CHANGES IN SUCROSE % CANE AND YIELD OF SUCROSE PER UNIT AREA ASSOCIATED WITH COLD, DROUGHT AND RIPENING

By J. GLOVER

South African Sugar Association Experiment Station

Abstract

The effect of cold and drought on sucrose % cane is considered.

Arising from this a simple model of ripening is examined with particular reference to changes in yield of total sucrose per unit area and associated fresh weight changes.

Finally the relative possible penalties in additional fresh weight associated with "ripening" and "non-ripening" are briefly discussed.

Sucrose % cane, cold and drought

It is well known that the sucrose content of the sugarcane plant changes throughout the year and that such changes are to some extent reflected by the changing values of sucrose % cane, an expression of total sugar content of the stalk on a fresh weight basis.

In South Africa the sucrose % cane is lowest in our warm, usually wet summers and highest towards the end of our usually cool, dry winters. However, in some years when there is an early drought, in late summer or early autumn, very high values of sucrose % cane may be encountered. In other words cold or drought or both combined affect the sucrose % cane.

It is difficult to study the effects of cold and drought separately because in winter either the coldness or the dryness or the combined effect of both would increase sucrose % cane while in summer heat or wetness or both together would produce the opposite effect. However, the accumulation of weather records from different regions of the Industry, irrigated and non-irrigated, now allow the study of each factor independently and permit rough calculations of the time required for each to produce its effect.

Records from the Pongola, Tongaat and Jaagbaan mills have been used to illustrate the responses to the changing climate. Those from Pongola, an irrigated area, have been chosen to illustrate the effect of cold or warmth on sucrose % cane when the water supply to the plants is adequate throughout the year: those from Tongaat to illustrate the responses found under non-irrigated conditions in the main Coastal Belt, while those from Jaagbaan illustrate responses in the non-irrigated colder upland regions.

The detailed records are those of the mean monthly sucrose % cane at each mill, as published in the Summary of Laboratory Reports by the Sugar Milling Research Institute which appears each month in the South African Sugar Journal during and after the milling season. They are compared with the records of total rainfall and monthly mean minimum temperatures recorded at meteorological stations which are at or close by the mills. The only exception is that the Jaagbaan records of sucrose % cane have been compared with the meteorological records from Windy Hill which is at the same altitude but some 20 km distant. No meteorological records were available at Jaagbaan.

These comparisons involve the following assumptions among others:

(1) that the meteorological records from a point source are representative of those of the area from which the mill draws its cane supplies

(2) that the cane varieties harvested have not changed markedly during the period of the comparisons, and

(3) that average minimum temperature represents in some manner the integrated effect of cold.

None of these assumptions is strictly valid. Nevertheless practical experience shows that they cannot be too erroneous.

Figure 1 illustrates the relationship between sucrose % cane and cold, month by month over four successive milling seasons in each of the three regions. The temperature records have been inverted so that increasing cold follows the upward trend of % sucrose and increasing heat follows its downward trend. Further the temperature records have been displaced by three months so that the correlation between the two factors can be easily appreciated visually. The displacement is such that the % sucrose records are plotted directly against the minimum temperatures which occurred three months earlier.

This figure shows that when water does not limit growth, as at Pongola, the relationship between mean minimum temperature and the percentage of sucrose in the fresh cane stalk is very close indeed. Thus as minimum temperatures fall the % sucrose content of the stalk rises and as they rise the % sucrose content decreases. At Tongaat, however, and at Jaagbaan the close relationship between temperature and % sucrose content is only apparent in certain years. In other years high percentages of sucrose may been seen before any cold effect could develop, that is when temperatures are still high.

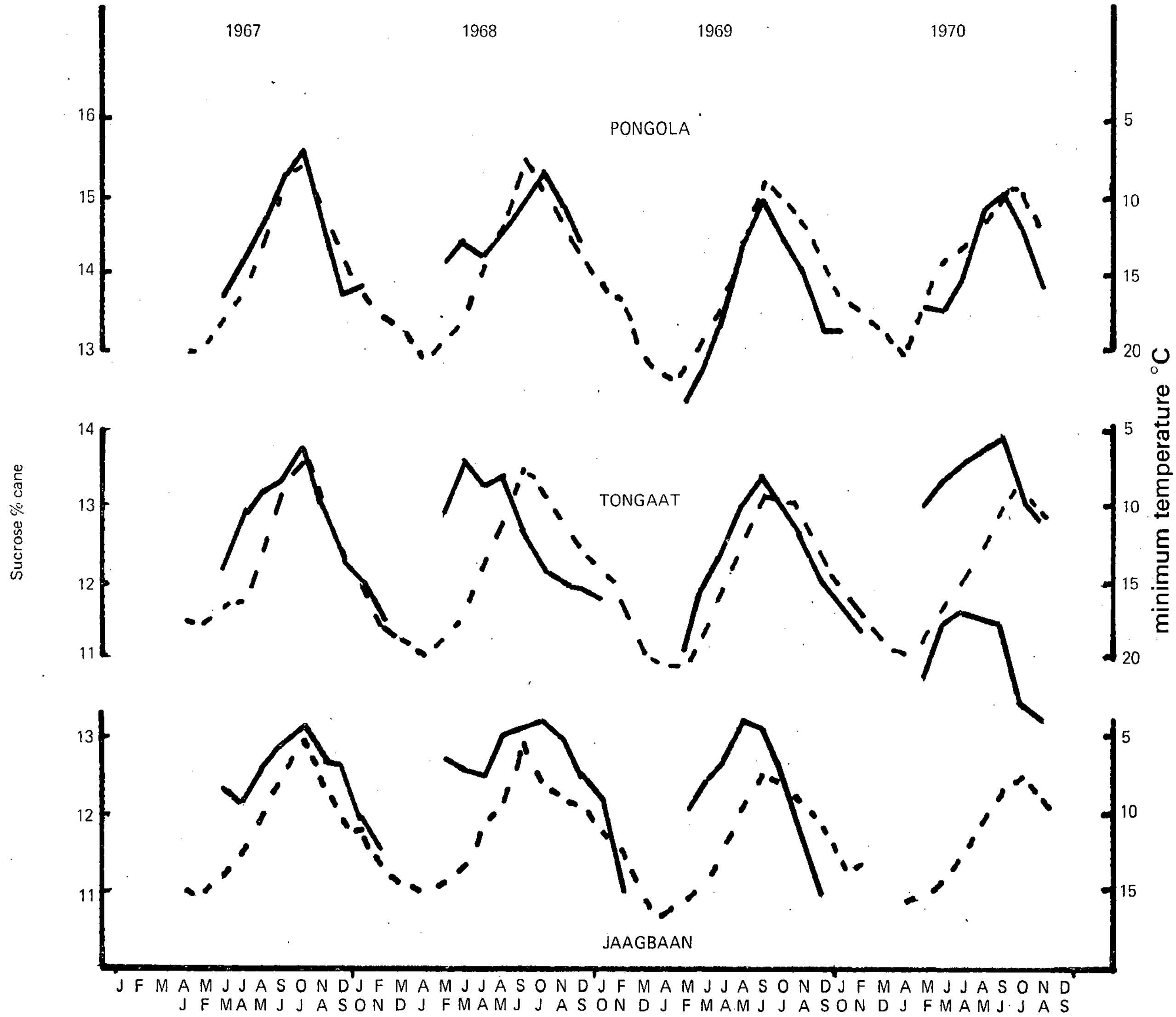

FIGURE 1: Four successive years of records of monthly average sucrose % cane (———) and mean minimum screen temperatures (- - - - - -) in three different regions. The temperature scale is inverted and displaced by three months.

This discrepancy is due to the complicating effect of drought on the rain grown crops. It is illustrated in Figure 2 which shows the relationship between sucrose % cane and monthly total rainfall.

The records of sucrose % cane shown in Figure 2 are the same as those in Figure 1 and cover the same milling seasons. The rainfall records have been inverted so that increasing dryness is associated directly with increasing sucrose % cane; further, they have been displaced by six weeks only; not by the three months as was shown for cold in Figure 1.

This figure shows that, as would be expected in an irrigated region, the effect of lack of rain at Pongola is slight or non-existent. But the effect is quite marked at both Tongaat and Jaagbaan. Consider the Tongaat records for 1968 and 1970, the agreement between severe lack of rain and the sucrose % cane six weeks later is obvious. Yet in these years the sucrose/cold relationship as shown in Figure 1 was aberrant. In like manner the effect of increasing dryness is well marked at Jaagbaan, particularly in explaining why high sucrose % cane can be found when temperatures are still high in this colder region.

It is unnecessary to present the numerical values of the statistical correlations between sucrose % cane and cold and dryness. That they are large and significant is obvious from the graphical records. Both increasing cold and increasing dryness apparently act independently through their effect on growth. However, in normal years in our surroundings they act conjointly. It is only in certain years, such as in 1968 or 1970 at Tongaat, when an early drought produces a marked effect that one can clearly distinguish the independent effect of failing moisture supplies in our soils.

To sum up increasing dryness produces a more rapid increase in sucrose % cane than does increasing cold on the scale encountered in the sugar growing regions of South Africa. The delay of some six weeks between the onset of dryness and rise in sucrose % cane is probably due in large measure to the buffering effect of reserves of soil moisture. On soils with low reserves of moisture the time displacement between cause and effect may be shorter than on soils with high reserves. Some four to six weeks difference between the onset of dryness and the increase in sucrose % cane seems to be average for the soils in the areas investigated.

The slow increase in cold, which is a seasonal phenomenon, reaches its peak in June/July and is followed three months later by the well-known September/October peak in sucrose % cane which may be observed in most years. An early autumn or late summer drought can, however, give high values early in the milling season which eliminates this normal peak.

Johnson[1] has found a strong correlation between average weekly sucrose % cane and the average weekly diurnal temperature range for the preceding calendar month. The results were obtained by analysis of the records in an irrigated region of Rhodesia. This correlation has been tested on the Pongola records without success. The relationship so obtained is shown in figure 3(a). When a three month displacement of the diurnal range of temperature records is made, the relationship at Pongola improves considerably as shown in Figure 3(b). However, it is still not as good a correlation as that with the mean minimum temperatures as shown in Figure 1 for Pongola. It is, however, worth noting that both diurnal range and mean minimum temperatures are only approximate measures of cold.

While the changes in sucrose % cane throughout the year are of considerable interest, particularly to the miller, they are not in themselves a good guide to the changes which take place during "ripening" which are of more interest to the agronomist and grower.

"Ripening"

Ripening has been defined as "storage of sucrose in the stem" (Van Dillewyn[2]) and may be regarded as a topping up process, usually associated with a slowing of growth, whereby nearly the whole stalk is charged to levels of sucrose as high or higher than may be found in old mature internodes. It should, therefore, be reflected to some extent in records of sucrose % cane. It is; but unfortunately sucrose % cane is not a reliable measure of its true

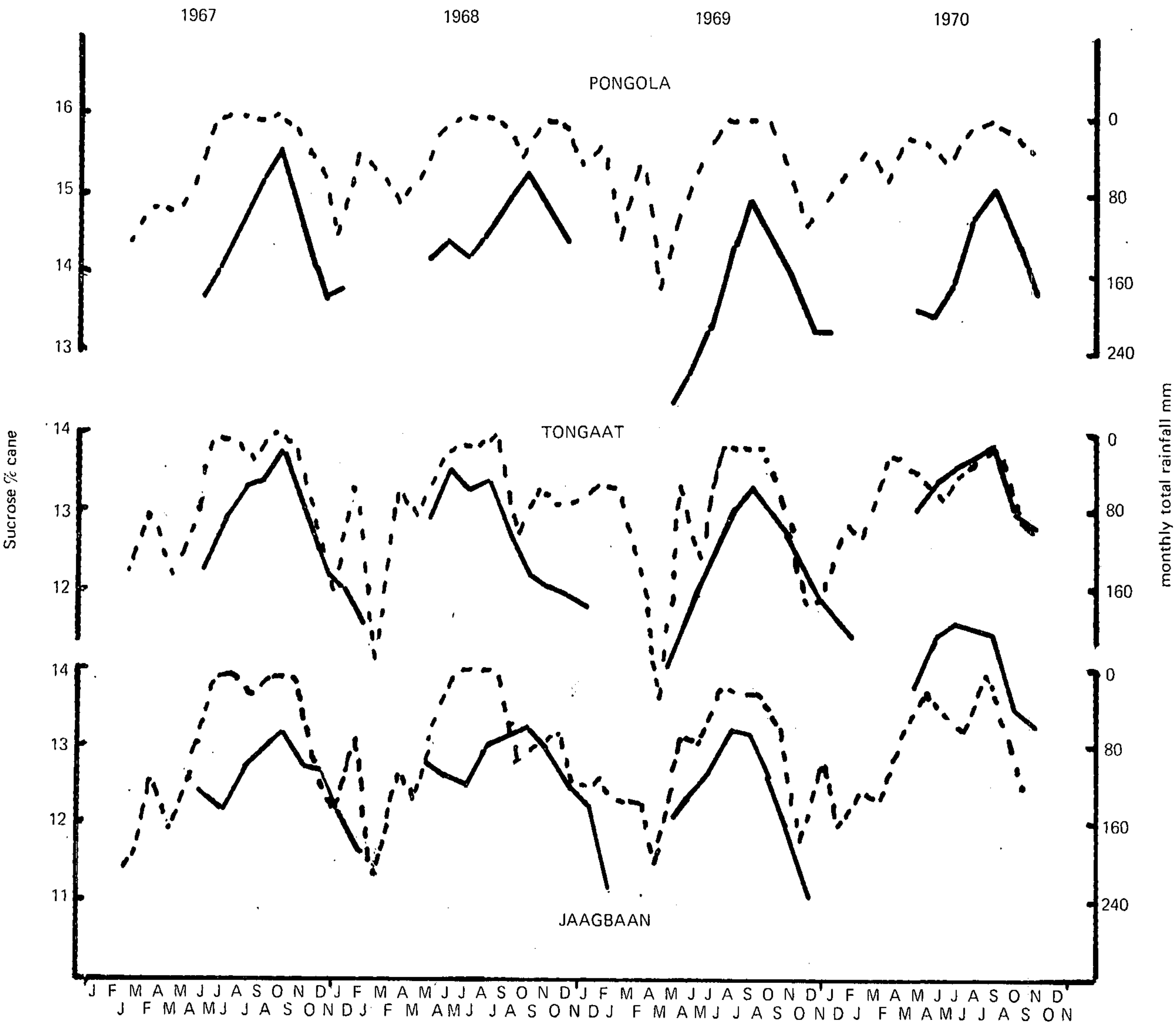

FIGURE 2: Four successive years of records of monthly average sucrose % cane (———) and rainfall (------) in three different regions. The rainfall scale is inverted and displaced by 1½ months.

extent. All measurements based on fresh weight can be very misleading because the water content of the plant is subject to quite wide fluctuations.

Consider the extreme case of very rapid reduction of water content of a stalk. Apart from the possible reconversion of some of the invert sugars to sucrose the total sucrose content of the stalk is unchanged, but the percentage sucrose content on a fresh weight basis is increased because of the fall in fresh weight. For example a stalk of 800 gm fresh weight at 78% moisture and 10% sucrose in cane holds 80 gm of sucrose. If the moisture content is lowered to 70% and there has been no gain of net photosynthate the stalk still holds 80 gm of sucrose but the sucrose % cane is now some 13,6%. The rise of sucrose % cane from 10 to 13,6% only reflects the loss of water, not any real gain in total sucrose content.

The only way to increase the sucrose content of the stalk during "ripening" is to ensure that there is time for net photosynthate to accumulate and that the partitioning of the photosynthate between sucrose and non-sucrose continues, preferably at the highest possible level.

True "ripening" consists of an accumulation of sucrose and is best measured on a dry weight basis. The effect that we see and record as sucrose % cane is the result of the interaction between changes in moisture content and the accumulation and distribution of net photosynthate. If we are to comprehend the ripening process we must at least consider these three changes simultaneously.

With this in mind it is possible to construct a simple model of the "ripening" process which takes into account falling moisture content over various periods of time and the concomitant possible loss in efficiency of net photosynthate production during the withdrawal of the water.

Such a model is described below. It is too simple in that no allowance has been made for other interactions which may occur under natural conditions. Neverthless, the resulting patterns of the changes in fresh and dry weight and of total and percentage sucrose resemble those found in experiments.

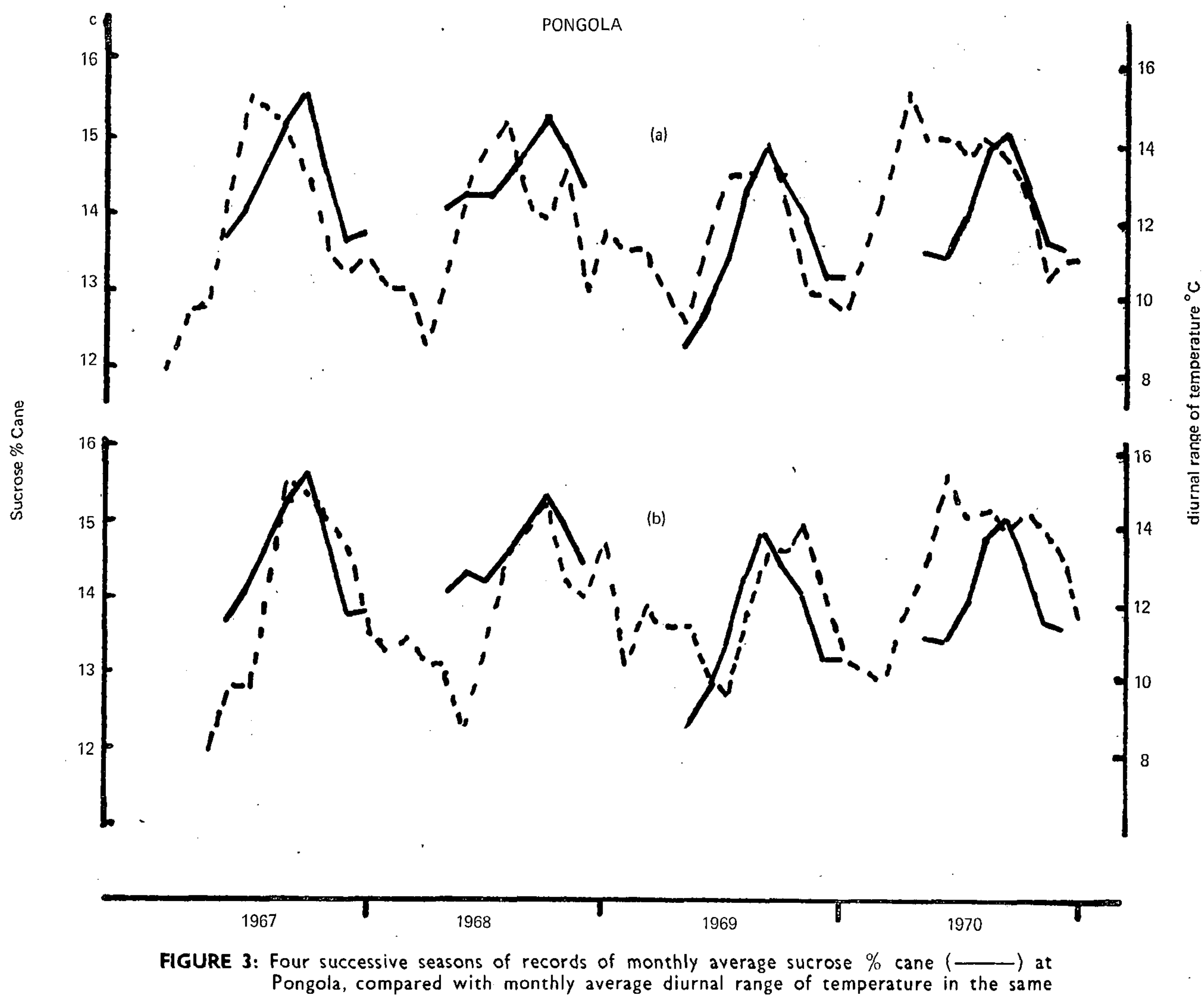

FIGURE 3: Four successive seasons of records of monthly average sucrose % cane (———) at Pongola, compared with monthly average diurnal range of temperature in the same area.
(a) Temperature records displaced by one month.
(b) Temperature records displaced by three months.

It is first assumed that the moisture content of the stalk falls during "ripening" from 78 to 70% along a logarithmic course. A moisture content of some 78% is usually found in the stalks of our varieties at the end of summer, while the crop is often harvested at about 70% moisture content.

In like manner the net gain of dry photosynthate is presumed to fall from 20 grams per stalk per week at the start of "ripening" to five grams per stalk per week at the end of the selected "ripening" period. This fall may be much more severe than actually occurs in normal circumstances. However, as we learn more about photosynthesis during "ripening" more accurate values may be substituted.

The partioning of the net photosynthate between sucrose and non-sucrose is assumed to be constant at 50%, although in practice the sucrose content of the dry matter of our commercial varieties is usually below 50% at the end of summer and slightly above 50% at harvest. It is, however, unnecessary to take such variation into account in the simple model.

The periods of "ripening" have been chosen as three, six and 12 weeks. The six week period is intended to represent the period of gradual decrease in soil moisture following the onset of drought as illustrated in Figure 2. The 12 week period may represent either the very slow withdrawal of water or the effect of increasing cold or the combined effect of both as illustrated in Figure 1. The three week period may represent hasty "ripening" induced by certain chemicals.

The results of such modelling are shown in Figure 4 where the changes in fresh and dry weight, total sucrose content and sucrose % cane of a 100 t/ha crop of millable cane of 78% moisture and 10% sucrose are plotted for each period.

Figure 4(a) shows that in the specified circumstances there is a gain in fresh weight shortly after the start of "ripening" which can be lost by the end of the three or six week ripening periods and even if the "ripening" takes 12 weeks the gain in fresh weight is only some 30% above the starting level, i.e. 28,6 tons over the low t/ha starting level.

At the same time there is a continuous curvilinear increase in both dry weight (4(b)) and total sucrose content(4 (c)) of the stalks resulting from the accumulation of net photosynthate during the ripening periods: the longer the ripening period the greater the gain.

Finally 4(d) shows the corresponding changes in sucrose % cane while the other changes are taking place. As would be expected the more rapid the withdrawal of water the more rapid is the increase in sucrose % cane associated with it.

Overall the figure shows that high levels of sucrose % cane are not necessarily associated with high gains of total sucrose per hectare. This is perhaps more clearly seen in Table I where the corresponding numerical values of each item at the end of each ripening period are listed.

Table I shows that in the particular example:

(a) the total yield of sucrose/hectare increases linearly with increasing time of ripening; that is the longer the ripening period the higher the yield of sucrose per hectare.

(b) that fresh weight does not change in the same manner. Thus after three weeks of ripening a gain of two tons of sucrose/ha is associated with a loss of some nine tons of fresh weight/ha: after six weeks of ripening a gain of four tons of sucrose/ha is associated with a gain of some $2\frac{1}{2}$ tons of fresh weight/ha, while after 12 weeks of ripening a gain of eight tons of sucrose/ha is associated with an additional $28\frac{1}{2}$ tons of fresh wt/ha.

It is obvious from this that although prolonged ripening gives higher yields of sucrose/ha there may be a point beyond which the higher yields are not worth having because of the penalty resulting from associated increase in fresh weight to be transported to the mill. This is a matter for the economists. However, before leaving the subject, it is worth looking at the sort of penalties in extra fresh weight associated with non-ripening.

If, as above, we consider a crop at 78% moisture content which continues growing at this level of moisture and the partition coefficient of net photosynthate remains constant at 50% then every additional ton of sucrose/ha will be associated with an additional 9,1 tons of fresh weight/ha irrespective of whether net photosynthate gain remains constant at high or low levels or if it varies because of climatic changes. This 9,1/1 relationship of fresh weight gain to sucrose gain is inherent in the conditions laid down, for

(1) fresh weight gain = dry wt. gain $\times \frac{100}{22}$ since at 78% moisture dry wt. is 22% of fresh wt

(2) but dry wt. gain = 2 $\times$ sucrose gain since the partition coeff. is 50% so

(3) fresh weight gain = 2 $\times$ sucrose gain $\times \frac{100}{22}$

$= 9{,}1 \times$ sucrose gain

(Had the moisture content been chosen as 80% and the partition coefficient remained at 50% then every ton increase of sucrose would be associated with a 10 ton increase of sucrose and so on.) Thus the time required to attain the additional tonnage of sugar under "non-ripening" conditions as defined above is unimportant, every ton of sucrose gain is associated with a fixed amount of gain of fresh weight which is defined only by the moisture content at which the sucrose is accumulated and the proportion of the net photosynthate which is stored as sucrose.

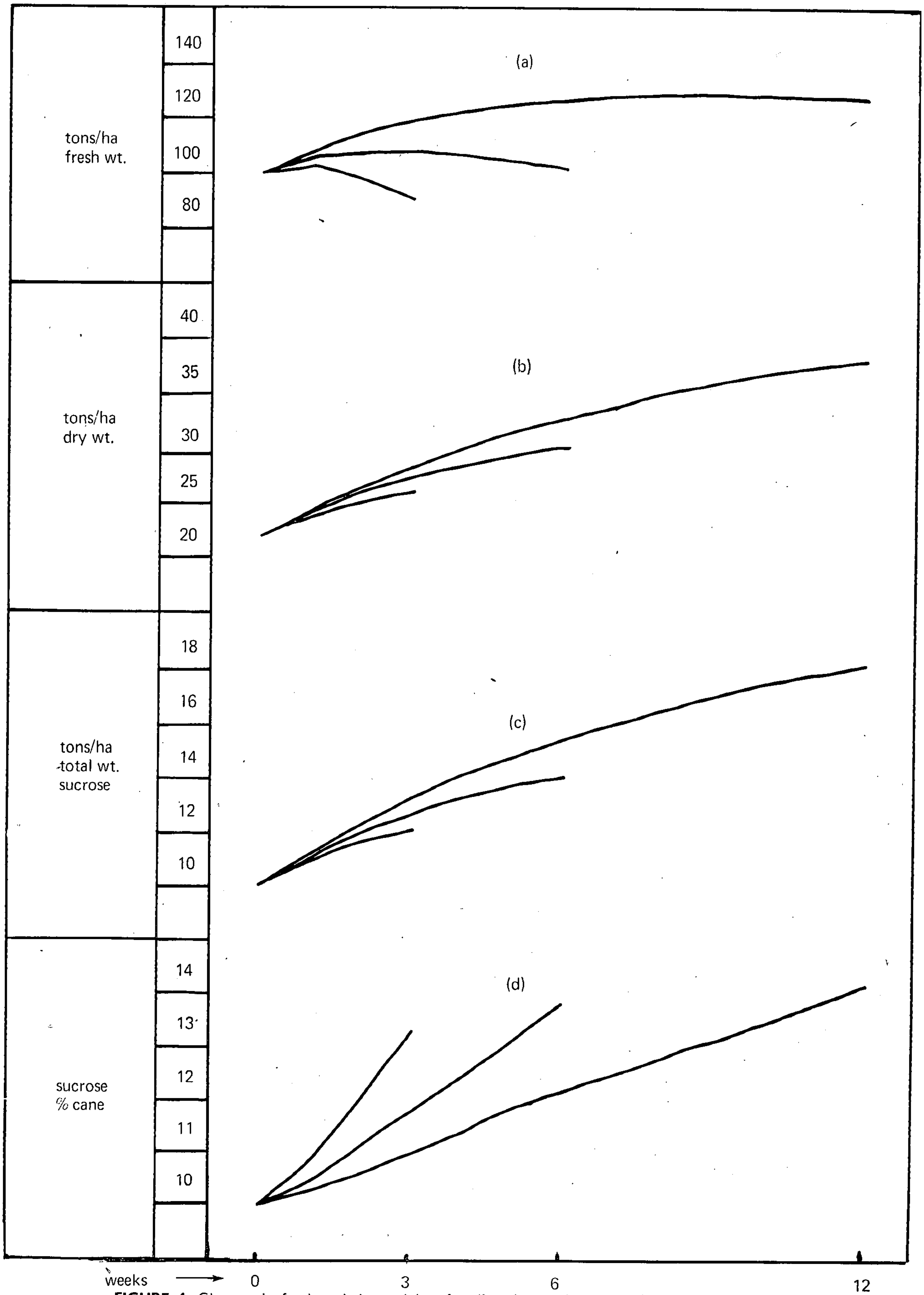

FIGURE 4: Changes in fresh and dry weight of stalks, the total weight of sucrose in the stalks and sucrose % cane during ripening for periods of 3, 6 and 12 weeks. For details see text.

A gain of eight tons of sucrose/ha under the "non-ripening" conditions specified above therefore carries with it the penalty of an additional 73 tons of fresh weight/ha to be cut, transported and milled, probably at low purity levels since sucrose % cane will not rise significantly above its low starting level. This may be compared with the penalty of 28½ tons of fresh weight/ha associated with a gain of the same tonnage of sucrose in a 12 week ripening period as listed in Table I. In addition purity levels are likely to be higher after ripening.

TABLE I

Gains or losses during the different ripening periods and corresponding levels of sucrose % cane.

	t/ha fresh wt	t/ha dry wt	t/ha sucrose	Sucrose % cane
Starting level	100	22	10	10,0
After 3 weeks	− 9,4	+ 4	+ 2	13,3
6 weeks	+ 2,6	+ 8	+ 4	13,7
12 weeks	+28,6	+16	+ 8	14,1

Enough has been presented to show that it is not difficult to produce simple models of "ripening" and "non-ripening" changes. The practical use of such will depend on better knowledge of the changes which take place within the plant. In particular we shall need to know more about moisture changes and changes in partitioning of photosynthate in relationship to climate and state of maturity, the recoverable sugar and not just total sucrose and so on before we can make more precise estimates of the value of ripening and the best means of obtaining it.

REFERENCES

1. Johnson, C. A., 1966. Some factors influencing sucrose % cane at Hippo Valley Estates. Proc. Ann. Congr. S. Afr. Sugar Techn. Assoc. 40: 299-303.
2. Van Dillewyn, C., 1952. "Botany of Sugarcane", Chronica Botanica Co. Waltham, Mass. U.S.A.

Discussion

Mr. Wardle: What would have happened if the graphs in Figure 4 had been continued beyond twelve weeks? The continuing increases in sucrose and dry weight are most noticeable.

Mr. Glover: It would not be wise to extrapolate on these figures.

We have selected a cane moisture of 78% to make that drying period work and assumed a 20 g per stalk input of sucrose at the beginning of the cold period, dropping to 5 g in three weeks. These figures are of the right order but may not be absolutely correct.

Although the graph shows an increase in sucrose it can be uneconomic to wait too long to produce a certain sucrose figure.

Dr. Thompson: The assumption must be that up to twelve weeks you did not have a severe drought and photo-synthesis was still operative.

Mr. du Toit: Mr. Glover shows that in dry weather and cold weather sucrose increases. Can there be a temperature, apart from frost, where sucrose accumulation is retarded? Taking the Jaagbaan area, sucrose is low considering the cold temperature.

Australia has high sucroses although temperatures are not as low as here.

The high sucrose at Jaagbaan last year has not been adequately explained although there was drought.

Mr. Glover: The level of sucrose is lower at Jaagbaan than Tongaat and Tongaat is lower than Pongola. It looks as if too much cold can also be harmful. The Jaagbaan figures may have been inflated by the carry over of older cane from the previous season.

Dr. Gosnell: What were the experimental conditions from which Mr. Glover derived information to construct his model?

In Rhodesian conditions the drying-off schedules would have to be completely different from those shown in this paper if they were to be used under field conditions.

Mr. Glover: This would have to be determined by local practice.

Dr. Gosnell: What were the conditions of the experiment which led to the model?

Mr. Glover: There was no actual experiment—it was based on reasoning.

Mr. van Schalkwyk: Has any work been done on moisture content in different varieties?

Mr. Glover: None at all.

Mr. Andries: Mr. Johnson read a paper some years ago where he correlated temperature range with sucrose and gave results for one season.

Dr. Gosnell: I think subsequent results showed that the figures only applied to one particular season.

Mr. Moberly: Gradual drying off as opposed to sudden drying off was tested at Pongola over a number of seasons. In a 12 month crop, drying off was done at six months and at ten months and the results were very similar.

From a practical point of view it is easier to dry off two months before harvesting the crop.

Mr. Glover: I have quoted extremes—it is up to the economist to decide the correct time for drying off.

Mr. Truen: I think Mr. Moberly got the results he did at Pongola because of the type of soil but I do not think the same results would be obtained on shallow soils.