes at Ayr. The difference was not due to disparity in ontogeneric criteria for recognising tops, but appears related to varietal response to growth environment.

1.3.3 Fibre yields

Data for Ayr showed that Q96, the variety with higher stalk fibre characteristics, significantly outyielded Q92 in total fibre production on more than 50% of occasions. At Bundaberg 'high fibre' Q108 produced more total fibre than Q111 at 65% of harvests. For both sites, occasions of inferior total fibre yields from the 'high fibre' cane were associated with markedly superior total dry matter yields of the lower fibre cane.

The propensity of varieties to accumulate different levels of fibre was shown to apply to green leaf, top and stalk sections of the plant as well as to stalks.

1.3.4 C_6 sugars

Varietal differences in C_6 sugar production were quite marked. At Ayr Q96 produced significantly more C_6 sugar per hectare than Q92 at 71% of harvests, and more but not significantly so on 25% of harvests; whereas at Bundaberg Q111 significantly outyielded Q108 for 90% of harvests.

C_6 sugar yield in stalk material increased with age at harvest for each month of initiation. Average yields in stalks at 15 months of age at Ayr and Bundaberg were 18.1 and 18.8 t/ha respectively.

Because of the heavier top section on cane grown at Bundaberg it was shown that yield of C_6 sugars from stalks alone could be boosted 9% for 12 month old cane, and 6% for 15 month old cane if top material was harvested with stalks. However, it was suggested that disadvantages associated with higher loadings of inorganic material may outweigh the value of higher yield of C_6 sugars.

Examination of the options for extending the crushing season beyond the current June-December period revealed that harvests for fermentation substrate (C_6 sugars) should be based around canes of at least 15 months of age in the March to June quarter.

1.3.5 Sucrose

The data for sucrose % in stalks revealed a strong interaction between age at harvest and month of crop initiation, or month of harvest, i.e. crops of all ages harvested between March and September showed increases in sucrose % in cane stalks, whereas only crops younger than 12 months of age generally showed increases in sucrose % stalks when harvested between September and March.

Unlike the prospects for a forward extension of the C_6 sugar crushing season, current regulations for payment of sucrose in cane would render commencement of the sucrose crushing in March, totally uneconomic. However, it was clearly shown that if sucrose extraction were to begin in early June, fields of at least 15 months of age gave the best sucrose % and sucrose yields.

1.3.6 Models

Models which describe the response of yield components to intercepted radiation, month of crop initiation, age at harvest and crop class were developed for:

Total dry matter production
Stalk yields
Total fibre yield
Stalk fibre yield
Yield of C_6 sugars in stalks
Yield of C_6 sugars in stalks plus tops.

1.4 Project evaluation

Results from the two experiments conducted within this project have led to the realisation of three of the four objectives set for the work.

The data have provided a unique data set which details the growth of the various vegetative components of sugarcane on a year round basis. Detailed data were provided which demonstrated the division of total dry matter into structural and soluble carbohydrate. It was shown that varietal as well as age x environmental interactions affected the distribution of total dry matter between soluble and structural components.

From an assessment of C_6 and sucrose levels in cane, it was considered that good prospects existed for a two to three month forward extension of the crushing season for production of alcohol. Such canes should be topped slightly above current topping points at Bundaberg. There appeared to be no point in major forward extension of the sucrose season.

The objective of comparing biomass production from well managed sugarcane in tropical and subtropical environments was not achieved. This failure resulted from limitations to production at Ayr, caused by moisture stress resulting from an irrigation system which was unsuited to the land units allocated to the experiment.

In addition to the greater understanding of the sugarcane growth process, the data base and models which have been developed will be of great value in any future evaluation of sugarcane as a source of sucrose and other energy products.

2. INTRODUCTION

2.1 Project objectives

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2.2 Literature review

2.2.1 Cane for sugar production

Rationale for timing the cultural operations of planting and harvesting sugarcane within the Queensland sugar industry have developed from experience within the industry and from results of research. In all cases the objective of both growers and research workers has been to maximise sugar (sucrose) yields from a combination of high yield of cane stalk with the highest achievable c.c.s. (commercial cane sugar) content. The emphasis on c.c.s. is engendered through a cane payment formula which allows for a division of the price received for manufactured sugar between growers and millers. The formula (1) encourages growers to supply canes with high c.c.s.

$$\text{Value 1 t of cane to grower} = 0.009\, P_s\, (\text{c.c.s.} - 4) + \$0.328 \qquad \ldots(1)$$

where P_s = manufactured sugar price \$

c.c.s. = commercial cane sugar content.

C.C.S., which is a measure of the quantity of commercial cane sugar that could be manufactured from a consignment of cane, is calculated from an empirical formula (2).

$$\text{c.c.s.} = \frac{3P}{2}\left(1 - \frac{F + 5}{100}\right) - \frac{B}{2}\left(1 - \frac{F + 3}{100}\right) \qquad \ldots(2)$$

where P = pol per cent first expressed juice

B = brix per cent first expressed juice

F = fibre per cent cane.

Thus the formula allows for the sucrose content of cane, other soluble impurities and losses associated with processing fibre in cane (BSES, 1970).

Therefore the varieties available for cane growing in Queensland have been selected on the basis of acceptable agronomic performance, while optimising sucrose yields in the period July to November. (Canes ripen in this period in response to checks in vegetative growth induced by cooler, drier weather during winter and spring.)

Canes are required to have sufficient fibre content to provide bagasse as fuel for processing; but too high a fibre level results in additional processing costs at the factory along with further sugar losses in bagasse. A fibre level of 11.5 to 12.5% in cane is currently considered desirable.

There has been no research or commercial evaluation in Queensland of sugarcane cultivars for purposes of energy production, where sucrose content may be only one of the desirable yield parameters.

Times of planting cane for sugar production in each of the sugar growing areas have traditionally developed around weather patterns, e.g. after the completion of the wet season, but while soil temperatures will allow rapid germination: or after winter.

Effects of different times of harvest (within the normal harvest season) upon current and subsequent yields, have been investigated at Bundaberg (unpublished data), at Mackay by Chapman & Leverington (1976) and in the Burdekin area by Leverington, Hogarth & Ham (1978). The

Mackay experiment showed that cane yield increased throughout the harvesting season and that c.c.s. and subsequent sugar yields varied from one harvest date to the next. A significant variety x time of harvest interaction suggested the desirability of harvesting varieties according to their maturity pattern. There was no apparent increase in cane yield throughout the harvesting period in the Burdekin experiment. Both experiments recorded the detrimental residual effect on cane yield of a subsequent ratoon crop, from cane harvested late in the season e.g. after mid October.

2.2.2 Sugarcane - an energy crop

Interest in sugarcane as an energy crop was rekindled as a result of the fuels crisis in 1973. This occurred because of the crop's ability to produce sucrose, and fermentable substrates for ethanol in addition to fibrous residues for direct combustion in boilers or for gasification to methanol.

Austin, Kingston, Longden & Donovan (1978) showed that gross energy contents of the biomass of U.K. and Californian sugar beet crops were about 222 GJ/ha/year, while those for Queensland and Transvaal sugarcane crops were about 682 GJ/ha/year. Recoverable sucrose constituted about 45% of the gross energy yield for sugar beet crops but only about 29% for sugarcane crops, largely due to higher yields of bagasse and leafy residues in cane. Because of the absence of data in the magnitude of the residues resource in Queensland, Stewart & Kingston (1979) examined data from crop nutrition experiments which showed linear relationships between residue dry matter and fresh weight yield of cane stalks for specific cultivars. These relationships were used with production statistics for the cultivars in the 1975 harvesting season to provide an estimate of a potential yield of 2.6×10^6 tonnes of dry matter from leafy residues in the 1975 season. It was also estimated that a further 1.1×10^6 tonnes of dry bagasse could be surplus to requirements at 1975 production levels, if significant but not prohibitive expenditure was undertaken to improve factory thermal efficiency.

2.2.3 Sugarcane biomass

Thompson (1978) in a review of growth analysis experiments with sugarcane in South Africa, reported that photosynthetic efficiency (total short wave radiation) for sugarcane biomass ranged from 0.5 to 1.0% for rainfed crops and averaged 1.7 and 1.6% for irrigated plant and first ratoon crops. Increases in plant density above that obtained from a 0.57 m square planting did not result in increased biomass yields. This planting produced similar yields to the normal 1.42 m spacing for NCo376 at a photosynthetic efficiency of 1.3%. However, Gascho & Shih (1981) reported higher biomass yields for irrigated cane planted to 0.5 m rows rather than 1.5 m rows, in Florida. Photosynthetic efficiency for the narrow rows ranged from 1.5 to 1.6% and from 0.9 to 1.0% for the wider rows.

Thompson (1978) reported that close row spacings for biomass production gave dramatic production advantages early in the growth cycle (77 days), but by harvest at 294 days these early growth advantages had largely disappeared. Mishoe, Jones & Gascho (1979) concluded from a biomass accumulation model, that two harvests per year under Florida conditions increased harvestable biomass from 0.50 m row spacings. The response of approximately 3.0 t/ha appears quite small and would not be of significance if yield components other than total dry matter were of interest e.g. total sugars or sucrose.

The early response in total dry matter accumulation to higher density plantings is a reflection of the increased interception of solar radiation by the sugarcane leaf canopy. Thompson (1978) reported that differences in biomass yield between four commercial varieties, of which two were planted at varying densities, were neither large enough nor sufficiently consistent to suggest a varietal preference for biomass production. There was, however, a difference in varietal reaction to higher plant populations in the proportion of total dry matter divided into stalks and leafy residues.

However, Bull (1975) contends that the limited response of commercial sugarcane cultivars may be a reflection of 10 to 15 years of selection pressure at wider row spacings. Reduction of interrow spacing from 1.4 m to 0.50 m significantly increased stalk and sucrose yield of a population of unselected and commercial cultivars. It is suggested that exploitation of increased productivity due to reduced interrow spacing would involve selection at the row spacing adopted.

Thompson (1978) reports data on the division of dry biomass into the vegetative components of the sugarcane cultivar NCo376 from one time of planting for ages from 0 to 24 months (planted on 1.37 m row spacing). Stalk and dry leaf material was not present until 5 to 6 months after planting, whereas for autumn planted NCo376 in another experiment stalk material was not harvested until around 9 months after planting.

3. BODY OF REPORT

3.1 Methodology

3.1.1 Growth environments

The biomass accumulation experiments were established on the Ayr (19°30' S, 147°15' E) and Bundaberg (24°47' S, 152°34' E) Sugar Experiment Stations to represent two distinct and geographically separated growth environments. Climatic data for both centres for the duration of the experiment are shown in Tables Ia and Ib. Ayr represents a dry tropical environment, while Bundaberg is a sub-tropical environment.

The soil type on the Ayr Experiment Station is an alluvial silty clay loam, while at Bundaberg the experiment was established on a krasnozem (clay loam) of volcanic derivation.

Both experiments were grown under irrigated conditions.

3.1.2 Treatments

There were 16 treatments in both experiments (four times of planting x four times of harvest). Planting and harvest schedules are shown in Table II. Each treatment was replicated twice at each site, with treatments being split by two varieties.

Planting commenced in March 1979, and the final harvest took place in December 1982.

Harvest dates were scheduled for mid month. Two replicates of each treatment could be processed in one day. Thus the harvests of six treatments conducted in December 1979 and 1980 and September 1981 were conducted over six working days.

Varieties:

Bundaberg: Q108 (high fibre), Q111 (low-medium fibre).
Ayr: Q92 (moderate early sugar), Q96 (high early sugar).

One of the objectives of the experiment was to examine dry matter accumulation and the division of fibre and soluble carbohydrate into the various vegetative components. Varieties suitable for growth in the Bundaberg environment were chosen to have high and low-medium fibre levels. The lower fibre Q111 has the potential to produce higher sugar yields than Q108.

Because varieties with markedly different fibre contents were not available at Ayr, two varieties with different sugar accumulation rates were planted.

All four varieties were cultivars bred in Queensland and with the exception of Q92 approved for commercial purposes in the relevant district.

TABLE Ia

Meteorological data for Ayr during period of biomass experiment

	1979				1980				1981				1982			
	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation * MJ.m^{-2}	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation * MJ.m^{-2}	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation * MJ.m^{-2}	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation * MJ.m^{-2}
Jan.	205.0	5.8	25.5	21.7	188.4	6.3	27.5	26.4	659.9	2.7	30.8	15.3	76.6	7.1	28.2	23.5
Feb.	556.8	4.6	25.3	21.7	101.0	5.4	27.5	21.8	320.5	4.9	32.6	20.2	1.0	7.1	27.6	21.8
Mar.	408.2	4.6	23.7	19.9	152.7	5.1	25.0	19.7	92.5	5.8	25.9	23.0	76.3	5.3	26.8	19.5
Apr.	46.8	3.9	22.2	19.5	10.4	4.9	23.4	18.6	68.2	5.3	24.8	18.2	13.0	3.7	24.7	15.4
May	7.7	4.0	19.8	16.5	81.3	3.7	23.6	16.0	121.8	3.6	21.6	14.2	21.0	4.0	21.0	16.1
June	38.6	3.1	17.8	15.2	0.6	3.1	20.1	16.3	47.8	3.3	19.0	16.6	10.4	3.8	16.3	14.5
July	18.5	3.5	16.2	16.6	1.2	3.5	18.8	17.9	24.0	3.1	18.9	15.2	4.2	4.0	16.9	15.6
Aug.	0.2	4.8	17.4	20.6	11.5	4.0	20.1	18.2	1.8	4.0	20.1	18.9	5.2	4.6	18.6	16.3
Sept.	4.4	5.0	20.6	23.6	0.0	5.6	22.3	24.6	0.0	6.1	20.7	20.6	2.4	5.1	21.0	20.9
Oct.	3.4	6.4	23.6	26.5	22.1	6.4	26.8	26.1	0.0	7.0	23.3	24.2	0.0	6.0	22.3	24.3
Nov.	4.3	7.7	24.7	27.9	12.4	7.8	29.3	28.0	250.3	6.3	26.1	21.5	4.6	6.8	24.1	24.9
Dec.	112.9	7.4	26.3	27.1	42.3	7.1	31.6	24.4	12.5	6.5	27.6	25.5	19.8	5.3	26.6	23.4
Total	1406.8	-	-	-	623.9	-	-	-	1599.3	-	-	-	234.5	-	-	-
Mean	-	5.1	21.9	21.4	-	5.2	24.7	21.5	-	4.9	24.3	19.5	-	5.2	22.8	19.7

*Radiation data for Townsville; 70 km north and in similar climatic zone.

TABLE Ib

Meteorological data for Bundaberg during period of biomass experiment

	1979				1980				1981				1982			
	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation MJ.m^{-2}	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation MJ.m^{-2}	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation MJ.m^{-2}	Rain mm	Eo mm.day^{-1}	Mean day temp. °C	Radiation MJ.m^{-2}
Jan.	67.1	7.4	26.4	19.8	216.6	7.5	26.7	20.5	88.6	6.9	24.4	19.2	256.4	6.7	26.4	19.0
Feb.	93.4	6.7	25.3	18.9	269.8	6.9	25.6	18.2	152.9	5.6	26.8	17.7	171.8	8.0	25.8	21.1
Mar.	138.0	5.2	24.1	18.5	29.0	6.1	23.9	19.8	131.4	5.6	24.5	17.9	180.0	6.0	25.2	18.8
Apr.	36.6	4.5	22.3	16.0	22.4	5.2	22.0	15.4	105.8	4.1	22.3	14.3	44.0	5.2	21.9	16.0
May	6.2	4.0	18.0	13.3	50.8	3.6	20.9	11.2	96.6	3.6	19.0	11.5	98.0	3.4	19.1	11.6
June	35.0	3.4	17.7	11.0	15.8	3.2	16.2	10.8	53.6	2.8	16.0	10.9	1.6	3.3	14.4	12.4
July	7.4	3.4	15.9	11.6	46.6	3.6	15.7	11.4	25.2	3.0	16.5	10.9	12.3	3.3	15.0	11.5
Aug.	6.4	4.3	16.6	14.8	14.6	4.5	17.4	14.1	38.6	4.0	16.5	13.6	17.8	4.1	17.1	12.8
Sept.	1.0	6.0	19.3	18.1	0.0	5.3	20.1	18.2	8.2	5.2	18.9	17.1	31.2	4.4	18.6	15.7
Oct.	71.2	7.3	22.2	20.2	95.4	6.6	22.9	19.2	41.2	6.5	20.7	17.6	36.8	6.5	20.0	20.2
Nov.	51.3	7.9	24.5	22.2	58.0	8.0	23.8	21.9	207.8	6.5	22.8	17.1	5.2	8.9	23.3	23.2
Dec.	60.8	8.2	27.2	25.2	149.2	7.0	24.4	20.3	97.6	7.2	25.9	21.2	39.0	7.6	25.3	22.3
Total	574.4	-	-	-	968.2	-	-	-	1047.5	-	-	-	894.1	-	-	-
Mean	-	5.7	21.6	17.5	-	5.6	21.6	16.8	-	5.1	21.2	15.8	-	5.6	21.0	17.1

TABLE II

Summary of ages at harvest and times of harvest for treatments 1 to 16

Treatment	Month of planting	Plant cane		First ratoon		Second ratoon	
		Month of harvest	Age (mths)	Month of harvest	Age (mths)	Month of harvest	Age (mths)
1	Mar. '79	Sept.'79	6	Dec. '80	15	June '81	6
2	Mar. '79	Dec. '79	9	Dec. '80	12	Sept.'81	9
3	Mar. '79	Mar. '80	12	Dec. '80	9	Dec. '81	12
4	Mar. '79	June '80	15	Dec. '80	6	Mar. '82	15
5	June '79	Dec. '79	6	Mar. '81	15	Sept.'81	6
6	June '79	Mar. '80	9	Mar. '81	12	Dec. '81	9
7	June '79	June '80	12	Mar. '81	9	Mar. '82	12
8	June '79	Sept.'80	15	Mar. '81	6	June '82	15
9	Sept.'79	Mar. '80	6	June '81	15	Dec. '81	6
10	Sept.'79	June '80	9	June '81	12	Mar. '82	9
11	Sept.'79	Sept.'80	12	June '81	9	June '82	12
12	Sept.'79	Dec. '80	15	June '81	6	Sept.'82	15
13	Dec. '79	June '80	6	Sept.'81	15	Mar. '82	6
14	Dec. '79	Sept.'80	9	Sept.'81	12	June '82	9
15	Dec. '79	Dec. '80	12	Sept.'81	9	Sept.'82	12
16	Dec. '79	Mar. '81	15	Sept.'81	6	Dec. '82	15

3.1.3 Plot size

Gross plot	14 rows x 10 m
Gross varietal sub-plots	7 rows x 10 m
Net harvest plots	4 rows x 5 m (Ayr) 3 rows x 5 m (Bundaberg)

Row spacing at Ayr and Bundaberg was 1.45 m and 1.40 m respectively.

3.1.4 Harvesting

Net harvest sections were cut and weighed by hand (Plate 1). All harvestable material including stalk, tops, leaves and dry trash was weighed in the field (Plate 2).

Three one metre sections of row were weighed separately and retained for fractionation into different components. All harvesting was confined to the hours 0800 to 1000 for standardisation with respect to diurnal movement of carbohydrate within the plant.

3.1.5 Sample fractionation

The samples obtained at each harvest were fractionated into four components (Plate 3):

(a) Millable stalk (stalk)
(b) Non-millable stalk and green leaf sheaths (tops)
(c) Green leaf blades (leaf)
(d) Dry leaf and sheaths (trash).

Fresh weight of each sample fraction was recorded. These fractions were selected on the basis of likely separation by pneumatic cleaning devices during any commercial harvesting operation.

The point of separation between millable and non-millable stalk was taken as the node bearing the second lowest green leaf, as this was the topping point that gave most economical returns to the cane grower for sugar production (Waddell, 1949). This topping point was retained in these experiments because information on dual production of sugars and dry biomass was required.

Green leaves were cut from the non-millable stalk at the top visible dewlap, and were also trimmed from sheaths adhering to the non-millable stalk.

Each of the four components was processed through a Jeffco cutter-grinder (Plate 4), and samples of the finely prepared material were taken for detailed analysis.

PLATE 1 - Hand harvesting of sugarcane in NERDDP sugarcane biomass accumulation experiment

PLATE 2 - Weighing whole cane samples in the field for yield determination

PLATE 3 - Vegetative components of sugarcane biomass. From left to right: trash (dry leaves), green leaf blades, top (non-millable stalk), stalk.

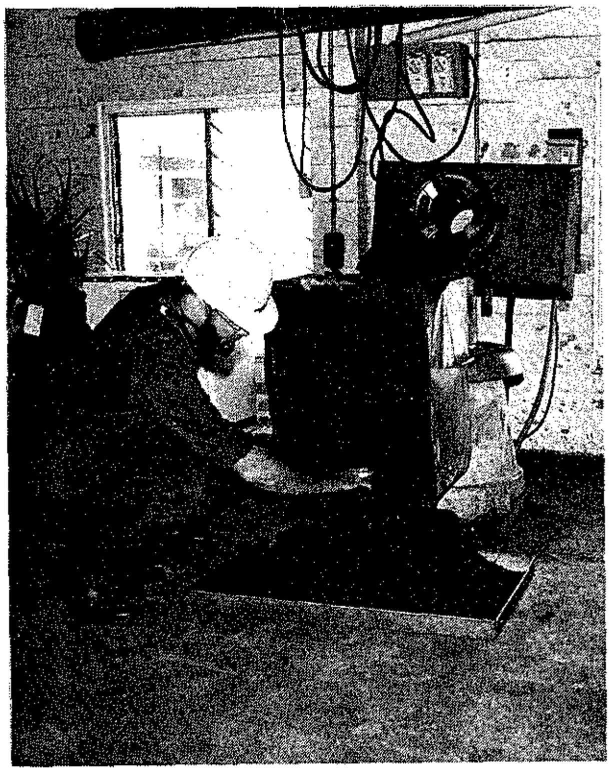

PLATE 4 - Removing hammer milled leaf material from cutter-grinder prior to sampling for moisture, fibre and wet disintegrator sub-samples

3.1.6 Sample analysis

The following detailed analyses were carried out on fibrated material:

(a) Moisture content - determined on duplicate samples of approximately 150 g.

(b) Fibre content - determined by the bag method (BSES, 1970) on a sample of approximately 250 g.

(c) Brix, pol, sucrose, glucose, fructose, polymers were determined on cane extracts prepared in two ways:

(1) Bundaberg. 2000 g of fibrated cane was mixed with 6000 g of boiling water and mixed for 30 minutes in a Jeffco wet disintegrator. The extract was then filtered off (Plate 5), quickly cooled to room temperature, adjusted to pH 7.0 with 1 M NaOH, and snap frozen in dry ice for later analysis.

(2) Ayr. 1000 g of fibrated material was pressed in a hydraulic press and the extract retained. The pressed material was then mixed with 3000 g of boiling water, heated for 10 minutes in a hot water bath and pressed again. The combined extract from the two pressings was sub-sampled, quickly cooled to room temperature, adjusted to pH 7.0 with 1 M NaOH, and snap frozen for later analysis. This procedure was standardised after some initial extraction experiments.

Details of analysis of the extract are as follows:

Brix was determined using a refractometer after filtration of the extract through acid washed filter aid.

Pol was determined using either a polariscope with 400 mm pol tube or an automatic saccharimeter.

Sugar components - soluble carbohydrate polymers, sucrose, glucose and fructose were determined using high pressure liquid chromatography following preparation as outlined below:

Samples were thawed quickly and the volume measured; the sample heated to boiling to solubilise polysaccharides; sample volume was re-adjusted to its original value and then centrifuged to remove any insoluble matter; an accurate 1.0 mL aliquot was taken and mixed with a microlitre of internal standard; this sample was decolorised and deionised prior to chromatographic analysis.

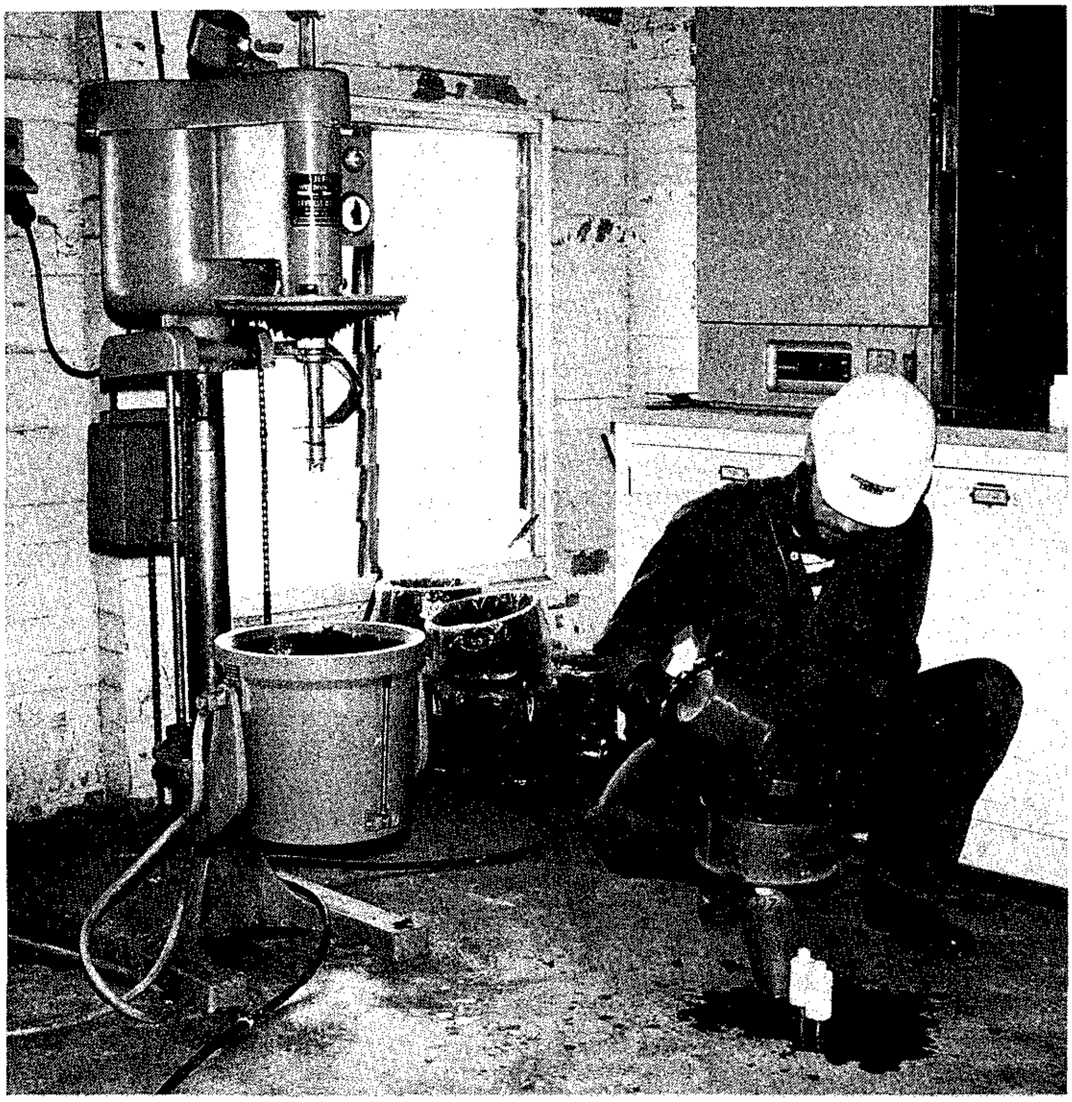

PLATE 5 - Filtration of wet disintegrator extract into sample bottles

3.1.7 Cultural operations

3.1.7.1 Fertiliser

Fertiliser practices were those recommended for optimum commercial sugar yields (not maximum vegetative yields) in each district, and were consistent for each treatment, although crop age at harvest ranged from six to 15 months. Details of fertiliser applications are shown below.

	Plant cane			Ratoon cane		
	kg N/ha	kg P/ha	kg K/ha	kg N/ha	kg P/ha	kg K/ha
Ayr	135	0	0	210	0	0
Bundaberg	113	22	107	138	0	100

Ayr soils are naturally fertile. Soil assays and nutrient experiments have indicated that phosphorus and potassium are not required for optimum growth. Similarly at Bundaberg phosphorus is not applied to ratoon cane grown on the krasnozem soil.

3.1.7.2 Irrigation

Both experiments were grown under irrigated conditions, with irrigation frequencies based on schedules related to 'class A' pan evaporation data. Irrigation water was applied by sprinkler and furrow techniques at Bundaberg and Ayr respectively.

During the plant crop it became apparent that yields at Ayr were being restricted by moisture stress. The problem was traced to the hard setting nature of the Ayr soil and poor water penetration; a problem which is the topic of current research projects. Short rows and inadequate water contact time was also a problem. Attempts to alleviate the problem resolved around reshaping furrows and longer contact time for water. Yield data indicated that these steps did not prevent stress, as Bundaberg yields were generally and unexpectedly superior to those from Ayr.

3.1.7.3 Cultivation

Field plots in both experiments received normal mechanical cultivation for weed control and management of soil cover on the cane stool.

3.1.8 Statistics

Data for the major yield parameters were subjected to analysis of variance using multiple regression techniques to construct the analysis of variance table. Effects attributable to months of initiation and harvest, age at harvest and crop class were recognised with dummy variables (Draper & Smith, 1966).

Models which described the effects on yield parameters of variables such as solar radiation, month of crop initiation, crop class, age at harvest and relevant significant interactions, were developed from multiple regression analyses.

3.2 Results

3.2.1 Total dry matter (aerial biomass)

Data for total dry matter production during plant, first and second ratoon crops for each variety grown at Ayr and Bundaberg are shown in Annex I.

Statistical analysis of these data revealed that crop class, month of crop initiation (planting or ratooning) and age of the crop at harvest, were statistically significant ($p < 0.05$) variables in total dry matter production at both sites. However, varietal differences in total dry matter production at Bundaberg were not significant for Q108 and Q111, whereas at Ayr Q96 produced significantly more total dry matter than Q92.

3.2.1.1 Crop class

Comparisons of total dry matter yield for each crop class are shown in Table III, where it can be seen that yields for plant and first ratoon crops at Ayr were similar, but second ratoon yields were 10% lower than for first ratoon. At Bundaberg yields were ranked in the order first ratoon > plant cane > second ratoon. The decline from first to second ratoon at Bundaberg was also 10%.

TABLE III

Average total dry matter yields for each crop class at Ayr and Bundaberg (t/ha)

	Plant cane	First ratoon	Second ratoon
Ayr	31.7	31.9	28.7
Bundaberg	35.0	37.4	33.8

3.2.1.2 Month of crop initiation

The form of total dry matter accumulation throughout the year is shown in Figures la and b for each crop class at Ayr and Bundaberg respectively. In this figure data are averaged across ages for ages greater than six months. Bundaberg data showed that quarterly dry matter accumulation rates were generally ranked in the order December-March > March-June > September-December > June-September, for each crop class. The poor performance of the September-December quarter in the second ratoon crop was the result of high yields in September and low yields in December.

This consistent pattern of growth was not apparent in the data for Ayr, where the superiority of December-March quarterly growth was the only consistent feature between crop classes.

The patterns of growth demonstrated for Bundaberg are a reflection of the crop response to seasonal climatic conditions. The youngest cane available for harvest was six months of age, thus all canes would be entering each quarterly period with a complete, or at least extensively developed, leaf canopy. Dry matter accumulation during the December-March quarter is during the months of highest mean day temperature, high radiation (Table Ia); this period was preceded by three months of increasing radiation. Growth during the March-June quarter is limited by a declining thermal and radiation inputs, while lowest growth rates were recorded during the winter quarter of June-September. Growth was enhanced during the September-December quarter by an increasing energy regime, but could not achieve December-March growth rates, presumably because checks in growth induced during the preceding winter quarter.

The 'erratic' pattern of growth shown for Ayr is probably a reflection of moisture stress limiting the response to radiation and temperature. Growth rate at Ayr was higher than the Bundaberg value in the December-March quarter for plant and second ratoon crops: this is the wet season quarter at Ayr when irrigation was generally not required. Growth during the December 1980-March 1981 quarter may have been limited by a very heavy wet season and restricted radiation (Table lb). However, meteorological data show a sharp termination to the wet season and poor performance in March-June and September-December quarters thus probably reflects moisture stress. Winter growth at Ayr was superior to that at Bundaberg.

Significant crop class x month of initiation and crop age x month of initiation interactions ($p < 0.05$) were detected for both Ayr and Bundaberg yields of total dry matter. These interactions implied that the effect of month of initiation was not the same for each crop class, and that the effect of month of initiation on dry matter yields was not the same for all ages of crop. Confirmation of these interactions can be obtained by observation of data in Annex I. The crop class x month of initiation interaction can be demonstrated by comparing the ranking of crop class dry matter yields within age groups for each month of initiation.

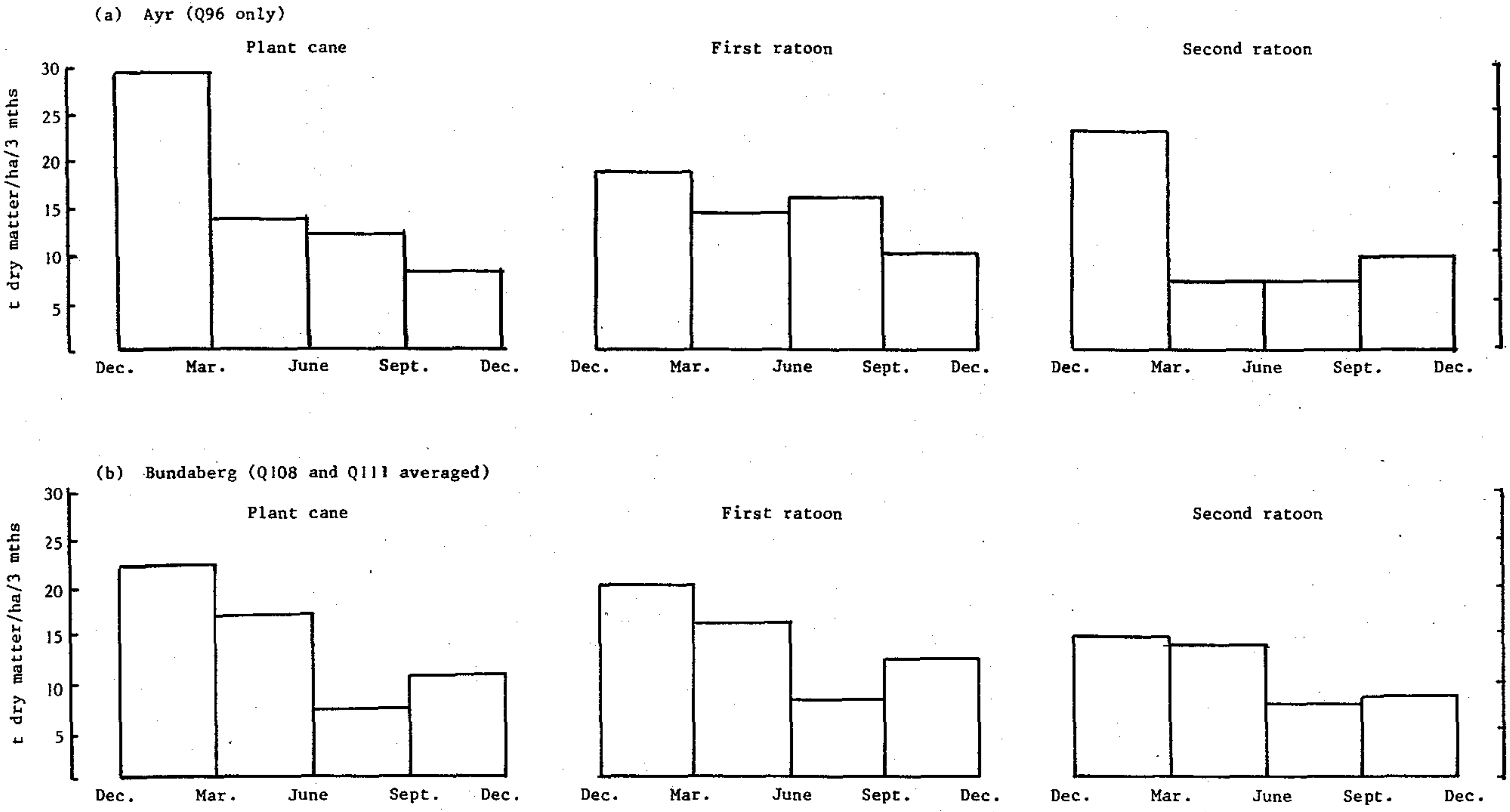

FIGURE 1 - Average yield of whole plant dry matter (t/ha/3 months) at Ayr and Bundaberg

There was no clear pattern to the crop class x month of initiation interaction in Burdekin data; however, at Bundaberg (Figure 2) it was shown for 12 and 15 month old crops that total dry matter yields (averaged for varieties) were ranked in the order plant cane > first ratoon > second ratoon for March and June initiations, whereas for September yields were ranked first ratoon > plant cane > second ratoon. First ratoon from December initiations also produced highest yields for both 12 and 15 month old crops, with lowest yields produced by plant cane for 6, 9 and 12 month old crops initiated in December.

These results again demonstrate the importance to yield of having a sugarcane crop with a well developed canopy to intercept high levels of radiation during the period September to March. Plant cane results would appear superior from March and June plantings because advantages of more rapid canopy development in ratoon cane are negated by autumn and winter regimes. With the onset of spring and summer physiologically younger plant cane is then able to support a small growth advantage over first ratoon. Conversely especially for December initiations more rapid canopy development in ratoon crops has allowed a quite marked general advantage over plant cane.

Similarly the age x month of initiation interaction is observed by comparing the ranking of month of initiation dry matter yields within crop classes for each age group. This interaction showed that young canes of 6 and 9 months of age both achieved best dry matter yields from September initiation and worst results from March, whereas 12 and 15 month old crops achieved best results from June and March planting respectively and worst results from December planting. These results can again be explained in terms of rates of canopy development and growing conditions. Data for 12 month old crops showed that in all crop classes March initiation gave lowest growth rates ($grams.m^{-2}.day^{-1}$); however, ratoon cane was not as susceptible as plant cane to depression in growth rates for crops initiated in December for both Ayr and Bundaberg. Data for this interaction at Ayr generally followed the pattern at Bundaberg, but moisture stress at Ayr limits the extent to which data can be discussed.

Varietal interactions with crop class, month of initiation and age at harvest were not significant at Ayr or Bundaberg.

3.2.1.3 Photosynthetic efficiency

Efficiency of conversion of total incident short-wave radiation to dry matter during relevant crop periods was calculated for Ayr and Bundaberg data. A factor of 1.76×10^{-2} was used to convert grams of dry $matter.m^{-2}$ to equivalent megajoules.

The data in Table IV show much lower overall photosynthetic efficiency at Ayr when compared to Bundaberg; presumably due to moisture stress at the former site. Lower levels of photosynthetic efficiencies in some 6 and 9 month old cane at Bundaberg and Ayr were associated with incomplete leaf canopy development and thus lower interception of incident radiation.

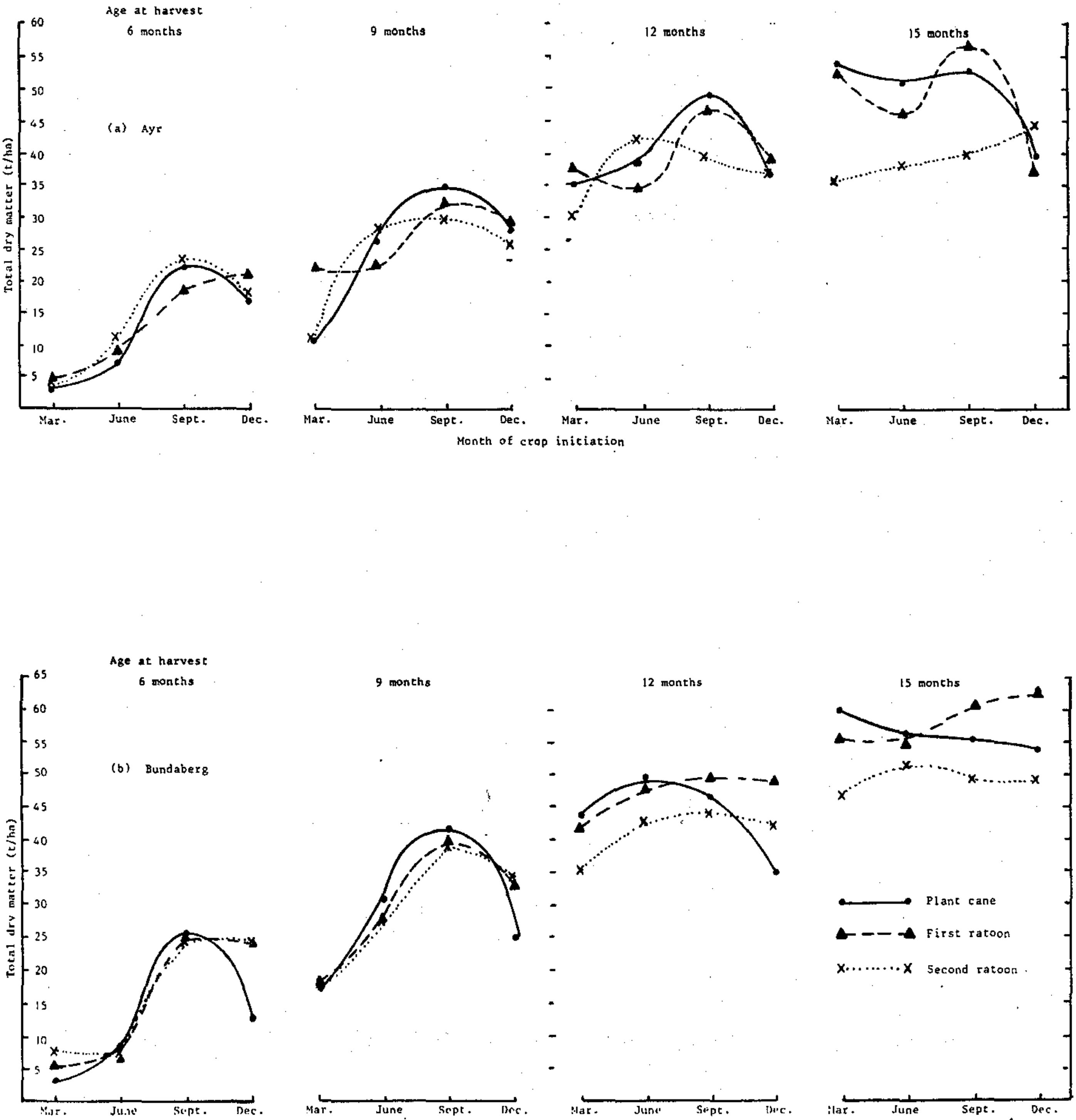

FIGURE 2 - Yield of total dry matter for sugarcane at (a) Ayr and (b) Bundaberg, in relation to month of crop initiation and age at harvest

TABLE IV

Photosynthetic efficiency* (%) in sugarcane at Ayr and Bundaberg for conversion of incident short-wave solar radiation to whole plant dry matter

Crop class	Month of initiation	Age at harvest (months)							
		Ayr				Bundaberg			
		6	9	12	15	6	9	12	15
Plant cane	Mar.	0.2	0.4	0.8	1.0	0.2	0.7	1.2	1.4
	June	0.3	0.7	0.8	0.9	0.4	1.0	1.4	1.3
	Sept.	0.9	1.0	1.0	0.9	1.2	1.5	1.3	1.2
	Dec.	0.8	0.9	0.8	0.7	0.8	1.0	1.0	1.2
First ratoon	Mar.	0.3	0.7	0.9	1.0	0.4	0.8	1.2	1.4
	June	0.2	0.7	0.8	0.9	0.4	1.0	1.4	1.3
	Sept.	0.8	1.0	1.1	1.0	1.2	1.5	1.4	1.3
	Dec.	1.1	1.0	1.0	0.7	1.5	1.4	1.5	1.4
Second ratoon	Mar.	0.2	0.4	0.7	0.7	0.6	0.7	1.1	1.2
	June	0.5	0.9	1.0	0.8	0.4	1.0	1.3	1.3
	Sept.	1.0	0.9	1.0	0.8	2.0	1.5	1.3	1.1
	Dec.	0.9	0.9	0.9	0.9	1.5	1.5	1.3	1.2

* 1.76×10^{-2} $MJ.m^{-2}$ $\equiv$ 1 g of dry $matter.m^{-2}$

3.2.1.4 Total dry matter models

Because of the dependence of total dry matter production on month of crop initiation and age at harvest and a functional relationship with radiation available for growth, several growth models for total dry matter production were derived from regression of total dry matter yields on intercepted short-wave solar radiation and the above variables.

Intercepted solar radiation was calculated as a function of total available solar radiation at Bundaberg and Ayr, and proportion of complete canopy development for each age and crop class combination. The latter data were estimated from knowledge of canopy development rates acquired during evapotranspiration experiments (Kingston & Ham, 1975).

Models which describe average dry matter production for the whole crop cycle at Ayr and Bundaberg are shown in Figure 3. Data at each site are the average of two varieties. The models in Figure 3 demonstrate the high degree of dependence of growth on intercepted radiation. The lower slope and vertical displacement of the Ayr model reflects the less efficient utilisation of intercepted radiation at Ayr due to moisture stress. Higher rates of canopy development were noted at Ayr in relation to Bundaberg.

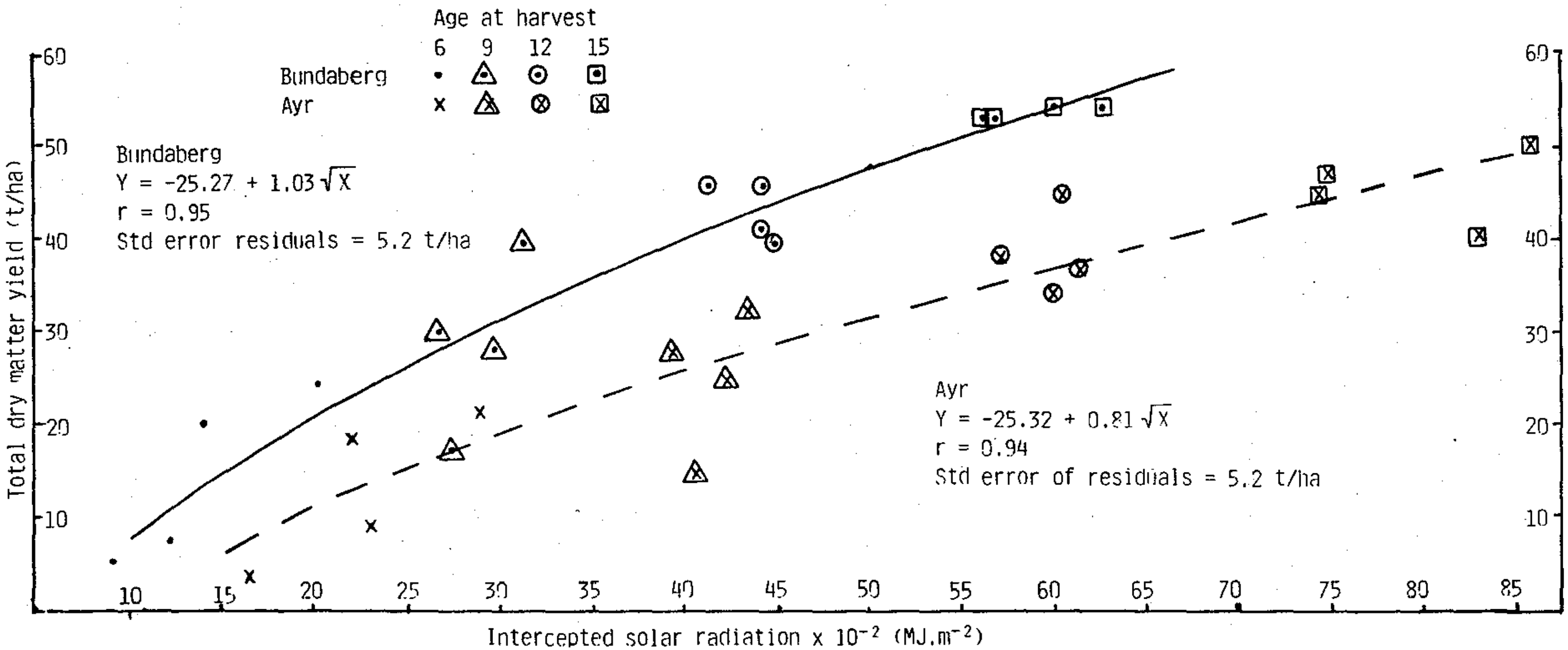

FIGURE 3 – Relationship between intercepted solar radiation and average crop cycle total dry matter production for sugarcane grown at Ayr and Bundaberg

More detailed models, which include allowances for crop class, intercepted radiation, month of initiation, month of harvest and (where significant) interactions of crop class and intercepted radiation, are contained in Annex II. These models allow extraction of total dry matter yields with respect to crop class, months of initiation or month of harvest.

3.2.1.5 Components of dry matter

3.2.1.5.1 Vegetative components

Data in Figures 4a and 4b summarise the growth process for the diversion of dry matter accumulation into the recognised above-ground vegetative components of the sugarcane plant. Data are presented for plant and first ratoon crops only, as first and second ratoon curves were very similar.

Comparison of plant and ratoon data shows the general and overall similarity of the growth process in plant and ratoon cane for comparable months of crop initiation.

In both crop classes it is apparent that crops initiated in March and June generally contain higher proportions of green leaf and tops in the biomass up to the age of 9 months than do crops planted or ratooned in September and December. From 12 to 15 months of age, crop class and month of initiation appeared to have little effect on the proportion of total dry matter represented by green leaf and tops, with values stabilising between 7 and 10% of total dry matter. However, cane planted in December appeared to support a higher proportion of green leaf over all age groups than similarly aged ratoon cane.

The slower rate of decline in green leaf dry matter yields in the 12 to 15 month old cane for first ratoons initiated in September at Bundaberg was due to heavy suckering (new growth) in Q108. This phenomenon is also reflected in a decline in trash per cent and an increase in top per cent in dry matter.

Trash (dead leaf) proportions in total dry matter increased with age of crop to stabilise at approximately 20% of total dry matter at 12 to 15 months of age.

Presence of stalk material in total dry matter was related to rates of growth imposed by the environment. Figure 4 shows that growth rates for crops initiated from September to December were such that the physiological age of the plant had advanced to the stage where stalk represented from 33 to 47% of total dry matter at 6 months of age. This is quite different to March and June initiations where the biomass was comprised mostly of green leaf and top material.

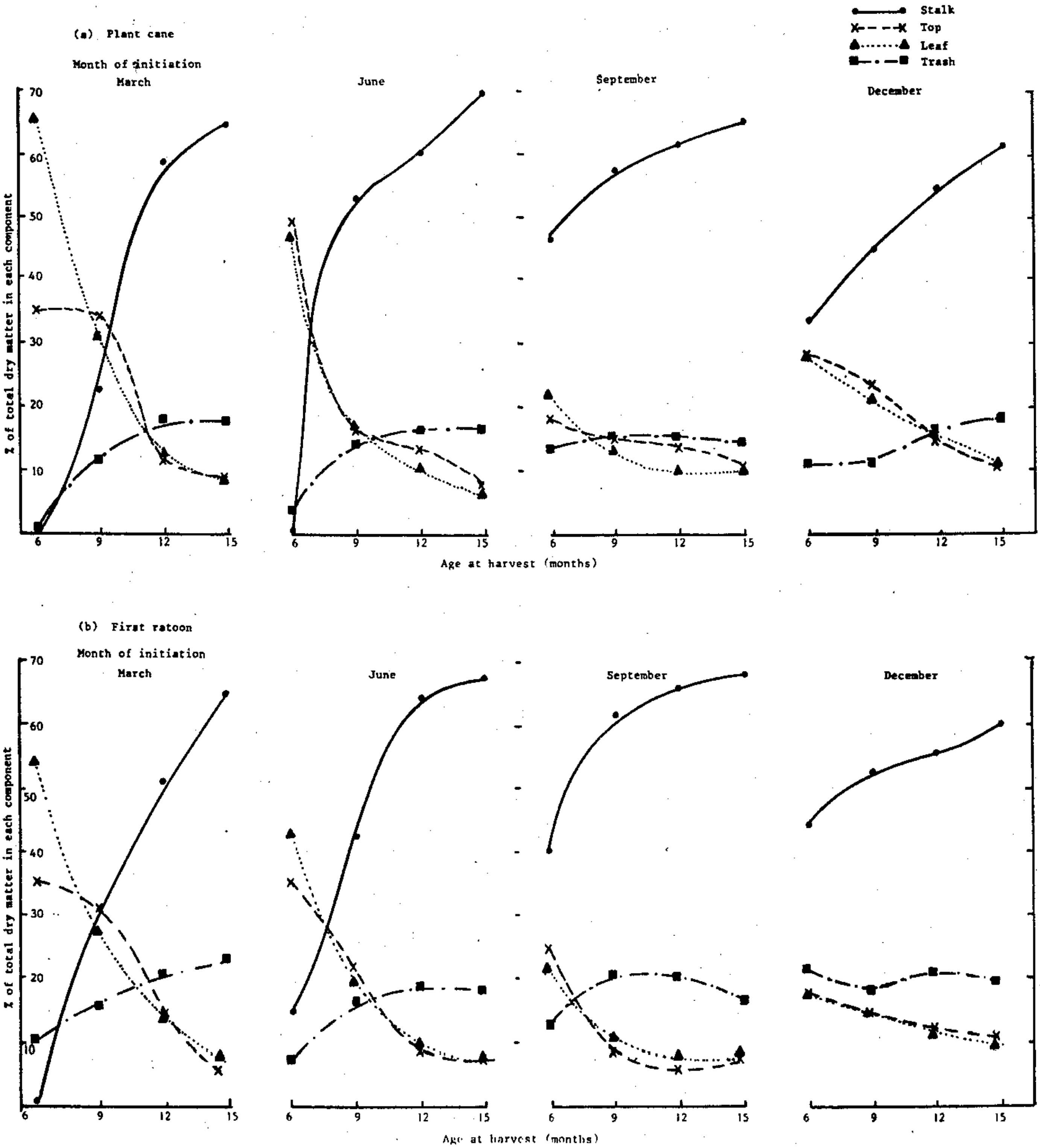

FIGURE 4 - Effect of month of initiation and age at harvest on proportions of plant vegetative components in total dry matter for (a) plant cane and (b) first ratoon sugarcane at Bundaberg

3.2.1.5.2 Fibre and soluble carbohydrate

Analysis of variance has shown that variety, month of crop initiation, and age at harvest were all significant variables ($p < 0.05$) affecting the proportion of total dry matter represented by C_6 sugars and dry fibre in sugarcane at Ayr and Bundaberg. Crop class was shown to have significant effects on the proportion of fibre in dry matter at both centres, but only on C_6 sugars at Ayr. Fibre was higher in ratoons than in plant cane. The data also showed a significant month of initiation x age at harvest interaction (similarly aged canes performed differently between months of initiation and conversely).

Examples of these data are shown in Figure 5 for the Bundaberg varieties where Q108 was known to have a high fibre characteristic, while Q111 stalks generally accumulated more sucrose. The data clearly demonstrated that a higher proportion of total dry matter production was directed to producing fibre in Q108 than in Q111. The term fibre is defined as 'dry, water insoluble matter in the cane' (BSES, 1970). This fraction comprises cellulosic xylem elements, lignins, cell walls, epidermal material and waxes.

Conversely it was shown that Q111 directed a higher proportion of total dry matter to soluble carbohydrate, expressed as C_6 sugars (glucose/fructose equivalents) than did Q108.

Examination of data for the division of total dry matter into vegetative components for each variety did not demonstrate any consistent varietal differences, yet fibre assay data revealed that all components of Q108 contained more fibre, as a percentage of total dry matter, than did Q111 components; with the exception of dead leaf where fibre percentages of dry matter were similar for both varieties. Thus this difference in utilisation of photosynthetate is a characteristic of the whole plant, and not just stalk material as had been previously recognised.

As with previous discussions of the growth process in sugarcane, the forms of curves shown in Figure 5 are readily interpreted in relation to crop growth phases. The shape of the C_6 curves in Figure 5 closely resemble the form of the curves for stalk component of total dry matter in Figure 4, especially for the ratoon crops. The implication in this observation is that rapid accumulation of C_6 sugars is associated with periods of major vegetative growth. This is confirmed by examination of C_6 sugar curves for cane older than 9 months in Figure 5, for each month of initiation. The C_6 sugar per cent of total dry matter remains relatively constant within varieties for canes of at least 9 months of age in June which are then harvested in the period June to December. As data in Figure 2 have shown that dry matter accumulation continues up to at least 15 months of age, the flattening of curves in Figure 5 is interpreted as a state of equilibrium between structural and soluble carbohydrate during the two quarters of the year with lower photosynthetic potential.

Crops initiated in December demonstrated lower equilibrium C_6 percentage and higher fibre percentages than did crops initiated in June and September. Reference to Figure 4 shows that cane from December

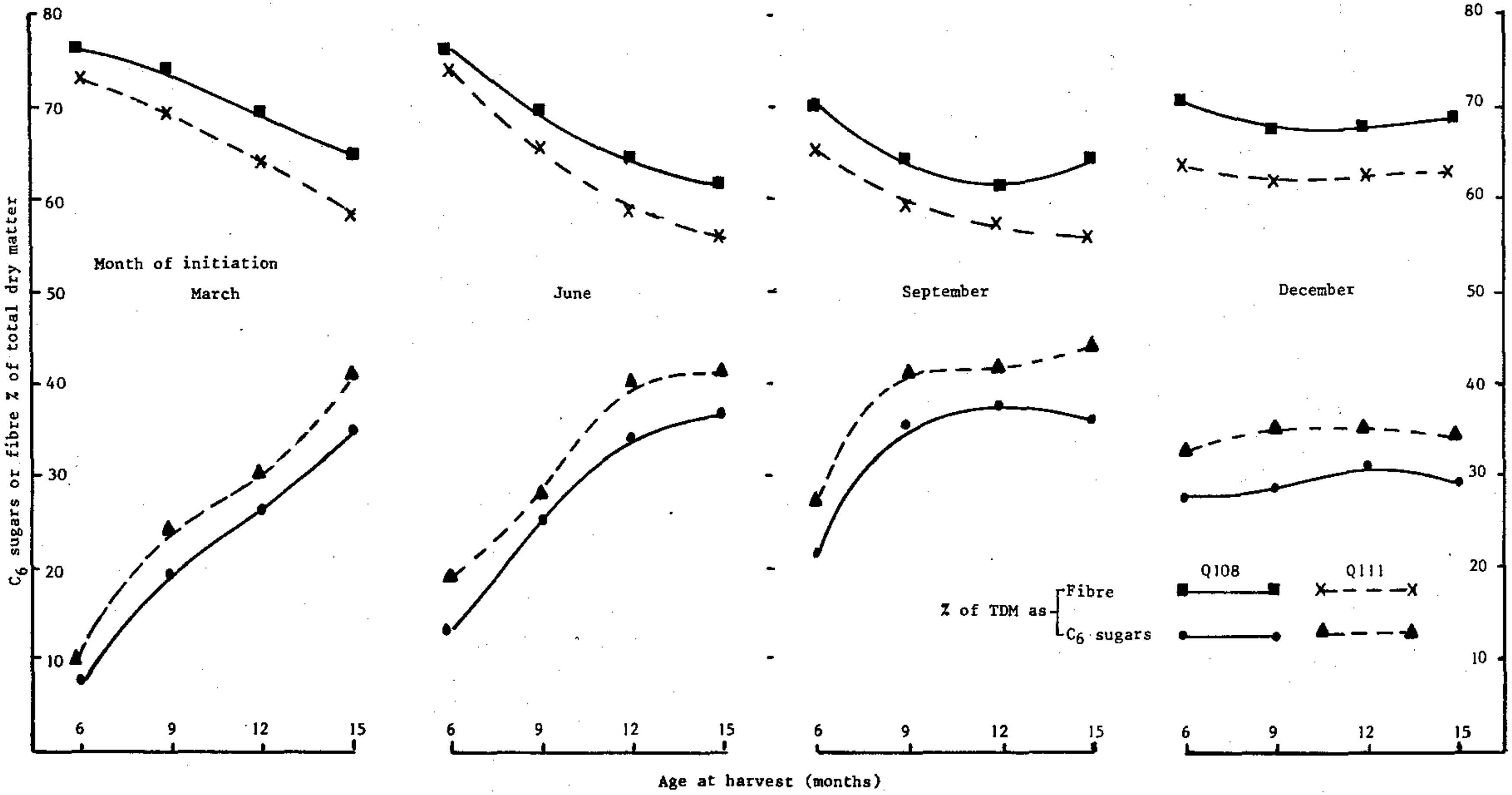

FIGURE 5 - Effect of month of initiation and age at harvest on the proportion of total sugarcane dry matter contained in C_6 sugars and fibre at Bundaberg/ Data are crop cycle averages.

initiations contained more leaf and top and less stalk in its dry matter during the June to December harvest period than did similarly aged cane from other initiation dates. Thus less potential existed for storage of C_6 sugars. It is suggested that this pattern of growth was the result of initiation into a period of declining incident radiation.

3.2.2 Total fresh weight

Total fresh weight yields of sugarcane at Ayr and Bundaberg are shown in Figure 6, with data averaged for the two varieties grown at each site. However, at Ayr Q96 generally produced more fresh material per hectare than did Q92, while at Bundaberg Q111 outyielded Q108 in total fresh weight. Q111 produced the highest fresh matter yields recorded during the entire experiment:- 192.4, 198.5 and 207.2 t/ha for 15 month old March plant cane, March initiated first ratoon and December initiated first ratoon.

3.2.2.1 Stalk yields

Fresh weight yield of cane stalks for Ayr and Bundaberg are shown in Annex III, along with relevant statistical data for examination of yield differences.

At Ayr, Q96 generally showed significantly higher stalk yields than Q92. There were several instances of this pattern being reversed, but there appeared to be no explanation for the effect. The Bundaberg data showed that Q111 generally produced significantly more stalk yield than did Q108; however, as at Ayr, there were several exceptions. Varieties were not involved in significant interactions with month of crop initiation, age at harvest or crop class.

Average stalk yields at both sites with respect to crop class were ranked in the order first ratoon > plant cane > second ratoon.

Graphed summaries of stalk yield data are contained in Figures 7 and 8. Month of crop initiation and age at harvest were recognised as significant variables affecting stalk yield at both sites (Annex III), and from Figures 7 and 8 it was apparent that trends in stalk yields related to these parameters were broadly similar for Ayr and Bundaberg.

Stalk yields increased from 6 to 15 months of age in all instances except for 15 month old second ratoon cane at Ayr for crops initiated in March, June and September (Figure 8). Both Ayr and Bundaberg data showed that rates of stalk growth in the 12 to 15 month period were generally lower than for 6 to 9 and 9 to 12 month intervals (Figure 7).

Significant interactions on stalk yield were recognised between crop class and month of initiation, crop class and age at harvest, and month of initiation and age at harvest.

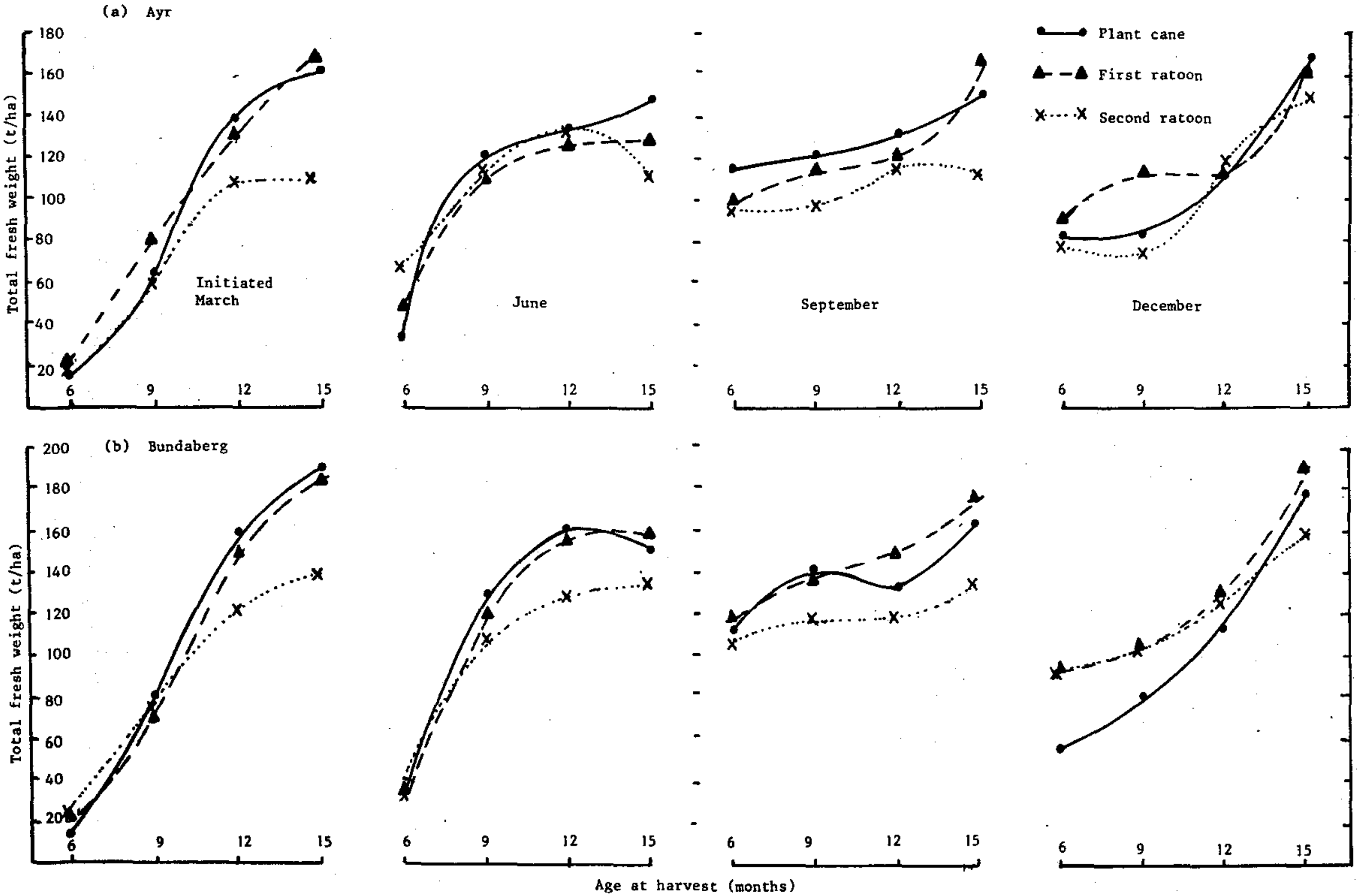

FIGURE 6 - Yield of total fresh weight (t/ha) for sugarcane grown at (a) Ayr and (b) Bundaberg, in relation to crop class, month of initiation and age at harvest

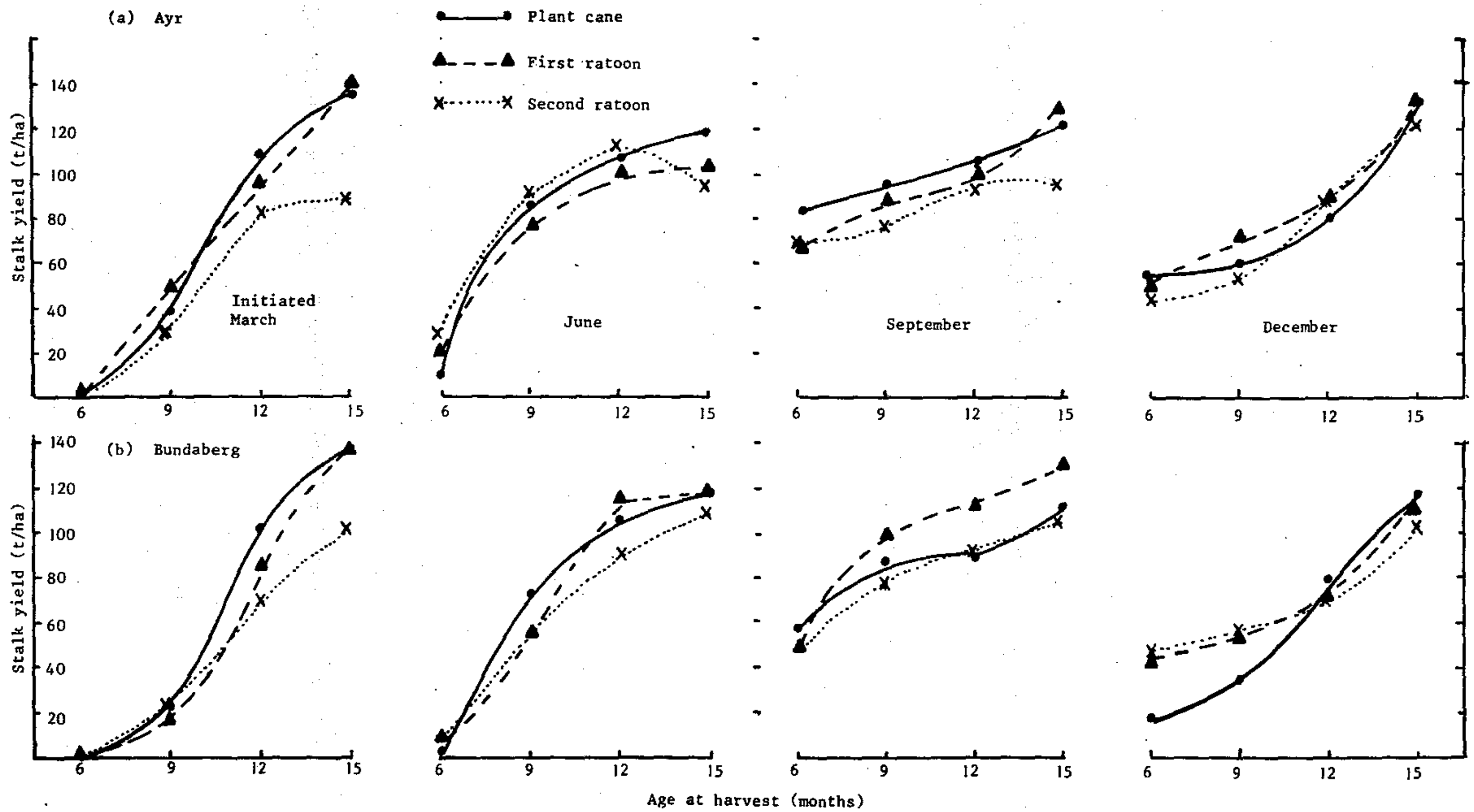

FIGURE 7 - Yield of stalks (fresh weight t/ha) for sugarcane grown at (a) Ayr and (b) Bundaberg, in relation to crop class and age at harvest

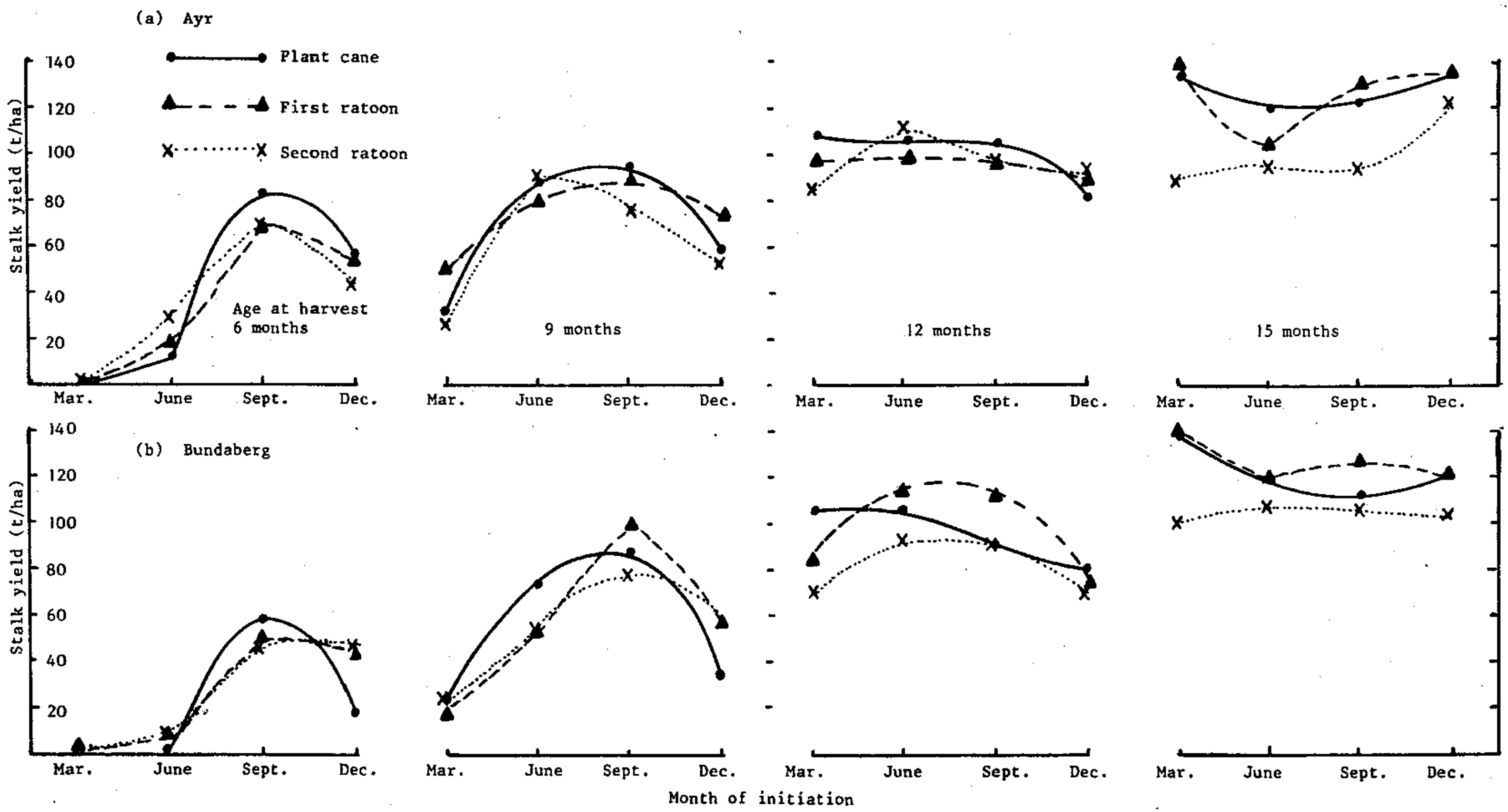

FIGURE 8 - Yield of stalks (fresh weight t/ha) for sugarcane grown at (a) Ayr and (b) Bundaberg, in relation to crop class and month of initiation

Figure 8 clearly illustrates the crop class x month of initiation interaction. Within 6 and 9 month old crops cane planted in December at Bundaberg gave lower stalk yields than similarly aged and initiated ratoon crops. Quite marked differences in crop class response to month of initiation was shown in 12 month old cane stalks at Bundaberg (Figure 8). This difference is probably attributable to slower development of canopy in plant cane. Canes planted in September and December were insufficiently advanced to take full advantage of high levels of incident radiation while being physiologically young. At both sites crops initiated in December generally gave lowest stalk yields for all crop classes, while June to September period was optimal for 12 month old ratoon crops.

Second ratoon cane was markedly inferior to plant and first ratoon crops at both sites. From Figure 8 it was apparent that the month of initiation x age at harvest interaction was demonstrated by a decreasing effect from month of initiation as age at harvest increased.

Average stalk yields at Ayr were generally greater than those recorded at Bundaberg (Table V), with the yield advantage for Ayr declining with increasing crop age. The stalk yield advantage for Ayr was obtained even though Bundaberg crops generally produced superior yields of total dry matter per hectare.

TABLE V

Crop cycle average yields of cane stalk (t/ha) at Ayr and Bundaberg. Data are averaged for varieties.

Month of initiation	Age at harvest (months)							
	Ayr				Bundaberg			
	6	9	12	15	6	9	12	15
March	0.0	34.9	94.4	120.2	0.0	20.7	85.1	125.0
June	19.4	84.9	105.3	105.4	4.6	59.9	103.0	114.4
September	72.8	86.5	99.0	115.3	50.2	88.2	96.4	114.5
December	49.8	60.7	85.8	130.2	35.8	49.0	73.6	113.5

Further comparison of the difference in dry matter yields of vegetative components at Ayr and Bundaberg is given in Table VI. These data show that cane at Bundaberg produced from 2.0 to 3.5 t/ha more dry matter in top material (leaf sheaths and immature stalk) than did varieties at Ayr, and that 12 and 15 month old crops at Ayr had produced 2.1 and 2.8 fewer tonnes of leaf dry matter than similarly aged cane at Bundaberg.

TABLE VI

Difference in dry matter yields of vegetative components of sugarcane grown at Ayr and Bundaberg (t/ha). Data are (for Ayr-Bundaberg) averaged for crop class, variety and month of initiation

Plant component	Age at harvest			
	6	9	12	15
Stalk	0.7	1.3	0.4	-3.0
Top	-2.0	-3.5	-3.3	-3.0
Leaf + trash	-0.2	1.5	-2.1	-2.8

It has been verified that sectioning between stalk and tops was performed within 5 cm of the same ontogenetic point on the stalk for the different varieties at Ayr and Bundaberg. Thus it has been concluded that the above differences in component dry matter yield and stalk fresh weight are again either a reflection of the stressed conditions encountered during crop growth at Ayr or due to different proportions of top and leaf to stalk between canes grown in tropical and sub-tropical environments.

In regard to moisture stress, it can be inferred that growth restrictions reduced the rate of expansion of new leaf and elongation of immature stalks, thus hastening senescence of lower leaves and increasing the proportion of stalk relative to top material. The reduced area of photosynthetic material was then reflected in poorer relative stalk yields at Ayr in comparison to Bundaberg for 15 month old canes.

In regard to differences in vegetative composition between canes grown in tropical and sub-tropical environments, there are limited data (Table VII) which suggest that sub-tropical canes may support a higher proportion of non stalk material when similar cane yields are encountered. These data were obtained from eight sites in each mill area of the State in association with a fertility monitoring project in which green leaf, tops and dry trash were treated as a single component.

TABLE VII

Vegetative components of tropical and sub-tropical sugarcane in Queensland (unpublished data)

District	Climate	Component % total fresh weight		Cane yield t/ha
		Cane	Tops, trash, and leaf	
Mossman-Cairns	Tropical	77.5	22.5	100.4
Babinda-Tully	Tropical	76.9	23.1	93.0
Ingham	Tropical	74.0	26.0	74.4
Burdekin	Tropical	75.5	24.5	118.8
Mackay	Tropical	78.7	21.3	84.2
Bundaberg	Sub-tropical	71.2	28.8	92.0
Maryborough-Rocky Point	Sub-tropical	73.9	27.1	85.2

Several growth analysis experiments have examined the potential for increases in cane stalk yield during the normal sugarcane crushing season. Moller (1973) at Bundaberg found an average growth of 8.6 and 4.0 tonnes stalk per hectare for three varieties from June to September and September to early November respectively; while Leverington, Hogarth & Ham (1978) reported no evidence of increasing stalk yields at Ayr from early July to mid December.

Quarterly average stalk yield data for Ayr and Bundaberg during this biomass experiment have been calculated and are shown in Figure 9, from which it is evident that the June-September value for Bundaberg is close to Moller's (1973) estimate. However, September to December growth at Bundaberg and growth during both quarters at Ayr was larger than previously reported.

3.2.2.2 Models for stalk growth

Models which describe the stalk yield of sugarcane at Ayr and Bundaberg in relation to month of crop initiation, month of harvest, crop class and intercepted solar radiation are shown in Annex IV. Stalk yields were modelled on average varietal data for each site.

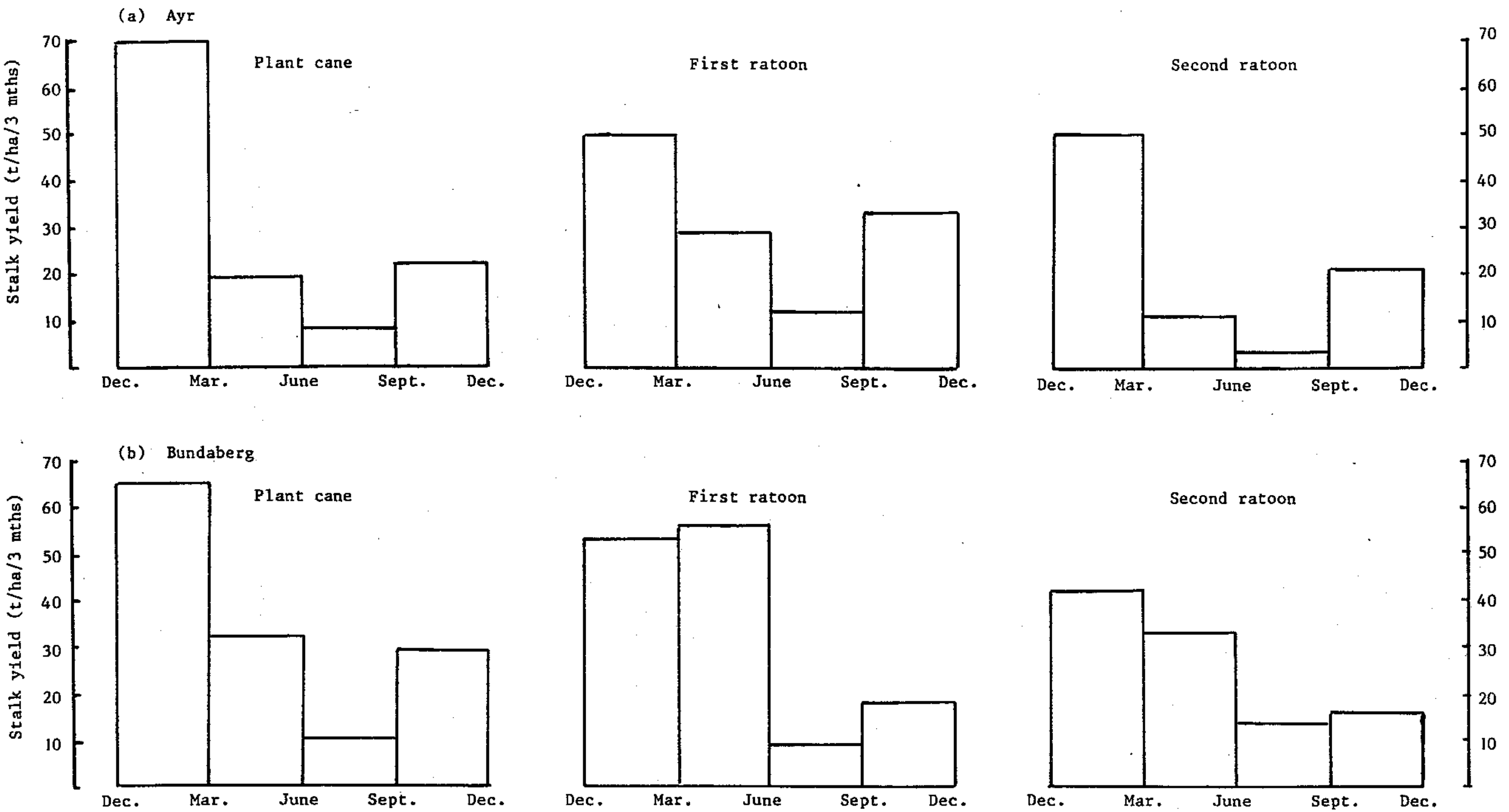

FIGURE 9 - Growth of cane stalk (t/ha/3 months) at (a) Ayr and (b) Bundaberg

3.2.3 Fibre

Fibre yields from sugarcane are of importance to the commercial sugar industry for provision of bagasse for boiler fuel. High levels of fibre in cane are regarded as undesirable because of the greater volume of material which must be processed to extract sugars.

Conversely if fibre attained a new value as raw material for enzymatic conversion of cellulose to C6 sugars, or for gasification to methanol, fibre yields may be seen with a different perspective.

3.2.3.1 Total fibre yield

Total fibre yields for Ayr and Bundaberg varieties are described in Annex V, along with relevant statistical information. Analysis of variance showed that crop class, variety, month of initiation and age at harvest were all significant variables affecting total fibre production. The only interaction which failed to achieve statistical significance was that between crop class and variety.

The data for Ayr showed that Q96, the variety with slightly higher stalk fibre characteristics, significantly exceeded Q92 yields of total fibre on more than 50% of occasions. Whereas at Bundaberg the 'high fibre' Q108 significantly out-yielded Q111 in total fibre in 64.5% of harvests, varieties were not significantly different in 8.4% of harvests, and in 27.1% of harvests total fibre yields of Q108 were lower than those of Q111. At both sites, occasions of inferiority in total fibre yield of the 'higher fibre' variety were associated with marked superiority of the lower fibre cane in total dry matter production.

The operation of the age at harvest x variety interaction on total fibre yields is demonstrated in Figures 10a and 10b, where crop cycle average total fibre yields for each variety are seen to diverge with increasing age at harvest. Examination of this divergence in relation to patterns of growth and stalk yield shows that the divergence is related to fibre accumulation in stalks.

As for dry matter yields, total fibre and stalk fibre yields increased with age at harvest for each month of initiation. Thus highest fibre yields were obtained from 15 month old crops, the average yields being 29.1 and 33.4 tonnes per hectare at Ayr and Bundaberg respectively.

3.2.3.2 Stalk fibre yield

At Ayr, stalk fibre yields of Q96 were significantly greater than those of Q92 on 73% of harvest dates, significantly less, and not significantly different on six and 21% of occasions respectively.

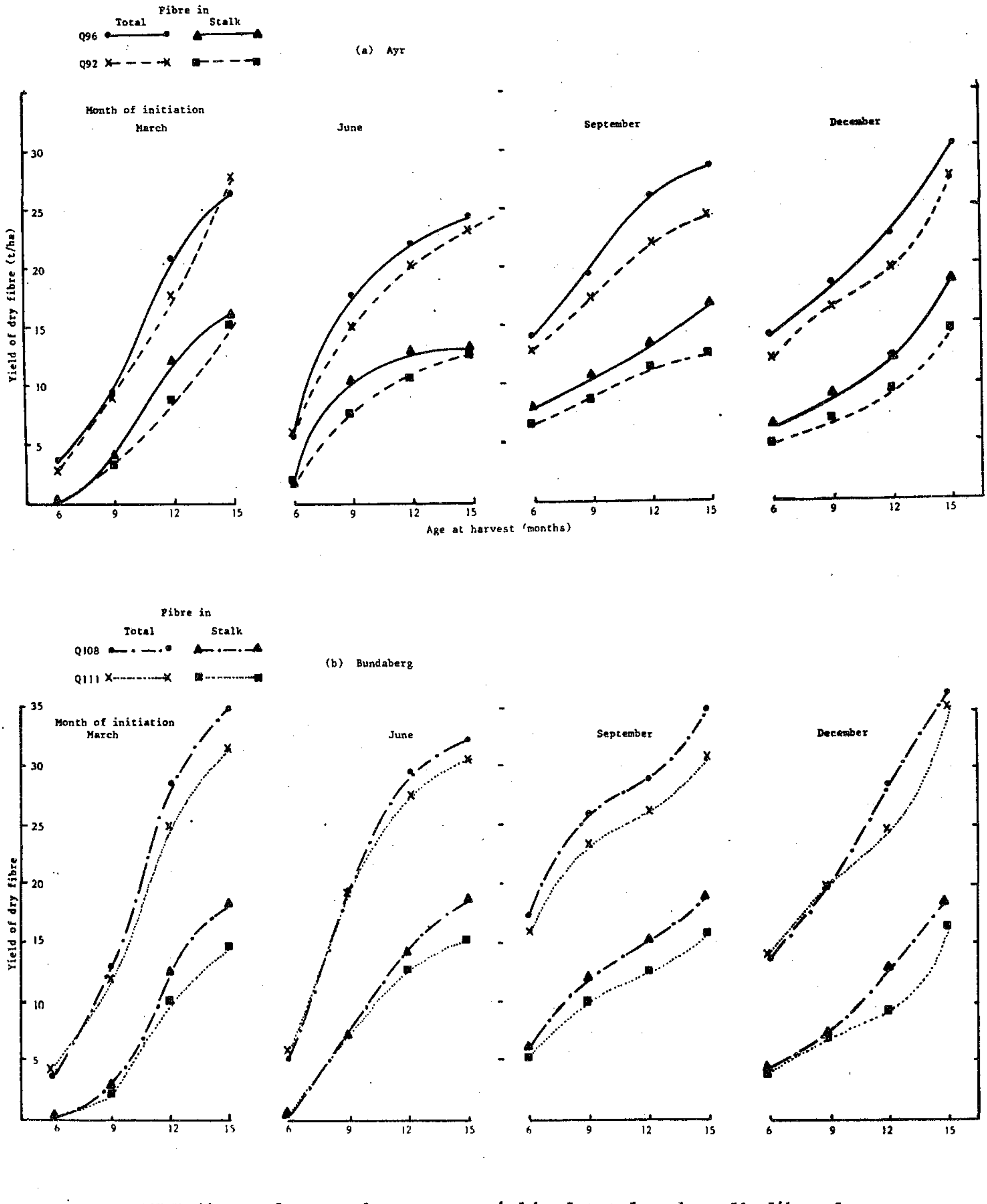

FIGURE 10 - Crop cycle average yield of total and stalk fibre for each sugarcane variety grown at (a) Ayr and (b) Bundaberg

At Bundaberg, stalk fibre yields from Q108 were significantly greater than those of Q111 for 79% of harvests and not significantly different on 21% of occasions.

The influence of stalk fibre yields on total fibre yield is shown in Figure 10.

3.2.3.3 Models for fibre yield

Models describing total fibre yields are shown in Annex V, while Annex VI models describe fibre yield from stalks.

3.2.4 C_6 sugars

If sugarcane was to be regarded as a source of soluble carbohydrate for production of sucrose and fermentation products, C_6 sugars (predominantly glucose and fructose) are just as important for fermentation as is the sucrose component. Therefore in this section sucrose, glucose and fructose have been expressed as C_6 equivalents.

3.2.4.1 Total C_6 sugar yield

Total C_6 sugar yields (stalk + top + green leaf) data are shown for each of the varieties at Ayr and Bundaberg in Annex VII. On average, sugarcane grown at Bundaberg produced a higher yield of C_6 sugars in the whole plant than did cane grown at Ayr. At both sites C_6 sugar yields were ranked in the order first ratoon > plant cane > second ratoon. At Ayr Q96 produced significantly more total C_6 sugars than Q92 for 71% of harvests, and more, but not significantly more sugars for 25% of harvests; whereas at Bundaberg Q111 significantly out-yielded Q108 in total C_6 sugar production for 90% of harvests. Total C_6 sugar yields of Q111 were significantly lower than those of Q108 on only 2% of harvest periods.

Total C_6 sugar yields generally increased with age at harvest for each month of crop initiation. Average total C_6 sugar yields at 15 months of age at Ayr and Bundaberg were 18.6 and 20.1 tonnes per hectare respectively.

3.2.4.2 C_6 sugars in stalks and tops

Yield of C_6 sugars in the more dense stalk and top components of the sugarcane plant generally followed the varietal pattern mentioned for total C_6 sugars, with yields being ranked Q96 > Q92 and Q111 > Q108 at Ayr and Bundaberg respectively. It was found that cane grown at Ayr generally produced a higher yield of C_6 sugars from stalk material than did cane from Bundaberg at 6, 9 and 12 months of age, whereas the converse applied for 15 month old cane (Figure 11). Due to the larger yield of tops in Bundaberg varieties, the inclusion of this material reduced the differences in C_6 sugar yields between Ayr and Bundaberg for the three younger ages of harvest (Figure 12).

Results in Table VIII for the crop cycle indicate the average percentage increase in yield of C_6 sugars which could be attributable to tops if they were harvested along with stalk material at Bundaberg.

TABLE VIII

Percentage of increase in yield of C_6 sugars due to tops, if stalks and tops were harvested together, over the whole crop cycle

Month of crop initiation	Age at harvest (months)			
	6	9	12	15
March	100.0	38.1	11.7	6.1
June	69.6	19.0	9.0	5.0
September	21.8	9.2	6.5	5.2
December	19.5	15.1	10.3	8.5

Thus at 12 and 15 months of age, 9.4 and 6.2% of the higher yield due to harvesting stalks and tops would be attributable to tops. The extra yield obtained must be balanced against the additional impurities due to inorganic and organic constituents, which must be processed along with the C_6 sugars. This aspect is discussed in a following section.

C_6 sugar yields in stalks increased with age at harvest for each month of crop initiation. Average C_6 sugar yields in stalks at 15 months of age at Ayr and Bundaberg were 18.1 and 18.8 t/ha respectively.

Examination of C_6 sugar accumulation rates (t/ha/month) in Figures 11 and 12 shows relative stability in the growth rate between 1.2 and 1.5 t/ha/month for crops initiated in September and harvested at 9, 12 or 15 months of age, 12 and 15 month old crops initiated in June and 15 month old cane initiated in March. These crops were all harvested in the June to December period. These data appear consistent with the observation made from Figure 5, that during the months of June to December there is a balance between C_6 sugar and structural carbohydrate production during the 'ripening period'.

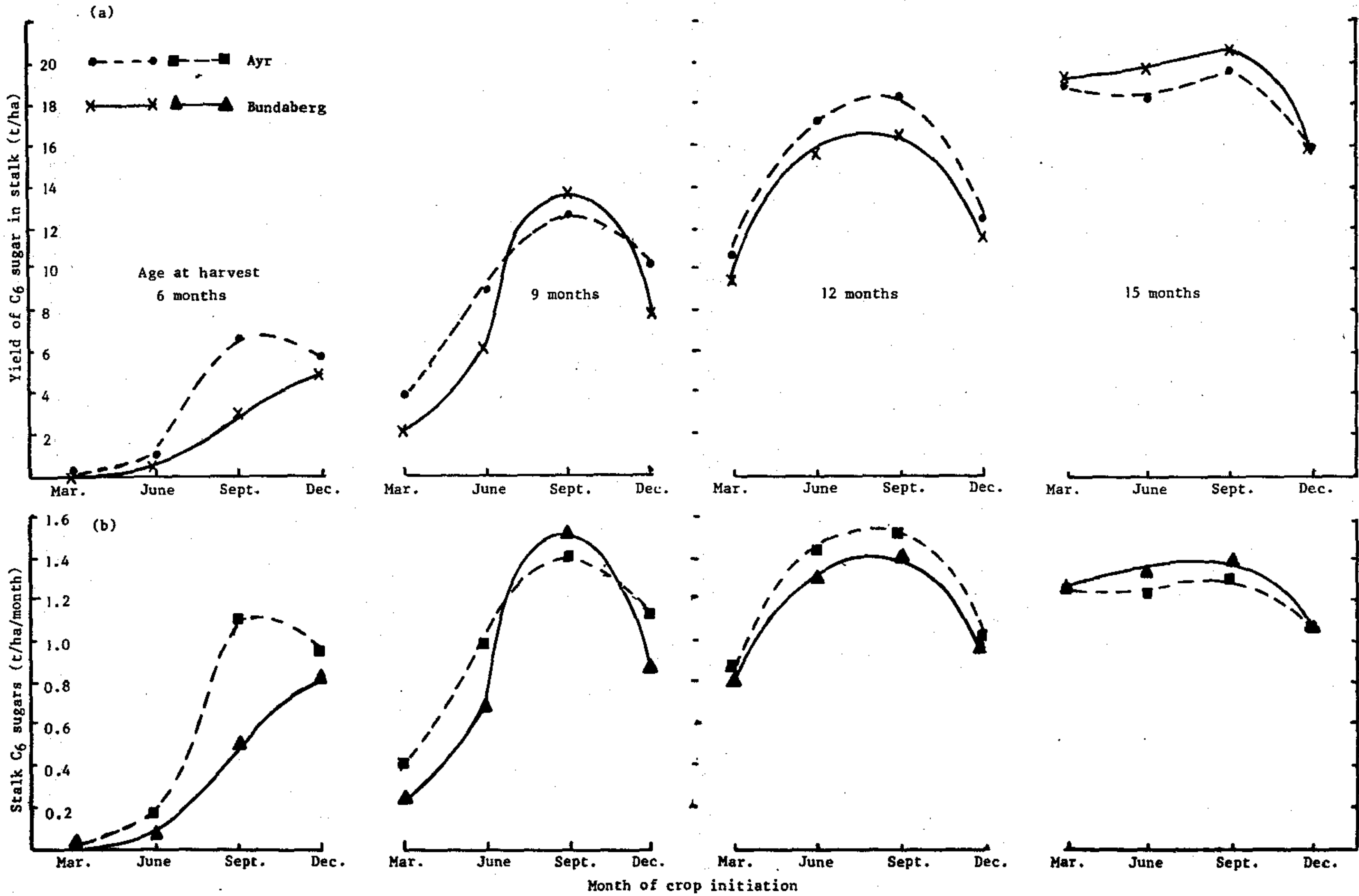

FIGURE 11 - Yield of C_6 sugars (a) t/ha and (b) t/ha/month in sugarcane stalks. Data are crop cycle and varietal averages.

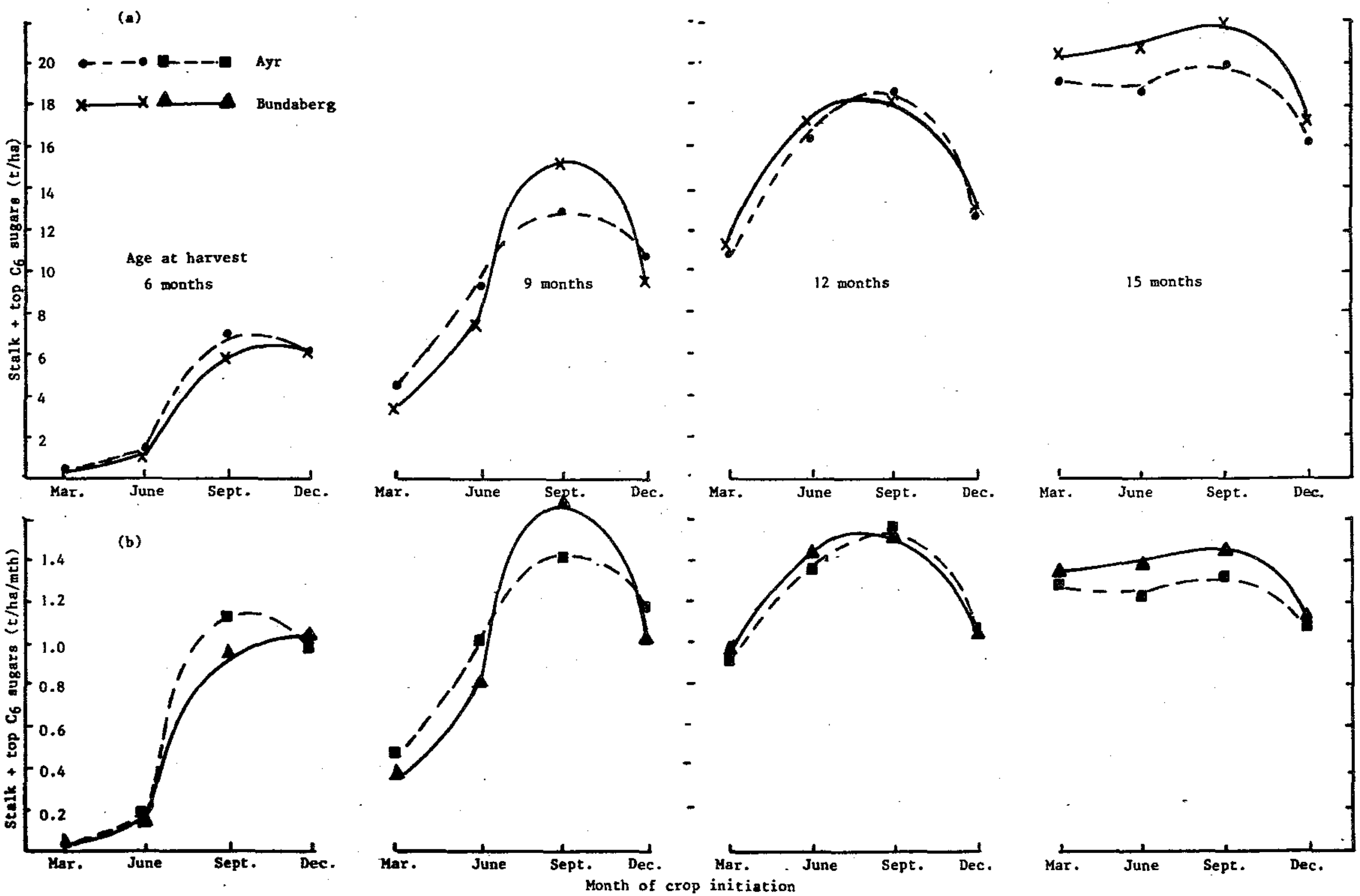

FIGURE 12 - Yield of C_6 sugars (a) t/ha and (b) t/ha/month in sugarcane stalk + tops. Data are crop cycle and varietal averages.

The existence of a significant interaction between month of crop initiation and age at harvest was noted from statistical evaluation of C6 sugar yields in stalks and stalk plus top material. This interaction is clearly demonstrated in Figures 11 and 12 by the different response of C6 sugar yield to month of initiation within each age grouping. The effect of month of crop initiation on yield became less significant as age at harvest approached 15 months. The adverse effects of initiating crops in March and December for harvest 12 months later was very obvious.

Therefore, in examining the options available for extension of the normal June-December sucrose harvesting season to allow harvest of fermentable sugars, it would appear that normal wet season activity would limit additional operations to the March-June quarter. Figures 11 and 12 clearly show that only cane of at least 15 months of age should be harvested in this period. From June harvest onwards, 12 and 15 month old canes gave the highest yield of C6 sugars. However, the high yield rate for 9 month old cane initiated in September and harvested in June suggests that this crop option should be closely examined in the development of initiation and harvesting strategies within crop cycles.

3.2.4.3 Models for C6 sugar production

Models which describe the accumulation of C6 sugars in stalk and stalk plus top material for each phase of the crop cycle in the Ayr and Bundaberg environments are shown in Annexes VIII and IX respectively.

As for earlier models of dry and fresh matter production, these models are functions of crop class, intercepted radiation, month of crop initiation and month of harvest. Models describe average performance of varieties at each site.

3.2.5 Sucrose

3.2.5.1 Sucrose per cent

Data for sucrose per cent in stalks showed that Q96 generally supported a higher sucrose per cent than did Q92 at Ayr, while a similar pattern prevailed for Q111 over Q108 at Bundaberg. For 12 and 15 month old cane at Ayr, Q96 was on average 2.0 and 1.6% respectively higher in sucrose than Q92. At Bundaberg, similarly aged Q111 was on average 1.0 and 1.6% higher in sucrose than Q108.

Results of sucrose per cent in stalks, averaged for varieties, at Ayr and Bundaberg (Figure 13) indicated that sucrose per cent generally increased with age at harvest from 6 to 15 months, for crops initiated in March, June and September. Notable exceptions were

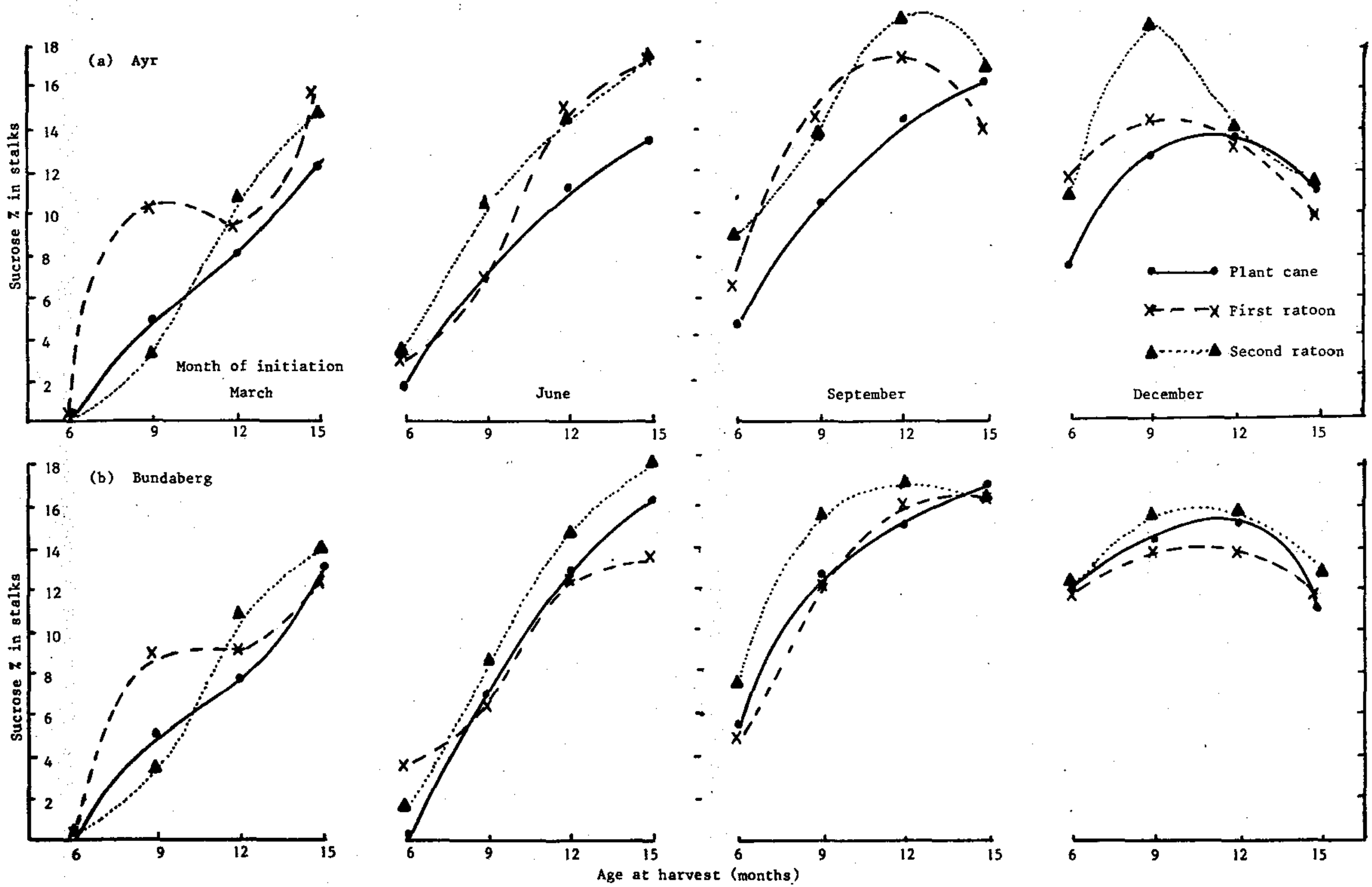

FIGURE 13 - Sucrose % in cane stalks grown at (a) Ayr and (b) Bundaberg for each crop class. Data are averaged for varieties.

first ratoon crops of 9 to 12 months of age at harvest from March initiations (i.e. crops harvested in December and March), and 15 month old first and second ratoon crops at Ayr only, where were initiated in September (i.e. December harvest).

At both sites crops initiated in December showed either little or no gain, or marked declines, in sucrose per cent beyond 9 months of age i.e. for harvests in December and March.

These data indicate a strong interaction between age at harvest and month of crop initiation, or month of harvest i.e. crops of all ages harvested between March and September showed increases in sucrose per cent in cane stalks, whereas only crops younger than 12 months of age generally showed increases in stalk sucrose per cent when harvested between September and March (Figure 13). These results imply that the arrest or decline in rate of increase of sucrose per cent in stalks of older cane between September and March is associated with hydrolysis of stored sucrose for active growth during the months of high insolation. Continued increases in stalk sucrose per cent for younger canes during this period is probably due to the fact that most stalk internodes were still physiologically young and elongating: increases in sucrose per cent from very low values $< 2\%$ to modest values approaching 6% reflect the ageing of lower internodes.

As was shown for C_6 sugars, any forward extension of the sucrose harvesting season into the autumn months must be based around cane of approximately 15 months of age. Figure 13 showed that sucrose per cent in stalks for 15 month old cane harvested in March at Ayr and Bundaberg ranged from 9.4 to 11% and 11.0 to 12.8% respectively. Regulations for payment of sugarcane are based on its sucrose content and do not allow sugar mills to pay growers for cane of c.c.s. inferior to 7.0. This would correspond to a sucrose per cent in stalks somewhat higher than 7.0%, due to empirical deductions for sucrose losses in processing which are attributed to fibre and other impurities in the stalk. Thus, given that seasonal variations will exist in sucrose per cent, there appears to be little economic potential, on current standards, for forward extension of the sucrose season as far as March.

3.2.5.2 Sucrose yields

Detailed data for yield of sucrose in cane stalks at Ayr and Bundaberg are shown in Annex X, along with relevant statistical information. The data show that stalk sucrose yields at Ayr were generally greater than those achieved at Bundaberg in plant, first and second ratoon crops. However, by second ratoon the proportion of harvests in which Ayr data outyielded Bundaberg was declining.

At Ayr, stalks from the variety Q96 produced significantly more sucrose per hectare than did stalks of Q92; while at Bundaberg, stalk sucrose yields from Q111 were generally significantly greater than those of Q108, especially for 12 and 15 month old cane.

Highest sucrose yield (averaged for varieties) of 21.9 t/ha was achieved at Ayr by 15 month old first ratoon cane harvested in June. At Bundaberg, highest average sucrose yield of 20.7 t/ha resulted from harvesting 15 month first ratoon cane in December.

Analysis of variance of data contained in Annex X revealed there was no significant interaction between crop class and variety for the cultivars used in this experiment. However, a significant interaction between crop class and age at harvest was demonstrated for both sites. No consistent pattern was evident to explain the difference in yield response of the crop classes to age at harvest.

Sucrose yields increased with age at harvest at both sites for all crop classes except 15 month old second ratoon cane initiated in September, harvested December, at Ayr (Figure 14).

Figure 15, which summarises stalk sucrose yield data for both sites over the whole crop cycle, clearly illustrates the adverse effect on sugar yield for crops of 9, 12 and 15 months of age which were initiated in December, and thus harvested in September, December and March respectively. Crops initiated in March performed poorly relative to other months of initiation for 6, 9 and 12 month old canes; however, by 15 months of age, crops initiated in March showed yields which were comparable to those of crops initiated in June and September. This performance can be explained quite adequately in terms of the interaction between crop growth phases and climate viz. 15 month old canes initiated in March develop relatively slowly during winter months but are able to take full advantage of peak growth months and then the ripening period during declining insolation from March to June in the second year.

As for C_6 sugar yields and sucrose per cent data it is quite apparent from sucrose yields (Figure 15) that any consideration to harvesting cane before June would best be based around canes of at least 15 months of age. The data also suggest that late harvests (December) can also be successfully based around older cane in terms of absolute sucrose yield and sucrose production efficiency (t/ha/month). The sucrose efficiency curves shown in Figure 15 show that peak production efficiencies are achieved from crops initiated in September and harvested at 9 or 12 months of age. However, the range of similar sucrose yield efficiencies shown in Figure 15 for canes of 9, 12 and 15 months of age at different months of harvest demonstrates the flexibility which exists for construction of optimal harvest schedules.

Average sucrose yields (t/ha) in top material for each age at harvest at both sites are shown in Table IX.

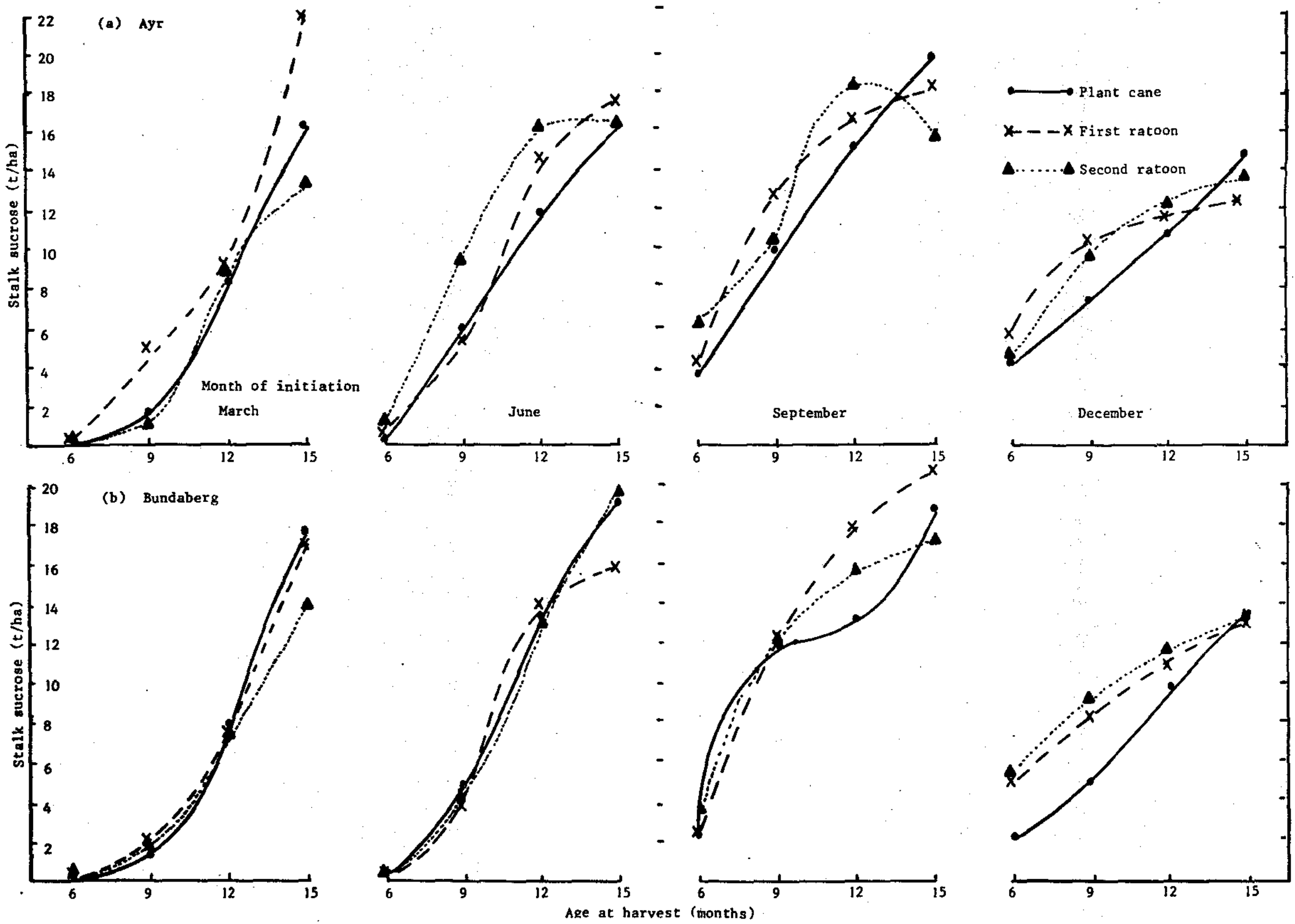

FIGURE 14 - Yield of sucrose (t/ha) from cane stalks grown at (a) Ayr and (b) Bundaberg for each crop class. Data are averaged for varieties.

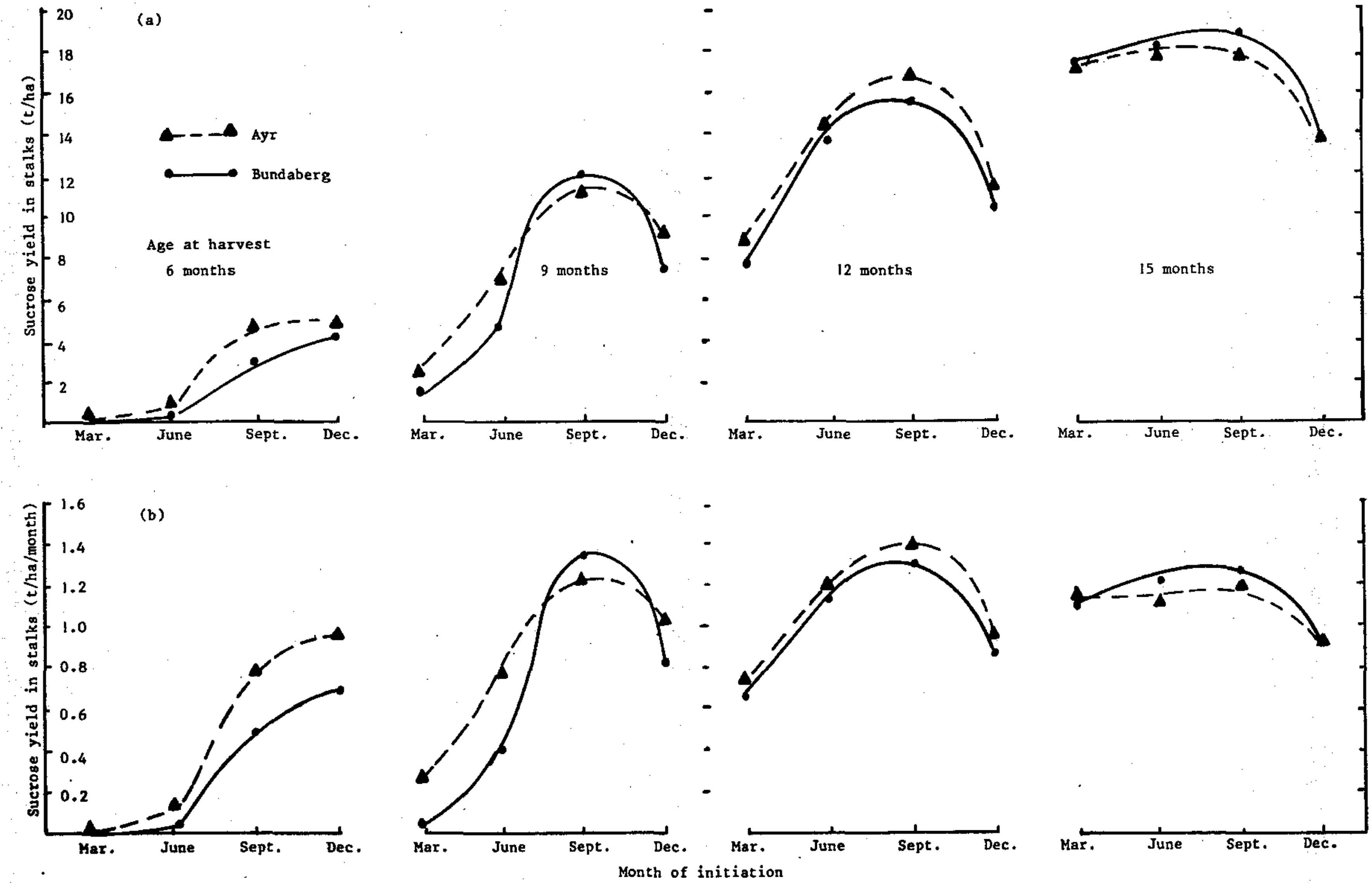

FIGURE 15 - Crop cycle average sugar yield (a) t/ha and (b) t/ha/month from stalks grown at Ayr and Bundaberg

TABLE IX

Average crop cycle sucrose yields in top material for each age at harvest at Ayr and Bundaberg (t/ha)

	Age at harvest (months)			
	6	9	12	15
Ayr	0.12	0.16	0.14	0.16
Bundaberg	0.32	0.70	0.83	0.79

These data are consistent with information reported earlier on higher yield of tops in cane grown at Bundaberg. While a maximum sucrose yield in tops of 1.7 t/ha was recorded for 12 month old plant cane harvested at Bundaberg in September, it is not considered desirable to harvest the whole of the top material to increase sugar yields. This situation pertains because top material contains higher levels of inorganic ions, and amino acids than does mature stalk section. The former contribute to ash levels in raw sugar (Kirby & Kingston, 1978), while amino compounds have been implicated in colour darkening of raw sugar during storage. Both of these characteristics are undesirable from a sugar quality viewpoint.

3.3 Discussion

3.3.1 Achievement of objectives

Three of the four objectives set for this project were attained. The detailed data on yield and analysis of growth components for four varieties of sugarcane comprise a unique data set for the description of the macro-growth process of sugarcane under Australian conditions. These data have allowed a better understanding of the growth response of sugarcane to the radiation environment outside the normal sucrose harvesting season.

The significance of the interaction between crop development stage and solar radiation was highlighted for most of the yield parameters. Crops initiated during summer months of high insolation generally performed poorly because of insufficient leaf area to intercept more than 75% of incident solar radiation.

The data summarised in Figure 4, used in association with total dry matter production models, will allow estimates to be made for all vegetative components of the biomass at various ages and times of the year.

Information gained from these experiments on the division of photosynthetate into structural and soluble carbohydrate for cane from 6 to 15 months of age at four harvest periods throughout the year would appear to be a unique data set in the sugarcane literature. It was of considerable interest to note that canes of 9 months or more of age in the June at December period demonstrated a plateau type equilibrium between the proportion of C_6 sugars and fibre in total dry matter. This equilibrium period occurred only in canes with sufficient stalk volume to allow apparent plant maturation through increasing sucrose per cent during the June to December period. This experiment did not, however, allow elucidation of the reasons for the balance between C_6 sugars and fibre during the maturation period, even though dry matter accumulation was still proceeding.

The complete analysis of vegetative components for soluble and structural carbohydrate at each harvest period has allowed thought to be devoted to possible re-optimising of the criteria for assessing harvestable material in cane for sugar and/or energy products.

The data have shown that for similar ontogenetic criteria, cane grown in South Queensland supported more top material than did cane grown at Ayr. There were limited data from other sources to suggest that this observation was due to an interaction with growth environments and rates of crop development between tropical and sub-tropical environments. It was suggested in the previous section that the topping height criteria should not be altered on cane destined for sucrose manufacture. However, it is suggested that topping heights could well be raised on cane destined for fermentation substrates alone. Harvesting of the whole top section (minus green leaf blades) is unlikely to be acceptable to distillery operations because the inorganic materials contained in green leaf sheath and leaf rolls may retard fermentation rates and result in stillage wastes which cause greater scaling problems if evaporation is undertaken to reduce effluent volume.

3.3.2 Unachieved objective

The unachieved objective of this project related to a comparison of realistic biomass production in tropical and sub-tropical environments. It was known that the Ayr environment would out-yield that of Bundaberg, from previously available commercial and experimental data. However, yields in the Ayr experiment were generally poorer than those at Bundaberg due to previously mentioned problems with the irrigation system.

Photosynthetic efficiency for total dry matter production (Table IV) in these experiments was generally lower than that reported in the literature for experimental conditions (see review section). The lower efficiency at Ayr was clearly related to moisture stress.

Average values for cane of at least 9 months of age at harvest for Bundaberg were 69 and 78% of average values reported by Thompson (1978) for irrigated plant and ratoon crops respectively from South Africa and Hawaii. It is not clear from Thompson's review whether efficiencies from irrigated plots were from cane irrigated to obtain potential yields. Data from the Bundaberg experiment were obtained from irrigation schedules and fertiliser regimes which are applied to commercial sugarcane. Crops were not subjected to obvious moisture stress; results are clearly similar to the values of 1.1% suggested by Thompson as being commercially obtainable under irrigation in South Africa.

3.3.3 Broader implications of results

The options for harvesting sugarcane as a source of dry biomass for gasification etc. are less clear because of the lack of demand at this stage. However, the options resolve into three broad categories:

1.
Current harvesting techniques could be employed for utilisation of bagasse (fibre) from surplus fuel after processing cane for sucrose or fermentation substrates. Such a scenario would involve the expenditure of capital to increase thermal efficiency of factories, and the calorific value of bagasse through drying.

The data also showed that fibre yields could be increased through choice of variety.

2.
The yield of dry biomass could be increased by harvesting stalk plus top material. This would be acceptable if soluble carbohydrate extraction is not required (increased inorganics in tops). Top and stalk material would have to be separated for sucrose or alcohol production. As this would almost certainly be undertaken pneumatically the operation would not be totally successful because of the similar aerodynamic density profile of top sections and cane stalk billets.

3.
Harvest of the whole plant could be undertaken if total biomass was the target yield parameter. Further research would be required into the optimisation of harvest schedules, as Mishoe et al (1979) have suggested multiple harvests per year to optimise total biomass production. However, the economic viability of total harvest has to be balanced against the ability of the agricultural system to sustain total harvest in the long term. Data in Table X show the nutrients removed by sugarcane crops in various districts of Queensland, (Chapman, Haysom & Chardon, 1981), along with the proportion of these nutrients contained in tops plus trash material. Nutrients and organic matter contained in tops plus trash therefore constitute a very significant potential resource of nutrients for recycling. While organic matter is largely destroyed by current practices of burning cane before harvest, a very large part of the nutrient supply

could be returned as ash. Removal of this source would presumably require additional fertiliser to maintain soil fertility, at some extra cost. Research is currently *en train* to examine the long term benefits of retaining in an unburnt condition all crop residues after sucrose harvest.

Thus total harvest of sugarcane biomass clearly requires further research into the feasibility of the operation in the long term. Methods of transporting the bulk of low density material to processing sites also requires examination.

TABLE X

Mean nutrient values (kg/ha) removed by whole cane plants, and the proportion of nutrients contained in tops plus trash, for Queensland districts. Source Chapman et al (1981).

Nutrient	Mossman Cairns	Babinda Tully	Ingham	Burdekin	Mackay	Bundaberg	Maryborough Rocky Point	% total nutrient in tops + trash
N	143	122	128	154	123	150	134	57
P	18	17	15	37	18	23	20	47
K	217	208	139	276	203	260	234	44
Ca	39	27	30	55	41	51	31	76
Mg	26	18	29	57	35	52	36	56
S	35	25	25	47	25	48	34	40
Cu	.09	.07	.09	.11	.09	.09	.12	38
Zn	.68	.46	.43	.59	.38	.37	.39	51
Fe	6.42	7.32	7.49	5.65	6.93	8.61	6.56	66
Mn	6.79	3.91	4.89	1.90	3.64	2.66	2.89	67
t cane/ha	100	93	74	119	84	92	85	-

3.4.1 Annex I

Yields of total dry matter (t/ha) at Ayr and Bundaberg in relation to crop class, month of initiation and age at harvest for each variety

Crop class	Month of initiation	Ayr								Bundaberg							
		Q96				Q92				Q108				Q111			
		6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths
Plant cane	March	3.7	12.2	40.8	56.3	3.1	10.4	29.1	51.6	3.0	18.4	44.7	61.2	2.8	16.7	42.4	58.6
	June	5.7	28.1	40.7	52.1	6.8	25.7	36.1	50.4	7.5	30.6	47.1	52.8	7.4	30.4	51.4	58.3
	September	22.1	36.4	48.6	56.7	23.4	33.9	48.8	48.9	26.0	41.0	46.8	55.0	24.4	42.0	45.6	55.3
	December	17.7	31.4	39.8	41.9	16.8	25.3	32.6	37.6	12.2	23.3	37.1	55.2	13.0	26.0	32.2	51.6
First ratoon	March	5.3	21.4	40.4	56.0	4.1	23.5	27.6	49.2	4.7	17.8	42.7	53.8	5.7	17.1	39.8	56.7
	June	8.4	27.1	36.8	55.6	9.7	18.4	31.9	37.2	6.1	24.7	46.8	51.3	7.3	30.6	48.4	57.7
	September	18.7	37.0	53.9	62.2	18.4	27.8	38.9	51.6	24.7	39.6	48.4	59.5	24.6	40.1	49.9	61.5
	December	22.8	35.8	41.9	41.3	20.0	23.5	35.5	32.9	22.4	30.6	47.6	59.5	25.5	33.9	44.6	65.2
Second ratoon	March	4.9	11.9	33.8	34.7	2.9	10.1	26.1	36.5	6.7	16.8	36.0	46.2	9.0	17.1	33.9	47.0
	June	10.7	34.6	44.7	34.4	11.3	23.2	39.2	41.7	6.2	26.6	43.6	52.9	8.3	27.3	41.8	50.0
	September	27.7	31.8	40.3	44.9	19.5	28.4	38.1	35.0	24.4	40.7	45.8	48.5	23.7	37.1	41.1	50.1
	December	20.8	26.6	38.9	47.3	15.2	25.3	34.4	42.3	22.5	32.8	41.3	45.6	26.1	35.4	42.1	53.3

	Ayr	Bundaberg
LSD between any two means/site	12.1	6.3
LSD between varieties (class, age, month of initiation)	1.7	0.5
LSD between ages (class, variety, month of initiation)	2.5	0.6
LSD between months of initiation (class, variety, age)	2.5	0.6
LSD between classes (variety, age, month of initiation)	2.1	0.6

3.4.2 Annex II

Models for total dry matter production at Ayr and Bundaberg

Ayr

$$Y = -28.99 - 4.15\ X_1 - 1.87\ X_2 + 8.02\ X_3 + 4.32\ X_4 + 7.97\ X_5 + 3.53\ X_6 - 1.89\ X_7 + 4.03\ X_8 + 6.27\ X_9$$

$R = 0.96$

Standard error of estimate = 4.6 t/ha

$N = 48$

Bundaberg

$$Y = -28.89 + 2.08\ X_1 - 4.53\ X_2 + 10.40\ X_3 + 5.64\ X_4 + 6.79\ X_5 + 4.01\ X_6 - 4.01\ X_7 + 2.52\ X_8 + 6.03\ X_9 - 0.17\ X_{10} + 0.12\ X_{11}$$

$R = 0.99$

Standard error of residuals = 3.0 t/ha

$N = 48$

where
Y = total dry matter (t/ha)
X_1 = crop class dummy variable P = 0; first rat. = 0; second rat. = 1
X_2 = crop class dummy variable P = 0; first rat. = 1; second rat. = 0
X_3 = square root (intercepted radiation ($MJ.m^{-2}$)/100)
X_4 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_5 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_6 = month of initiation dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0
X_7 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_8 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_9 = month of harvest dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Bundaberg only
X_{10} = crop class x intercepted radiation/100 dummy = $X_1 \times X_3 \times X_3$
X_{11} = crop class x intercepted radiation/100 dummy = $X_2 \times X_3 \times X_3$

3.4.3 Annex III

Fresh weight yield of cane stalk (t/ha) at Ayr and Bundaberg, in relation to crop class, month of initiation and age at harvest for each variety

Crop class	Month of initiation	Ayr								Bundaberg							
		Q96				Q92				Q108				Q111			
		6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths
Plant cane	March	0	35.7	116.2	133.8	0	24.2	94.7	132.0	0	21.2	95.9	134.3	0	19.5	109.0	137.9
	June	7.7	82.5	102.1	118.4	10.7	92.2	108.7	119.8	0	68.5	97.3	109.6	0	74.8	112.0	125.9
	September	73.5	94.5	103.0	126.3	88.3	95.5	105.2	115.4	55.4	86.2	90.4	109.1	57.5	87.1	85.5	112.2
	December	51.8	64.3	84.9	143.9	59.0	52.4	74.0	126.7	16.6	32.2	71.7	116.7	17.3	35.6	56.2	120.8
First ratoon	March	0	45.3	112.0	136.2	0	51.4	77.1	141.0	0	18.4	82.1	126.2	0	20.1	86.5	151.2
	June	20.1	89.7	102.6	116.5	19.1	65.7	95.1	89.8	4.4	47.0	106.1	109.1	7.2	57.9	121.9	125.8
	September	65.7	97.7	106.4	143.0	69.2	78.6	88.1	120.3	48.3	96.0	104.7	127.1	46.7	101.2	116.2	129.6
	December	52.7	76.2	92.6	144.5	48.5	67.6	82.3	121.6	41.3	49.5	76.1	110.3	46.9	61.3	69.4	128.1
Second ratoon	March	0	27.7	88.9	88.3	0	24.7	77.4	89.7	0	24.6	62.7	95.0	0	20.3	74.3	105.5
	June	29.7	102.9	114.1	80.7	29.2	76.4	109.3	107.0	6.8	50.4	88.9	108.9	9.0	60.4	91.6	106.8
	September	77.1	77.7	97.4	104.8	63.1	74.8	94.0	81.8	44.3	78.7	91.7	102.7	48.6	80.0	89.7	106.3
	December	48.8	54.3	90.9	134.0	37.8	49.3	89.8	110.6	43.1	53.8	68.0	93.5	49.4	61.7	69.9	111.6

	Ayr	Bundaberg
LSD between any two means/site	26.0	22.6
LSD between varieties (class, age, month of initiation)	3.8	3.3
LSD between ages (class, variety, month of initiation)	5.3	4.6
LSD between months of initiation (class, variety, age)	5.3	4.6
LSD between classes (variety, age, month of initiation)	4.6	4.0

3.4.4 Annex IV

Models for fresh weight yield of sugarcane stalks at Ayr and Bundaberg

Ayr

$$Y = -53.32 - 12.28 X_1 - 5.30 X_2 + 19.97 X_3 + 14.23 X_4 + 20.02 X_5 + 13.27 X_6 - 29.86 X_7 - 19.69 X_8 + 0.68 X_9$$

R = 0.97

Standard error of residuals = 9.9 t/ha

N = 48

Bundaberg

$$Y = -74.79 + 1.78 X_1 - 11.20 X_2 + 24.44 X_3 + 5.35 X_4 + 16.48 X_5 + 10.72 X_6 - 17.45 X_7 + 0.86 X_8 + 17.55 X_9 - 0.40 X_{10} + 0.26 X_{11}$$

R = 0.98

Standard error of estimate = 9.0 t/ha

N = 48

where

Y = cane stalk yield (fresh wt) (t/ha)

X_1 = crop class dummy variable P = 0; first rat. = 0; second rat. = 1

X_2 = crop class dummy variable P = 0; first rat. = 1; second rat. = 0

X_3 = square root (intercepted radiation ($MJ.m^{-2}$)/100)

X_4 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1

X_5 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0

X_6 = month of initiation dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

X_7 = month of crop harvest dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1

X_8 = month of crop harvest dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0

X_9 = month of crop harvest dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Bundaberg only:

X_{10} = crop class x (intercepted radiation/100) $X_1 \times X_3 \times X_3$

X_{11} = crop class x (intercepted radiation/100) $X_2 \times X_3 \times X_3$

3.4.5 Annex V

Models for total fibre yield from sugarcane grown at Ayr and Bundaberg

Ayr

$$Y = -0.10 - 1.45\ X_1 + 1.18\ X_2 + 0.32\ X_3 + 4.75\ X_4 + 3.95\ X_5 + 1.97\ X_6 - 3.54\ X_7 - 0.47\ X_8 + 1.81\ X_9$$

R = 0.96

Standard error of residuals = 2.6 t/ha

N = 48

Bundaberg

$$Y = -14.55 + 2.02\ X_1 - 1.95\ X_2 + 6.17\ X_3 + 3.70\ X_4 + 3.19\ X_5 + 1.63\ X_6 - 3.64\ X_7 - 0.69\ X_8 + 2.10\ X_9 - 0.11\ X_{10} + 0.07\ X_{11}$$

R = 0.99

Standard error of residuals = 1.8 t/ha

N = 48

where Y = total dry fibre production (t/ha)
X_1 = crop class dummy variable P = 0; first rat. = 0; second rat. = 1
X_2 = crop class dummy variable P = 0; first rat. = 1; second rat. = 0
X_3 Ayr = (intercepted radiation ($MJ.m^{-2}$))/100)
X_3 Bundaberg = square root (intercepted radiation ($MJ.m^{-2}$)/100)
X_4 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_5 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_6 = month of initiation dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0
X_7 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_8 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_9 = month of harvest dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Bundaberg only
X_{10} = crop class x (intercepted radiation/100) $X_1 \times X_3 \times X_3$
X_{11} = crop class x (intercepted radiation/100) $X_2 \times X_3 \times X_3$

3.4.6 Annex VI

Models for yield of fibre from cane stalks at Ayr and Bundaberg

Ayr

$$Y = -0.89 - 1.27 X_1 + 0.06 X_2 + 0.20 X_3 + 2.29 X_4 + 2.21 X_5 + 1.17 X_6 - 3.25 X_7 - 1.50 X_8 + 0.43 X_9$$

R = 0.97

Standard error of residuals = 1.3 t/ha

N = 48

Bundaberg

$$Y = -4.28 + 1.44 X_1 - 0.99 X_2 + 0.35 X_3 + 1.93 X_4 + 2.79 X_5 + 2.03 X_6 - 1.95 X_7 + 0.81 X_8 + 1.92 X_9 - 0.07 X_{10} + 0.02 X_{11}$$

R = 0.99

Standard error of residuals = 1.1 t/ha

N = 48

where Y = yield of dry fibre from stalks (t/ha)

X_1 = crop class dummy variable P = 0; first rat. = 0; second rat. = 1

X_2 = crop class dummy variable P = 0; first rat. = 1; second rat. = 0

X_3 = intercepted radiation ($MJ.m^{-2}$)/100

X_4 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1

X_5 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0

X_6 = month of initiation dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

X_7 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1

X_8 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0

X_9 = month of harvest dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Bundaberg only X_{10} = crop class x intercepted radiation ($X_1 \times X_3$)

X_{11} = crop class x intercepted radiation ($X_2 \times X_3$)

3.4.7 Annex VII

Yield of C_6 sugars (glucose/fructose equivalents) t/ha in the whole cane plant at Ayr and Bundaberg in relation to crop class, month of initiation and age at harvest for each variety

Crop class	Month of initiation	Ayr								Bundaberg							
		Q96				Q92				Q108				Q111			
		6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths
Plant cane	March	0.5	3.9	12.6	18.7	0.3	2.4	8.8	17.3	0.2	3.2	11.2	21.0	0.3	4.1	12.8	22.9
	June	1.1	8.8	14.0	18.3	1.0	8.2	13.4	17.9	1.0	7.7	15.8	20.3	1.2	8.6	19.0	24.1
	September	6.5	12.0	17.2	23.0	6.3	11.1	16.8	21.6	5.5	14.8	16.0	20.3	6.1	15.5	17.0	24.7
	December	5.4	9.7	13.9	17.9	5.5	8.3	11.2	17.3	3.0	6.3	13.1	16.3	3.8	8.2	12.3	17.5
First ratoon	March	0.7	6.2	14.0	28.4	0.4	6.2	8.4	21.3	0.4	3.6	10.7	19.2	0.6	4.8	10.5	24.8
	June	1.6	10.1	19.3	23.7	1.4	5.4	14.5	16.3	0.8	5.9	16.6	16.1	1.6	7.5	20.0	20.8
	September	7.4	17.3	20.1	22.5	5.6	11.9	17.5	17.9	5.1	14.1	18.7	21.5	6.2	17.0	21.7	26.7
	December	8.1	13.0	14.8	16.8	6.4	11.3	10.5	13.5	6.5	9.0	13.9	15.5	9.0	11.7	13.6	19.9
Second ratoon	March	0.9	2.3	12.8	15.9	0.3	1.9	9.2	14.1	0.4	3.1	10.2	16.0	0.9	3.2	11.2	18.8
	June	2.0	14.6	20.9	16.1	1.5	8.9	16.7	19.8	0.8	6.9	15.1	21.1	1.4	8.3	17.4	22.8
	September	9.3	13.6	21.6	21.4	6.5	11.5	19.2	13.8	5.3	14.3	17.8	16.9	7.4	16.3	18.3	21.1
	December	6.8	12.0	15.2	17.6	4.6	10.4	11.0	14.6	6.5	8.8	11.3	14.2	8.8	13.4	15.2	19.8

	Ayr	Bundaberg
LSD between any two means/site	4.9	3.5
LSD between varieties (class, age, month of initiation)	0.7	0.3
LSD between ages (class, variety, month of initiation)	1.0	0.4
LSD between months of initiation (class, variety, age)	1.0	0.4
LSD between classes (variety, age, month of initiation)	0.9	0.3

3.4.8.1 Annex VIII

Models for yield of C_6 sugars in stalks for cane grown at Ayr and Bundaberg

Ayr

$$Y = -17.42 + 3.60\,X_1 + 1.96\,X_2 + 4.14\,X_3 + 2.31\,X_4 - 1.12\,X_5 + 2.95\,X_6 + 3.93\,X_7$$

$R = 0.96$

Standard error of residuals = 1.9 t/ha

$N = 48$

Bundaberg

$$Y = -7.80 + 0.39\,X_1 + 1.63\,X_2 + 4.38\,X_3 + 2.69\,X_4 + 0.54\,X_5 + 4.10\,X_6 + 5.49\,X_7 - 0.0006\,X_8 + 0.000\,03\,X_9$$

$R = 0.99$

Standard error of residuals = 1.3 t/ha

$N = 48$

where Y = yield of C_6 sugars from stalks (t/ha)

Ayr:

X_1 = square root (intercepted radiation ($MJ.m^{-2}$)/100)
X_2 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_3 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_4 = month of initiation dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0
X_5 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_6 = month of harvest dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_7 = month of harvest dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Bundaberg:

X_1 = intercepted radiation ($MJ.m^{-2}$)/100
X_2 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_3 = month of initiation dummy variable Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_4 = month of initiation dummy variable Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Annex VIII (Continued)

X_5 = month of harvest dummy variable
Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_6 = month of harvest dummy variable
Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_7 = month of harvest dummy variable
Mar. = 0; June = 1; Sept. = 0; Dec. = 0
X_8 = (intercepted radiation/100)^2 x crop class
P = 0; first rat. = 0; second rat. = 1
X_9 = (intercepted radiation/100)^2 x crop class
P = 0; first rat. = 1; second rat. = 0

3.4.8.2 Annex IX

Model for yield of C_6 sugars in stalk plus top material in cane grown at Ayr and Bundaberg

Ayr

$$Y = -17.17 + 3.60 X_1 + 1.98 X_2 + 4.07 X_3 + 2.31 X_4 - 0.99 X_5 + 3.00 X_6 + 3.91 X_7$$

$R = 0.96$

Standard error of residuals = 1.9 t/ha

$N = 48$

Bundaberg

$$Y = -6.83 + 0.39 X_1 + 1.93 X_2 + 4.32 X_3 + 2.13 X_4 + 0.67 X_5 + 3.79 X_6 + 5.40 X_7 - 0.0005 X_8 - 0.0004 X_9$$

$R = 0.98$

Standard error of residuals = 1.4 t/ha

$N = 48$

where Y = yield of C_6 sugars in stalks + tops (t/ha)

Ayr:

X_1 = square root (intercepted radiation $(MJ.m^{-2})/100$)
X_2 = month of initiation dummy variable
Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_3 = month of initiation dummy variable
Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_4 = month of initiation dummy variable
Mar. = 0; June = 1; Sept. = 0; Dec. = 0
X_5 = month of harvest dummy variable
Mar. = 0; June = 0; Sept. = 0; Dec. = 1
X_6 = month of harvest dummy variable
Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_7 = month of harvest dummy variable
Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Bundaberg:

X_1 = intercepted radiation $(MJ.m^{-2})/100$
X_2 = month of initiation dummy variable
Mar. = 0; June = o; Sept. = 0; Dec. = 1
X_3 = month of initiation dummy variable
Mar. = 0; June = 0; Sept. = 1; Dec. = 0
X_4 = month of initiation dummy variable
Mar. = 0; June = 1; Sept. = 0; Dec. = 0

Annex IX (Continued)

X_5 = month of harvest dummy variable
Mar. = 0; June = 0; Sept. = 0; Dec. = 1

X_6 = month of harvest dummy variable
Mar. = 0; June = 0; Sept. = 1; Dec. = 0

X_7 = month of harvest dummy variable
Mar. = 0; June = 1; Sept. = 0; Dec. = 0

X_8 = (intercepted radiation/100)^2 x crop class
P = 0; first rat. = 0; second rat. = 1

X_9 = (intercepted radiation/100)^2 x crop class
P = 0; first rat. = 1; second rat. = 0

3.4.9 Annex X

Yield of sucrose (t/ha) from cane stalks at Ayr and Bundaberg in relation to crop class, month of initiation and age at harvest, for each variety

Crop class	Month of initiation	Ayr								Bundaberg							
		Q96				Q92				Q108				Q111			
		6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths	6 mths	9 mths	12 mths	15 mths
Plant cane	March	0	2.2	10.5	17.0	0	0.8	6.3	15.3	0	1.1	7.7	17.1	0	1.0	8.3	18.3
	June	0.2	6.8	12.4	16.5	0.1	4.9	11.3	15.6	0	4.9	12.1	17.5	0	4.8	14.5	20.9
	September	4.3	10.6	15.4	20.7	3.0	9.3	15.0	18.7	3.0	11.5	13.0	16.5	3.0	12.0	13.4	21.0
	December	4.2	8.0	11.7	15.1	4.0	6.8	9.6	14.4	1.9	4.3	10.1	12.9	2.2	5.4	9.4	13.4
First ratoon	March	0	5.1	11.6	25.1	0	4.8	6.0	18.7	0	1.5	7.6	15.6	0	1.9	7.2	18.8
	June	0.6	7.6	17.1	21.2	0.5	3.2	12.2	14.2	0.1	3.6	13.0	13.9	0.3	4.0	15.4	17.9
	September	5.1	15.3	18.2	20.1	3.6	10.3	15.5	16.4	2.5	11.0	16.6	18.2	2.1	13.0	19.2	23.2
	December	6.4	11.1	13.3	14.4	5.0	9.6	9.4	10.5	4.5	7.2	11.0	12.5	5.5	9.3	10.3	15.5
Second ratoon	March	0	0.9	10.9	14.6	0	0.9	7.2	11.8	0	1.6	7.0	12.9	0	1.3	7.6	14.9
	June	1.7	12.1	18.4	14.6	0.3	6.6	14.0	17.8	0.1	4.2	12.4	18.8	0.1	5.2	14.2	20.2
	September	7.5	11.7	19.6	19.2	4.7	9.2	17.3	12.2	2.8	11.5	15.1	14.6	4.0	13.1	16.0	19.6
	December	5.6	10.4	13.4	15.0	3.5	9.0	11.3	12.1	4.8	7.0	9.0	11.1	5.9	11.0	12.5	15.2

	Ayr	Bundaberg
LSD between any two means/site	4.5	3.9
LSD between varieties (class, age, month of initiation)	0.7	0.3
LSD between ages (class, variety, month of initiation)	0.9	0.4
LSD between months of initiation (class, variety, age)	0.9	0.4
LSD between classes (variety, age, month of initiation)	0.8	0.3

4. DEFINITIONS

For convenience of expression in reference to fermentable sugars glucose, fructose and sucrose are expressed in this report as six carbon sugar equivalents (C_6 sugars). Boiling water extracts were used to solubilise starch in plant components.

Other six carbon sugars such as mannose and galactose were not assayed and therefore have not been included in the broad definition of C_6 sugars.

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