A STATISTICAL ANALYSIS OF THE EFFECT OF CANE QUALITY ON EXTRACTION PERFORMANCE

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Abstract

Multiple linear regression analyses of daily extraction figures from a number of mills have been carried out to identify the effect of cane quality on extraction performance. Cane quality is expressed in terms of pol and fibre content, and all forms of milling criteria proposed in the past are found to be dependent to a greater or lesser extent on cane quality. A corrected reduced extraction is derived which should be essentially independent of cane quality.

Introduction

The performance of a milling train is influenced by a large number of different variables. Basically, these may be classified into three categories:

(*a*) Fixed variables, such as number and type of mills, number of rollers, etc.

(*b*) Those variables under control of operating personnel, such as mill speeds and settings, amount of imbibition applied, etc.

(*c*) Variables with random features, associated with the characteristics of the cane crushed which vary in a random fashion from one consignment to the next.

It is the third category over which we have no control, and which therefore makes comparison of milling performance very difficult. The effect of cane quality on milling performance has attracted a fair amount of attention in the past, and it is this aspect with which this paper is concerned.

If it were possible to control the type and composition of cane, it would be possible to design an experiment to determine the effect of cane quality. As this is not possible, we have to resort to statistical methods which are designed to bring out significant associations between variables in the presence of random variations. Regression analysis is a useful technique which was used in this case, since it can make use of historical data, without the need for further experimentation. A word of warning should be sounded however; such data should be as accurate and reliable as possible if any confidence is to be put in the results. The old adage "garbage in means garbage out" is appropriate in this type of analysis.

Although three categories of variables were mentioned above we are interested only in (*c*). The effect of the first category can be circumvented by analysing the data from each individual mill independently. The effect of the second group of variables such as imbibition and crushing rate must be allowed for in the regression analysis where possible. In this way it is hoped that the effect of these variables can be extracted, thereby clarifying the true dependence of milling performance on cane quality.

This procedure assumes that interaction between variables does not play a significant part. For instance Hugot[2] has suggested that the effect of the sucrose content in cane is more pronounced for shorter milling trains than longer units. Such interaction effects are hopefully small enough to neglect.

The primary objective here is to investigate how and to what extent each of the published yardsticks of milling performance is affected by cane quality. Ideally, the figure which is least dependent on cane quality is the best criterion of performance. On the basis of these results a new milling performance criterion can be derived which is expected to be less dependent on cane quality.

Methods of Analysis

The I.C.L. 1900 Statistical Analysis package was used for the regression analysis. Regression equations of the following kind are normally obtained:

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + \;\ldots\ldots \qquad (1)$$

where Y is the dependent variable (for instance extraction), the x_i represent independent variables (such as fibre % cane) and the a_i are constants determined by the regression analysis, called regression coefficients. With this program two procedures are possible: a fixed number of specified independent variables can be included in the equation; or else a set of independent variables to be considered for inclusion in the regression equation is submitted to the program, which then selects only those variables which are significant at a specified significance level (5% in this case). The latter procedure was used as being more rigorously correct.

Instead of a linear equation (1) a product form of regression equation was obtained:

$$Y = Cx_1^{b1}x_2^{b2}x_3^{b3} \;\ldots\ldots \qquad (2)$$

through the use of log transformations. Such a form is easier to manipulate and can represent both linear and non-linear relationships.

Data used in analyses

Regression analyses of some South African milling results were previously undertaken roughly two years ago. The data used for this purpose was weekly average data covering five years' operations but the results were unsatisfactory because of the wide discrepancies shown in the effect of cane quality on results at different mills. In addition in a few cases some spurious and incorrect associations between variables were manifested, so that the reliability and accuracy of the data were questioned.

During the last few years the Sugar Industry Central Board have extended sampling and analysis of all quantities of interest determining extraction to all mills in South Africa. Now that their systems have been operating for a few years it was felt that the data which they are now collecting is considerably more accurate and reliable than anything previously available. Consequently it was felt that the time was ripe for a further look at the effect of cane quality on extraction performance.

Daily figures for ME, DL, GH, UK and SZ for the 1973/74 season and for ME and DL for the 1974/75 season were supplied by the Central Board. Data from these mills was considered to be the most reliable of the single-tandem non-diffuser mills. Daily data covering a single season's operation for a single mill was found to show sufficient variation in the quantities of interest for significant associations to be established. For the Huletts mills, ME and DL, past records were available for data validification. The observations for any period representing abnormal operation (e.g. one mill by-passed) were discarded. Such information for the other sets of data was, however, not readily available. Data validification was then confined to plotting residuals and examining outliers. Only those outliers for which some explanation could be found were rejected. As a consequence residual errors for equations based on data from the non-Hulett mills were generally higher, implying some additional variance not attributable to the independent variables.

In all cases, data for the first three weeks and the last week of each season were discarded.

Table 1 shows mean values, standard deviations and the range of quantities of interest in each set of data used. Of interest is the considerably higher variation in pol % cane, as shown by the higher standard deviation, for the 1974/75 season when a significant amount of drought cane was processed.

Variables considered

Dependent variables

As dependent variables, the milling performance criteria discussed by Hugot[2] were used, namely milling loss, extraction ratio, reduced extraction (Deer) and reduced extraction (Mittal), in addition to pol extraction, sucrose % bagasse and two lost absolute juice % fibre figures, one based on brix and one on pol. These quantities are all defined in the appendix.

Independent variables

In the absence of any figures representing the mechanical properties of cane such as strength of fibres, only the composition of cane may be used to represent cane quality. Consideration of milling as a leaching process might suggest that cane quality be expressed in terms of the concentration of sucrose in the juice of the cane and the juice/fibre ratio in cane. It can easily be shown however that over the limited range of values of P_c and F_c experienced in practice the functional form has a negligible effect on results. For example the juice/fibre ratio in cane may be almost exactly represented by a constant multiplied by F_c to the power $-1{,}17$. Thus to preserve simplicity, F_c and P_c only were utilised to represent cane quality. Brix % cane was also tried, but was found to be highly correlated with P_c, and no advantage was to be gained from its use instead of P_c.

Initially a large number of other independent variables were included in the analysis for consideration by the regression routines. Apart from crushing rate and imbibition level, such factors as time efficiency, moisture % bagasse, week number and brix of first expressed juice were considered in earlier analyses. This was done in an attempt to remove as much as possible of the variance in the data due to known disturbances, in the hope that the correct dependence on cane quality would be realised. In practice the large amount of intercorrelation between different quantities led to some unusual results and in some cases masked the effect of cane quality. Eventually, apart from F_c and P_c, only crushing rate and imbibition level

TABLE 1

Mean, minimum, maximum values and standard deviations

	ME 1973/74	DL 1973/74	GH 1973/74	SZ 1973/74	UK 1973/74	ME 1974/75	DL 1974/75
TCH	186,9	205,0	257,2	235,7	171,9	189,8	218,0
	152,9	169,0	175,4	209,8	153,3	158,0	179,0
	214,0	241,1	293,5	274,8	189,8	220,0	246,1
	11,0	12,4	16,1	9,6	6,7	11,8	12,3
TFH	27,9	30,0	39,9	36,7	24,2	28,5	33,1
	19,7	23,5	26,2	30,4	20,7	19,7	24,6
	39,4	36,3	46,4	43,4	26,4	36,4	39,9
	2,9	2,4	3,3	2,2	1,0	2,8	2,7
F_c	15,47	15,23	16,15	16,23	14,60	15,55	15,79
	12,94	13,05	13,62	13,58	13,01	13,05	13,57
	18,88	17,51	18,49	18,13	16,31	18,65	17,94
	1,03	0,80	0,78	0,93	0,64	1,11	0,93
P_c	13,33	13,44	13,26	13,38	13,11	13,11	13,50
	11,38	11,97	11,23	11,82	11,75	10,44	10,47
	14,63	14,69	14,56	14,71	14,32	15,70	15,95
	0,61	0,60	0,65	0,61	0,54	1,02	1,18
IMB % F	307,5	334,9	253,8	336,3	319,0	299,1	325,8
	218,4	254,3	201,2	217,7	256,9	225,8	267,5
	405,6	435,6	351,4	415,7	365,4	406,5	442,0
	31,8	31,2	24,2	30,8	18,2	29,8	26,0
M_B	52,6	52,34	52,36	52,43	53,52	51,80	53,27
	49,45	51,37	50,46	50,37	52,54	49,44	51,32
	54,94	56,16	54,90	54,81	55,49	55,29	57,55
	0,92	0,90	0,79	0,93	0,40	1,00	1,07
P_B	1,37	1,83	1,60	1,66	1,55	1,29	1,53
	1,14	1,32	1,31	1,52	1,25	1,00	1,23
	1,55	2,35	1,90	1,82	1,85	1,53	2,27
	0,07	0,25	0,08	0,06	0,11	0,12	0,17
E	96,61	95,34	95,75	95,62	96,17	96,73	96,04
	95,15	93,05	94,42	94,59	95,10	95,32	94,05
	97,56	96,81	96,77	96,62	96,85	97,74	97,05
	0,38	0,86	0,41	0,45	0,33	0,48	0,51

Note.—The 4 figures in each block represent in descending order the mean, minimum, maximum values and the standard deviation.

TABLE 2

Values of regression coefficients in the equation $Y = CTFH^a\ IMB\ \%\ F^b\ P_c^c\ F_c^d$

$Y = P_B$

	a	b	c	d	r
ME 73/74	—	– ,167	,758	,233	,545
DL 73/74	—	—	—	,716	,282
GH 73/74	—	– ,114	—	—	,202
SZ 73/74	—	– ,145	—	– ,297	,443
UK 73/74	—	– ,545	,764	– ,263	,524
ME 74/75	—	—	,937	,543	,703
DL 74/75	—	– ,181	,718	,345	,646

Y = E

	a	b	c	d	r
ME 73/74	– ,0071	—	,0121	– ,0381	,914
DL 73/74	—	—	,0647	– ,0821	,655
GH 73/74	—	,0073	,0427	– ,0389	,748
SZ 73/74	—	,0068	,0628	– ,0278	,878
UK 73/74	—	,0225	,0157	– ,0320	,649
ME 74/75	—	—	,0069	– ,0537	,816
DL 74/75	—	,0099	,0131	– ,0511	,723

Y = ERATIO

	a	b	c	d	r
ME 73/74	—	– ,223	– ,314	—	,588
DL 73/74	—	—	– 1,116	,729	,470
GH 73/74	—	– ,110	– ,986	—	,626
SZ 73/74	—	– ,140	– 1,368	– ,394	,785
UK 73/74	—	– ,515	– ,385	—	,495
ME 74/75	—	—	—	,621	,436
DL 74/75	—	– ,285	– ,317	—	,415

Y = MLOSS

	a	b	c	d	r
ME 73/74	—	– ,223	,686	—	,505
DL 73/74	—	—	—	,761	,281
GH 73/74	—	– ,109	—	—	,163
SZ 73/74	—	– ,140	– ,368	– ,394	,440
UK 73/74	—	– ,515	– ,615	—	,455
ME 74/75	—	—	,865	,568	,615
DL 74/75	—	– ,285	,683	—	,601

Y = LAJ

	a	b	c	d	r
ME 73/74	,070	—	– ,659	—	,694
DL 73/74	—	—	– ,740	,641	,393
GH 73/74	—	—	– ,981	—	,618
SZ 73/74	—	– ,188	– 1,378	– ,701	,737
UK 73/74	—	– ,363	– ,743	– ,373	,696
ME 74/75	—	—	– ,549	—	,582
DL 74/75	—	—	– ,619	,231	,593

Y = PLAJ

	a	b	c	d	r
ME 73/74	—	– ,146	– ,226	—	,444
DL 73/74	—	—	– 1,115	,550	,434
GH 73/74	—	—	– ,986	—	,605
SZ 73/74	—	– ,139	– 1,369	– ,585	,782
UK 73/74	—	– ,551	– ,353	– ,378	,524
ME 74/75	—	—	—	,437	,345
DL 74/75	—	– ,210	– ,311	—	,380

Y = REXD

	a	b	c	d	r
ME 73/74	– ,0052	—	,0086	—	,449
DL 73/74	—	—	,0680	– ,0249	,452
GH 73/74	—	—	,0442	—	,605
SZ 73/74	—	,0065	,0619	,0264	,782
UK 73/74	—	,0244	,0172	,0167	,520
ME 74/75	—	—	,0060	– ,0129	,369
DL 74/75	—	,0090	,0131	—	,372

Y = REXM

	a	b	c	d	r
ME 73/74	– ,0080	—	,0122	—	,597
DL 73/74	—	—	,0679	– ,0340	,482
GH 73/74	—	,0048	,0444	—	,622
SZ 73/74	—	,0064	,0626	,0179	,786
UK 73/74	—	,0225	,0184	—	,493
ME 74/75	—	—	,0062	– ,0194	,480
DL 74/75	—	,0123	,0135	—	,409

were considered as independent variables as they have an established cause-effect relationship with milling performance.

Results

Regression equation of the following form were obtained for each set of data individually:

$$Y = C\ TFH^a\ IMB\%F^b\ P_c^c\ F_c^d \qquad (3)$$

where TFH = throughput in tons of fibre/hour, IMB %F = imbibition % fibre, P_c = pol % cane and F_c = fibre % cane. Y is the dependent variable under consideration.

Results in the form of regression coefficients a, b, c and d, together with values of multiple correlation coefficient r are given in Table 2, for different dependent variables Y. The absence of a regression coefficient represented by a dash in the table means that the variable considered was not found to be statistically significant at the 5% level.

A feature of the results is that TFH is generally not significant, at least over the range of throughputs given in Table 1. This supports the contention expressed by Webre[7] that the effect of fibre rate on extraction is small, and certainly not as marked as the effect of imbibition % fibre.

Pol and fibre in cane generally show up more often than imbibition % fibre as significant variables. This may be due to the fact that values of imbibition % fibre are high in the data used, mostly greater than 300. Gledhow figures alone show a low imbibition % fibre value, and perhaps as a result the effect of imbibition at GH is generally significant.

The regression coefficients on P_c and F_c in Table 2 still show fairly wide discrepancies between different mills, which indicates different degrees of dependence on cane quality. They are however slightly more consistent than previous results indicated, and no anomalous correlations were obtained. Mean values of regression coefficients calculated from Table 2 are shown in Table 3.

TABLE 3

Mean values of regression coefficients on P_c and F_c in equation (3)

Dependent variable (Y)	Regression coefficient on P_c(= c)	 on F_c(= d)
P_B	0,454	0,182
E	0,0311	– 0,0462
MLOSS	0,354	0,134
ERATIO	– 0,641	0,137
PLAJ	– 0,623	0,003
LAJ	– 0,810	– 0,029
REXD	0,0313	0,0008
REXM	0,0322	– 0,0051

It is clear that all forms of milling performance criterion are dependent on cane quality to a greater or lesser extent. Table 3 indicates that pol in bagasse and extraction are higher when P_c is higher, and that extraction is adversely affected by a high fibre content. Those performance yardsticks which claim to correct for cane quality clearly do not account for the effect of P_c. ERATIO, PLAJ and LAJ all show a considerable inverse dependence on P_c, while the two forms of reduced extraction show a dependence on P_c similar to that of plain extraction.

It appears however that reduced extraction and lost absolute juice figures adequately compensate for fibre content, although the low mean values of the regression coefficient on F_c hide the variations in individual values above and below zero given in Table 2.

Discussion

The average values of the regression coefficients given in Table 3 are calculated with the implicit assumption that each mill is influenced in the same way by cane quality. Obviously the response of different mills or different extraction plants to changes in cane quality need not be the same. In fact Russell and Murry[5] showed that theoretically the effect of cane quality is less important in long milling trains than in short ones and at high imbibition levels than low ones.

It can be seen from Table 2 that high coefficients on pol in cane, with extraction as dependent variable, are obtained at SZ which has a five-mill tandem and at GH which has the lowest imbibition rate, and the lowest coefficient is obtained with data from ME with a seven-mill tandem. This trend however is not consistent, but is sufficient to suggest that a single figure which accounts accurately for cane quality in every extraction plant (or even milling plant) could be an infeasible objective.

It is possible to compare the theoretical results of Russell and Murry[5] predicted by their mathematical model with those in Table 3. Some numerical results are given by Shaw;[4] from these it was calculated that brix extraction is proportional to Bx_c to the power of 0,041 and F_c to the power — 0,046 for a six-mill train at constant throughput and imbibition % fibre of 250. With a seven-mill train, these coefficients drop to 0,033 and — 0,035 respectively. These values compare very well with the mean regression coefficients in Table 3 for pol extraction.

Results obtained from a mathematical model of a moving bed diffuser[4] show that brix extraction is probably less dependent on brix in cane and fibre in cane in a diffuser. Regression coefficients in Bx_c and F_c of 0,01 and — 0,01 respectively are indicated, at constant imbibition % fibre. The dependence on fibre is however probably greater than this, because of certain simplifying assumptions made in the model.

As a further test of the magnitude of the values of the regression coefficients in Table 3, a limited amount of data given by Follet-Smith[1] was used to calculate the dependence on P_c. This indicated that E, MLOSS, ERATIO and REXM are proportional to P_c to the power 0,028, 0,45, — 0,55 and 0,03 respectively, which is also good agreement with the corresponding values in Table 3.

Derivation of a new milling performance criterion

Since it has been established that the existing milling criteria do not adequately correct for cane quality, it is possible to use the results of this analysis to derive a new criterion. The results shown in Table 2 differ from one mill to the next, so that it is still not possible to state with certainty that the effects of cane quality have been accurately quantified. However through the use of the results given in Table 3 it is possible to derive a milling criterion which at the present time is as nearly independent of cane quality as we can possibly make it.

There are two approaches, either to correct extraction for fibre and pol in cane, or else modify an existing milling criterion.

Corrected extraction

The effect of cane quality on extraction shown in Table 3 may be written as follows:

$$E \propto P_c^{0,031} F_c^{-0,046} \qquad (4)$$

This may be used to derive a corrected extraction C.E. which corrects extraction figures for changes in cane quality to standard conditions of 13% pol in cane and 15,5% fibre in cane. The following equation results:

$$C.E. = E\left(\frac{13}{P_c}\right)^{0,031}\left(\frac{15,5}{F_c}\right)^{-0,046} \qquad (5)$$

In simplified form this may be written as

$$C.E. = 0,9545\ E\ P_c^{-0,031} F_c^{0,046} \qquad (6)$$

If $P_c = 13{,}0$ and $F_c = 15{,}5$, then C.E. = E. Under conditions favourable to high extraction, namely a high value of P_c and a low value of F_c, C.E. has a value less than E.

Corrected reduced extraction

All reduced extractions take as their start point some loss criterion which supposedly gives the same value when different canes are processed. These are:

$$\text{Deer}^1 : \frac{(100-E)\,(100-F_c)}{F_c} = \text{PLAJ}$$

$$\text{Mittal}^2 : \frac{100\,(100-E)}{F_c} = \text{ERATIO}$$

$$\text{Mittal}^3 : \frac{(100-E)\ P_c}{F_c} = \text{MLOSS}$$

$$\text{Hugot}^2 : \frac{(100-E)\,(P_c)^{1-1/N}}{F_c} = \frac{\text{MLOSS}}{P_c^{1/N}}$$

Table 3 shows that these quantities are not independent of cane quality. ERATIO and MLOSS are dependent on F_c and P_c while PLAJ is dependent on P_c only. Hugot's figure, like MLOSS, must also be dependent on F_c; for the dependence on P_c to be correct, $\frac{1}{N}$ (where N = number of mills,) should be equal to 0,354, or N = 2,8 mills.

Since PLAJ is apparently independent of fibre content in cane, it is the best choice as starting point, but must be used in a form which also corrects for P_c. Using the regression coefficient from Table 3, the best loss criterion based on the present results is:

$$\text{PLAJ} \times P_c^{0,6}$$

which may be written as:

$$\frac{(100-E)\,(100-F_c)\,P_c^{0,6}}{F_c}$$

Using this, a corrected reduced extraction (C.R.E.) can be derived in the same way as REXD, shown in Appendix 1. This leads to

$$C.R.E. = 100 - \frac{F_{c1}}{(100-F_{c1})\,P_{c1}^{0,6}}\ \frac{(100-E)(100-F_c)\,P_c^{0,6}}{F_c} \qquad (7)$$

To normalise these values to 13% pol in cane and 15,5% fibre in cane, P_{c1} and F_{c1} are given the values 13 and 15,5 respectively. Then equation (3) reduces to:

$$\text{C.R.E.} = 100 - 0{,}03936\,\frac{(100-\text{E})\,(100-\text{F}_c)\,\text{P}_c^{0{,}6}}{\text{F}_c} \qquad (8)$$

Expressed in another form,

$$\text{C.R.E.} = 100 - 0{,}1834\,\frac{(100-\text{E})\,(100-\text{F}_c)}{\text{F}_c}\left(\frac{\text{P}_c}{13}\right)^{0{,}6} \qquad (9)$$

This is exactly the same as Deer's reduced extraction, with the addition of the pol correction term in brackets. The pol correction is unity when $P_c = 13$ and then C.R.E. is identical to Deer's reduced extraction. At other values of P_c the magnitude of the pol correction is shown in Table 4 below:

TABLE 4
Magnitude of the pol correction term in C.R.E.

P_c	10	11	12	13	14	15	16
$(P_c/13)^{0,6}$	0,854	0,905	0,953	1,000	1,045	1,090	1,133

Applicability of the corrected extractions

Both the corrected extraction (equation 6) and the corrected reduced extraction (equation 8) give virtually identical results. This however is not surprising since they are both derived from analysis of the same data. The corrected reduced extraction has the slight advantage over the former that it includes only one expotential term.

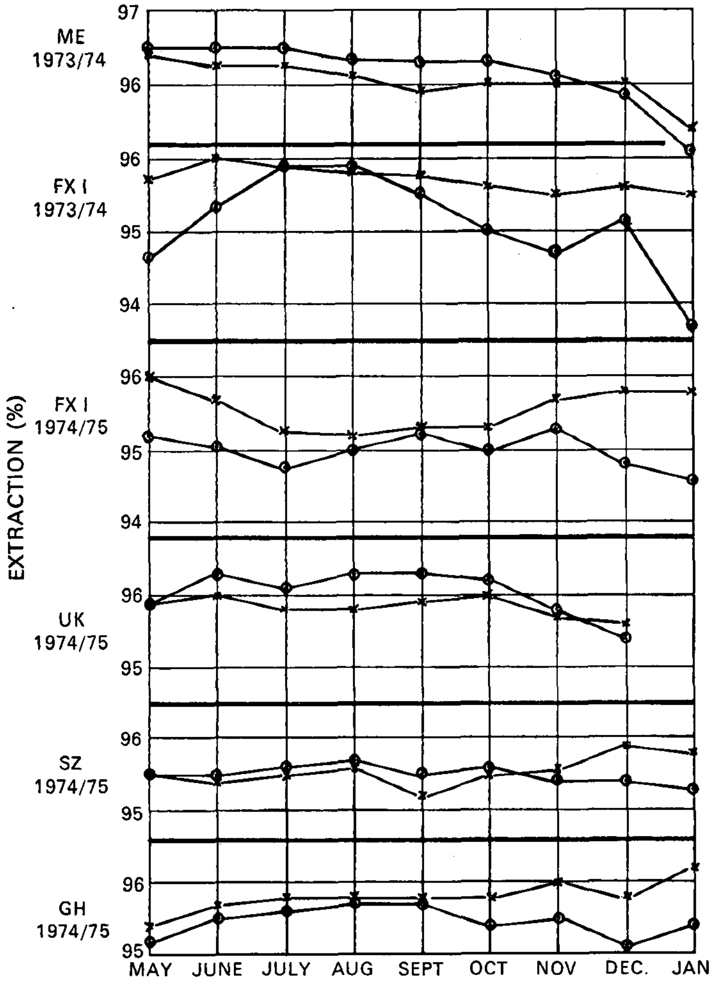

FIGURE 1 Comparison between values of extraction and corrected reduced extraction.
Key: ⊙ extraction
× corrected reduced extraction

Fig. 1 shows monthly extraction figures from a number of different mills compared with corresponding corrected reduced extraction values. The C.R.E. values in general fluctuate less widely during a season indicating a more constant milling effort through the course of a season than extraction figures alone suggest.

Fig. 2 shows values of E, REXD, C.R.E. and LAJ for one season's results for comparison purposes. The difference between C.R.E. and REXD at the extremes of the season represent the correction due to a drop in P_c to 12%.

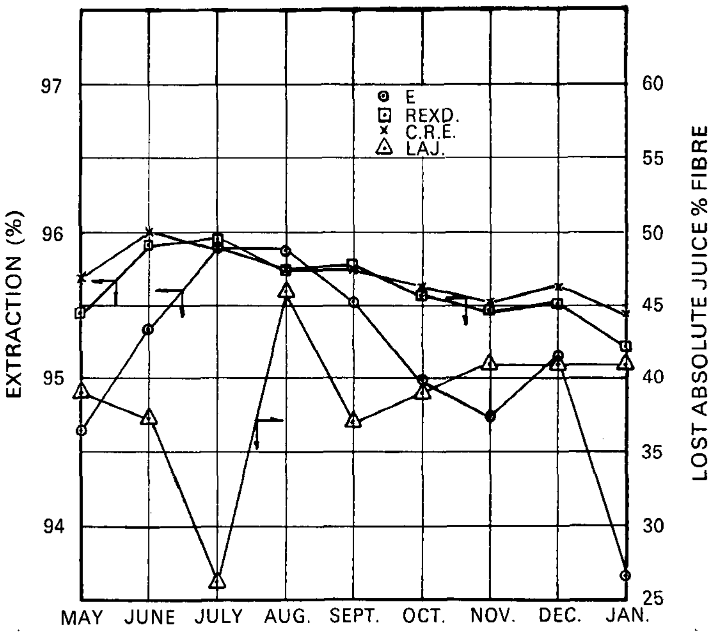

FIGURE 2 Comparison of various extraction performance figures for Felixton I, season 1973/74.

It would be premature to claim that the exponents in equations (6) and (8) represent the effect of cane quality accurately. A wider-ranging analysis of information from all mills would be necessary before such a claim would be justified. However at the present time these equations yield the best estimate we can make of the extraction performance independent of cane quality.

As such it has been accepted that C.R.E. will be used during the coming season in the South African sugar industry as a measure of extraction performance. It is anticipated however that the exponent on pol in cane in equation (8) may well be altered in the future if further work is able to determine the exponent with greater confidence.

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Nomenclature

Bx_B	brix % bagasse
Bx_c	brix % cane
C.E.	corrected extraction, defined by equation (6)
C.R.E.	corrected reduced extraction, defined by equation (8)

ERATIO	extraction ratio
E	extraction (%)
F_B	fibre % bagasse
F_c	fibre % cane
IMB%F	imbibition % fibre
LAJ	lost absolute juice % fibre
M_B	moisture % bagasse
MLOSS	milling loss
P_B	pol % bagasse
P_c	pol % cane
PLAJ	lost absolute juice % fibre calculated on pol
r	multiple correlation coefficient
REXD	reduced extraction due to Deer (%)
REXM	reduced extraction due to Mittal (%)
TCH	crushing rate in tons cane/hour
TFH	crushing rate in tons fibre/hour
Y	general symbol representing milling performance figure

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Appendix

Mill performance yardsticks considered

1. Pol % bagasse P_B

2. Extraction $E = \dfrac{\text{pol \% mixed juice} \times \text{mixed juice \% cane}}{\text{pol \% cane}}$

3. Milling loss MLOSS $= 100\ P_B/F_B$

4. Extraction ratio ERATIO $= \dfrac{100\ (100 - E)}{F_c}$

5. Lost absolute juice % fibre LAJ $= \dfrac{100\ Bx_B\ (100 - F_c)}{Bx_c\ F_B}$

6. Lost absolute juice % fibre based on pol

$$\text{PLAJ} = \frac{(100 - E)\ (100 - F_c)}{F_c}$$

7. Reduced extraction (Deer), REXD

$$\frac{(100 - E_1)\ (100 - F_{c1})}{F_{c1}} = \frac{(100 - E)\ (100 - F_c)}{F_c}$$

$$\therefore\ E_1 = 100 - \frac{(100 - E)\ (100 - F_c)}{F_c} \times \frac{F_{c1}}{100 - F_{c1}}$$

Deer originally proposed that this figure be reduced to 12,5% fibre in cane. This is totally unrealistic for South African conditions and a reduced extraction based on a fibre content of 15,5% has been used, i.e.

$$F_{c1} = 15{,}5 \quad \text{Then}$$

$$E_1 = 100 - 0{,}1834\ \frac{(100 - E)\ (100 - F_c)}{F_c}$$

$$= \text{REXD}$$

8. Reduced extraction (Mittal) REXM $\dfrac{100 - E_1}{F_{c1}} = \dfrac{100 - E}{F_c}$

Putting $F_{c1} = 15{,}5$ and re-arranging leads to

$$E_1 = 100 - \frac{15{,}5\ (100 - E)}{F_c}$$

$$= \text{REXM}$$