APPLICATION OF NIR CANE ANALYSIS TECHNOLOGY TO SMALL CONSIGNMENTS OF CANE IN FIJI

By

M. HABIB1, G.A. BENTLEY2, S. STAUNTON3, P.G. ATHERTON4 and C. HENDERSON5

1Sugar Commission of Fiji, Lautoka, Fiji, 2Fiji Sugar Corporation, Fiji
3Bureau of Sugar Experiment Stations (BSES), Meringa, Queensland, Australia
4Consulting Engineer, Bundaberg, Australia; 5FOSS-Pacific

Abstract

Near infrared (NIR) technology for rapid, on-line determination of sugar content in prepared cane has been applied at Lautoka Mill during the 1999 and 2000 seasons. The overall aim of the project is to achieve an analysis on at least 95% of consignments of cane sent to the factory. Over an extended period of operation, however, only 33% of cane consignments were successfully analysed by the NIR installation. Small cane consignments, typical of Fiji, resulted in poor tracking integrity and limited the time available for on-line NIR measurement. Subsequent developments in the system at Lautoka have allowed the minimum consignment size to be reduced to seven tonnes. Calibration databases and equations developed in Australian sugar mills were used in the Lautoka trial. The predictive capabilities of these calibrations are reported.

Introduction and background

Fiji lies roughly 17° south of the equator and on the 180th meridian, which places it in the tropical weather range of Northern Queensland in Australia. The factories operating in Fiji today are Lautoka (8500 TCD), Rarawai (7000 TCD), and Penang (2200 TCD) on the main island of Viti Levu, and Labasa (8000 TCD) on the island of Vanua Levu.

The amount of extractable sugar in cane in Fiji has been measured as pure obtainable cane sugar (POCS) (BSES, 1991). The POCS formula was devised late in the 19th century in Australia and assumes that 75% of soluble impurities in cane go through to molasses at 40 true purity and that no other pol losses occur. The formula is regarded as giving a good estimate of the commercial value of cane at the factory gate.

Fiji has suffered a serious decline in the sugar content of cane over the past 25 years. The seasonal average POCS has fallen 20% from 14 units in 1968 to 11 at the present time. Cane deliveries in Fiji have been paid on a weight only basis except for a brief period before 1940. The lack of a cane payment system based on quality and producing an average of 200-500 tonnes of cane per farm annually. The application of a quality cane payment (QCP) system based on clear identification of each delivery has so far been considered very difficult. The development of rapid cane analysis by NIR spectroscopy has provided an opportunity to establish a quality-based system in Fiji. Successful trials have been reported in Australia (Staunton et al., 1999). NIR analysis has the ability to directly report POCS as well as a host of other parameters.

Cane is supplied to the factories in whole stick form by two transport systems, namely road lorries and rail trucks. Individual grower consignments are generally small, particularly those supplied by rail. On a typical day, 1000 to 1500 consignments are delivered to the factory by the two transport systems. Individual consignment analysis by conventional means would be impossible.

This paper describes the steps taken to apply NIR technology to the Fiji situation. Lautoka Mill has two feeding stations, A-side, a milling train and B-side, a cane diffuser. The QCP project was commenced in early 1999 with the installation of the computer network system, the NIR system and a tracking system on B-side. This system was developed during 1999 season, and was running by the end of the season. It was extended to A side during the 2000 season with an enhanced version of the NIR software.

The aims of this project are as follows:
- To confirm that the NIR analytical technique is applicable and acceptable for Fiji.
- To achieve a valid analytical result for at least 95% of the consignments (rakes) delivered to Lautoka Mill.
- To extend the NIR system to the other factories and introduce an industry-wide cane payment system based on quality.

NIR system description and requirements

The NIR system at Lautoka is similar to that described previously by Staunton et al., (1999). The scanning head is mounted on the number one mill feed chute for A side and on a specially constructed chute for B side. For the NIR to provide consistent results, prepared cane must have the following characteristics:
- Well prepared cane. Pol in open cells (POC) greater than 80% (BSES, 1991, Method 5).
- No voids in the mat passing the scanner.

KEYWORDS: Cane Tracking, Rake, On-Line Reflectance Spectroscopy, NIR, Cane Analysis.
Lautoka Mill has heavy duty shredders on both feeding stations, and an acceptable level of preparation is achieved. The void situation is achieved by maintaining at least 100mm of prepared cane in a chute above the read head thereby providing compressive force on the cane at the read head. The required prepared cane height is maintained by the devices feeding the chute in the case of A side and variable speed rollers at the chute exit in the case of B side. Acceptable cane height sensing allows continuous scanning.

The initial MK1 cane analysis system (CAS) installed performed a scan and therefore produced a set of results in 40 seconds. Each scan comprises a number of sweeps of the NIR spectrum from which analytical results are produced if all other interlocks are correct. The MK2 version, installed on the A side, performs scans in 20 seconds. This reduced time will have a large bearing on the success of the project. The B side system will be upgraded to MK2 for the 2001 season.

The system also requires regular reference scans to ensure that there has not been a drift in the system calibration. The reference scan for the MK2 version takes 40 seconds. The system does a reference scan before each consignment.

**Brief description of the cane tracking system**

Individual consignments of cane must be tracked from the weighbridge to the NIR read head. The dual transport/multiple weighbridge system and multiple tipping points for lorries at Lautoka provided some difficulties in this area. Briefly, the system uses radio frequency (RF) tags and strategically placed tag readers to track both rail trucks and lorries to the tip. Once in the carrier, the consignments are tracked to the NIR read head by conventional movement sensors on the carrier drive and elevators.

NIR analytical data and farm/weight data are matched up by a cane payment computer system once NIR results on individual consignments become available.

Computer monitors allow the progress of cane consignments to be followed through the system.

**Development of the system**

Initially, dye was used to identify individual consignments so that samples could be taken for validation analyses. Later the tracking system was used to identify the selected consignments. The cane analysis parameters determined were brix and pol in juice, dry matter, POCS and fibre in cane. The method of sampling the prepared cane was as described by Staunton et al. (1999). The methods of analysis used were: fibre in cane, (BSES, 1991, Method 4) dry matter by drying to constant weight at 100°C, refractometer brix in juice and pol in juice by analysis of juice extracted by Carver press. The Carver press extraction is by juice extraction from 900 grams of prepared cane at 89 kN (20 000 pounds force) for one minute. Direct cane analysis was by wet disintegrator (WD) (BSES, 1991, Method 5).

The NIR analyser scans the prepared cane as it passes the read head. The analysis from that scan is then assigned to the particular consignment and the individual grower. If a consignment is sufficiently large, several scans may be run and the average of these successful scans is used to determine the analysis. Not all scans are successful. Scans may be rejected due to physical limitations or elimination by the NIR software internal checks. If there is no successful scan for a particular consignment, an analysis cannot be assigned. If less than 20% of the consignment is scanned, the result is deemed as not representative and is rejected.

Because of the uncertainty of where the actual interface between consignments occurs due to mixing in the knitting area of the carrier, scans covering the interface zone cannot be accepted, since it is not certain to whom this cane belongs. This part of the consignment is ignored and is referred to as the ‘wash section’. Any scanning that occurs within this part of the consignment cannot be used to allocate cane analysis to a particular grower. However, it could be used for mill control purposes. The CAS cannot abort a scan once it has been commenced. So, if a scan begins validly but goes into a wash section of the consignment, the analysis from that scan must be ignored. By the same token, any scan, which commences in a wash period, must also be ignored. Consignment size therefore has a large bearing on the ability to produce enough scans for a successful result.

Dye was also used to verify the tracking accuracy and to estimate the amount of cane that becomes mixed in the consignment interface. It was found that, at a normal B side throughput of 240 t/h of cane, around half a minute was required for the dye to appear and decay. To ensure the integrity of the samples it was decided to double this value and so a wash period of one minute was introduced, half a minute on each end of a consignment.

As mentioned previously, CAS MK2 requires 20 seconds for a scan and 40 seconds for a reference scan. The reference scan can be accommodated in the one minute wash period. Since there is a possibility of the first or last analytical scan of the consignment being partly in the wash period, at least two scans are considered as the minimum requirement for an analysis. At least 40 seconds of cane supply is therefore required as well as the one minute wash period. This means that a consignment must be at least one minute and forty seconds in length. At 240 t/h, this is equivalent to about seven tonnes of cane.

Figures 1 and 2 show the normal spread of consignment sizes on a typical day at Lautoka for rail and lorry cane. The figures show that with the seven tonne minimum consignment, 94% of lorry cane could be analysed and 18% of rail cane. Effort has subsequently been directed towards increasing the rail consignment size. A minimum consignment size of 10 t has been set in the field operations. The effect of this will become evident in 2001 season.
Fig. 1—Rail cane consignment size distribution.

Fig. 2—Lorry cane consignment size distribution.
Cane Analysis System (CAS)

The CAS utilises a core Foss NIR Systems DL5000 spectrophotometer to provide on-line predictions for multiple constituents of post-shredder prepared cane. (Staunton et al., 1999).

Global calibration equations, developed in Australia by BSES, using data collected from five mill areas over several seasons, were used to provide analytical results for evaluation purposes. The calibration statistics for each constituent equation are described in Table 1. The table includes: the constituent name, the standard error of cross validation (SECV), an estimate of equation performance in prediction, the linear regression correlation coefficient between predicted and actual, the mean conventional analysis value of the calibration set, the standard deviation of laboratory values in the calibration set, the effective range of the equation, the number of samples in the calibration set, and the number of variables (terms) used in the calibration equation.

Samples with laboratory values outside the effective range should not be used for validation purposes, as these equations do not predict well when extrapolating. These statistics provide a means of evaluating system performance. Validation statistics significantly worse than those reported in Table 1 indicate problems in CAS operation, the need to capture samples for further calibration work, or poor laboratory performance.

Results

The CAS system at Lautoka provides a report on scan failures. Table 2 summarises the reasons for failure.

Failures were due to scans going into the wash period and due to low prepared cane height above the scan head not being achieved. The failure rate due to results being outside the previous history will reduce as the database covers more Fiji results.

Over an extended period of continuous operation, the current consignment analysis success rate was 33%. This is well below the 95% target, but changes to the operational requirements should improve this situation.

Work carried out previously in Australia had established strong correlations between NIR analysis of cane, laboratory analysis of the pressed juice from a Carver press at 89 kN for 1 minute on cutter ground cane and the routine analysis of number one mill first expressed juice (FEJ). These results are shown in Table 3. The table includes: the standard deviation of the difference between determinations (SDD) or predictions (SEP), the linear correlation coefficient between determinations or predictions, the slope of the regression line, the average difference or bias, the range of values of the FEJ analyses and the number of samples analysed. Brix and Pol in cane were calculated using the empirical relationship described by BSES (1984) Volume 1.

The results show the carver extract analysis produces a higher value when compared to FEJ analysis for all constituents except POCS. Bias adjustments to the CAS based on carver extract validation results will need to allow for the bias inherent between the carver extract and FEJ methods.

The different sampling techniques employed for each analysis method contributed to the relatively large differences reported between carver analysis

<table>
<thead>
<tr>
<th>Constituent</th>
<th>SECV</th>
<th>R²</th>
<th>Mean value</th>
<th>Std dev.</th>
<th>Range</th>
<th>No. of determinations</th>
<th>No. of variables</th>
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<tbody>
<tr>
<td>Pol in juice</td>
<td>0.507</td>
<td>0.982</td>
<td>15.35</td>
<td>3.74</td>
<td>7.87-22.83</td>
<td>1650</td>
<td>11</td>
</tr>
<tr>
<td>Pol in cane</td>
<td>0.282</td>
<td>0.975</td>
<td>12.33</td>
<td>1.787</td>
<td>8.76-15.90</td>
<td>737</td>
<td>11</td>
</tr>
<tr>
<td>Brix in juice</td>
<td>0.473</td>
<td>0.983</td>
<td>18.25</td>
<td>3.58</td>
<td>11.00-25.41</td>
<td>1737</td>
<td>12</td>
</tr>
<tr>
<td>Brix in cane</td>
<td>0.296</td>
<td>0.966</td>
<td>14.85</td>
<td>1.622</td>
<td>11.61-18.10</td>
<td>737</td>
<td>11</td>
</tr>
<tr>
<td>POCS</td>
<td>0.445</td>
<td>0.976</td>
<td>12.53</td>
<td>2.89</td>
<td>6.75-18.31</td>
<td>1318</td>
<td>12</td>
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<table>
<thead>
<tr>
<th>Constituent Name</th>
<th>Carver vs FEJ</th>
<th>Carver vs NIR</th>
<th>NIR vs FEJ</th>
<th>FEJ values</th>
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<tbody>
<tr>
<td></td>
<td>SDD</td>
<td>R²</td>
<td>Bias</td>
<td>SEP</td>
</tr>
<tr>
<td>Brix in juice</td>
<td>0.50</td>
<td>0.88</td>
<td>0.90</td>
<td>-0.93</td>
</tr>
<tr>
<td>Pol in juice</td>
<td>0.52</td>
<td>0.91</td>
<td>1.02</td>
<td>-0.64</td>
</tr>
<tr>
<td>Brix in cane</td>
<td>0.42</td>
<td>0.87</td>
<td>0.87</td>
<td>-0.74</td>
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<tr>
<td>Pol in cane</td>
<td>0.43</td>
<td>0.90</td>
<td>0.98</td>
<td>-0.51</td>
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<tr>
<td>POCS</td>
<td>0.54</td>
<td>0.87</td>
<td>1.08</td>
<td>0.18</td>
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</table>
and the two other methods. The FEJ sample was obtained by continuously sampling juice over the whole consignment, the NIR sample by collecting the average of 32 spectra every 36 seconds, and the carver sample by collecting and compositing a small snap sample of prepared cane every 30 seconds. The very strong correlations between NIR and FEJ analyses indicates the two sampling methods employed produce representative samples that are directly comparable. This is supported by the similarity in the comparison statistics between the carver against FEJ and carver against NIR. This similarity would suggest that the increase in error reported between the carver against FEJ and NIR analyses resides in large part with the carver analysis itself and is probably due to differences in the samples collected. This effect will be strongly influenced by the amount of variation encountered across the consignment.

The SEP between Carver and NIR for all constituents are commensurate with the performance obtained in the calibration statistics of Table 1. The statistics for the comparison of carver and FEJ analyses can be considered as the best possible result for system validation using this method.

It was not possible to obtain a FEJ sample for system validation from the Lautoka B side. The above results justify the use of the analysis from the carver extract as the basis for comparison with the NIR analysis and direct cane analysis by wet disintegrator (WD). Direct cane analysis was performed to determine if it could provide a better method of validating the CAS system as compared to the carver extract.

Validation samples were collected from the prepared cane belt feeding the Lautoka diffuser after the NIR scanning point as previously described. The composite sample was thoroughly mixed and subsampled for analysis. Brix and Pol were determined immediately on both the carver and wet disintegrator extract.

The comparison statistics for these samples are shown in Table 4.

The average global and neighbourhood Mahalonobis nearness statistics for the spectra collected were 0.72 and 0.43 respectively. These are well within the system limits of less than 3 and less than 0.6 respectively. The average number of system results per sample was 2.8.

The results show stronger correlation and lower differences between the NIR and carver results than for the direct cane analysis for all constituents tested which indicates that the carver extract analysis is a superior method for system validation. The reported errors are significantly higher than those described in Table 1 indicating the equations need to be extended with the inclusion of some Lautoka data or that the laboratory precision was poor or both. Unfortunately no repeatability data were available to determine laboratory precision for these analyses.

The prediction performance of the same equations at an Australian mill which also had no data included in the calibration set is shown in Table 5. This mill used the CAS MK2 system that provides faster scanning rates and reduced reference times. This mill operated at crushing rates of greater than 500 t/h and, as a result, each 20 second scan represented approximately 2.8 t of cane.

The results for all constituents tested are within the errors reported in Table 1. The average global and neighbourhood mahalonobis nearness statistics for the spectra collected were 0.78 and 0.11 respectively and the average number of system results per sample was 23. The system consignment analysis success rate was 98.6% of 8240 consignments processed.

Assuming an average crushing rate of 500 t/h then the average successfully scanned consignment size was 64.4 t of cane. The improvement in results for the Australian situation highlights the importance of large consignment sizes and faster scanning rates to system performance. They also indicate that the changeover to the CAS MK2 system for the 2001 season will result in an improvement in prediction performance and scan success rate at Lautoka.

<table>
<thead>
<tr>
<th>Constituent Name</th>
<th>Carver vs NIR</th>
<th>WD vs NIR</th>
<th>Carver vs WD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SEP</td>
<td>R²</td>
<td>Slope</td>
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<td>Brix in Juice</td>
<td>0.82</td>
<td>0.66</td>
<td>0.91</td>
</tr>
<tr>
<td>Pol in Juice</td>
<td>1.02</td>
<td>0.68</td>
<td>0.95</td>
</tr>
<tr>
<td>Brix in Cane</td>
<td>0.75</td>
<td>0.57</td>
<td>0.78</td>
</tr>
<tr>
<td>Pol in Cane</td>
<td>0.76</td>
<td>0.67</td>
<td>0.77</td>
</tr>
<tr>
<td>POCS</td>
<td>0.97</td>
<td>0.69</td>
<td>0.89</td>
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<tr>
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</table>
Comments and conclusions

It is possible to develop a cane quality assessment system that provides individual rake results using NIR analysis of prepared cane for the Fijian sugar industry. The hardware systems necessary for the implementation of such a system have been successfully installed and operated at Lautoka mill.

System analysis of individual rakes during the 2000 season did not meet the project aim of 95% due to three major factors. These factors were: small consignment size predominantly from the rail supply system, poor chute height control, and calibration equation transferability. Larger consignment sizes and tight chute height control will improve the system analysis success rate. Field reorganisation is being currently carried out with the aim of improving the rail consignment size to 10 t.

Further developments in the CAS are needed to improve system performance. Improvements in scanning speed and reference management are required to increase the percentage of samples successfully analysed. Calibration equation prediction performance was below that expected of the system and re-calibration, preferably with the inclusion of some Lautoka data, is required. Some effort is also required in determining the laboratory repeatability for the carver extract analysis at Lautoka.

Validation of CAS results using carver press extract analysis is superior to that obtained using direct cane analysis by wet disintegrator. The use of the carver press extract method for system validation will mean that Fiji will need to accept slightly larger validation errors than are apparent in Australia. An acceptable level for Fiji has not yet been determined.

Acknowledgments

The authors would like to thank the Sugar Commission of Fiji and Fiji Sugar Corporation for permission to publish this paper. The authors wish to thank Mr Gary McNair from Mirrabooka Systems for his assistance in the project. They also wish to acknowledge the assistance of the staff of Lautoka Mill.

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APLICACIONES DE LA TECNOLOGIA NIR EN ANALISIS DE CAÑA PARA PEQUEÑAS ENTREGAS DE CAÑA EN FIJI

M. HABIB1, A. BENTLEY2, S. STAUNTON3, P.G. ATHERTON4 y C. HENDERSON5

1Sugar Commissin of Fiji, 2Fiji Sugar Corporation, Fiji
3Bureau of Sugar Experiment Stations (BSES), Meringa, Queensland, Australia
4Consulting Engineer, Bundaberg, Australia, 5FOSS-Pacific

Resumen
La tecnología de infrarrojo cercano para rápida determinación del contenido de azúcar en caña preparada ha sido aplicada en el Ingenio Lautoka durante las zafra de 1999 y 2000. El objetivo general del proyecto es realizar el análisis de al menos el 95% de las entregas de caña a la fábrica. Sin embargo, sobre un período continuo de operación, solamente el 33% de las entregas de caña fueron analizadas exitosamente vía NIR. Pequeñas entregas de caña, típicas en Fiji, resultaron en un pobre seguimiento integral y limitaron el tiempo disponible para medidas en línea en el NIR. Desarrollos posteriores en el sistema de Lautoka han permitido establecer un tamaño de entregas mínimo de siete toneladas. Se utilizaron bancos de datos de calibración y ecuaciones desarrolladas en ingenios Australianos durante los ensayos de Lautoka. Se reportan las capacidades de predicción de estas calibraciones.

Palabras claves: Seguimiento de Caña, muestra, espectroscopía de reflectancia en línea, NIR, análisis de Caña.