CRYSTAL RECOVERY EFFICIENCY AS AN OVERALL MEASURE OF SUGAR MILL PERFORMANCE

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Abstract

The South African sugar industry has recently moved from a cane payment scheme based on the sucrose content of cane to one based upon the concept of recoverable value (RV), which is itself a modification of the estimated recoverable crystal (ERC) quantity as originally presented by van Hengel (1974). While the definitions of ERC and RV attempt to discount the effect of cane quality on factory performance, it has been acknowledged that some important factors, such as the quality of the non-sucrose fraction in the cane (as typically represented by the reducing sugar to ash ratio), are not effectively accounted for. An additional limitation of the new RV system lies in the lumping together of cane evaluation and payment terms into one concept, which can result in the measured value recovery (VR) of a sugar mill varying from month to month as a result of changes in the relative prices of raw sugar and molasses, even if the actual performance of the mill has remained constant. Thus, while value recovery properly represents the financial outcome of mill operations, it is not an effective tool for the evaluation of the process performance of mill operations. The concept of crystal recovery efficiency is proposed as a new factory performance yardstick which allows for the optimal evaluation of mill performance independent of cane quality factors. The use of the new measure is outlined and factory data for all South African mills is presented, highlighting the variation of the crystal recovery efficiency during the season and from year to year.

Keywords: factory performance, estimated recoverable crystal, recoverable value, crystal recovery efficiency, cane quality, yardsticks

Introduction

Until 1999, the cane payment system in South Africa was based on sucrose content. However, it has long been accepted that the sucrose recovery of a raw sugar mill is influenced by a number of cane quality factors, most notably the purity, as well as by factory performance. From the beginning of the 2000 / 01 crushing season, the South African sugar industry thus moved to a more equitable cane payment scheme based on the concept of *recoverable value* (RV), which is itself a modification of the *estimated recoverable crystal* (ERC) quantity postulated by van Hengel (1974). The definition of RV attempts to allow for the effect of cane quality on sucrose recovery, providing a more accurate measure of the real value of the cane supply to the miller.

While the definitions of RV and ERC attempt to discount the effect of cane quality on factory performance, it has been shown that some important factors, such as the quality of the non-sucrose fraction within the cane (as typically represented by the reducing sugar to ash ratio), are not effectively accounted for (Smith, 1976). An additional limitation of the new RV system lies in the lumping together of cane evaluation and payment terms into one concept. This can result in the *value recovery* (VR[1]) of a sugar mill varying from month to month as a result of changes in the relative prices of sugar and molasses, even if the actual performance of the mill has remained constant. Thus, while VR properly represents the financial outcome of mill operations, it is not an effective tool for the evaluation of process performance.

[1] The term *value recovery* is defined at a later stage, under the section entitled *Recoverable Value*.

The objective of the current study is to describe the development of a new factory performance yardstick, based on a modification of the ERC formula, which allows for the optimal evaluation of mill performance independent of cane quality factors. The use of the new *crystal recovery efficiency* (XRE) concept is outlined, and factory data for all South African sugar mills is presented, highlighting the variation of XRE both during the season and from year to year.

Estimated recoverable crystal

In terms of the ERC concept postulated by van Hengel (1974), the performance of a sugar factory may be assessed in terms of its production of a hypothetical component known as *crystal*. The actual sugar produced by the mill is assumed to consist of a core of pure sucrose, coated with a layer of exhausted final molasses at a standardised molasses purity. The *crystal* produced by the factory is defined as only that sucrose which is contained within the hypothetical pure sucrose core. Accordingly, a procedure is required to determine the quantity of *crystal* contained within any given product sugar, as some of the total sucrose content of the sugar is associated with the layer of exhausted final molasses and must therefore be excluded from the calculation. This procedure is detailed in the original study by van Hengel (1974).

Not all of the sucrose entering a sugar mill in the cane supply can be recovered in the form of *crystal*. Four major losses of sucrose occur within a mill, namely:

- sucrose lost to bagasse during the extraction process,
- sucrose lost to final molasses,
- sucrose lost in filter cake, and
- sucrose lost through undetermined losses.

The first two of these losses are affected by cane quality, while the latter two losses are only affected by cane quality to a limited extent, and are thus considered to be essentially independent of cane quality for the purposes of performance evaluation. All four of the loss items may be influenced by factory efficiency.

The purpose of the ERC formula is to predict, based on a simple set of cane quality parameters, the actual recovery of *crystal* which should be achievable from a given cane supply by a factory operating at a standardised level of efficiency, as this represents the real value of the cane supply to the miller. Van Hengel (1974) proposed that this recovery of *crystal* be approximately related to cane quality by an equation of the form:

$$ERC\,\%\,Cane \; = \; a \cdot S \; - \; b \cdot N \; - \; c \cdot F \qquad (1)$$

where ERC % Cane is the estimated quantity of *crystal* which can be recovered from the incoming cane supply (expressed in terms of *crystal* % cane), S is the sucrose % cane, N is the non-sucrose % cane (calculated as brix % cane minus sucrose % cane), F is the fibre % cane and a, b and c are constant parameters related to the sucrose losses within the factory. The constant parameter “a” represents the fraction of the sucrose entering the mill in the cane supply which passes out of the mill in the form of product sugar, bagasse or final molasses. This parameter thus accounts for sucrose losses in filter cake or through undetermined losses. The constant “b” parameter represents the loss of sucrose in final molasses per unit of non-sucrose entering the mill in the cane supply[2]. This parameter thus accounts for the effect of cane quality on the sucrose loss in final molasses, with increased non-sucrose levels in the cane resulting in increased sucrose losses in final molasses.

[2] In terms of the ERC formula, the sucrose lost in final molasses includes both the sucrose loss to the final molasses stream itself, as well as the sucrose loss to the layer of exhausted final molasses surrounding the hypothetical *crystal* core of the product sugar.

The constant “c” parameter in the ERC formula represents the loss of sucrose in bagasse per unit of fibre entering the mill in the cane supply. This parameter thus accounts for the effect of cane quality on the sucrose losses in bagasse, with increased fibre levels in cane resulting in increased sucrose losses in bagasse.

The values of the three constant parameters in the ERC formula represent the sucrose losses from a factory operating at a standardised level of efficiency and are calculated using the methods of van Hengel (1974). Typically, in the South African sugar industry, the parameter values are determined using weighted rolling average figures for the performance of the industry over the past three seasons.

A measure of the factory efficiency actually achieved by a sugar mill may be calculated by dividing the quantity of *crystal* produced by the factory in the form of crystalline sugar by the quantity of *crystal* which could theoretically have been recovered from the cane supply, and expressing the result as a percentage. This measure of efficiency is referred to as the *factory performance index* (FPI):

$$FPI \;=\; 100\left[\frac{T_X}{T_C}\cdot\left(\frac{100}{ERC\,\%\,Cane}\right)\right] \qquad (2)$$

where T_X is the tons of *crystal* actually produced and T_C is the tons of cane crushed.

Limitations of the ERC formula

Smith (1976) compared the sucrose losses in bagasse and final molasses as predicted by the ERC formula against the individual losses predicted using the *corrected reduced extraction* (CRE) equation of Rein (1975) and the SMRI revised target purity formula (Anon., 1972). While the results of the ERC and CRE formulas did not differ in their assessment of the sucrose loss in bagasse to any material extent, a substantial difference was found between the losses predicted by the ERC equation and the target purity formula. Smith (1976) attributed this difference to the use of a fixed ratio of sucrose lost in molasses to non-sucrose in cane within the ERC formula. No allowance is made for the effect of the quality of the non-sucrose fraction in the cane (*i.e.* the reducing sugar to ash ratio) on the exhaustibility of final molasses. The ERC formula, and hence any assessment of factory performance based on FPI, is thus not entirely independent of the influence of cane quality. This limitation was noted by van Hengel (1974), but was not considered to be a serious disadvantage at the time.

Recoverable value

The idea of *recoverable value* (RV), as currently used for cane payment purposes within the South African sugar industry, was developed by modification of the original ERC formula:

$$RV\,\%\,Cane \;=\; S \,-\, d\cdot N \,-\, c\cdot F \qquad (3)$$

The constant “a” parameter in the ERC formula is excluded from equation (3) on the grounds that the cane growers have no control over the areas of sucrose loss that it represents. Additionally, the RV formula recognises that the final molasses stream produced by a sugar mill has an economic value. As such, while each unit of non-sucrose entering the mill in the cane supply is responsible for removing a fixed quantity of sucrose from the mill as final molasses, it is also responsible for generating a saleable product (namely the final molasses itself). The constant molasses loss “b” parameter in the original ERC formula is thus replaced in the RV formula by a constant parameter, called "d", which represents the quantity of sucrose lost to final molasses per unit of non-sucrose entering in the cane supply, with a credit for the value of the molasses recovered per unit of non-sucrose.

As for ERC, the values of the constant parameters in the RV formula represent the performance of a factory operating at a standardised level of efficiency and are calculated using weighted rolling average figures for the performance of the industry over the past three seasons. However, while the ERC parameters are calculated on an annual basis, the RV formula "d" parameter contains variable pricing terms for saleable sugar and molasses and is thus updated on a monthly basis during the crushing season.

A measure of the factory efficiency actually achieved by a sugar mill may be obtained by dividing the *recoverable value* actually derived from the cane supply by a sugar mill (known as the *derived value*, or DV[3]) by the *recoverable value* which could theoretically have been derived from the incoming cane supply and expressing the result as a percentage. This measure of factory efficiency is known as *value recovery* (VR):

$$VR = 100\left[\frac{DV\,\%\,Cane}{RV\,\%\,Cane}\right] \tag{4}$$

Limitations of the RV formula

As with the ERC equation, the greatest disadvantage of the RV concept is the assumption of a fixed ratio of sucrose lost in final molasses to non-sucrose in cane. No allowance is made for the effect of the quality of the non-sucrose fraction in the cane (*i.e.* the reducing sugar to ash ratio) on the exhaustibility of final molasses. The RV formula, and hence any assessment of factory performance based on *value recovery*, is thus again not entirely independent of the influence of cane quality.

An additional limitation of the RV cane payment system lies in the lumping together of cane evaluation and payment terms in one concept, with the constant "d" parameter in the RV formula containing pricing terms for saleable sugar and final molasses. As a result, it is possible for the measured *value recovery* of a sugar mill to vary from month to month as a result of changes in the relative prices of sugar and molasses, even if the actual performance of the factory has remained constant. Thus, while VR properly represents the economic outcome of milling operations, it is not an effective tool for evaluation of the process performance of a sugar factory.

Development of a modified ERC formula

A factory performance yardstick which is truly independent of cane quality can be developed by suitable modification of the existing ERC formula, so as to account for the effect of the quality of the non-sucrose fraction in the cane supply on the sucrose loss in final molasses. The resulting equation would provide a more accurate measure of actual factory efficiency than either the ERC formula or the RV formula. The basis of the modification is the adjustment of the "b" parameter in the ERC equation according to changes in the reducing sugar to ash ratio in the incoming cane supply, as originally devised by Smith (1985)[4]. At that time, the adjusted ERC formula was not implemented because it was considered impractical to vary the value of the "b" parameter on a monthly basis (and from mill to mill) according to changes in the reducing sugar to ash ratio. However, the RV cane payment system currently requires the value of the "d" parameter in the RV

[3] Calculation of the *derived value* does not fall within the scope of the current study, and is thus not discussed further.

[4] Smith, I.A. (1985), "An ERC formula which allows for quality of impurity", *Tongaat-Hulett Sugar Internal Memorandum* (Unpublished).

formula to vary from month to month in order to account for changing sugar and molasses prices. Consequently, non-sucrose quality adjustments to each mill's "b" parameter value could be made simultaneously with very little additional effort[5].

The development of an adjusted "b" parameter which takes into account the quality of the non-sucrose fraction in the cane supply is detailed in Appendix A. The value of the "b" parameter is given by:

$$b \;=\; R_{NS}\;\left\{\frac{TPD \,+\, k_1 \,+\, k_2\,\left[1 \,-\, \exp\left(R_{FG}\cdot k_3\cdot I_{FGA}\right)\right]}{100 \,-\, TPD \,-\, k_1 \,-\, k_2\,\left[1 \,-\, \exp\left(R_{FG}\cdot k_3\cdot I_{FGA}\right)\right]}\right\} \qquad (5)$$

where R_{NS} is the industry average recovery of non-sucrose in final molasses and product sugar as a fraction of the non-sucrose entering in the cane supply, TPD is the industry average target purity difference (based on molasses)[6], k_1, k_2 and k_3 are constants in the exponential target purity formula (Smith, 1995):

$$k_1 \;=\; 43{,}1$$
$$k_2 \;=\; -17{,}5$$
$$k_3 \;=\; -0{,}74$$

R_{FG} is the industry average recovery of reducing sugars in final molasses and product sugar as a fraction of the reducing sugars in the mixed juice and I_{FGA} is the reducing sugar to ash ratio in the mixed juice.

In terms of the new factory performance yardstick, it is proposed that the value of the constant "b" parameter be calculated on a monthly basis, with a separate value determined for each mill in the South African sugar industry. While most of the parameters in equation (5) above are industry average values (for which rolling three-year weighted average figures could be used), the value of the reducing sugar to ash ratio in the cane would need to determined separately for each mill, based on mixed juice analyses carried out in the previous month. This adjustment of the molasses loss factor would result in a modified ERC formula which is truly independent of cane quality.

While the optimal factory performance yardstick would include the constant "a" parameter from the ERC equation, it is recognised that there is an inexplicably high level of grower resistance to the incorporation of this factor into any cane evaluation formula. As a result, the value of the "a" parameter has been set at unity, resulting in the following form for the *modified ERC* (MERC) equation[7]:

$$MERC\,\%\,Cane \;=\; S \,-\, b\cdot N \,-\, c\cdot F \qquad (6)$$

where MERC % Cane is the estimated quantity of *crystal* (as determined by the modified ERC formula) which can be recovered from the incoming cane supply (expressed in terms of *crystal* %

[5] It is not possible to vary the value of the "b" parameter based on the reducing sugar to ash ratio of individual cane consignments, as the required analytical data is not available (although future developments, such as NIR analysis of shredded cane, may make this possible). As a result, adjustment of the value of the "b" parameter for each mill would need to be carried out monthly, based on analyses carried out by the SMRI.

[6] A similar definition of the modified "b" parameter may also be derived using an industry average standardised target purity difference value based on mixed juice analyses. There is no conceptual reason for the choice of approach utilised in the current study, as either method should yield identical results in principle.

[7] If the proposed yardstick were to be used for factory performance evaluation only (with no consideration of its potential use for cane payment purposes), then there would be no need to exclude the constant "a" parameter from the definition, as has been done in the current study.

cane), S is the sucrose % cane, N is the non-sucrose % cane (calculated as brix % cane minus sucrose % cane), F is the fibre % cane, b is the molasses loss parameter calculated according to equation (5) above and c is a constant bagasse loss parameter determined using the methods of van Hengel (1974).

A measure of the factory efficiency actually achieved by a sugar mill may be calculated by dividing the quantity of *crystal* produced by the factory in the form of crystalline sugar by the quantity of *crystal* which could theoretically have been recovered from the cane supply, and expressing the result as a percentage. This measure of efficiency is referred to as the *crystal recovery efficiency* (XRE):

$$XRE = 100\left[\frac{T_X}{T_C}\cdot\left(\frac{100}{MERC\,\%\,Cane - (1-a)\cdot S}\right)\right] \quad (7)$$

where T_X is the tons of *crystal* actually produced (calculated according to the methods of van Hengel, 1974) and T_C is the tons of cane crushed. The presence of the $(1 - a).S$ term in the denominator of equation (7) is necessary to compensate for the removal of the constant a parameter from the MERC equation. This technique is currently used in the calculation of *derived value* under the RV cane payment scheme.

Application of the crystal recovery efficiency yardstick

In order to demonstrate the use of the proposed *crystal recovery efficiency* yardstick, factory data for all South African sugar mills was collected and analysed in terms of the new factory performance measure. Figure 1 shows the results of analysis of annual performance data from each of the local mills over the past three seasons. A summary of the results is also presented in Appendix B, with a sample calculation included in Appendix C.

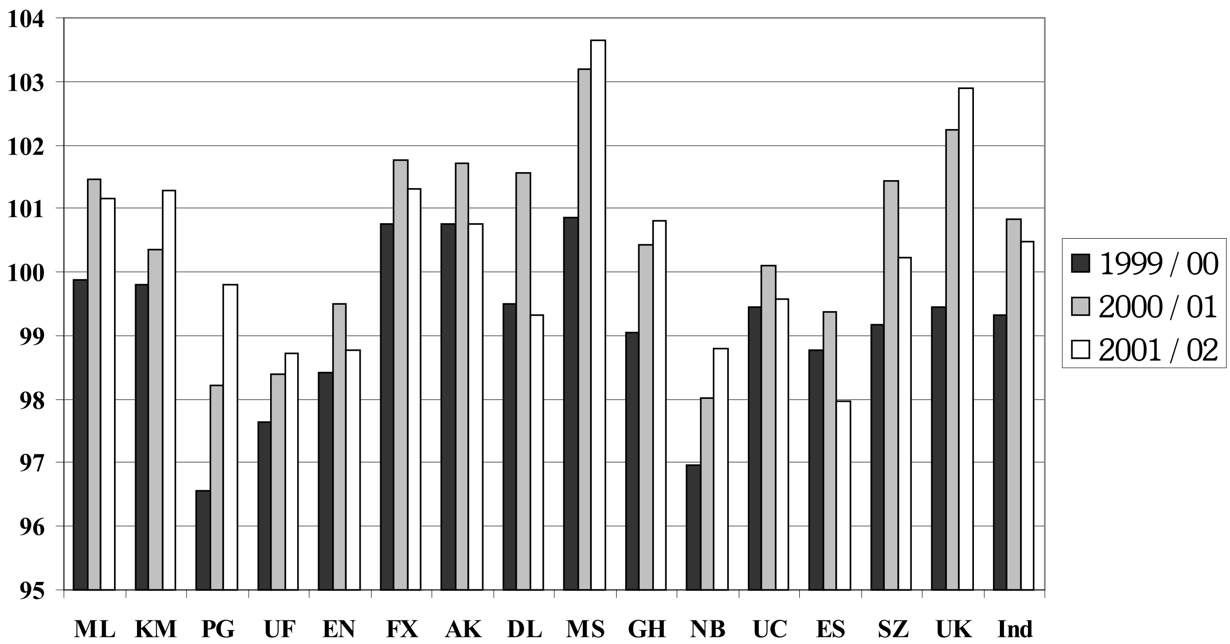

Figure 1. Annual performance data for the South African sugar industry.

Given that the development of the modified ERC formula is based on a standardised level of factory performance, it could be expected that the industry average XRE for any given season would be 100%. However, the actual standardised level of efficiency used is based on weighted rolling average performance data for the previous three years. As a result, the industry average XRE is close to, but does not actually equal, 100%.

Figure 2, displayed over the next four pages, shows the variation of the calculated *crystal recovery efficiency* during the 2001/02 crushing season for individual mills in the South African sugar industry. A summary of the results for the individual mills is also presented in Appendix D. The graphs in the figure clearly show the variation of the *MERC % Cane* with changing cane quality during the crushing season. The level of factory efficiency achieved by each mill, independent of the effects of cane quality, is represented by the XRE curves within the figure. The reference purposes, the monthly variation of the newly defined "b" parameter during the same period is displayed in Figure 3 (for the Malelane, Maidstone and Sezela mills).

Conclusions

The concepts of ERC and RV were developed by the South African sugar industry in an attempt to discount the effects of cane quality on factory performance, thus providing an accurate measure of the real value of the cane supply to the miller. However, it has previously been shown that the quality of the non-sucrose fraction within the cane supply is not effectively accounted for by these concepts. An additional limitation of the RV system lies in the lumping together of cane evaluation and payment terms into one concept, making the assessment of process performance difficult.

A new factory performance yardstick has been proposed, based on a modification of the traditional ERC formula, which allows for the optimal evaluation of mill performance independent of cane quality factors. The use of the new measure has been outlined, and the variation of the *crystal recovery efficiency* during the season, and from year to year, was demonstrated.

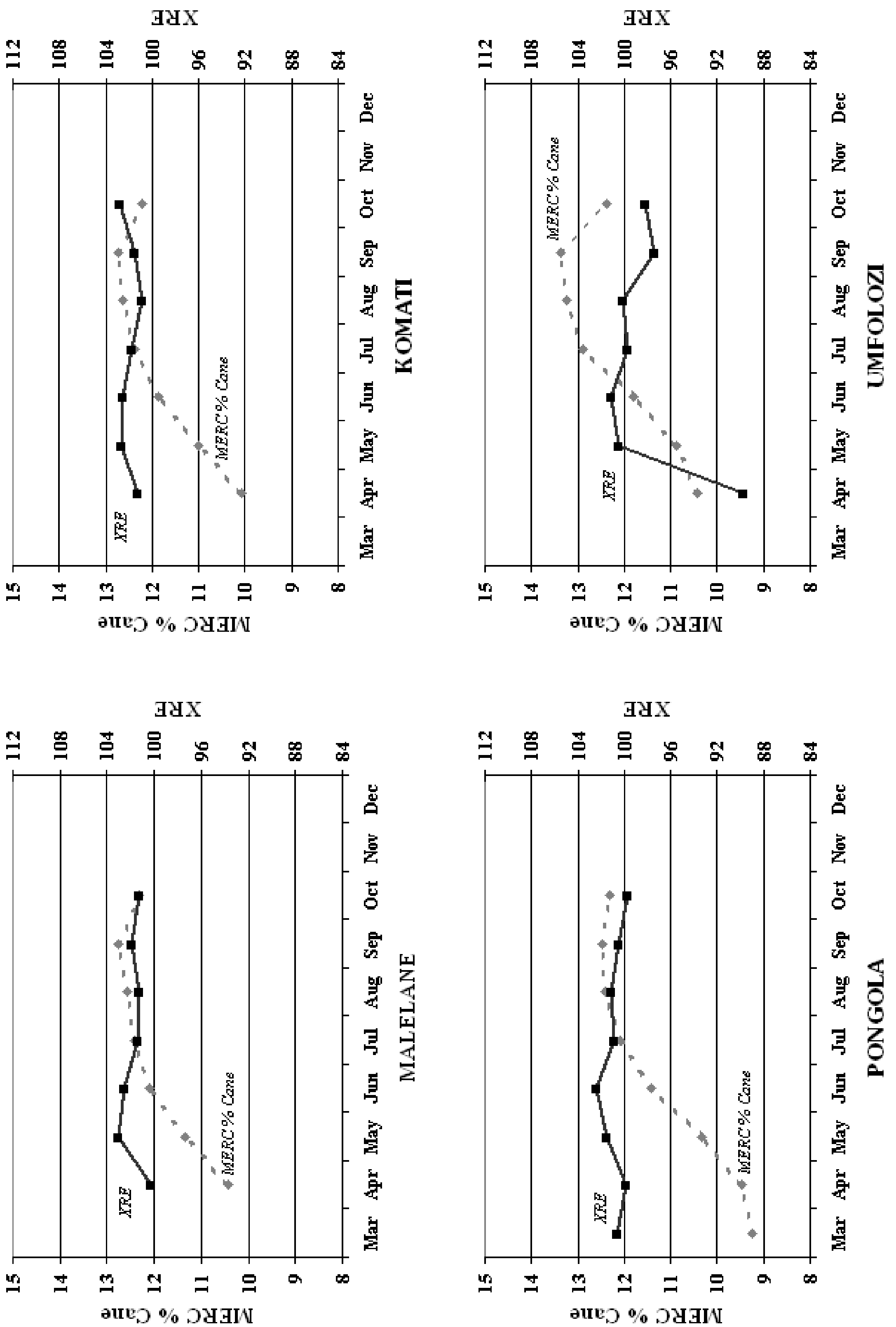

Figure 2. Performance of individual South African sugar mills during the 2001/02 season.

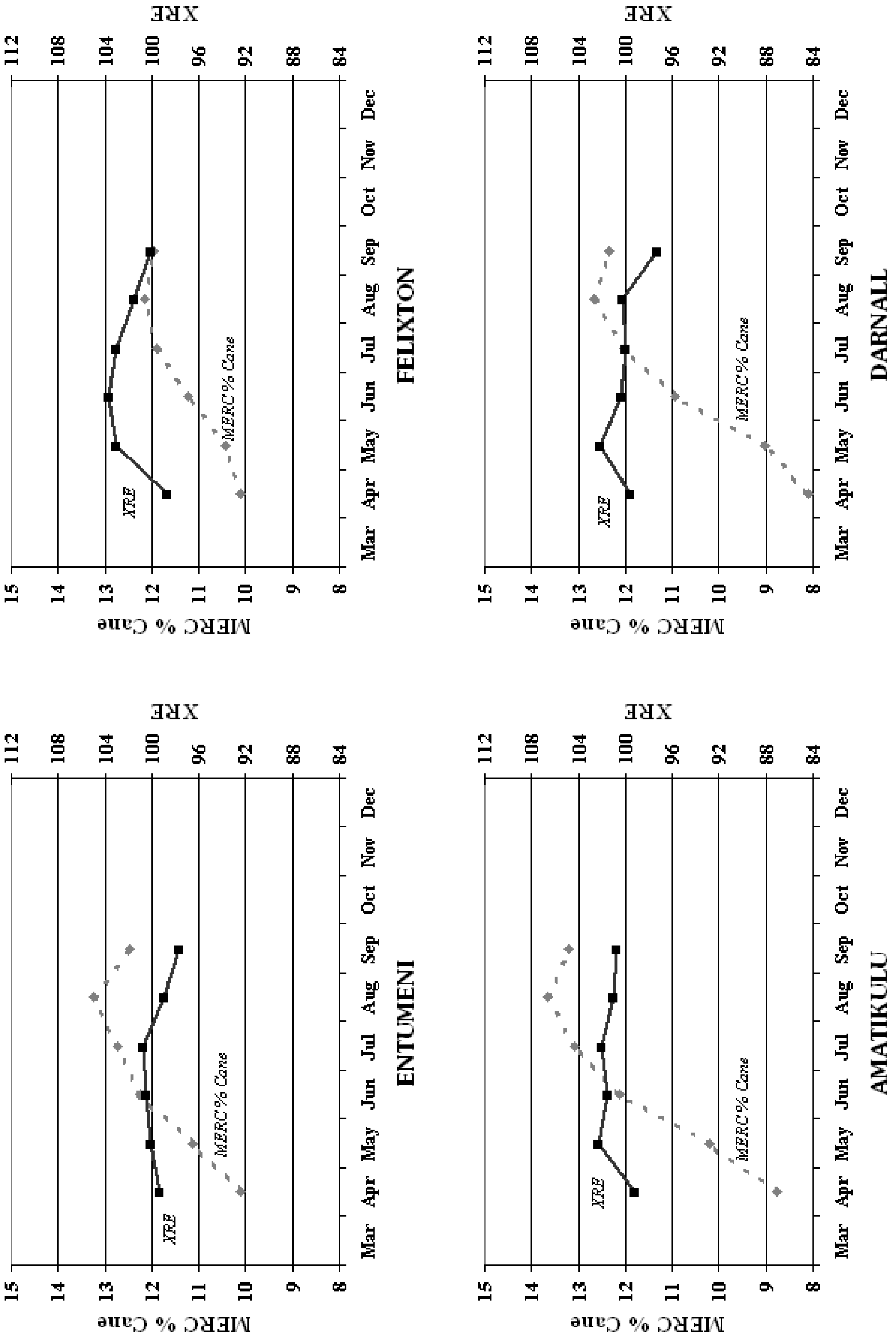

Figure 2 (cont). Performance of individual South African sugar mills during the 2001/02 season.

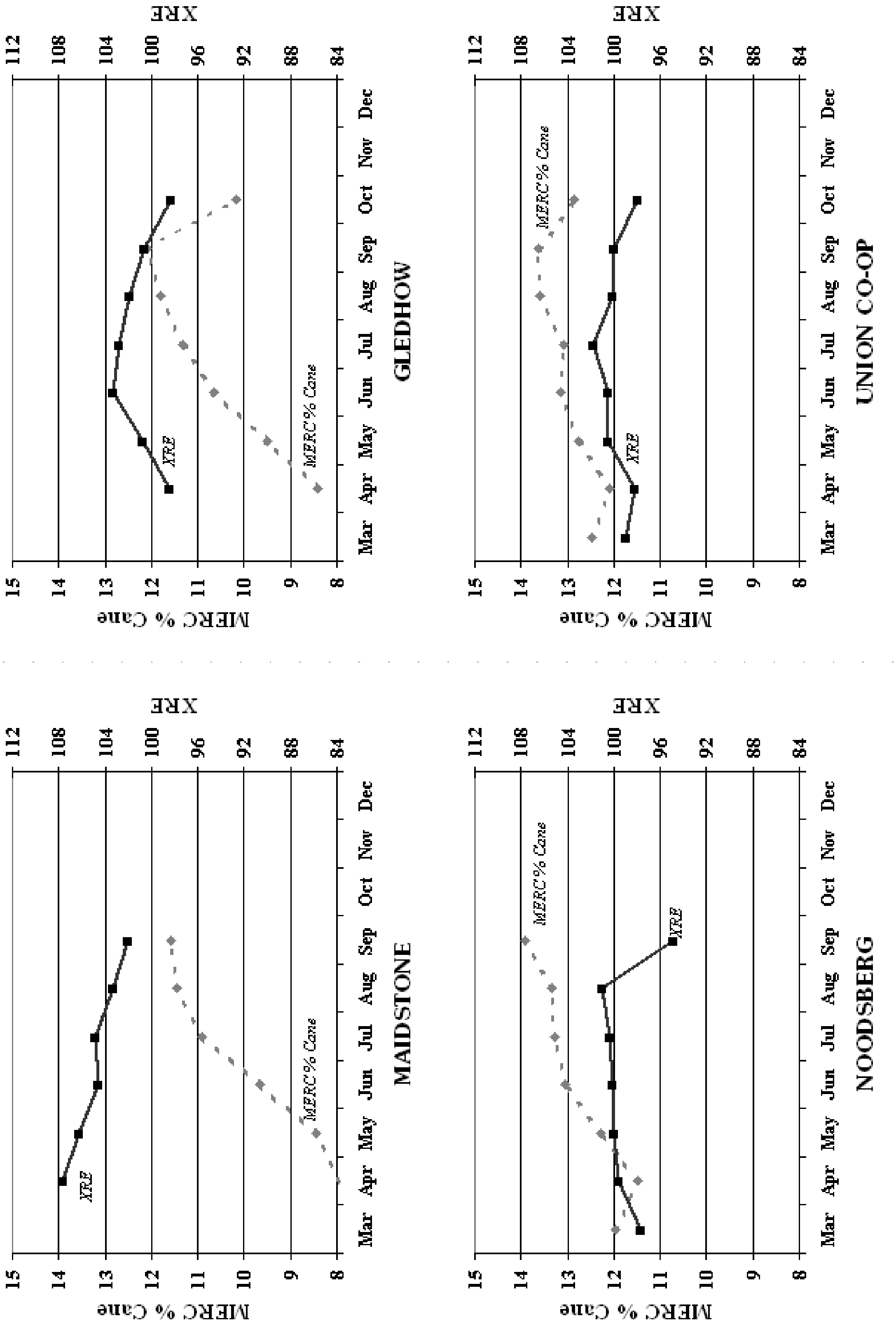

Figure 2 (cont). Performance of individual South African sugar mills during the 2001/02 season.

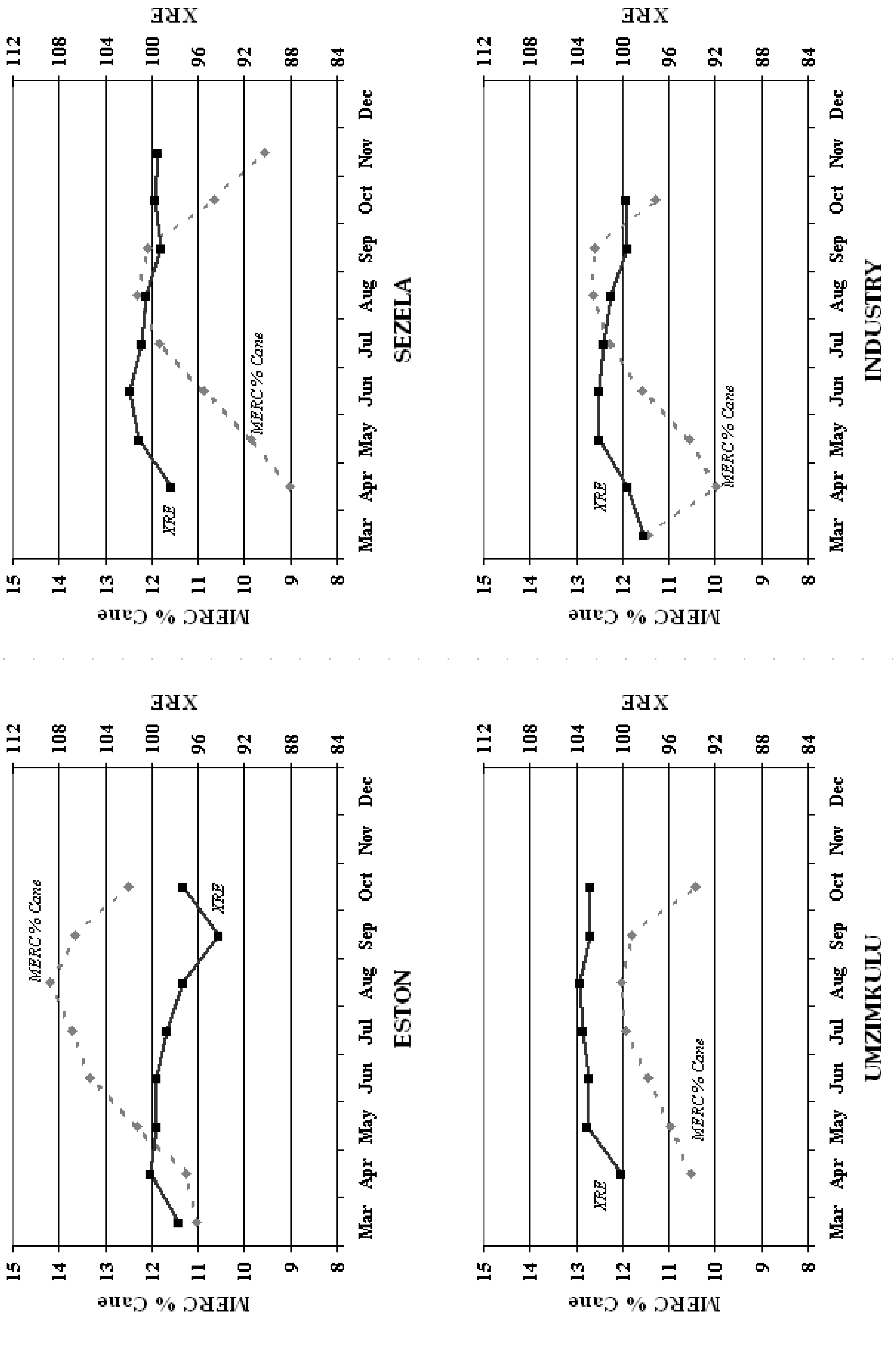

Figure 2 (cont). Performance of individual South African sugar mills during the 2001/02 season.

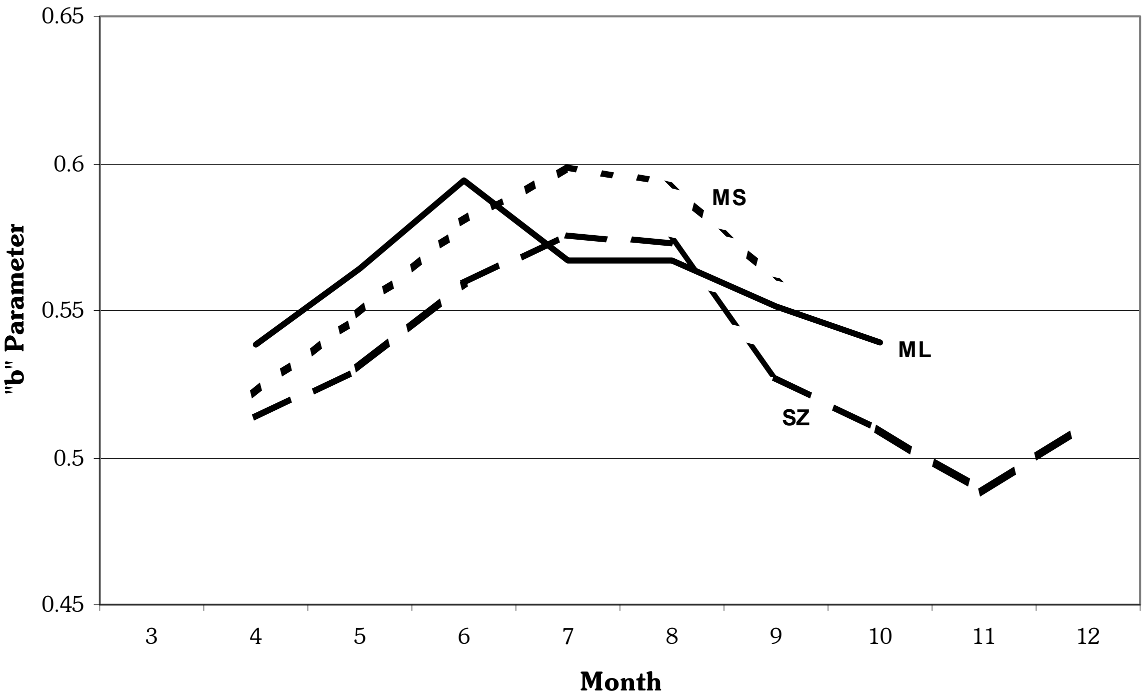

Figure 3. Monthly variation of the "b" parameter during the 2001/02 crushing season.

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APPENDIX A: Derivation of an ERC formula adjusted for non-sucrose quality

The principle of the development of the modified ERC formula is that the value of the "b" parameter in the original ERC equation is, in fact, not constant, but varies according to the characteristics of the non-sucrose fraction in the cane. In the standard ERC formula (van Hengel, 1974), the constant "b" parameter is defined as:

$$b = \frac{tons\ sucrose\ lost\ in\ molasses}{tons\ non - sucrose\ in\ cane} \qquad \text{(A1)}$$

where "molasses" includes both the final molasses stream exiting the factory and the hypothetical film of exhausted final molasses surrounding the *crystal* core of the product sugar. The definition of "b" may be further expanded as follows (van Hengel, 1974):

$$b = \frac{tons\ non - sucrose\ in\ molasses\ and\ sugar}{tons\ non - sucrose\ in\ cane} \times \frac{sucrose\ in\ molasses}{non - sucrose\ in\ molasses} \qquad \text{(A2)}$$

The first term in equation (A2) is the industry average non-sucrose recovery in molasses and sugar as a fraction of the non-sucrose entering with the cane, R_{NS}, while the second term in the relationship, the ratio of sucrose to non-sucrose in final molasses, may be replaced by:

$$\frac{sucrose\ in\ molasses}{non - sucrose\ in\ molasses} = \left[\frac{P_{mol}}{100 - P_{mol}}\right] \qquad \text{(A3)}$$

where P_{mol} is the standardised purity of exhausted final molasses, yielding the following result:

$$b = R_{NS} \cdot \left[\frac{P_{mol}}{100 - P_{mol}}\right] \qquad \text{(A4)}$$

In terms of the traditional ERC formula, the standardised final molasses purity utilised in equation (A4) would be a three-year rolling weighted average value for the entire industry. However, in order to derive a "b" parameter which varies from mill to mill according to non-sucrose quality, it is necessary to use a standardised final molasses purity which is defined in terms of the molasses target purity and an industry average target purity difference value. The standardised molasses purity for the mill of interest may thus be defined as:

$$P_{mol} = P_{Target} + TPD \qquad \text{(A5)}$$

where TPD is the industry average target purity difference (based on molasses) and the target purity, P_{Target} is given by the exponential relationship developed by Smith (1995):

$$P_{Target} = k_1 + k_2 \left[1 - \exp\left(k_3 \cdot J_{FGA}\right)\right] \qquad \text{(A6)}$$

In equation **(A6)**,

$$k_1 = 43{,}1$$

$$k_2 = -17{,}5$$

$$k_3 = -0{,}74$$

and J_{FGA} is the reducing sugar to ash ratio in the final molasses stream. This ratio may be related to the reducing sugar to ash ratio in the mixed juice stream by making use of the industry average monosaccharide recovery fraction, R_{FG} (assuming that all of the soluble ash in the mixed juice stream is recovered in the final molasses):

$$R_{FG} = \frac{monosaccharides\ in\ molasses}{monosaccharides\ in\ mixed\ juice} \qquad \text{(A7)}$$

Combining equations (A5), (A6) and (A7), the standardised molasses purity may be given by:

$$P_{mol} = TPD + k_1 + k_2 \left[1 - \exp\left(R_{FG} \cdot k_3 \cdot I_{FGA}\right)\right] \ldots \qquad \text{(A8)}$$

where I_{FGA} is the reducing sugar to ash ratio in mixed juice. Combining equations (A4) and (A8) yields a definition for the variable "b" parameter as a function of the reducing sugar to ash ratio in mixed juice:

$$b = R_{NS} \left\{\frac{TPD + k_1 + k_2 \left[1 - \exp\left(R_{FG} \cdot k_3 \cdot I_{FGA}\right)\right]}{100 - TPD - k_1 - k_2 \left[1 - \exp\left(R_{FG} \cdot k_3 \cdot I_{FGA}\right)\right]}\right\} \qquad \text{(A9)}$$

APPENDIX B: An analysis of annual performance data in terms of XRE

Mill	XRE 1999/00 season	XRE 2000/01 season	XRE 2001/02 season
Malelane	99.88	101.45	101.15
Komati	99.81	100.34	101.29
Pongola	96.57	98.21	99.79
Umfolozi	97.63	98.39	98.73
Entumeni	98.43	99.49	98.77
Felixton	100.75	101.77	101.32
Amatikulu	100.75	101.72	100.75
Darnall	99.50	101.57	99.31
Maidstone	100.85	103.19	103.64
Gledhow	99.06	100.42	100.81
Noodsberg	96.97	98.02	98.81
Union Co-Op	99.45	100.10	99.58
Eston	98.78	99.37	97.96
Sezela	99.17	101.43	100.23
Umzimkulu	99.45	102.23	102.89
Industry	99.32	100.83	100.48

APPENDIX C: Sample calculation of the crystal recovery efficiency

For the purposes of this sample calculation, the following hypothetical data has been used:

Cane quality / factory performance parameter	Value used
Constant "a" parameter in the ERC equation	0,9795
Constant "c" parameter in the ERC equation	0,0198
Industry average target purity difference (based on molasses)	5,1 %
Industry average monosaccharide recovery ratio	0,79
Industry average non-sucrose recovery ratio	0,82
Tons cane crushed	2 000 000 t
Brix % cane	15,00 %
Sucrose % cane	12,90 %
Fibre % cane	15,30 %
Reducing sugar / ash ratio in mixed juice	1,05
Tons raw sugar produced	225 000 t
Raw sugar polarisation	99,30 %
Raw sugar moisture	0,10 %

From equation (5), the value of the modified “b” parameter may be calculated as

$$b = R_{NS} \left\{ \frac{TPD + k_1 + k_2 \left[1 - \exp\left(R_{FG} \cdot k_3 \cdot I_{FGA}\right)\right]}{100 - TPD - k_1 - k_2 \left[1 - \exp\left(R_{FG} \cdot k_3 \cdot I_{FGA}\right)\right]} \right\}$$

yielding

$$b = (0{,}82) \left\{ \frac{5{,}1 + 43{,}1 - 17{,}5\left[1 - \exp\left(0{,}74 \cdot [-0{,}74] \cdot 1{,}05\right)\right]}{100 - 5{,}1 - 43{,}1 + 17{,}5\left[1 - \exp\left(0{,}74 \cdot [-0{,}74] \cdot 1{,}05\right)\right]} \right\}$$

and

$$b = 0{,}5506$$

From equation (6),

$$MERC\,\%\,Cane = S - b \cdot N - c \cdot F$$

giving

$$MERC\,\%\,Cane = 12{,}90 - 0{,}5506 \cdot (15{,}00 - 12{,}90) - 0{,}0198 \cdot (15{,}30)$$

and

$$MERC\,\%\,Cane = 11{,}44\,\%$$

Using the methods of van Hengel (1974), the tons of crystal produced by the hypothetical mill may be calculated as follows:

$$T_X = T_{RS} \cdot \left[1{,}724 \cdot P + 0{,}724 \cdot M - 72{,}4\right]$$

where T_{RS} is the tonnage of raw sugar produced, P is the raw sugar polarisation and M is the raw sugar moisture. Thus

$$T_X = 225000 \cdot \left[1{,}724 \cdot (99{,}30) + 0{,}724 \cdot (0{,}10) - 72{,}4\right]$$

and

$$T_X = 222447{,}6\, tons$$

Thus, from equation (7), the crystal recovery efficiency of the hypothetical factory may be calculated:

$$XRE = 100 \left[\frac{T_X}{T_C} \cdot \left(\frac{100}{MERC\,\%\,Cane - (1 - a) \cdot S} \right) \right]$$

giving

$$XRE = 100 \left[\frac{222447{,}6}{2000000} \cdot \left(\frac{100}{11{,}44 - (1 - 0{,}9795) \cdot 12{,}90} \right) \right]$$

and

$$XRE = 99{,}52\%$$

APPENDIX D: An analysis of individual mill performance in terms of XRE.

Mill	MERC % Cane March	MERC % Cane April	MERC % Cane May	MERC % Cane June	MERC % Cane July	MERC % Cane August	MERC % Cane September	MERC % Cane October	MERC % Cane November	MERC % Cane December	MERC % Cane 2001 / 02
Malelane		10.43	11.35	12.11	12.41	12.56	12.77	12.32			11.82
Komati		10.07	11.01	11.86	12.36	12.64	12.72	12.21			11.85
Pongola	9.24	9.46	10.33	11.43	12.09	12.41	12.49	12.31			11.34
Umfolozi		10.44	10.89	11.79	12.90	13.24	13.36	12.39			12.09
Entumeni		10.12	11.14	12.26	12.74	13.25	12.47				11.74
Felixton		10.12	10.43	11.23	11.90	12.14	11.96				11.25
Amatikulu		8.77	10.20	12.11	13.09	13.64	13.22				11.83
Darnall		8.09	9.02	10.95	12.02	12.67	12.35				10.84
Maidstone		7.94	8.43	9.66	10.90	11.44	11.59				10.09
Gledhow		8.42	9.49	10.65	11.34	11.80	12.10	10.17			10.58
Noodsberg	11.97	11.48	12.29	13.06	13.29	13.33	13.92				12.69
Union Co-Op	12.48	12.10	12.77	13.15	13.08	13.60	13.63	12.85			12.88
Eston	11.05	11.26	12.32	13.33	13.72	14.21	13.66	12.51			12.65
Sezela		9.01	9.85	10.89	11.84	12.30	12.10	10.67	9.57		10.84
Umzimkulu		10.52	10.98	11.45	11.93	12.03	11.80	10.42			10.98
Industry	11.44	10.00	10.55	11.59	12.28	12.64	12.61	11.30			11.50

APPENDIX D: An analysis of individual mill performance in terms of XRE. (Continued)

Mill	XRE March	XRE April	XRE May	XRE June	XRE July	XRE August	XRE September	XRE October	XRE November	XRE December	XRE 2001 / 02
Malelane		100.28	103.07	102.58	101.39	101.33	101.85	101.27			101.15
Komati		101.23	102.61	102.48	101.83	100.83	101.56	102.81			101.29
Pongola	100.66	99.81	101.55	102.46	100.91	101.11	100.47	99.68			99.79
Umfolozi		89.74	100.54	101.09	99.68	100.17	97.48	98.15			98.73
Entumeni		99.38	100.10	100.50	100.76	98.97	97.73				98.77
Felixton		98.74	103.06	103.73	103.09	101.47	100.05				101.32
Amatikulu		99.26	102.23	101.50	101.98	100.95	100.69				100.75
Darnall		99.64	102.17	100.33	99.99	100.18	97.32				99.31
Maidstone		107.69	106.29	104.64	104.82	103.36	101.99				103.64
Gledhow		98.42	100.74	103.36	102.74	101.90	100.65	98.38			100.81
Noodsberg	97.64	99.61	99.92	100.07	100.40	100.96	94.82				98.81
Union Co-Op	98.91	98.24	100.54	100.56	101.74	100.09	99.95	97.90			99.58
Eston	97.74	100.15	99.66	99.61	98.69	97.27	94.19	97.32			97.96
Sezela		98.36	101.11	101.89	100.84	100.45	99.24	99.72	99.44		100.23
Umzimkulu		100.08	102.99	102.89	103.39	103.75	102.82	102.83			102.89
Industry	98.22	99.58	101.96	102.00	101.60	101.02	99.60	99.69			100.48