

SUGARCANE FOR ETHANOL — SHOULD FIELD MANAGEMENT PRACTICES BE MODIFIED?

PART I — VARIETY AND SEASONAL INFLUENCES

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Abstract

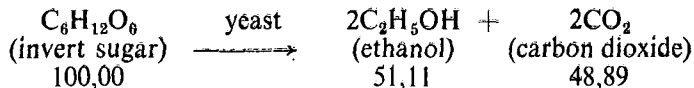
To evaluate optimum management practices for ethanol production, studies were first undertaken to compare recoverable yields of sucrose and total fermentable sugars in relation to the effects of varieties and harvest seasons. It was shown that total fermentables could be satisfactorily estimated from brix data in trials where reducing sugars had not been measured. Variety studies revealed that NCo 376 was the best available variety for both sucrose and ethanol production, and that improved yields of total fermentables could only be expected from varieties with lower sucrose content than NCo 376. Variations in sucrose and total fermentables throughout the year showed that it would be feasible to start harvesting sugarcane for ethanol production about two months earlier than the normal start for sugar production.

Introduction

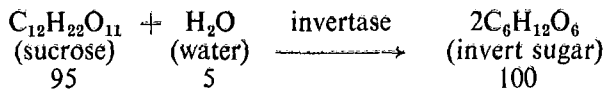
A new development in the Zimbabwe sugar industry in 1980 was the completion of a distillery at the Triangle Mill for the production of ethanol for motor fuel. This, together with the planned expansion of the industry for the production of both sugar and ethanol, has emphasised the need to determine whether standard field management practices for sugar production will be satisfactory for ethanol production, or whether such practices need to be changed or modified.

In past years research has been aimed solely at optimising sucrose yields, but the production of ethanol has added a new dimension to research, necessitating that cognizance must now be taken of the influence of treatments on the yields of total fermentable sugars in addition to sucrose yields.

Ethanol is produced from the fermentation of invert sugar (glucose and fructose) by yeast as shown by the following reaction:



To produce ethanol from sucrose, this reaction must be preceded by the conventional hydrolysis of sucrose by the enzyme invertase:



The percentage of total fermentable sugars (TF) in sugarcane thus comprises the percentage sucrose (pol) plus the percentage of reducing sugars (RS), and it can be represented either in terms of sucrose or in terms of invert according to the following relationships:

$$\begin{aligned} \text{TF (as sucrose)} &= \text{Pol} + (0,95 \text{ RS}), \\ \text{or TF (as invert)} &= \frac{\text{Pol}}{0,95} + \text{RS}. \end{aligned}$$

In a situation where all cane is produced solely for ethanol manufacture the latter relationship is relevant, but in the case of ethanol produced as a by-product of a sugar factory it is more meaningful to consider TF as sucrose, and this is the measure of fermentability which has been used in these papers.

This is the first of two papers reviewing the results of certain trials conducted in the Zimbabwe lowveld in which treatments had a measurable effect on sucrose quality. It serves to establish a reliable means of estimating total fermentables from brix data for trials in which reducing sugar content was not measured, but it is primarily concerned with the evaluation of varieties in relation to ethanol production, and with seasonal quality variation and its effect on optimum harvest periods.

Estimating total fermentables from brix

Prior to the advent of ethanol production, it had never been standard practice on the Experiment Station to measure the reducing sugar (RS) content of cane samples from all experiments. However, due to the need to measure total fermentable (TF) yields, RS determinations were carried out routinely from the beginning of 1979.

In order to determine the effects of various treatments on TF yields in trials when RS% cane was not recorded, i.e. all those harvested prior to 1979, data collected from variety trials in 1979 and 1980 were used to determine whether TF could be estimated satisfactorily from brix data.

Linear correlations were calculated between TF and brix, expressed either as % cane or tons/ha, and correlation coefficients for six variety trials harvested in 1979 are shown in Table 1. The correlations were very highly significant in all cases, with the yield data (t/ha) giving consistently better correlations than the % cane data.

The data were then examined to determine whether the slopes of the regression lines varied (a) within harvest seasons, and/or (b) between harvest seasons.

Figure 1 shows the relationships between brix and TF yields for three variety trials harvested respectively in June, August, and November, 1979, and Figure 2 shows similar relationships for two variety trials harvested in June and September, 1980.

Relevant parameters for these data are given in Table 2.

Results show that the regression lines were very similar within harvest seasons, with only small variations in slope and intercept.

TABLE 1
TF and brix correlation coefficients

Trial Project ref.	n	Correlation coefficient (r)	
		% cane	t/ha
2200/16	16	0,9743	0,9926
2200/19	25	0,9892	0,9960
2200/20	9	0,9922	0,9983
2200/22	30	0,9845	0,9930
2130/1	60	0,9725	0,9964
2130/2	30	0,9715	0,9969
Total	170	0,9830	0,9936

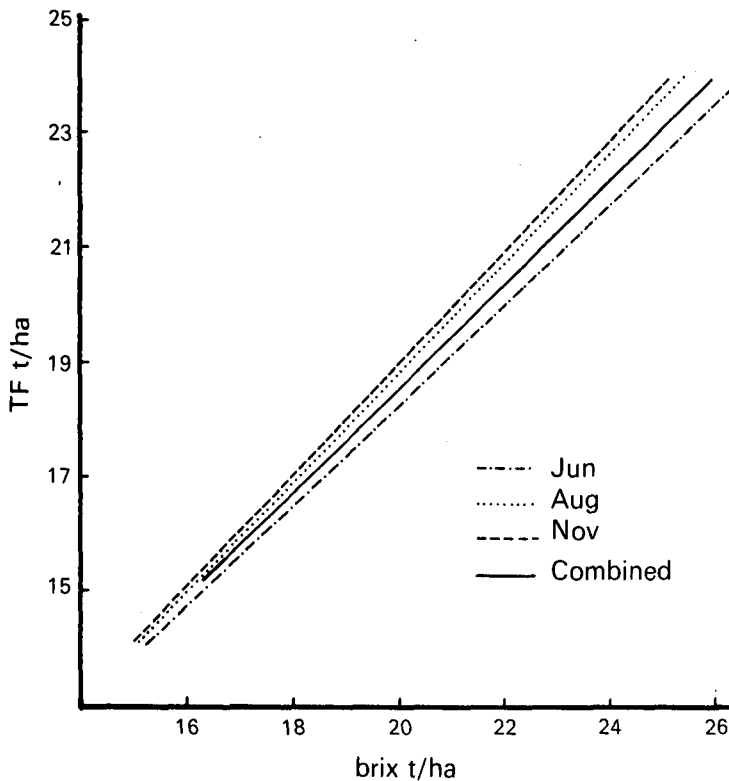


FIGURE 1 Relationship between brix and TF yields at different harvest dates in 1979.

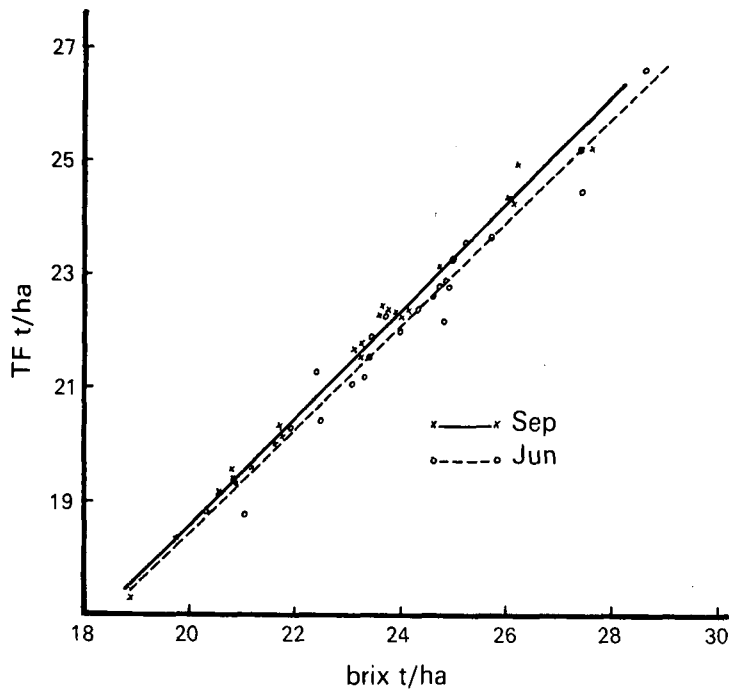


FIGURE 2 Relationship between brix and TF yields at different harvest dates in 1980.

TABLE 2

Effects of harvest season on brix and TF yield correlations

Project ref.	Harvest date	n	r	b	c
2200/22	Jun. 1979	30	0,9930	0,8691	0,8791
2200/19	Aug. 1979	25	0,9960	0,9544	- 0,2700
2200/20	Nov. 1979	9	0,9983	0,9570	- 0,2299
Combined data (1979)		64	0,9878	0,9272	0,0329
2200/23(a)	Jun. 1980	25	0,9785	0,9139	0,1917
2200/23(b)	Sept. 1980	25	0,9947	0,9520	- 0,4637
Combined data (1980)		50	0,9875	0,9175	0,2136

To compare different seasons, correlations were calculated separately for six variety trials harvested in 1979, and for seven variety trials harvested in 1980. It was not possible to show all thirteen regression lines on one graph because they were all very similar and several were superimposed. However, the means for all data in 1979 and 1980 are shown separately in Figure 3, where it can be clearly seen that the relationship between TF and brix was unaffected by seasonal differences in growing conditions.

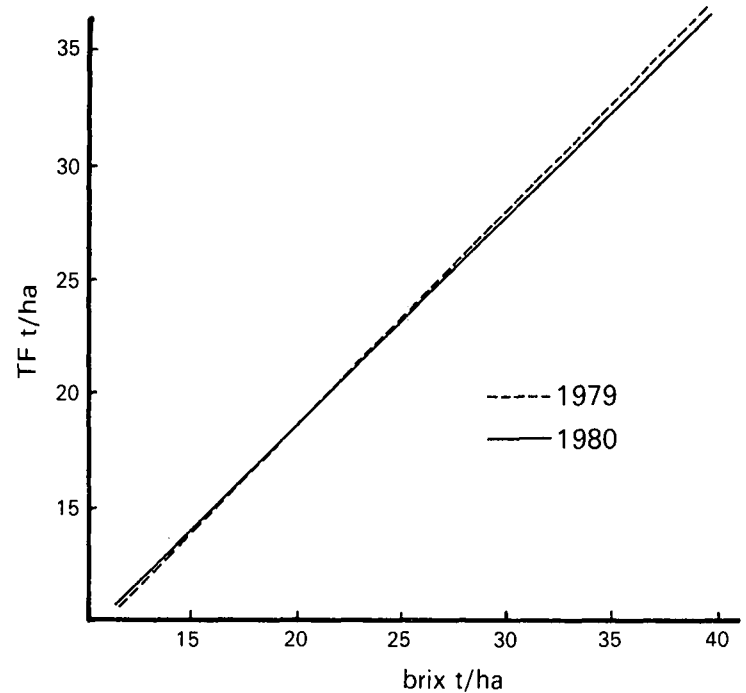


FIGURE 3 Relationship between brix and TF yields in different seasons.

As a result of this study it was concluded that a single regression equation, derived from all variety trial data in 1979 and 1980, could be used to derive estimates of TF yields from brix yields with a high degree of accuracy. This equation was as follows:

$$TF (t/ha) = 0,9366 \text{ brix } (t/ha) - 0,0890$$

n = 374 r = 0,9952

Similarly the regression of TF % cane on brix % cane was calculated from all variety trial data in 1979 and 1980, with the equation as follows:

$$TF (\% \text{ cane}) = 0,9880 \text{ brix } (\% \text{ cane}) - 0,9061$$

n = 374 r = 0,9872

In the examination of quality effects which follow, these two equations were used to derive estimates of TF for those trials in which RS % cane had not been measured.

ERC (estimated recoverable crystal) has been used throughout as the measure of sucrose quality, calculated from the formula:

$$ERC \% \text{ cane} = 0,980 \text{ pol } \% \text{ cane} - 0,417 \text{ non-pol } \% \text{ cane} - 0,035 \text{ fibre } \% \text{ cane},$$

the constants having been derived from average mill performance data to represent pol losses in filter cake, molasses, and bagasse respectively.

In most cases ERC has been compared directly with TF, but where fibre content was variable an estimate of recoverable fermentables (ERF) was derived from the equation:

$$ERF \% \text{ cane} = 0,980 \text{ TF } \% \text{ cane} - 0,038 \text{ fibre } \% \text{ cane}$$

Variety effects

The relationship between ERC and TF yields was studied in a range of sugarcane varieties to determine whether varieties with high cane yields but poor ERC % cane (a low ranking in terms of ERC yield) were of above average RS content and thus deserved recognition as high yielders of total fermentable sugars.

Thompson³ compared ERS and brix yields from selected stages in the Natal breeding programme and concluded that only small gains could be expected by selecting for TF rather than sucrose content, and that large gains would have to evolve from recourse to more suitable parent material. In Brazil, the selection of varieties for high TF yields has been based on the need for high stalk populations, and the ability to respond to chemical ripeners and high fertiliser applications (Humbert¹).

For the purpose of this study RS % cane was estimated as (brix-pol) % cane for a number of varieties selected from eighteen variety trials conducted between 1967 and 1980. Varieties were chosen with varying ERC % cane values, regardless of yield potential, and in all cases the data were expressed as percentages of NCo 376 values as this was the only variety common to all trials.

In preparing the data it became evident that RS % cane was closely related to ERC % cane, and this relationship is shown in Figure 4 for 106 varieties covering a total of 475 crop cycles; the plotted points are the means of all ratoons per trial for each variety. The regression was significantly linear ($r = -0,8307^{***}$), and it showed that varieties with ERC % cane higher than NCo 376 had relatively lower RS content, and vice-versa.

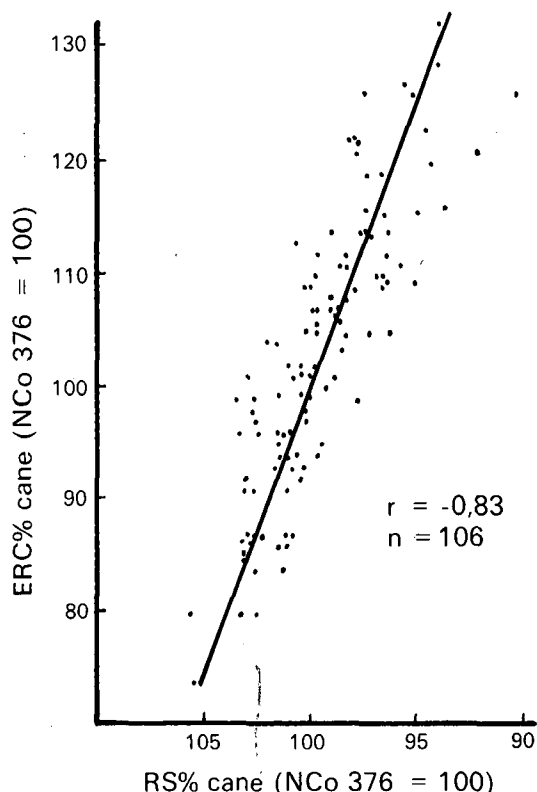


FIGURE 4 Relationship between ERC and RS% cane relative to NCo 376.

It was thus apparent that TF yields could not be estimated directly from ERC yields because RS % cane varied inversely with ERC % cane. To demonstrate this, the data were first divided into ERC % cane groups, i.e. greater than 110%, 100-110%, 90-100% and less than 90% of NCo 376 values, and linear correlations between ERC and TF yields were calculated separately for each group, expressed in all cases as

percentages of NCo 376 values. The regression lines are shown in Figure 5, where it can be seen that although the slopes of the regression lines were similar, the intercepts varied considerably.

Results showed that varieties with higher ERC % cane than NCo 376 had lower TF than ERC yields (relative to NCo 376), whereas varieties with lower ERC % cane had higher TF than ERC yields. The relationship between ERC and TF yields was thus strongly dependent on ERC % cane, indicating that a multiple linear regression would express this relationship more satisfactorily than a series of linear regressions applied to arbitrary groupings as in Figure 5. The multiple regression equation was calculated as:

$$\hat{Y} = 1,0241 X_1 - 0,3516 X_2 + 32,8848 \quad (n = 95)$$

where \hat{Y} = TF yield, X_1 = ERC yield, and X_2 = ERC % cane all data being expressed as percentages of NCo 376 values. The highly significant nature of this regression is shown by the following F test:

Variation due to	d.f.	s.s.	m.s.	F
Regression ..	2	4 532,32	2 266,16	763,02 (P < 0,001)
Deviations ..	92	273,36	2,97	
Total ..	94	4 805,68		

This multiple regression equation thus provides an accurate means of estimating the TF yields of variety trial entries when related to the performance of NCo 376 in the same trial. When applied to trial results it confirmed that the TF yield ranking of a variety relative to the performance of NCo 376 would be better than its ERC yield ranking only if the ERC % cane of the variety was lower than that of NCo 376. As NCo 376 is recognised as a variety of below average sucrose quality, alternative varieties of lower quality would be undesirable for dual-purpose needs (i.e. sugar and ethanol), but if produced for ethanol only a variety of lower sucrose quality could be of benefit if the increased RS content changed it from an ERC yield ranking lower than NCo 376 to a TF yield ranking which was higher.

A review of varietal performance in all trials conducted at the ZSA Experiment Station revealed that, from the standpoint of disease resistance and agronomic considerations, only two varieties were worthy of investigation as potentially higher

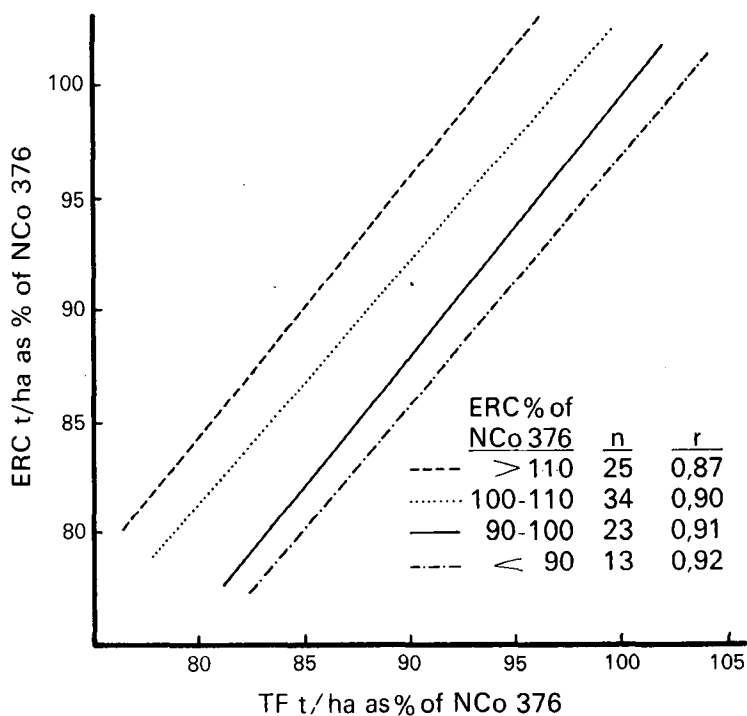


FIGURE 5 ERC and TF yield relationships in variety trials.

yielders of total fermentables, viz. Co 678 and B 47419. Both had proved to be of high cane yield but relatively poor ERC% cane, with average ERC yields of 86% and 92% of NCo 376 respectively.

Relationships between ERC% cane, ERC t/ha, and TF t/ha are shown in Table 3, where it can be seen that although both varieties gave higher TF than ERC yields relative to NCo 376, the gain was insufficient to raise TF yields above those of NCo 376.

TABLE 3
ERC and TF yields of Co 678 and B 47419

Project ref.	Number of crops	Percentage of NCo 376		
		ERC% cane	ERC t/ha	TF t/ha
Co 678				
2200/2	4	85,2	94,0	98,0
2200/3	4	85,4	83,5	90,2
2200/6	7	92,3	86,6	92,5
2200/18	4	91,3	81,9	86,3
2200/23(a)	1	81,1	78,9	86,2
2200/23(b)	1	92,4	91,4	91,4
Weighted mean ..		88,9	86,4	91,6
B 47419				
2200/8	6	97,2	90,2	90,2
2200/11	3	93,9	94,6	97,2
2200/14	4	92,6	95,9	98,5
2200/23(a)	1	81,6	82,5	89,5
2200/23(b)	1	98,8	91,5	99,4
Weighted mean ..		94,4	92,2	94,4

The results of this study showed that (a) there were no varieties available in Zimbabwe which could match the ERC yield of NCo 376 but outyield it in terms of total fermentables, and (b) although varieties with high cane yields but poor quality had a higher proportion of reducing sugars, the increase was insufficient to raise their TF yields above those of NCo 376.

Seasonal effects

The optimum harvest season in the Zimbabwe lowveld is from May to November inclusive, but in practice harvesting normally starts in April and extends into December and sometimes into January.

Variation in sucrose content throughout the year is shown by the ERC% cane curve in Figure 6 (Lonsdale and Gosnell²). ERC% cane is relatively low at the start of the harvest season in April/May; it rises to a peak in September; and it falls steadily from November to March/April. Comparable ERF% cane values are also shown in Figure 6, where it can be seen that they are not subject to the same extremes as ERC% cane. Lowest values are from December to March, and high values are attained earlier and maintained for a longer period than ERC% cane.

The short cold winters have a considerable effect on cane yields, and 6-year means from Triangle Limited (1974 to 1979) have been plotted in Figure 7 to show the pattern of yield variation throughout the year in 12-month old cane. The period of highest yields from April to June is the result of optimum summer growing conditions coinciding with the period of rapid stalk elongation, whereas poorer yields in mid-summer reflect the restriction on growth imposed by low winter temperatures. A comparison of this seasonal yield variation with the variation in ERC% cane shown in Figure 6 reveals that the period of highest cane yields occurs when

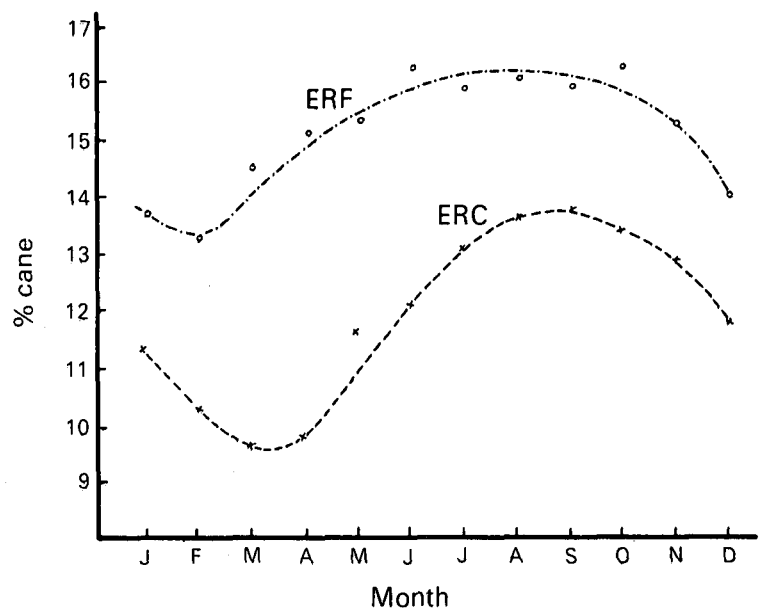


FIGURE 6 Quality variation during the year.

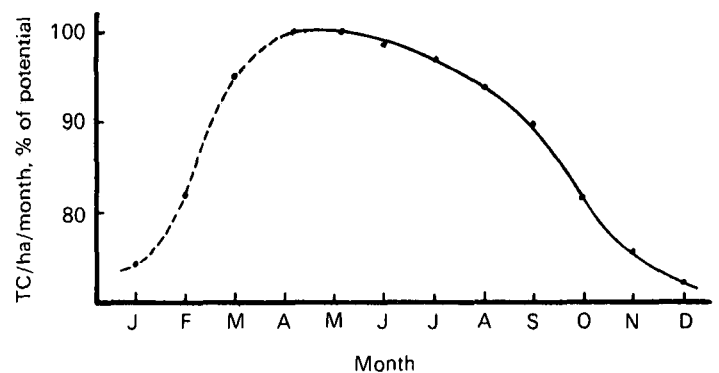


FIGURE 7 Seasonal variation in cane yield, t/ha/month.

sucrose content is just starting to rise after the summer trough, whereas high quality is associated with the period of yield decline from July to December.

The only true measure of productivity in sugarcane is yield of ERC/ha/month, or in the case of ethanol production yield of ERF/ha/month, and seasonal variations in these two factors are shown in Figure 8.

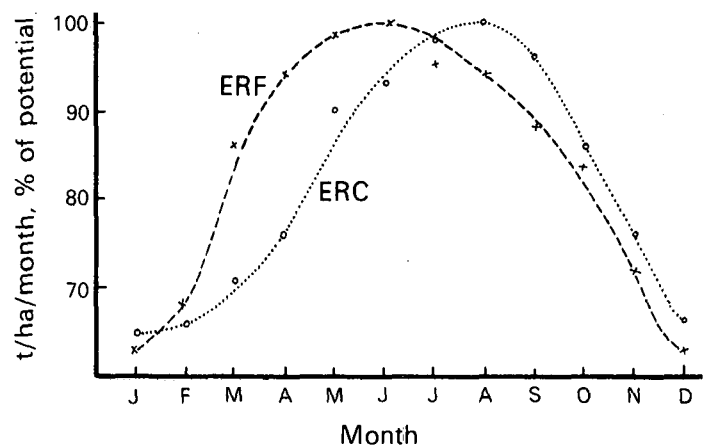


FIGURE 8 Seasonal variation in ERC and ERF yields, t/ha/month.

Considerable differences are evident during the period February to July, with ERF yields rising earlier, and much more steeply, than ERC yields. Harvesting for sugar production normally starts in April when yields are about 75% of potential, and on this basis the harvest season for ethanol production

could be extended to start at the beginning of March. Differences were small at the end of the season, with ERF yields dropping about two weeks earlier than ERC yields.

Discussion

The many factors which affect yield and quality in sugarcane have to be recognised and understood to ensure that field management practices are aimed at optimum productivity. The economic yield of a crop is the yield of the marketable product, and it is the criterion upon which productivity must be based. For sugar production it is a function of cane yield and sucrose content, and it is normally expressed as tons sugar per hectare per month. In the case of ethanol production the basis of quality is different, and productivity must be re-defined to take account of the reducing sugar content of the cane in addition to sucrose content, and it must be measured in terms of total fermentable solids.

Perhaps the most common question posed is whether alternative varieties should be grown for ethanol production. The fact that no varieties are available in Zimbabwe capable of producing higher TF yields than NCo 376 is a reflection of both the adaptability and the versatility of this variety. For sugar production the search is for varieties of high yield potential with better sucrose quality than NCo 376, but it has been shown that such varieties would be unlikely to give improved yields of total fermentables. An extensive screening

programme of varieties bred for sucrose production would thus stand little chance of exposing material with higher TF yields than NCo 376, and it is probable that varieties need to be specially bred for ethanol production from alternative gene pools.

Although the optimum harvest season can readily be defined by yield and quality criteria, it is invariably extended to satisfy economic rather than agronomic considerations. Poor quality gives rise to low sucrose yields in mature cane during the summer months, but the reducing sugar content of the cane is high during this period so that ERF % cane is less severely depressed than ERC % cane. It would thus be feasible to start crushing about two months earlier if the cane was being grown exclusively for ethanol production. However, in-field loading and transport of cane stacks under wet conditions to satisfy factory demand during the rainy months of February and March could have disastrous long-term effects on soil physical properties.

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