THE GROWTH AND PRODUCTIVITY OF SUGARCANE

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Abstract

In a brief review of growth and light utilisation by sugarcane crops, data are presented to show that there should be considerable scope for increasing yields beyond the limits of existing varieties. It is confirmed that radiation, temperature and plant age, or size, are important factors affecting growth when water and nutrients are freely available. It is concluded that detailed investigations are necessary to determine what morphological and physiological characteristics should be incorporated into new varieties in order to maximise sucrose production per hectare per unit time.

Introduction

It is a relatively easy task to improve crop yields when they are low, by such practices as improved fertilisation or better weed control. However, as better cultural practices are adopted and yields become higher, so it becomes more difficult to increase them further.

The tremendous advances made by South African sugarcane farmers during the past 20 years are clearly illustrated in Fig. 1. Sugar production per hectare under cane has gradually increased from 3,08 tons per year in 1949-50 to 5,05 tons in 1969-70. If the present rate of increase is maintained until 1995, production should then be about 7,7 tons of sugar per hectare per annum from about 70 tons of cane. This would be a high yield for our predominantly rain-grown sugarcane as it represents approximately 9 tons of cane per 100 mm of effective rainfall, a level of production achieved at present only in experiments and by our more successful growers.

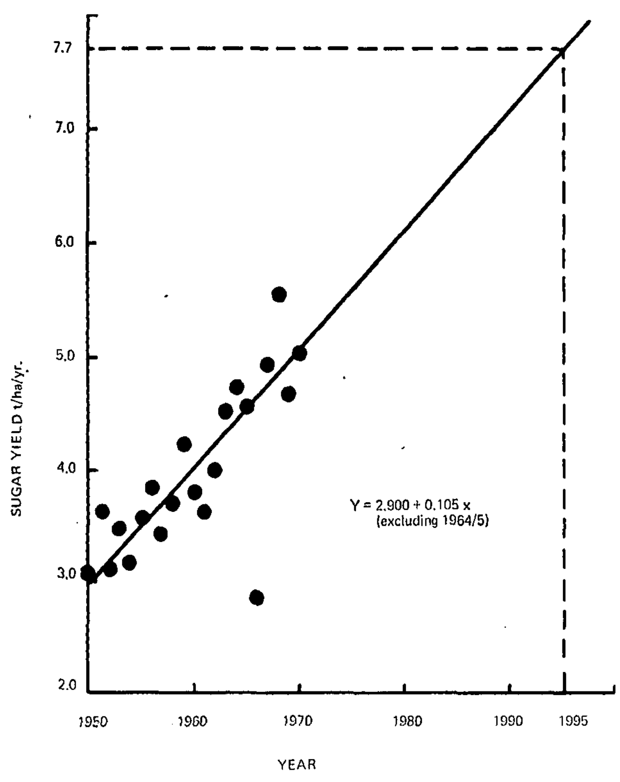

FIGURE 1: Sugar yield (96° pol) per hectare under sugarcane in South Africa. (Data obtained from the South African Sugar Yearbook, 1969/70.)

Twenty five years is not a long period of time in terms of sugarcane breeding as it takes some 10-14 years between the initial crossing and the release of a new variety. Further increases beyond this projected ceiling yield will depend on the introduction of new varieties, better adapted to our climatic conditions. In order to produce better varieties, the plant breeder must know what morphological and physiological characteristics are necessary for maximum sucrose yields and the physiologist must provide him with this information. We need to know what our potential maximum yields of recoverable sucrose are under a range of weather conditions, how far yields of existing varieties fall below this, and why we are not achieving our full potential.

It is imperative that we begin to understand what constitutes a high yielding sugarcane variety because ultimately the continued profitable production of sugar in South Africa depends on it. In an efficient enterprise profit margins per unit of land are maintained, or improved, either by reducing costs, or increasing income. Unfortunately, farmers have restricted control over either their costs, or the long term average price of sugar, and costs can be expected to rise faster than returns, unless progressively higher yields of sugar per hectare are obtained.

General aspects of crop growth

The growth of any plant is dependent ultimately on the efficiency with which it converts solar energy into dry matter. Growth of sugarcane is often measured only in terms of stalk elongation and increase in stalk fresh weight (t.c.ha.) but these measures are of limited value. Stalk elongation is a good measure of increase in stalk fresh and dry weight when conditions are favourable for growth but when elongation is restricted by drought, or low temperature, sugar and dry matter accumulation may still continue. Sugarcane productivity is best measured, therefore, as tons recoverable sucrose produced per unit land area per unit time and the efficiency of sucrose production as the proportion of the total dry matter produced that is present as sucrose.

Fig. 2 shows a simple diagram of the production of sucrose by sugarcane. Water, nutrients and carbon dioxide are built into plant material by the process of photosynthesis, and the photosynthate is used either for growth, or for storage as sugar in the stalk. From this diagram it can be seen that sucrose yields may be increased by (a) increasing the net amount of dry matter produced, (b) increasing the proportion of stalk to roots and leaves, (c) increasing the sucrose per cent dry matter of the stalk, or by a combination of all three.

Both dry matter production and the sucrose content of the stalk are equally important in determining final yield. However, stalk must be produced before sucrose storage can occur, and as is well known, a high sucrose percentage in the cane does not necessarily mean a high yield of sugar per hectare.

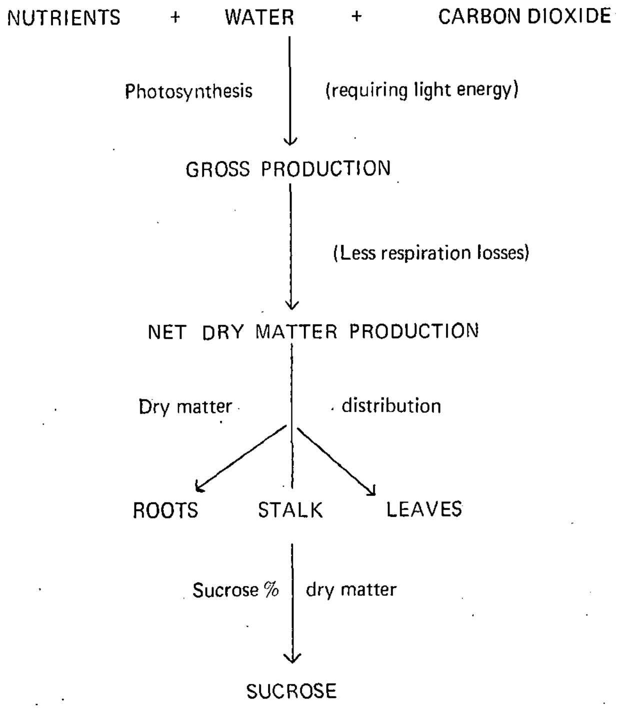

FIGURE 2: Diagrammatic representation of sucrose production by sugarcane.

Light energy and growth

The amount of dry matter produced by a crop per unit time, when water and nutrients are non-limiting, ultimately depends on the amount of light energy available and the proportion of this light intercepted and used by the leaves. In the field it is not possible to separate the effects of radiation and temperature, as illustrated by data from a time of harvest trial at Pongola, in which fully irrigated crops of a similar age were ratooned at eight week intervals throughout the year (Fig. 3). Growth during the first 32 weeks of the following crop was directly related to the mean daily temperature and the amount of radiation received during that period. These data must not be taken to indicate that July to November cutting will necessarily result in high yields because other factors, in particular the age at which the crop is cut, will alter the pattern indicated in Fig. 3.

The efficiency of dry matter production for a range of sugarcane crops here and in Hawaii (Borden [1,2,3]) is presented in Table I. Productivity per hectare is lower in South Africa than in Hawaii, but this is because less radiant energy is available, and the efficiency of conversion of visible light

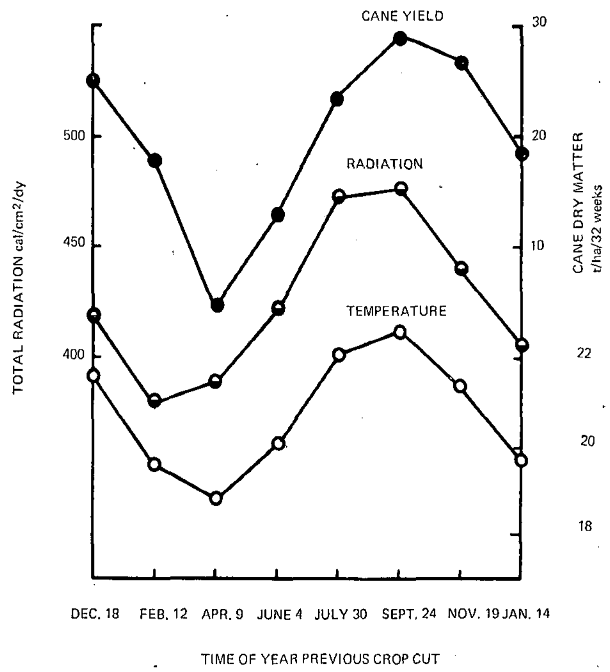

FIGURE 3: Dry matter produced, mean daily temperature and average radiation during the first 32 weeks of growth. Irrigated cane cut at different times of the year at Pongola.

energy into dry matter of 3,1-3,7% under good growing conditions is similar in the two countries. Assuming that there is a 50% loss or wastage due to incomplete ground cover, respiration, etc., the production by existing varieties accounts for about 7% of visible radiation.

This figure of 7% is low, compared with estimates that 12% (Loomis and Williams[4]) to 18% (Monteith[5]) of incident visible radiation can be converted into plant dry matter. Whilst it is unlikely that existing yields of sugarcane can be doubled, the discrepancy between actual and estimated efficiencies indicates the possible scope for improvement. Because crop yield is determined by a complex of plant and weather factors much more must be known about their interaction before we can breed varieties better adapted to our conditions.

Weather factors limiting sugarcane productivity

Low temperature is a major factor restricting the growth of sugarcane and its effect is to increase the time taken by a plant to reach its full potential. Whiteman, Bull and Glasziou[6] found appreciable cold tolerance amongst species of sugarcane and it should be possible to select varieties suited to a particular environment. Cold tolerant species appear to have a different biochemical make-up from non-tolerant ones and if there is a deficiency of some essential growth factor it might be possible to correct it by the application of growth regulating compounds.

Low rainfall is also a serious factor limiting yields, but unlike temperature it can be corrected, although it is often not economic to do so. In other grasses there are appreciable differences in the amount of plant material produced per unit of water transpired (Downes[7]) and it is possible that sugar-

TABLE I

The efficiency of conversion of incident visible radiation into dry matter by field grown sugarcane. (It is assumed that 45% of total radiation is visible and an allowance has been made for stool weight but not for respiration, reflection or incomplete canopy).

Source	Age (days)	Cane yield (t/ha)	Radiation (cal/cm²/dy)	Crop Growth Rate (g/m²/dy)	Efficiency %
Chaka's Kraal — Plant crop (Gosnell[9])					
Not irrigated	365	80,0	367	10,8	2,7
Irrigated	365	105,1	367	13,1	3,3
Pongola — irrigated					
Plant crop	343	141,1	421	15,4	3,4
Ratoon crop	365	146,2	494	17,9	3,4
C.F.S. — Plant crop					
Irrigated — close spacing	365	148,1	377	14,9	3,7
Hawaii					
Plant crop, treatment D (Borden[1])	348	191,2	489	18,1	3,5
Plant crop, treatment C (Borden[2])	365	193,5	524	19,9	3,5
Ratoon crop, treatment C (Borden[3])	365	213,9	630	21,1	3,1

cane varieties can be produced that will use water more efficiently than current varieties.

Ageing and dry matter distribution amongst plant parts

The growth rate of sugarcane falls with increasing age, beyond about 6-9 months (Borden[2,3], Shaw and Innes[8], Gosnell[9]), although optimum yields of sucrose may not be obtained until much later. In many instances it is difficult to separate the effects of age from those of cold and drought on productivity but Gosnell[9] found that growth in the second year (17-23 months) was only 20% of that in the first. Results from the Pongola time of harvest trial referred to earlier also show that when crops of different ages are growing together, the oldest plants have the lowest growth rate in both summer and winter (Table II).

TABLE II

The effect of age on the productivity of irrigated cane at Pongola. Cane dry matter increments in winter and summer (t/ha/8 wk).

Age of Crop (weeks)	Summer (Feb — April)	Winter (June — Aug)
32 - 40	12,2	6,7
40 - 48	11,6	4,0
48 - 56	7,5	2,3
56 - 64	0,1	-2,5
64 - 72	No data	0,9
Radiation (Cal/cm²/dy)	514	358

Plants normally increase in size as they become older and it is possible that size, rather than age determines subsequent productivity, as suggested by a comparison of Gosnell's results with those of Du Toit[10]. Du Toit, who had a cane yield of only 45 t/ha at 12 months, compared with 81 t/ha in Gosnell's experiment, reported a similar rate of dry matter production in the second summer as in the first, in contrast to the 80% reduction in cane yield increment reported by Gosnell. There are obvious dangers in comparing results of different experiments in this way but confirmation that size might be a determination of a plant's ability to grow is presented in Fig. 4. This shows a strong negative curvilinear relationship of plant size and subsequent

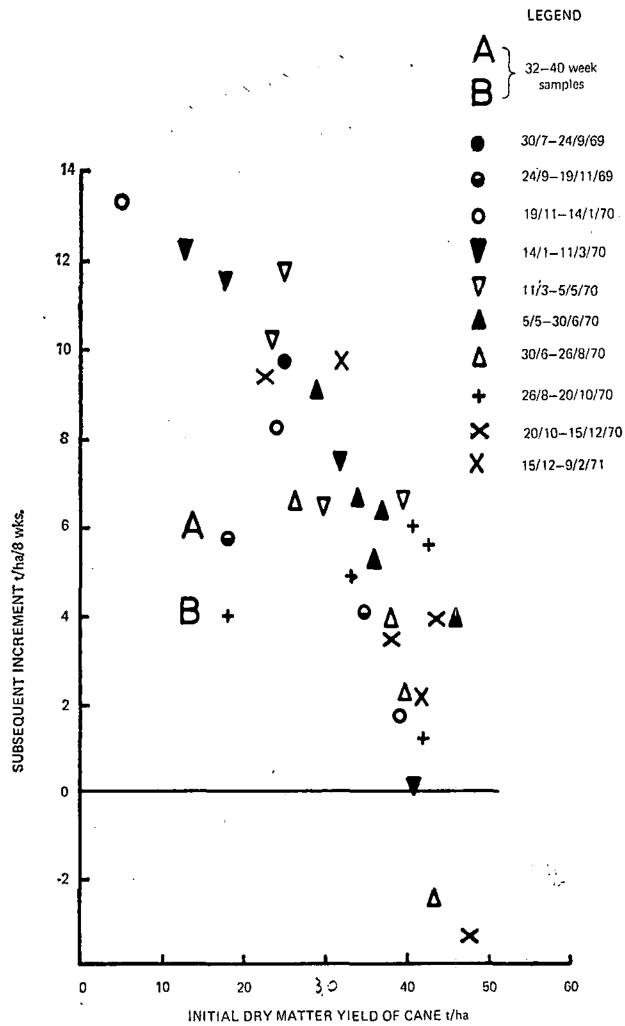

FIGURE 4: The relationship of initial dry cane weight and yield increment in the following eight weeks. Irrigated sugarcane at Pongola, crops ranging in age from 32 to 64 weeks of age (each point the mean of six observations).

growth under a wide seasonal range of growing conditions. Exceptions to this general relationship (points A and B) are for 32-40 week old plants in September-November, 1969 and August-October, 1970 respectively, and these presumably reflect an adverse effect of winter conditions on subsequent growth of relatively young sugarcane.

One of the main problems facing plant physiologists, therefore, is to obtain a better understanding of the reasons for a decline in productivity with age, or size. An increase in the proportion of respiring to photosynthesising tissue as plant size increases will cause a gradual decline in net productivity. It is also known that the rate of photosynthesis of sugarcane leaves declines with age and that young leaves on old shoots have lower rates of photosynthesis than similar leaves on young shoots (Kortschak[11]). Whatever the reasons for the decline in productivity with age it is evident that in order to achieve the maximum dry matter yield per hectare per unit time plants must not be allowed to become too old, or too big.

In conflict with the need to harvest at an early age to maximise rates of dry matter production is the fact that the proportion of this dry matter contained in the stalk increases with age (Table III) and that sucrose per cent cane dry weight is low in young plants (Fig. 5b).

There is little information about varietal differences in dry matter distribution amongst plant parts but it is known that some varieties are leafier than others. Preliminary results from an experiment with rain-grown cane at Mount Edgecombe (Table IV) show that the greater productivity of NCo 376, compared with NCo 310, was due not only to its greater production of dry matter, but also to the larger proportion of this dry matter in the stalk. These results may be due to the dry conditions experienced but they indicate that dry matter distribution can be important under some conditions.

Sucrose content of sugarcane stalks

Sucrose content is usually expressed as a percentage of the fresh weight, but this can be misleading because a drop in moisture content due to drying off, or to winter conditions, can result in a higher sucrose per cent fresh weight, although the actual amount of sucrose present remains unchanged (Boyce[12], Glover[13]). A high sucrose per cent fresh weight is obviously desirable because it reduces transport costs and improves the efficiency of sucrose recovery in the mill. However, sucrose per cent fresh weight can be altered by time of harvest, or by irrigation practice and when considering the inherent ability of varieties to produce sucrose it is preferable to look at sucrose per cent dry weight.

TABLE IV

The productivity of NCo 376 and NCo 310. Twelve month old rain-grown crops, planted 10 Dec., 1969 (Rainfall 782 mm).

	Whole plant Dry weight (t/na)	Cane yield (t/ha)	ERS % cane	t ERS/ ha	% of total dry weight in stem
NCo 376	11,2	38,8	7,9	3,1	37,4
NCo 310	10,3	26,9	7,8	2,1	28,6
C of V (%)	9,7	9,7	10,7	15,5	5,6
L.S.D. (P=0,05)	1,6	4,8	N.S.	0,6	2,8
(P=0,01)	2,4	7,4		0,9	4,3

NOTE: Crop growth was greatly reduced by drought between February and April, 1970.

Data from the Pongola time of harvest trial show that as cane becomes older so its sucrose per cent fresh weight increases, irrespective of growing conditions (Fig. 5a). However, comparison with Fig. 5b shows that above 56 weeks of age there was little difference in sucrose content due to age, the apparent differences in Fig. 5a being due to differing moisture contents. In this experiment, season had only a small effect on sucrose content, expressed on either a fresh or a dry weight basis, after 56 weeks of age.

Care is necessary in selecting varieties for a high sucrose content. Moberly[14] and Gosnell[15] have found that differences in sucrose per cent fresh weight amongst varieties can vary with the age and time of year at which the crop is cut. Thus, varieties of the same chronological age may be physiologically different, causing them to mature at different ages. Because moisture content falls with increasing maturity, selection of varieties for a high sucrose content should be based on the amount of sucrose per cent dry matter. Some varieties may be at a disadvantage if harvested at only one age.

TABLE III

Variation in dry matter distribution amongst plant parts (%) Pongola, irrigated cane.

Age (days)	Plant crop (from Nov. 8)			Ratoon crop (from Jan. 14)		
	Stalk	Foliage	Trash	Stalk	Foliage	Trash
153	40,1	44,5	15,4	—	—	—
218	59,1	28,3	12,6	—	—	—
224	—	—	—	56,0	28,2	15,9
274	60,5	22,2	17,3	—	—	—
280	—	—	—	61,0	20,4	18,9
336	—	—	—	62,8	15,9	21,3
343	69,2	19,3	11,5	—	—	—
392	—	—	—	64,9	12,6	22,5

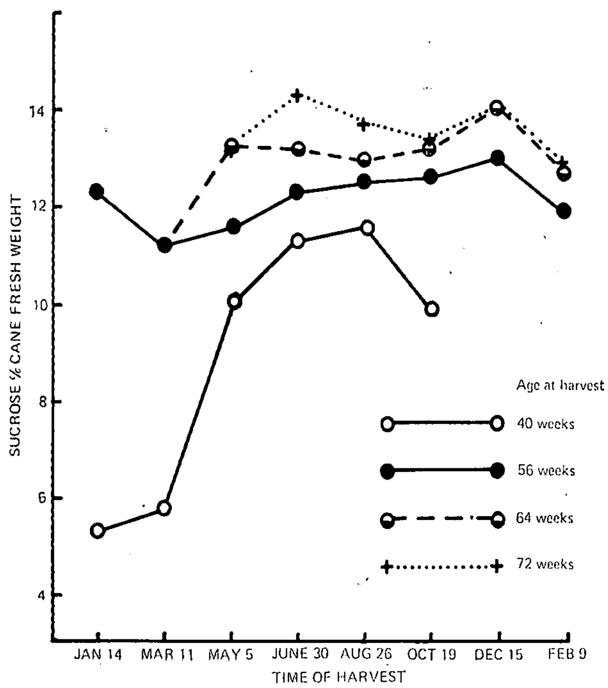

FIGURE 5a: The effect of age of harvest on the sucrose per cent fresh weight of cane. Irrigated sugarcane at Pongola.

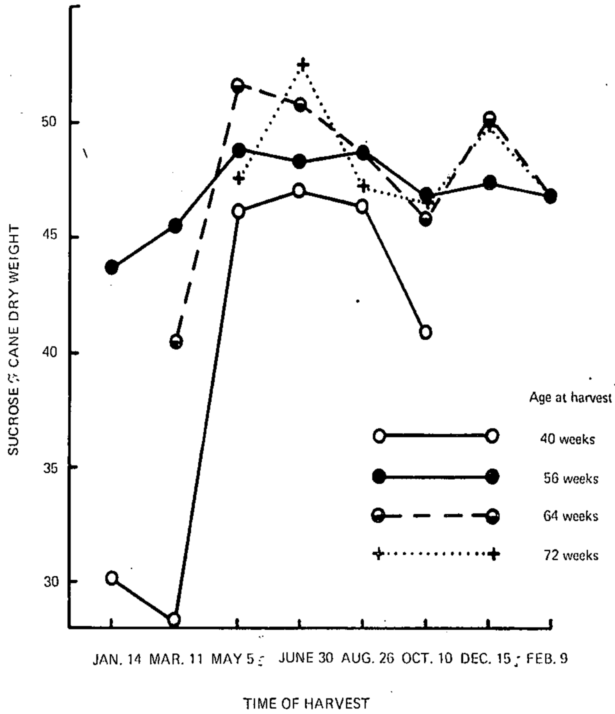

FIGURE 5b: The effect of age of harvest on the sucrose per cent dry weight of cane. Irrigated sugarcane at Pongola.

Conclusions

Current levels of productivity of sugarcane represent a conversion of about a half of the 12-18% of incident visible light energy that is available for plant growth. Therefore, there should be considerable scope for increasing sugarcane yields.

Increasing plant age, or plant size, is an important factor causing a decline in productivity and more information is needed about the reasons for this decline.

There may be conflict between the requirements for maximum dry matter production and maximum yields of sucrose per hectare.

There is insufficient information about differences amongst varieties in rates of dry matter production, distribution of dry matter amongst plant parts and sucrose content. Detailed investigations are necessary to determine what morphological and physiological characteristics should be incorporated into new varieties.

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Discussion

Mr. Wilson (in the chair): Mr. Rostron mentions the value of plant physiology to plant breeding and certainly the efficiency of any plant by the plant breeder needs to be closely examined. There are difficulties, however, because even if the physiologist can tell us what to look for this has to be done in the field where there are a large number of plants to examine under very variable conditions. There seems little doubt that many good varieties will continue to be discarded before reaching the later stages of selection.

Dr. Gosnell: The paper shows clearly the effect of reduced growth rates on increase in size. Would Mr. Rostron also like to comment on the effects of varieties and of lodging?

Mr. Rostron: Regarding varieties, the Pongola experiment was carried out only with NCo 376. However, there has been a comparison made here on the station between NCo 376 and NCo 310. At 12 months the expected differences were observed in size and yield. Sucrose per cent cane was similar so that NCo 376 gave a much higher yield of recoverable sucrose because of its greater total dry matter and because a greater proportion of this dry matter was in the stalk.

Growth between twelve and fifteen months was phenomenal, owing to the favourable weather we experienced, NCo 376 increasing to 105 t/ha and NCo 310 to 95 t/ha. Although sucrose per cent cane favoured NCo 310 the higher cane yield of NCo 376 offset this and yields of recoverable sugar were similar. Surprisingly, the percentage of dry matter in the stalk, 49%, was the same for both varieties.

All crops at Pongola lodged at between 45 and 52 weeks. Cane coming away in November/December had a rapid rate of elongation and lodged early. Cane with slower growth rates lodged at about 55 tons cane but lodging was not so severe. The manner of lodging should not affect comparisons between adjacent points on the curves shown in the paper, although extremes at each end may have been affected.

Mr. Tucker: Was there any noticeable difference in growth between plant and ratoon crops?

Mr. King: Conversion of radiation into dry matter is presumably related to the amount of leaf tissue on which the sun falls. Therefore, in this respect would one select a variety with vertical leaves, which would offer a bigger surface of leaf?

Mr. Rostron: Yes, but a variety with upright leaves would not have much value if planted at the same spacing as a broad floppy leafed variety that was yielding well since some sunlight would fall onto bare ground and be wasted.

Even our standard varieties seem to have a small amount of green leaf compared with other crops so I think we would be better employed investigating this at present rather than deciding on whether to select either upright or broad leafed varieties.

Mr. Hoekstra: Referring to Figure 3. If you plot a year's growth so that the plant has had six months each of summer and winter growth, do you still get a peak and where will it be?

In the second graph, how do maximum, minimum and ground temperatures correlate?

There appears to be a better correlation between yield and temperature than between yield and radiation.

If there was a line comparing yield month by month at the same age with the amount of effective water used by the plant would the relationship remain the same?

Mr. Rostron: I have drawn data from an experiment that only finished a week ago in order to demonstrate the points that I wished to make so I cannot answer the questions as the data has not been fully analysed.

The picture given in Figure 3 would undoubtedly have changed if extended over a year instead of 32 weeks. Both tons cane and sucrose would have changed.

Regarding radiation/temperature correlation with cane yield this awaits further analysis, as does the relationship between pan factor and yield.

Mr. Buchanan: Have the figures in Figure 1 been corrected for the decline of rainfall between 1960 and 1970?

Mr. Rostron: No, the figures have not been corrected in any way.

Mr. Bax: Is there any correlation between the curve shown in Figure 1 and the trend of fertilizer application in the last twenty years?

Mr. Wilson: The increase in yield cannot be attributed entirely to varieties. Fertilizer application and better management would also have contributed.

Mr. du Toit: I agree that variety, fertilizer and management have been responsible for the increase in yield. In the graph the regression line is 2,9 + 0,105 × with a present sugar output of 5 tons per hectare, giving an increase at present of 2,1%, uncorrected for rainfall. This just about equals our annual increase in consumption and sales of sugar which means we can possibly maintain present markets without extending land under cane.

In connection with fluctuation in sucrose reflected in Figure 5 (a). I agree that the younger the cane the more pronounced will be the fluctuation due to seasonal variation. But it is difficult to accept that there will be no seasonal change if the cane is more than 50 weeks old, unless this can be explained by very low topping.

Mr. Rostron: I do not think there is data available comparing crops of the same age at different times of the year. Our typical sucrose pattern during the season is mixed up with the effect of age. When cutting from May to December, the May to August crops ratoon slowly so that in growing terms the May crop is no older than the August crop. Therefore when we come round to the next cutting cycle, cane cut at the beginning of the season that is not carry-over cane, will be physiologically younger than that cut later.

Regarding topping, when the sticks were small they were topped by hand at the base of the sixth leaf, because at this stage the height of topping relative to the total length of the stick was very important. When the cane was older it was topped, as is usual, with knives.