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THE DEVELOPMENT AND EVALUATION OF A PREDICTIVE MILL-SCALE SUGARCANE QUALITY MODEL

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Abstract

Sugarcane quality has important implications for mill operations and mill supply area profitability. Accurate predictions of quality enable better management of mill operations and maintenance, harvest schedules, payments to growers and even the marketing of sugar.

Sugarcane quality is predominantly controlled by preceding weather conditions across the mill area. In this study a simple and robust model to predict cane quality, based on rainfall and temperature, was developed. The model, named the SQ-model, predicts the components of the RV equation. The SQ-model estimated daily brix, pol and fibre contents with an acceptable degree of accuracy after 98 coefficients were mathematically calibrated. For calibration the SQ-model uses readily available quality and climatic data collected by the sugar industry. Independent verifications at Sezela and Umfolozi yielded R^2 values between 0.52 and 0.74.

Keywords: sugarcane quality, modelling, fibre, pol, brix

Introduction

Accurate prediction of sugarcane quality over the milling season enables improved planning for mill operations, maintenance, harvest schedules, payments to growers and even sugar marketing. To predict the quality of sugarcane a robust and transferable model, named the SQ-Model, was developed.

The SQ-model is based on the fact that strong relationships exist between recent rainfall and temperature and daily average pol%, brix% and fibre% of cane delivered to the sugar mill (Glover, 1971; Inman-Bamber, 1994a; Inman-Bamber *et al.*, 2002; Malik and Tomar, 2003; Singels *et al.* 2003). The aim of this study was to develop, calibrate and test the SQ-model.

Model Development

Glover (1971) reported correlations between quality and the weather during the preceding three months; however, recent rainfall also affects post-harvest delays and the inclusion of trash in consignments (Donaldson, 1998; Hildebrand, 1998).

The SQ-model estimates average Cane Testing Service (CTS) tested cane quality on a day based on (a) daily rainfall over the preceding seven days and (b) weekly average weather over the preceding 10 weeks, as based on drying-off recommendations (Donaldson and

Bezuidenhout, 2000). Cane quality is also adjusted according the day of the week based on Sibomana and Bezuidenhout (2013). Equation 1 depicts the model formulation.

$$Pol\%, Brix\%, Fibre\% = C + \sum_{d=0}^{6} \alpha_d PF_d + \sum_{i=1}^{10} \gamma_i \bar{P}_i + \sum_{i=1}^{10} \delta_i \overline{HU}_i + \theta_{dow} \quad (1)$$

where:
- C : offset constant
- α_d : rainfall weighting factor for day *d* in week 0 (today = 0, six days ago = 6)
- γ_i : rainfall weighting factor for week *i*
- δ_i : heat unit weighting factor for week *i*
- PF_d : effective precipitation for day *d* in week 0 (mm)
- $\bar{P}_i$: average daily effective precipitation for week *i* (mm)
- $\overline{HU}_i$: average daily heat units for week *i* (°C.d)
- θ_{dow} : adjustment determined by the day of the week (where θ_1 is Monday, θ_2 is Tuesday, and so on)

During rainfall water is lost to runoff, interception, evaporation and drainage (McGlinchey, 1998). These losses are accounted for by assuming that only a limited amount of rainfall (PF_{max} and P_{max}) affects cane quality. For example, if PF_{max}=10 mm, a rainfall event of 100 mm will be equivalent to an event of 10 mm.

PF_d (mm) is the effective rainfall for day *d* in week 0 (Equation 2):

$$PF_d = \begin{cases} P_d & |P_d < PF_{max} \\ PF_{max} & |P_d > PF_{max} \end{cases} \quad (2)$$

where:
- P_d : measured rainfall (mm)
- PF_{max} : daily effective rainfall limit during week 0 (mm).

$\bar{P}_i$ (mm) is the average effective weekly rainfall for weeks 1 to 10 (Equation 3):

$$\bar{P}_i = \frac{1}{7}\sum_{j=0}^{6} \begin{cases} P_j & |P_j < P_{max} \\ P^* & |P_j > P_{max} \end{cases} \quad (3)$$

where:
- P_j : rainfall on day *j* of week *i* (mm)
- P_{max} : daily effective rainfall limit during weeks 1 to 10 (mm).

Growth in sugarcane only occurs when temperatures are above a base temperature of 10°C (Inman-Bamber, 1994b). It was assumed that sugarcane quality parameters will only be influenced by temperatures above certain temperature thresholds. The average effective daily heat units for week *i*, $\overline{HU}_i$ (in °C.d), were calculated according to Equation 4.

$$\overline{HU}_i = \frac{1}{7}\sum_{j=0}^{6} \begin{cases} T_j - HU_{base} & |T_j > HU_{base} \\ 0 & |T_j \le HU_{base} \end{cases} \quad (4)$$

Where:
- T_j : average temperature for day *j* in week *i* (°C)
- HU_{base} : base temperature (°C).

Calibration and Verification

The model was calibrated at Umfolozi and Sezela. Daily average fibre%, pol% and brix% values were obtained for both mills for 2002 to 2012. Years were randomly divided for calibration and verification purposes. Rainfall and temperature data were retrieved from the SASRI Weather Web. Weather data were averaged across weather stations in a mill area for any day.

The model was calibrated using the generalised reduction gradient (GRG) non-linear approach with 100 random resampling points in Solver, a Microsoft Excel add-in. The objective function was to maximise the R^2 between the simulated and observed cane quality data. This was achieved by concurrently calibrating C, PF_d, P_{max}, HU_{base}, α_d, γ_i, δ_i and θ_{dow} for each quality parameter. A total of 98 coefficients were calibrated for each mill.

Verifications on independent data yielded R^2 values between 0.52 and 0.74.

Discussion and Conclusion

The SQ-model performed better at Umfolozi than Sezela; most likely because Umfolozi has a more concentrated growing area with 70% of the cane originating from the Umfolozi flats (Boote, 2012). The Sezela area has a greater variability in climate, and thus using weather data at a mill scale resulted in less accurate predictions. The model could be adapted to calibrate the weighting of various weather stations within a mill supply area (MSA) to provide a more accurate picture of antecedent weather conditions.

As a typical example of model output, Figure 1 displays simulated and observed pol% cane for 2005 at Umfolozi. The model predicts the general trend of quality, but is unable to produce the short term variations evident in observed data. The model also fails to predict certain sharp changes in quality, an indication that these are not rainfall or temperature related. At certain times an offset between simulated and observed values exists. Generally pol% cane is under-predicted.

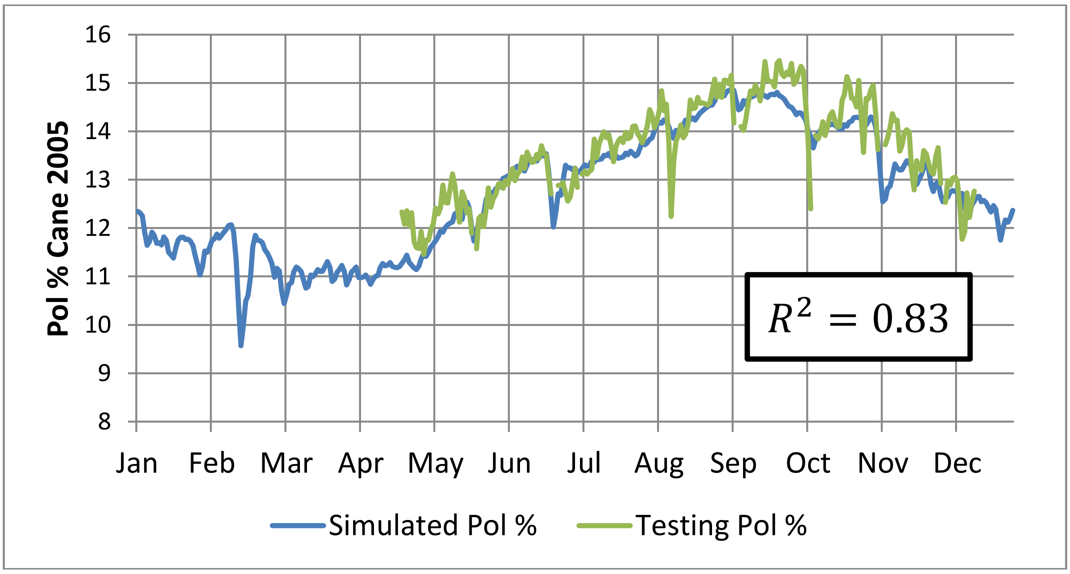

Figure 1. Simulated vs observed pol % cane for 2006 at Umfolozi.

Apart from predicting cane quality, the SQ-model can be used to analyse the sugarcane supply chain. For example, comparison of calibrated daily rainfall coefficients can indicate the average cut to crush delay at a particular MSA. In Figure 2 the daily rainfall coefficients are insignificant for days 0-1, but show a marked increase for days 2-6. Fibre % cane is sensitive to recent rainfall, because more trash is delivered to the mill during wet weather. It can thus be deduced that the cut to crush delay is at least two days, and most likely on average four days at Umfolozi.

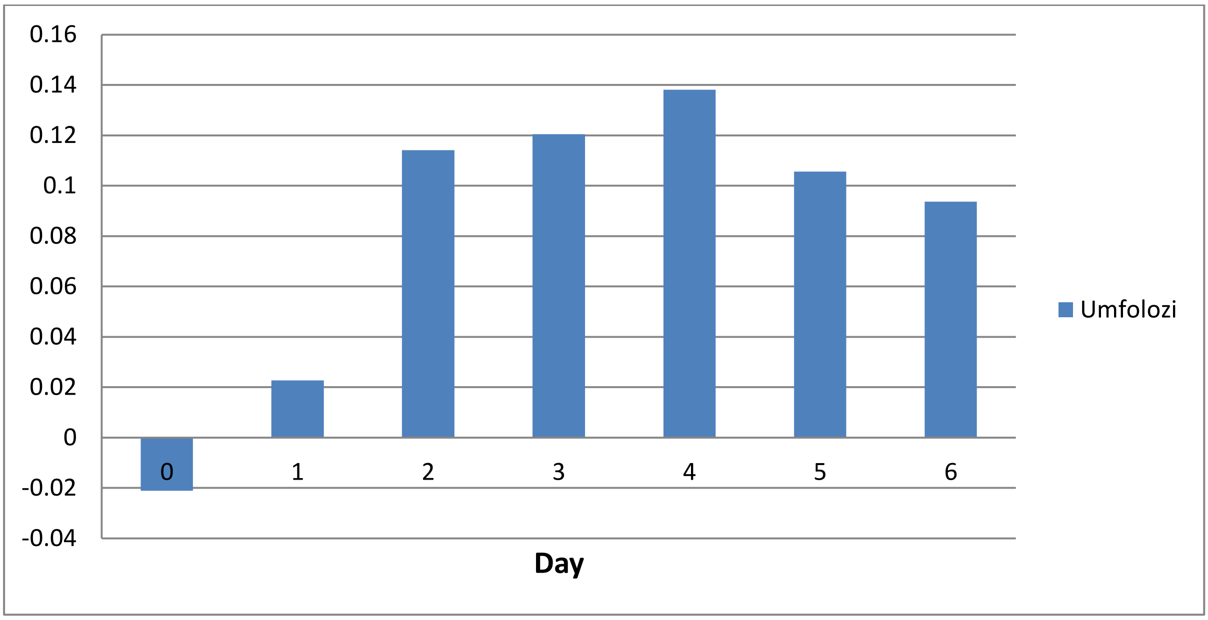

Figure 2. Daily rainfall coefficients (α_{0-6}) during week 0 for fibre % cane at Umfolozi.

Future research could identify ways to improve the predictive accuracy of the SQ-Model and its usefulness as a decision making tool. The SQ-Model is calibrated using quality data collected during the harvesting season, therefore any quality predictions for times of the year out of the usual harvesting season should be viewed with caution. It must also be noted that the SQ-Model predicts sugarcane quality at the point where it is delivered to the sugar mill, and thus after deterioration has occurred.

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