DIFFERENCES IN ADJUSTMENT FOR CANE QUALITY BETWEEN THREE FACTORY PERFORMANCE YARDSTICKS

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Abstract

Three indicators of factory performance are in general use in South Africa. These are Factory Performance Index, Corrected Reduced Extraction and Target Purity Difference for molasses using the SMRI revised target purity formula. The respective predictions of loss of pol in bagasse and loss of sucrose in molasses on the overall Factory Performance Index basis are compared with the allowances made by the two individual performance yardsticks. It is shown that the differences for loss in bagasse are not material. Comparison of molasses loss allowance is complicated by uncertainties regarding the balance of impurities between cane and output streams, but variation in the proportion of reducing sugars in the impurities does result in significant differences. It is concluded that adjustments for cane quality in the assessment of factory performance should include consideration of the level of reducing sugars in cane. Unreliability of the necessary analytical procedures is a handicap in this regard.

Introduction

Many formulae designed to eliminate the effect of cane quality on factory performance have been proposed in the past, and doubtless will be in the future. There is usually little agreement among technologists as to their validity. Three such yardsticks have however recently gained fairly widespread acceptance in South Africa. These are Factory Performance Index (FPI), Corrected Reduced Extraction (CRE) and the SMRI revised target purity formula. The first gives an indication of the overall performance of the factory in making sugar from cane, while the second two relate to the individual loss streams of bagasse and molasses respectively.

Due to the averaging principle in the Division of Proceeds system, comparison of a factory's performance with current average for the industry assumes greater importance in South Africa than in other cane-producing countries. With most factories operating within a narrow performance range, conclusions on relative performance either between factories or for the same factory at different times may differ significantly depending on the criteria used. The purpose of this paper is to assess the extent to which the overall performance indicator is compatible with each of the individual yardsticks.

Derivation and application of performance yardsticks

The derivation of each of the three formulae has been fully described previously and will only be summarised briefly here.

Factory Performance Index

FPI expresses the percentage ratio of crystal in raw sugar to Estimated Recoverable Crystal in cane, as described by Van Hengel.[6] The basic principle is that average losses of pol in bagasse are directly related to fibre in cane, and average losses of sucrose in molasses to non-pol in cane. As applied in South Africa, new ERC factors are derived each season from the relevant data for the industry as a whole, so that industrial average FPI for the season is exactly 100.

Corrected Reduced Extraction

The CRE formula was derived by Rein[5] by statistical analysis of cane quality and extraction plant data from a number of South African mills. The formula requires values for actual extraction, pol % cane, fibre % cane and fibre in bagasse % cane (i.e. excluding suspended solids in mixed juice).

SMRI revised target purity formula

In recent years an extensive programme of laboratory boiling-down tests on final molasses samples has been carried out by the Sugar Milling Research Institute. This work was reported by Bruijn *et al.*[2] After subsequent inclusion of additional data the linear regression originally proposed was replaced[1] by a formula reading

$$\text{Target purity} = 39{,}94 - 19{,}60 \log \left\{ \frac{\text{reducing sugars \% molasses}}{\text{sulphated ash \% molasses}} \right\}$$

Purity here refers to sucrose as a percentage of true solids.

Method of comparison

The procedure applied here involves use of the CRE and target purity formulae to calculate individually variable values for the Factors b and c in the ERC formula. These factors are then applied to the relevant fibre and non-pol % cane figures to arrive at adjusted ERC % cane and hence FPI values. These in turn are then compared with the figures derived using the conventional seasonally fixed ERC factors.

The principle of using base data specific to a particular season has been applied here as for the ERC formula derivation. Industry average ERC factors, and hence FPI's, for the season are thus identical for fixed and variable values. The changes in FPI shown later thus reflect only the different allowances for cane quality between the standard ERC formula and the relevant individual performance yardstick.

Derivation of the formulae for an adjusted bagasse loss Factor c^1 is given in Appendix 1, and for an adjusted molasses loss Factor b^1 in Appendix 2.

Both principle and practice of comparing bagasse loss allowance by the ERC and CRE formulae are straightforward. The same cannot be said for the molasses loss comparison due to a number of complicating factors discussed below.

(i) Reducing sugars/ash ratio in molasses is not a direct indicator of cane characteristics. The ratio can be altered during processing and there is no doubt that this sometimes occurs. In the majority of cases such changes should however be relatively small and differences in the ratio are primarily a reflection of the composition of impurities in the cane.

(ii) Industrial average values for true purity and reducing sugars/ash ratio are required. Analysis for true solids and sulphated ash are not reported by the mills, which usually lack the necessary equipment. Data used here for the industry - wide comparison is derived from averages of the SMRI analysis carried out monthly on samples representing only one week's production at each mill. Due to the incomplete coverage these averages may differ significantly from the true values for the total production. This does not detract from the validity of comparison between different molasses characteristics *per se*. On an individual mill basis the changes shown in Table 4 are not however necessarily correct in absolute terms and should be taken as an indication of trends only. For the monthly data presented for Huletts mills, molasses analyses by Huletts Research and Development Laboratory have been used. These analyses are representative of total molasses output and the above reservations therefore do not apply.

(iii) A balance of impurities between the output streams (molasses and sugar) and cane is required. The analytical methods used in estimating impurities are completely different for the two main impurity streams — refractometer brix and direct pol in mixed juice, true solids and sucrose in molasses. The result is a major deviation from levels that would be expected if there were no real loss or gain. This would not matter if the impurity recovery ratio remained constant or showed only random variation. There is however evidence that the ratio is influenced by the proportion of reducing sugars in the impurities. This aspect is covered in Appendix 3. It need only be noted here that the data presented later is based on an assumption of constant impurity recovery ratio, which will tend to overestimate the differences in performance evaluation between ERC and target purity difference relationships.

Results of comparisons

(1) *Monthly data from individual mills*

If comparisons are made between seasons for one mill, the range of cane quality is usually too small for adequate representation of differences. Comparison between mills in one season has the disadvantage that base performance levels vary widely. The initial data presented here therefore refers to monthly results over one season at individual mills. The mills selected are Triangle with its low fibre, high reducing sugars and generally wide range of cane quality over the season; Empangeni to represent high fibre and low reducing sugars; and Amatikulu as an example of a mill where cane quality does not differ widely from industrial average.

Table 1 and Figure 1 show ERC % cane derived both from the conventional fixed ERC factors, and from adjusted ERC factors b^1 and c^1 calculated as described in the appendices. Despite the wide ranges in cane quality for the Triangle data used for this comparison, the differences shown are small.

It would be premature to conclude from the ERC % cane comparison that the effect of ERC factor adjustment is negligible. The reason is that pol % cane has an overriding influence on ERC % cane. The proportional change in ERC is what counts, and in the present context this will be shown by the change in FPI, as illustrated in Figure 2.

TABLE 1

ERC % cane using normal and adjusted ERC factors (Triangle 1974)

ERC Factors	Normal	Adjusted
April	9,43	9,71
May	10,24	10,45
June	11,20	11,41
July	11,48	11,59
August	12,23	12,27
September	12,73	12,71
October	12,73	12,65
November	11,00	10,98
December	9,68	9,74

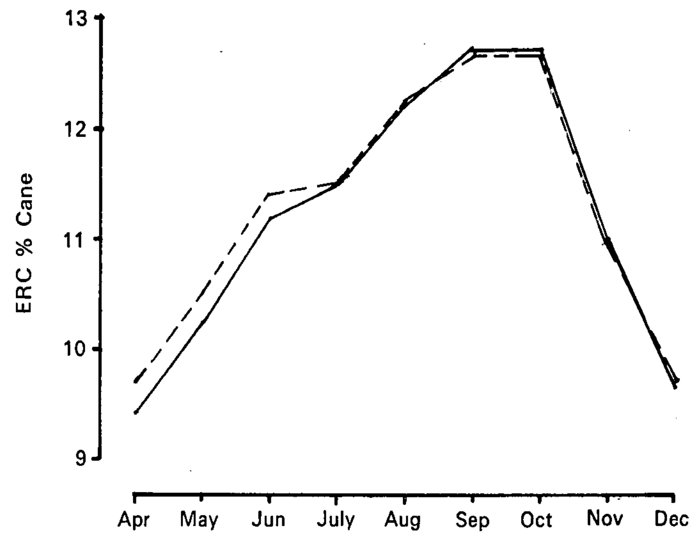

FIGURE 1 Triangle 1974: Normal (———) and adjusted (- - - - - -) ERC% cane.

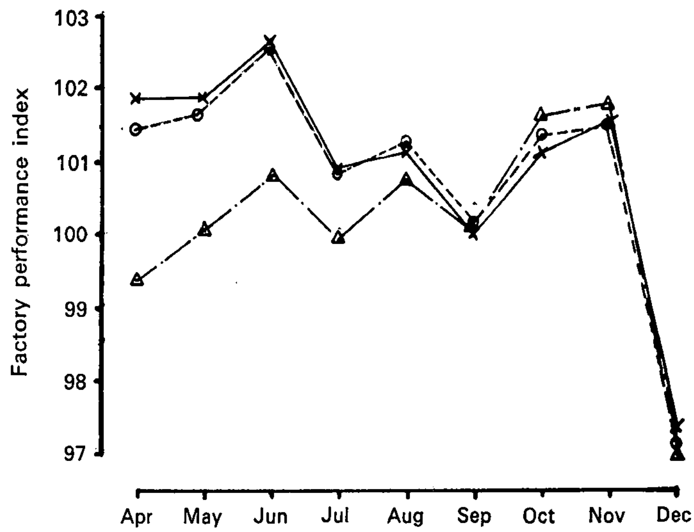

FIGURE 2 Triangle 1974: Factory Performance Index: Normal (X——X), adjusted for *bagasse* loss only (O - - - - - O) and adjusted for *molasses* loss only (△ — . — △).

The three plots in Figure 2 represent FPI calculated with Factors b and c fixed, fixed b but adjusted c^1, and adjusted b^1 but fixed c. The two broken-line plots thus reflect the individual effect of changing the allowance for loss in bagasse and loss in molasses respectively.

It is evident that the changes resulting from adjustment of the bagasse loss allowance cannot be classed as significant. This is in spite of the presence of nearly all possible combinations of high, medium and low pol and fibre % cane (the exception is high fibre/high pol). It can therefore be concluded without further discussion that the ERC and CRE formulae do not differ in their assessment of loss in bagasse to any material extent.

The molasses loss adjustment on the other hand does change the assessment of performance significantly, in terms of pattern over the season as well as season-average level.

For the three mills considered, monthly values of cane quality, molasses characteristics and adjusted ERC factors appear in Table 2. Resultant FPI figures together with the normal values are shown in Table 3. All this data is plotted in Figure 3. The heavy horizontal lines represent industrial average levels, which enable comparison of individual quality and performance values with the average to be made. Note

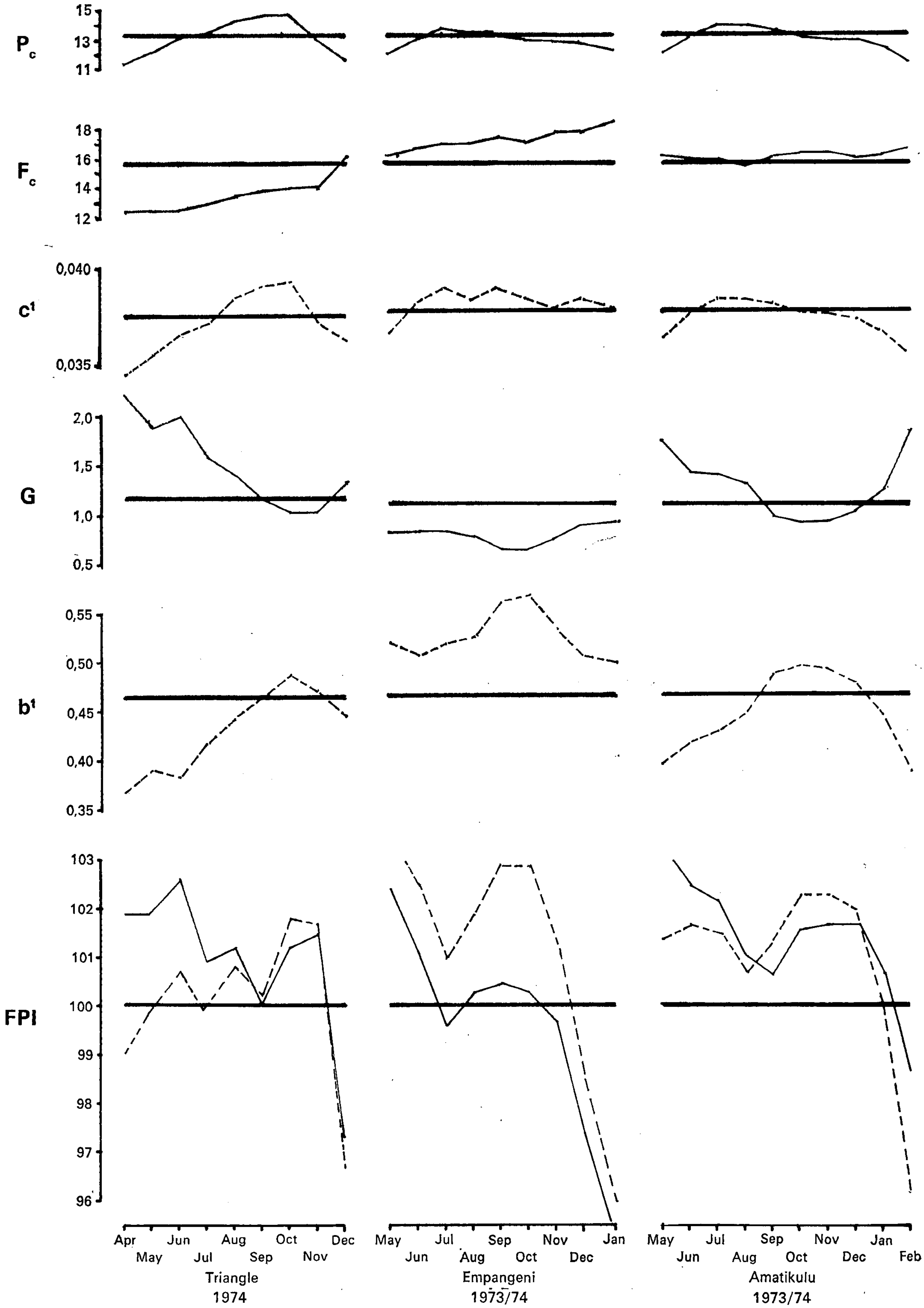

FIGURE 3 Triangle 1974, Empangeni and Amatikulu 1973/74: Cane quality, molasses characteristics, adjusted ERC factors, Factory Performance Index. Heavy lines — Industrial averages Broken lines — Adjusted ERC factors and resultant FPI.

TABLE 2

Cane quality, molasses characteristics and adjusted ERC factors

Month	Pol % cane P_c			Fibre % cane F_c			Adjusted factor c^1			RS/ash ratio G			Adjusted factor b^1		
	TG	EM	AK	TG	EM	AK	TG	EM	AK	TG	EM	AK	TG	EM	AK
April . .	11,2	—	—	12,5	—	—	0,0344	—	—	2,22	—	—	0,367	—	—
May . . .	12,0	12,0	12,1	12,6	16,0	16,0	0,0355	0,0366	0,0363	1,88	0,81	1,73	0,390	0,520	0,399
June . . .	13,0	12,9	13,1	12,7	16,8	15,8	0,0366	0,0380	0,0376	1,98	0,82	1,42	0,383	0,518	0,428
July . . .	13,3	13,6	13,8	13,4	16,7	15,7	0,0372	0,0388	0,0383	1,56	0,81	1,40	0,417	0,520	0,430
August . .	14,1	13,3	13,8	14,1	17,1	15,5	0,0384	0,0383	0,0381	1,33	0,77	1,30	0,441	0,529	0,441
September .	14,6	13,3	13,4	14,6	16,9	15,9	0,0389	0,0387	0,0378	1,14	0,64	0,97	0,466	0,564	0,489
October . .	14,7	13,0	13,0	14,7	17,4	16,1	0,0392	0,0383	0,0374	1,01	0,62	0,92	0,486	0,570	0,498
November .	13,0	12,8	12,8	15,0	17,2	16,2	0,0372	0,0378	0,0373	1,09	0,75	0,94	0,473	0,534	0,494
December .	11,6	12,8	12,8	16,1	17,7	15,9	0,0362	0,0383	0,0371	1,27	0,87	1,02	0,448	0,507	0,480
January . .	—	12,2	12,2	—	18,2	16,1	—	0,0377	0,0365	—	0,91	1,26	—	0,500	0,446
February. .	—	—	11,3	—	—	16,6	—	—	0,0356	—	—	1,84	—	—	0,390
Season . .	13,2	12,9	13,0	13,8	17,0	15,9	0,0372	0,0381	0,0374	1,48	0,77	1,21	0,425	0,529	0,452

Key: TG — Triangle 1974 EM — Empangeni 1973/74 AK — Amatikulu 1973/74

that the averages of the South African ERC factors for 1973/74 and 1974/75 are used in the formula applied at Triangle, and the industry levels shown here are therefore also averages for those two seasons.

TABLE 3

Normal (N) and adjusted (A) Factory Performance Index

Mill	Triangle		Empangeni		Amatikulu	
Season	1974		1973/74		1973/74	
FPI	N	A	N	A	N	A
April . .	101,9	99,0	—	—	—	—
May . . .	101,9	99,8	102,4	103,6	103,3	101,4
June . . .	102,6	100,7	101,1	102,5	102,5	101,7
July . . .	100,9	99,9	99,6	101,0	102,2	101,5
August . .	101,2	100,8	100,3	101,9	101,1	100,7
September .	100,0	100,2	100,5	102,9	100,7	101,3
October . .	101,2	101,8	100,3	102,9	101,6	102,3
November .	101,5	101,7	99,7	101,3	101,7	102,3
December	97,3	96,7	97,4	98,5	101,7	102,0
January . .	—	—	95,1	96,0	100,7	100,0
February. .	—	—	—	—	98,6	96,2
Season . .	101,2	100,2	99,8	101,4	101,6	101,3

The adjusted FPI values provide different impressions of performance in some respects. For the Triangle data, if the dip in December due to boil-off and the random month-to-month variations are discounted, then the trend in performance over the season changes from downwards to upwards. The latter trend is more in line with the pattern of high back-end loadings early in the season, as shown in Figure 4. The Empangeni performance level rises from indifferent to above-average and on a par with Amatikulu over the season. Of particular interest is the elimination of the large late-season gap in performance between the two mills. As is the case for the Triangle comparisons, these differences are primarily due to variation in reducing sugars/ash ratio and mainly reflect the very low Empangeni levels.

(2) 1975/76 *season data for Industry*

To provide a somewhat wider indication of the differences in performance assessment between the overall FPI figures and the individual performance yardsticks, the data in Table 4 has been included. Four mills showing lower performance figures due to abnormal circumstances have been excluded from the list.

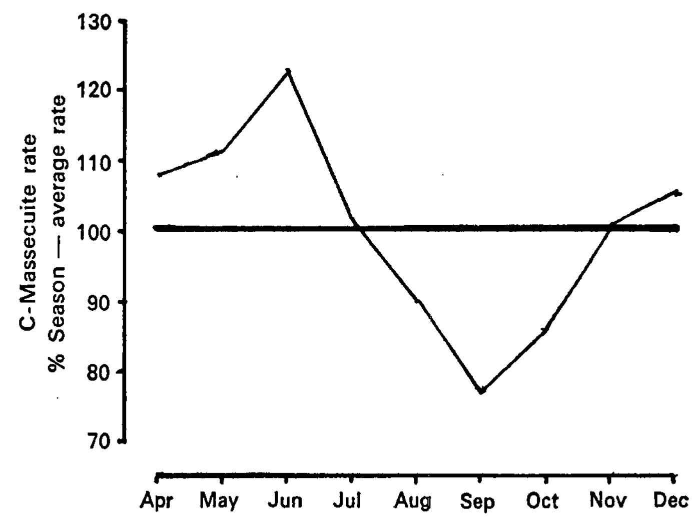

FIGURE 4 Triangle 1974: m³ C-massecuite per hour % season — average m³ C-massecuite per hour.

TABLE 4

1975/76 Season — normal and adjusted FPI

Factory	Adjusted FPI	Normal FPI	Difference (adjusted-normal)
MV	104,0	103,7	+0,3
DL	102,4	101,5	+0,9
PG	101,8	101,1	+0,7
ME	101,3	101,8	−0,5
JB	101,3	101,6	−0,3
TS	100,9	101,0	−0,1
UF	100,7	100,5	+0,2
RN	100,5	100,9	−0,4
SZ	100,0	100,5	−0,5
GH	99,8	99,2	+0,6
EM	99,7	98,8	+0,9
FX	99,3	99,2	+0,1
AK	99,3	99,0	+0,3
IL	99,2	100,0	−0,8
GD	98,6	98,0	+0,6

Changes in FPI are all below one unit. These changes are plotted against reducing sugars/ash ratio in molasses in Figure 5, which confirms the earlier finding that the differences are almost entirely due to the molasses loss adjustment alone.

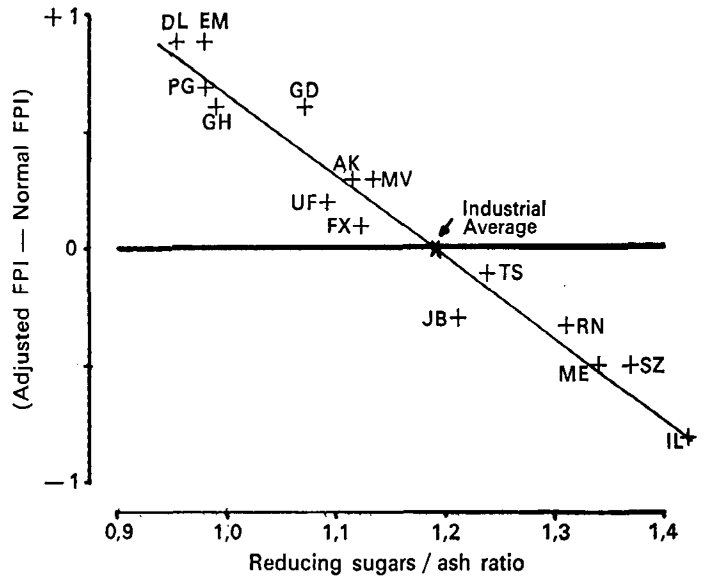

FIGURE 5 Industry 1975/76: Change from normal to adjusted Factory Performance Index versus reducing sugars/ash ratio in molasses.

Conclusions

Differences in performance assessment between the overall Factory Performance Index method and the individual yardsticks of Corrected Reduced Extraction and target purity difference have been investigated. With regard to the bagasse loss allowance, it is concluded that there is no material difference between the ERC and CRE formula relationships.

The molasses loss comparison is complicated by the need to introduce a value for apparent impurity recovery ratio. There is evidence that this ratio varies with the proportion of reducing sugars in total impurities, in such a manner as to reduce the magnitude of the differences calculated assuming a fixed impurity recovery ratio. In the absence of reliable quantitative relationships the latter assumption has been made in the calculations reported here. The resultant maximum difference between the two molasses loss criteria is in the region of 0,3 units FPI per 0,1 unit deviation in reducing sugars/ash ratio from industrial average.

It is not suggested that changes be made to the form or application of any of the three performance indications simply because of the discrepancies highlighted here. On the other hand, if importance is to be attached to relatively small differences in overall performance as measured by FPI, then the contribution of any major differences in impurity composition in terms of reducing sugars/ash ratio should be borne in mind.

In the longer term the introduction of an overall performance indicator incorporating some measurement of reducing sugars seems desirable, such measurement being as early in the process as is practicable. Unfortunately the obvious choice of mixed juice appears undesirable with the present dubious method of reducing sugars determination in this stream. The need for reliable figures for performance evaluation purposes will hopefully provide added impetus to the search for an improved method.

Acknowledgements

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Nomenclature

P_c = Pol % cane
F_c = Fibre % cane
F_{bc} = Fibre in bagasse % cane
E = Extraction
M = True purity of final molasses
T = Target purity
Δ = Target purity difference
G = Reducing sugars/ash ratio in molasses
R_n = Ratio non-sucrose output/non-pol in cane
b^1 = Adjusted ERC Factor b
c^1 = Adjusted ERC Factor c

Additional subscripts:
i = Industrial average value
s = Standard value

Appendix 1

Derivation of Factor c adjustment formula based on Corrected Reduced Extraction (CRE) relationship.

Factor c in the ERC % cane formula is the average ratio of pol in bagasse to fibre in cane, which can be expressed as

$$c = \frac{P_{ci}\,\dfrac{100 - E_i}{100}}{F_{ci}}$$

If a "standard extraction" E_s can be defined, then a variable Factor c for different cane quality levels can be calculated as

$$(2) \qquad c^1 = \frac{P_c\,\dfrac{100 - E_i}{100}}{F_c}$$

The standard extraction can be derived from the CRE formula reading

$$C_i = 100 - 0{,}03936\,\frac{(100 - E_s)\,(100 - F_{ci})\,P_{ci}^{0,6}}{F_{bci}}$$

which can be transformed to

$$(3) \qquad E_s = 100 - \frac{(100 - C_i)\,F_{bci}}{0{,}03936\,(100 - F_{ci})\,P_{ci}^{0,6}}$$

Standard extraction for any individual cane quality will similarly be given by

$$(4) \qquad E_s = 100 - \frac{(100 - C_i)\,F_{bc}}{0{,}03936\,(100 - F_c)\,P_c^{0,6}}$$

Substituting (4) in (2) and simplifying yields

$$c^1 = \frac{(100 - C_i)\,F_{bc}\,P_c^{0,4}}{3{,}936\,F_c\,(100 - F_c)}$$

Appendix 2

Derivation of Factor b adjustment formula based on SMRI revised target purity formula relationship.

Factor b in the ERC % cane formula is the average ratio of sucrose in molasses to non-pol in cane. Two stages are required to derive a formula for adjustment of Factor b. Firstly the industrial average true purity of molasses and the individual reducing sugars/ash ratio in molasses are used to calculate a "standard" ratio of sucrose to non-sucrose in molasses. A value representing the ratio of non-sucrose in molasses to non-pol in cane must then be introduced in order to relate the expected sucrose loss to non-pol in cane.

Industrial average data for 1975/76 is shown in the examples below.

(*a*) "Standard" ratio of sucrose to non-sucrose in molasses:

For the Industry,		1975/76
True purity	M_i	41,2
Reducing sugars/ ash ratio	G_i	1,19
Target purity	$T_i = 39{,}9 - 19{,}6 \log G_i$	38,5
Target purity difference	$\Delta_i = M_i - T_i$ . . .	2,7

The value Δ_i is used together with the individual reducing sugars/ash ratio to give the "standard" purity M_s:

$$M_s = (39{,}9 - 19{,}6 \log G) + \Delta_i \quad 42{,}6 - 19{,}6 \log G$$

Ratio of sucrose to non-sucrose in molasses is then

$$(1) \quad \frac{M_s}{100 - M_s}$$

(*b*) Impurity balance:

Again for the industry,		1975/76
Ratio sucrose/non-sucrose in molasses	$\frac{M_i}{100 - M_i}$	0,701
Ratio sucrose in molasses/ non-pol cane	(Factor) b	0,460233

Therefore,

Ratio non-sucrose in molasses/non-pol in cane

$$(2) \quad R_{ni} = \frac{b\, M_i}{100 - M_i} \qquad 0{,}657$$

The adjusted Factor b is then given by the product of equations (1) and (2):

$$b^1 = \frac{R_{ni}\, M_s}{100 - M_s} \qquad \frac{0{,}657\,(42{,}6 - 19{,}6 \log G)}{100 - (42{,}6 - 19{,}6 \log G)}$$

Appendix 3

Dependence of impurity recovery ratio on proportion o reducing sugars in impurities.

Significant correlations between the amount of extracted non-pol entering the molasses and the ratio of reducing sugars to non-pol in mixed juice have been reported by Buchanan.[3] A similar relationship with reducing sugars/ash ratio in molasses would be expected. Monthly data from Triangle for 1974, and from the Huletts Mills for 1973/74 and 1974/75, were therefore subjected to linear regression analysis of the form

$$R_n = aG + b$$

Only four of the eleven regressions were found to be statistically significant, and coefficients, constants, correlation coefficients and significance levels for these are shown below.

Factory	Season	a	b	r	Significance Level
Darnall	1973/74	0,22	0,43	0,86	1%
Mount Edgecombe	1973/74	0,08	0,59	0,68	5%
Felixton	1974/75	0,13	0,52	0,79	1%
Triangle	1974	0,10	0,53	0,87	1%

Using the Triangle data as an example, adjusted FPI's incorporating a variable R_n derived from the above regression for Triangle were calculated. Resultant figures are plotted in Figure 6 together with those using both the fixed Factor b and the Factor b calculated with a fixed value for R_n.

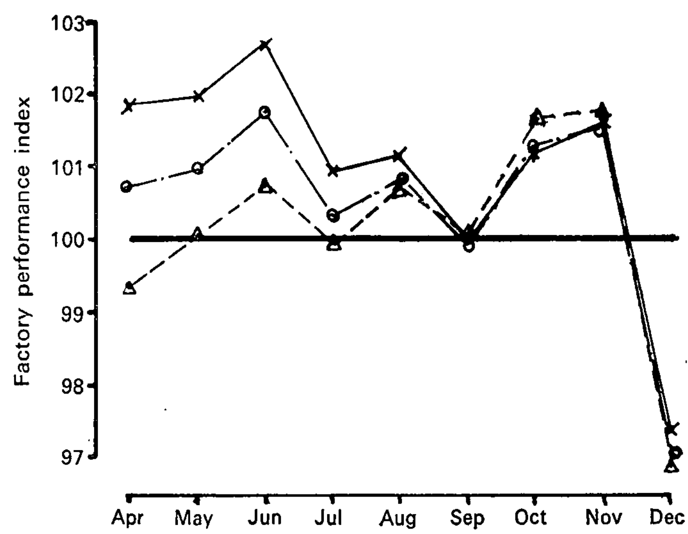

FIGURE 6 Triangle 1974: Factory Performance Index — Normal (——), molasses loss adjusted with fixed R_n (- - - - -) and molasses loss adjusted with variable R_n (. — . — .).

The use of a variable R_n value obviously reduces considerably the change in FPI due to adjustment of the molasses loss allowance. The validity of applying a regression formula for R_n in the overall calculations is however questionable due to the small proportion of such regressions that show statistical significance. Furthermore it has been noted by Buchanan[4] that there is also an *inverse* correlation between pol loss in filter cake and reducing sugars/non-pol ratio, which would tend to offset the reduction in molasses loss difference. For these reasons no attempt has been made to introduce variable R_n values elsewhere in this paper.