THE EFFECT OF GREEN CANE ON DOWNSTREAM FACTORY PROCESSING

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Abstract

There is a world-wide shift from burnt to green cane harvesting. In many countries, including the United States and South Africa, certain areas are changing to green cane harvesting due to public, tourism and environmental pressures against open field burning, increasing labour costs, and the potential use of sugarcane trash as biomass for the production of bio-products. While some countries have already converted to total green cane harvesting, of the 23 million tonnes of cane that is annually processed in South Africa, almost 85% is still burnt.

Since the 1940s there have been factory trials all over the world on green cane processing but, due to the sheer magnitude of such trials, none have managed to shed much light on the effect on downstream processing beyond clarification. This paper reports on the effects of harvesting green billeted sugarcane compared to burnt billeted and/or whole-stalk sugarcane on factory front end processes and on downstream processing in a pilot plant. Pilot plant processing was done on samples collected from two factories situated in the Midlands area of South Africa. Sufficient cane of each treatment was harvested and processed to purge the extraction plant of other cane. Trash materials and mixed juice were collected and analysed. The effects of trash levels on prepared cane, bagasse and mixed juice are reported. Factory mixed juice (300 L) was transported to the SMRI in Durban and further processed in the SMRI pilot plant to clarified juice, syrup, A-massecuite, A-molasses, A-sugar, and affinated sugar. Various differences in physico-chemical parameters including colour and ash are presented.

Keywords: tops, trash, harvesting, burnt cane, green cane, billets, processing, clarification, evaporation, boiling house, pilot plant

Introduction

With increasing labour costs and reduced availability of agricultural labour in South Africa there has been a slow but marked shift to mechanised sugarcane harvesting. Furthermore, there has been a concomitant shift from burnt to green cane. While the amount of trash associated with field sugarcane depends on many factors, particularly on the variety, further increases in trash content of cane supplies due to green and mechanical cane harvesting can be expected at South African factories (Rein, 2005; Kent, 2007). The challenge is to harvest green without adverse consequences to factories from the higher cane supply trash content. This challenge is further motivated by increasing opportunities to utilise trash as a source of energy.

Terminology for sugarcane trash has not been clearly defined. The SASTA Laboratory Manual (Anon, 2005) defines trash as leaves and sheaths delivered with the clean cane stalk. Trash has also been defined as tops, leaves and soil. Elsewhere, green tops sometimes equate to green leaves (GL) together with the growing point region (GPR) or apical internodes (Tulip and Moore, 2007). However, a complete definition of sugarcane trash should include both brown, dried leaves (BL), GL, and the GPR. Not enough is known about (i) the physico-chemical differences between the different types of trash materials and stalk (S) material; (ii) the effects of the different materials on processing; and (iii) the amount and impact of the extra impurities entering the factory with trashy sugarcane. In particular, the differences in the processing effects of brown versus green trash have been mostly ignored (Eggleston *et al.*, 2009a; Eggleston *et al.*, 2009b).

The traditional harvesting procedure in South Africa is burning of the BL from the stalk in the field followed by manual cutting and topping, resulting in the delivery of stalks free from GL and GPR with minimal associated brown leaves attached. However, many variations are currently observed, including not topping, green cane harvesting (manual and mechanical) and mechanical (combine) harvesting. Some factories may even encourage the delivery of increased trash in order to increase their boiler fuel (bagasse) without realizing the detrimental effects this would have on processing operations (Reid and Lionnet, 1989).

Bernhardt *et al.* (2000) reported a significant reduction in factory front end throughput rates with green relative to burnt whole-stalk cane because (i) more effort is required to harvest green cane and growers cannot maintain the same harvesting rates with their existing cutting crews, and (ii) chokes can occur with green cane. From a four-day trial of processing green harvested cane it was shown that, although only approximately one third of the total cane delivered was unburnt, there was still a reduction in the harvest and supply rates, an increase in choking tendencies, an increase in sugar colour and a decrease in boiling house recovery. Reid and Lionnet (1989) found that the presence of tops and trash reduced the milling capacity and throughput of a milling tandem and predicted a substantial increase in the VHP sugar colour and a significant reduction in sugar recoveries.

While the sucrose content of burnt and unburnt or green cane essentially remains the same (Waddell and Price, 1965), the real issue is whether the factory will be able to produce the same amount and quality of sugar from the diluted cane compared to burnt cane. Burnt cane is known to deteriorate faster than unburnt (green) cane (Valence and Young, 1959; Lionnet and Moodley, 1993; Bernhardt *et al.*, 2000; Eggleston *et al.*, 2001, 2008). Researchers throughout the world (Arceneux and Davidson, 1944; Mayoral and Vargas, 1965; Scott *et al.,* 1978; Foster, 1979; Lamusse and Munsamy, 1979; Reid and Lionnet, 1989; Purchase *et al.,* 1990; Lionnet and Reid, 1993; Bernhardt *et al.*, 2000; Kent *et al.,* 2003; Gomez *et al.,* 2006) agree that an increase in tops and trash entering a factory (mill or diffuser) with the cane generally results in the following:

- reduced payloads per consignment due to the lower density of trash and tops resulting in increased transport costs and sometimes reduced payment, e.g. the Australian CCS system (Milford, 1989) and the South African RV system (Moor, 2000)
- reduced crush rates and throughputs due to the larger volume of fibre associated with any given amount of sucrose (also resulting in a longer milling season)
- slippage on the mill rolls due to leaves
- chokes in the knives and shredders due to high fibre load
- mill settings and/or diffuser operation needs adjusting
- lower extraction due to sucrose losses to an increased volume of bagasse
- higher bagasse moisture content

- lower mixed juice purity due to increased levels of impurities, such as reducing sugars, ash and colourants, with associated effects on clarification
- reduced mixed juice pH (higher lime demand) due to the presence of organic acids (the reduction in pH is not as great as with deteriorated cane)
- evaporator fouling due to impurities
- low exhaustion due to losses to molasses (polysaccharides, reducing sugars, and ash, especially potassium).

Purchase *et al.* (2008) considered the changing value of sugarcane trash and concluded that the best solution for the South African industry at the time was to trash and collect the solar dried trash in the field. Allen and McDonald (1999) considered the cost of trash to the Australian industry as a whole and Rein (2005) considered the same for the Louisiana (USA) industry. Both papers indicated that it was probably more advantageous to collect the trash at the factory through dry cleaning, although trashing in the field was not discouraged.

This paper reports on factory trials undertaken in South Africa during the 2008/09 mid-season to determine the effect of green and mechanical harvesting on trash levels received at the factories, and on upstream and downstream processing. Such trials have been previously attempted but never quite realised. In particular, N12 burnt whole-stalk cane was compared to burnt and green billeted cane received at Noodsberg (NB) in the KZN Midlands, and to burnt and green billeted cane received at UCL in the same area (the two factories are approximately 10 km apart). On the KZN northern coastal area at Felixton (FX), N27 burnt whole-stalk cane with tops still intact was compared to green billeted cane received. The main objective was to estimate the effects of the increased trash levels on downstream processing in the boiling and raw houses of the factories with emphasis on the different types of trash that were delivered.

Experimental

Direct measure of trash and stalk components of field sugarcane

Approximately twenty-five randomly chosen hand-cut whole-stalks, with tops and green and brown leaves still attached were obtained from each of the fields used for the trials. Each sample was separated into the following components: brown, dried leaves (BL); green leaves (GL); the growing point region (GPR) which is the immature apical internodes above a natural breaking point in the stalk; and the remaining stalk (S) composed of hardened nodes and internodes. Each material type was weighed and the percent trash on a wet mass basis calculated. Randomly chosen samples of the separated materials were transported to the SMRI and shredded by passing through a Jeffco cutter grinder (Jeffress Engineering Pty Ltd, Australia). Shredded material was then mixed with water (1:4 for GL, 1:7 for BL and 1:2 for GPR and S) and processed in a cold digester to obtain an extract for analyses of sucrose, fructose and glucose by GC (SASTA Method 1.9, 2005) and solution colour according to ICUMSA Method GS1/3-7, 2003. Moisture analyses (SASTA Method 1.4, 2005) were determined on the shredded portion of each material type after drying in an oven at 105ºC for 1 h.

Direct measure of trash and stalk components in harvested sugarcane at the factory

Four random grab samples (~16 kg) were obtained from the factory piles in the cane yard or carousels of green or burnt billeted cane. For burnt whole-stalk cane two random grab samples of ~16 stalks were obtained from piles or carousels. Each sample was separated into BL, GL, GPR and S. If roots were present these were associated with the S. Leaves with any green colour were designated GL. Each material type was weighed and the percent trash on a wet mass basis calculated. The separated materials were then bagged and transported to the SMRI in Durban and treated as described for field sugarcane above.

Fibre retention time in the extraction plants

The fibre retention time in the NB milling tandem was unknown. A small amount of red artificial fibre material was, therefore, cut into stripes and rolled into a ball (~150 mm diam.) and covered with non-sticky red tape. The ball was dropped into the Donnelly chute feeding the first mill and retention time was measured when red shreds were visible leaving the last mill, which was ~6.5 min under normal operation crushing burnt whole-stalk at 275 tonnes cane per h. The fibre retention time in the UCL diffuser was reported at 1 h when the crushing rate was 135 tonnes cane per h (normal conditions).

Factory operation during the trial

NB factory

Cane preparation equipment at the NB factory consisted of a leveller and a whole-stalk shredder. Due to the higher density of billeted cane, the conveyer belt speed was adjusted as a matter of routine when billeted cane was being crushed. The factory operated a 5-mill tandem plus one drying mill with a fibre residence time of 6.5 min. In the morning, before the first trial commenced (green billets), the factory experienced several chokes in the second mill under the Donnelly chute. The same problem, but to a lesser extent, was experienced on the second day (burnt billets) but not on the last day (burnt whole-stalks). For each of the three trials at NB, the factory biocide dosage for the morning shift was discontinued before and during the trial.

UCL factory

Cane preparation equipment at the UCL factory consisted of a leveller, a set of knives and a shredder. Due to the higher density of billeted cane, the conveyer belt speed was adjusted as a matter of routine when billeted cane was being crushed. The factory operated a 60 m chainless cane diffuser controlled under normal conditions at 1 m/min advance speed. For each of the two trials at UCL, the factory biocide dosage for the morning shift was discontinued before and during the trial.

Harvesting

NB factory

A three-day trial was conducted at NB factory from 18-20 June 2008. One grower supplied the cane for the billet trials (days 1 and 2) from a single field in the Midlands area of KZN and another grower supplied the burnt whole-stalk cane on day 3. All the cane was N12 variety and 20-24 months of age. Approximately 150 tonnes of cane was supplied for each trial date. The first trial, green billets, was conducted on 18 June under slightly wet environmental conditions. The field cane was combine harvested (Claas^{TM} CC 3000; ground speed 4 km/h and blower and fan speeds 1624 and 1398 r/min, respectively) between 7:00 and 10:30 am and immediately delivered to the factory and processed. For the second trial, burnt billets, the field cane was first burned in the field in the early evening of 18 June (slightly wet conditions). It was then combine harvested (ground speed 7 km/h and blower and fan speeds 1624 and 1398 r/min, respectively) between 8:00 and 11:00 am on 19 June and immediately delivered to the factory and processed. For the third trial, burnt whole-stalks, the field cane was first burned in the field in the early evening of 19 June. Hand-cutting began soon afterwards and all the cane was delivered to the factory by 10:00 am the following morning (20 June) to minimise deterioration.

UCL factory
A two-day trial was conducted at UCL factory from 25-26 June 2008 under the same conditions as the NB factory trials. One grower supplied the cane (N12 variety and 20-24 months age) from a single field in the Midlands of KZN area from the same farm as the field used for the NB billets. Harvesters and settings were exactly the same as for the NB billeted cane. Approximately 250 tonnes of cane was supplied on each trial date. The first trial, green billets, was conducted on 25 June under cold and dry conditions. For the second trial, burnt billets, the cane was first burned in the field in the early morning of 26 June.

FX factory
A two-day trial was conducted at FX factory from 23-24 July 2008. A single field in the northern coastal area of KZN was used for the two days with N27 variety of approximately 18 months of age. Approximately 350 tonnes of cane were supplied on each trial date. Harvesting for the first trial, green billets, was started in the morning of 21 July. The field cane was combine harvested (Claas$^{\mathrm{TM}}$ CC 3000; ground speed was 4 km/h and blower and fan speeds were 1624 and 1398 r/min, respectively) and delivered to the factory where it was stored in the delivery point carousels until 23 July. For the second trial, burnt whole-stalk, the rest of the cane in the field was burned in the early evening of 23 July. The burnt cane was manually harvested and delivered to the factory carousels until late morning of 24 July to minimise deterioration. As per normal practice by the particular grower, the tops were not removed in the field.

Crushing and extraction

For all factories every effort was made to minimise cut-to-crush delays and, therefore, deterioration to evaluate the effects of trash alone. Towards the end of each trial, twelve 25 L containers each containing two drops of mercuric chloride preservative were filled with mixed juice (MJ) and transported immediately to SMRI in Durban for sub-sampling (for later analysis) and processing of the bulk into clarified juice.

NB factory (milling tandem)
Each trial at NB (crush rate ~275 tonnes cane per h) lasted 1 h to ensure that the prepared cane and bagasse samples collected were representative of the trial cane supplied. Prepared cane samples (at least eight) were collected across the hour and analysed by the factory's Cane Testing Services (CTS) laboratory. Sampling of bagasse started 30 min after the trial started. Three catch bagasse samples were obtained across the next 30 min, composited and analysed by the factory laboratory.

UCL factory (diffuser)
Each trial at UCL (crush rate ~135 tonnes cane per h) lasted 2 h to ensure the prepared cane and bagasse samples collected were representative of the trial cane supplied. Prepared cane samples (at least nine) were collected across the 2 h period and analysed by the factory laboratory. After 1.5 h, bagasse sampling and analysis took place using the same procedures as at NB.

FX factory (diffuser)
Each trial at FX (crush rate ~220 tonnes cane per h; line A only) lasted 2-3 h. The cut-to-crush and burn-to-crush delays were no more than 48 h for the green billeted cane and maximum

18 h for the burnt whole-stalk, respectively, and were deemed to not be significant (compared to typical industrial delays of 72 h). No bagasse samples were taken.

Factory sampling and analyses

Direct Analysis of Cane (DAC)

DAC quality parameters of the cane were measured: pol, Brix, purity, fibre (calculated) and moisture (SASTA Methods 1.1 to 1.5, 2005). Samples of the cane were taken after preparation (knives and shredding) but before extraction (diffusion or milling) on a continual basis for nominated consignments, and were fully representative of a specific cane consignment through an automated tracking system. Over the years the term DAC has become synonymous with prepared cane samples and will be used as such in this report.

Bagasse

Composite bagasse samples were analysed for pol, Brix and moisture in the factory laboratory on each day (SASTA Methods 1.2 to 1.4, 2005).

Pilot plant processing

The SMRI pilot plant facility (Lionnet and Reid, 1993) was used to produce clarified juice (CJ), final evaporator syrup (FES), A-massecuite, A-molasses, A-sugar and affinated sugar from the mixed juice collected at the factories. A hot lime clarification method was followed and clarification took place in a 150 L clarifier tank. Phosphoric acid (25% H_3PO_4) was added at 50 mg/kg juice to the UCL MJ only. The juice was heated to a light boil with a steam coil, limed to pH 7.2 (95ºC) with milk of lime (MOL; 10%) and then boiled again. Polyanionic flocculant (same as factory: 0.1% of LT027) was added at a dosage of 3 mg/kg juice and the mud allowed to settle for 30 min before CJ was decanted. The CJ was immediately placed in the evaporator feed drum (300 L) and fed from the drum into the plate-type evaporator (Alfa-Laval; 6 m^2 heat transfer area). The evaporator was operated at a steam pressure of between 10 and 20 kPa(g) and the vapour pressure was maintained at -10 kPa(g). The evaporation rate typically varied from 0.8 to 1.2 kg/min. The evaporator was operated on a continuous recycle system and the FES produced was removed at 65-68ºBrix. The FES was then boiled in a pilot vacuum pan at approximately 65°C and a pressure of -90 kPa(g).

The syrup was concentrated to approximately 70°Brix, seeded with a small amount of slurry (ground refined sugar crystals in methylated spirits, SASTA Lab Manual, 1985, pp 160-162), and crystals were allowed to grow. The resulting massecuite was crudely separated into A-sugar and A-molasses in a laboratory centrifugal without adding wash water and without control of temperature or elapsed time. The pilot plant A-sugar does not represent factory A-sugar and is in particular much smaller in size (<100 μm). Some of the A-sugar produced was mingled with a saturated refined sugar solution and centrifuged again. The remaining sugar was allowed to air dry. This washed sugar (200 g) was then mixed with a further saturated refined sugar solution (400 g) for 15 min and then filtered under vacuum through a sinter glass (coarse) funnel. This mix was further rinsed and filtered with (i) saturated refined sugar solution (200 g), (ii) 95% methanol saturated with refined sugar solution (400 cm^3), and (iii) 100% methanol saturated with refined sugar (200 cm^3). The final produced affinated sugar was then left to air dry.

Laboratory clarification tests

Mixed juice (1 L) in a covered stainless steel container with a heating element was heated with constant magnetic stirring to boiling. Each test was done in duplicate with and without the addition of phosphoric acid. The acid (25% H_3PO_4) was added at 50 mg/kg juice to the MJ before heating. Milk of lime (MOL; 10%) was added dropwise to the hot juice with stirring until the juice pH reached 7.2 (95°C). The heated, limed juice was then brought to a second boil for 1 min to remove interfering bubbles, and flocculant (LT027; 0.1%) solution was added at 3 mg/kg using a pipette. The juice was immediately poured into a settling tube (3.5 cm $\phi \times 32$ cm) in a glass water bath (96°C) to a volume of 250 cm^3 and stoppered. Mud level readings were taken between 0 and 18 min, and also after 30 min settling. The tube was then removed and the contents cooled to room temperature (~25°C). Brix and pH of the CJ were measured.

Settling rates and mud volumes

Settling rate and mud volume (MV) measurements and calculations were based on the methods of Schmidt (1953) and Lionnet and Ravnö (1976) with modifications. Mud volume (cm^3) was plotted against time (min). Break point (s) was the time it took for the mud to settle to half its original volume. The mud volume after 18 (MV_{18}) and 30 min (MV_{30}) were read directly and expressed as percentage of the original volume.

Sample analyses

Oscillatory Deformation Rheometry (ODR). Mechanical spectra of syrup, molasses, and massecuite samples were recorded on a AR1000 Advanced [Oscillatory Deformation] Rheometer (TA Instruments, USA) using cone and plate geometry of angle 2° and diameter 4.0 cm. Sample temperature was 20°C controlled to within ± 0.01°C by a pelicular cell. Readings were taken 1 min after the sample had attained thermal equilibrium. A frequency sweep of 0.1 to 1000 rad/s was applied to each sample.

Digital micrographs of settled pilot plant and laboratory clarification muds were taken with an Olympus Tokyo light microscope with an attached microscope digital camera (DCM300, 3 megapixels) and using ScopePhoto^{TM} v2.0 software. At least five random sub-samples of each sample were photographed at 10x magnification after adding a few drops of water.

Conductivity ash in the samples was determined according to ICUMSA Method GS1/3/4/7/8/-13 (1994). The specific conductivity of a juice at a concentration of 5 g/100 cm^3 or less was determined and compared to the specific conductivity of water. The equivalent ash content of the sample as per convention was calculated by the application of a generic conversion factor.

Gums. The total gums in mass percentage were determined according to SMRI method TM 019 (2006) in which the mass of gums was measured gravimetrically after precipitation with acid alcohol, drying at 105°C and incineration at 650°C.

Sucrose, fructose and glucose were measured using gas chromatography (GC) according to SASTA Method 1.9 (2005).

Other

Statistical analyses were undertaken using Microsoft™ Office Excel (2003).

Expected recoverable crystal (ERC) was calculated according to the formula give in the SASTA Laboratory Manual (Chapter 1: 6-7). The constants for the 2008/09 season were: a=0.997709904; b=0.5470134; and c=0.0201082.

Results and Discussion

Trash levels at three factories

Trash level measurements for each trial were an average from four replicates. Since the cane variety (N12), age (20-24 months) and growing conditions (KZN Midlands) for the NB and UCL trials were similar, these measurements were considered together. The total trash levels for the N12 field cane (NB and UCL) were 30% (m/m on a wet basis) of the material, comprising 9% BL, 12% GL and 9% GPR (Figure 1 and Table 1). The total trash levels for the field N27 cane (FX) were 25%, comprising 7% BL, 12% GL and 7% GPR (Figure 2 and Table 2). The amount of trash delivered to the factory was always lower than the field cane trash because some of the trash was either burnt or left in the field by the combine harvester.

Figure 1. UCL & NB N12 field cane.

Figure 2. FX N27 field cane.

For the NB trial, the N12 green billeted cane contained a total of 17.4% trash (Figure 3) and the burnt billeted cane contained a total of 11.3% trash (Figure 4). In comparison, the burnt whole-stalk cane comprised of only attached and associated BL of less than 2% of the sample (Figure 5), indicating that the manually-harvested burnt whole-stalk cane was topped and had most BL manually removed. (Visually, ~2-5% (volume) BL was associated with the stalks; sampling was difficult.) It was quite clear from these results that there will always be some associated trash delivered to the factory, even with 'clean burnt cane' from a near-perfect burn and diligent manual cleaning in the field.

Figure 3. NB N12 green billeted cane.

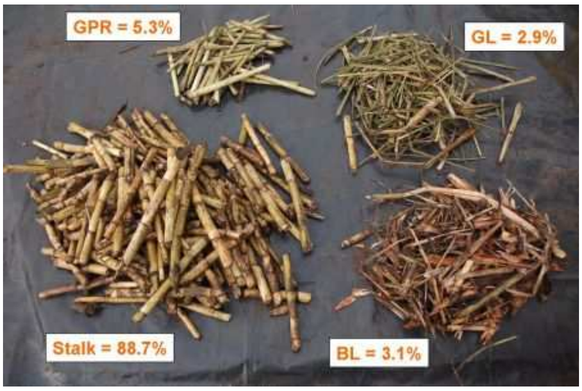

Figure 4. NB N12 burnt billeted cane.

Figure 5. NB N12 burnt whole-stalk cane.

Figure 6. UCL N12 green billeted cane.

Figure 7. UCL N12 burnt billeted cane.

At UCL the green billeted cane contained 11.5% total trash (Figure 6) and the burnt billeted cane contained 10.8% total trash (Figure 7). Compared to the NB cane, there were no significant differences between the UCL total trash levels, most probably because of the wet and dry conditions during the NB and UCL harvesting, respectively. Overall, the NB trial showed marked significant differences for individual and total trash levels between the green and burnt billets while the UCL trial showed no significant differences except for BL (Table 1). Furthermore, the GL/BL ratios between the green and burnt billets were 0.8 and 0.9 at NB while significantly different ratios of 0.5 and 2.1 (Table 1) were observed at UCL, the effects of which have yet to be explored.

Table 1. Trash levels of N12 cane (NB and UCL) on a wet material mass basis (%).

Trash material	Field cane[*]	NB 1 Green billets[†]	NB 2 Burnt billets[†]	NB 3 Burnt whole-stalk[†]	UCL 1 Green billets[†]	UCL 2 Burnt billets[†]
Stalk	70.0	82.7a[⌘]	88.7b	98.3	88.5a	89.2a
BL	9.4	5.2a	3.1b	1.4	4.6a	1.9b
GL	11.8	3.9a	2.9a	0.3	2.4a	3.9a
GPR	8.8	8.3a	5.3b	0.0	4.5a	5.0a
Total Trash (BL+GL+GPR)	30.0	17.4a	11.3b	1.7	11.5a	10.8a
GL/BL ratio	1.6	0.8a	0.9a	n/a[✪]	0.5a	2.1b

[*] *Average of 2 replicates;* [†] *Average of 4 replicates*

[⌘] *The same lower case letters represent no statistical differences (P<0.05) among the billeted cane types for an individual material and factory only*

[✪] *n/a = not applicable*

Table 2. Trash levels of N27 cane (FX) on a wet material mass basis (%).

Trash material	Field cane[*]	Green billets[†]	Burnt whole-stalk[†]
Stalk	75.5	88.7a[⌘]	89.8a
BL	6.6	3.7a	0.9b
GL	11.5	2.8a	3.2a
GPR	6.5	4.8a	6.1b
Total Trash (BL+GL+GPR)	24.5	11.3	10.2
GL/BL ratio	1.8	0.8	3.7

[*] *Average of 2 replicates;* [†] *Average of 4 replicates*

[⌘] *The same lower case letters represent no statistical differences (P<0.05) between the green billets and burnt whole-stalk cane for an individual material*

For the N27 variety (FX), the green billeted cane contained 11.3% trash (Figure 8) and the burnt whole-stalk cane 10.2% trash (Figure 9). As expected, the burnt cane contained very little BL. During the NB and UCL trials, burnt whole-stalk cane could be used as a "control" to represent the type of cane that the factory received under normal operational conditions; the burnt whole-stalk cane contained only attached and associated BL of less than 2% of the sample. At FX there was almost no difference between the total trash levels of the green billets and burnt whole-stalk cane, although the ratios of types of trash varied markedly. These results were primarily due to the practice of not removing the tops in the field.

Figure 8. FX N27 green billeted cane.

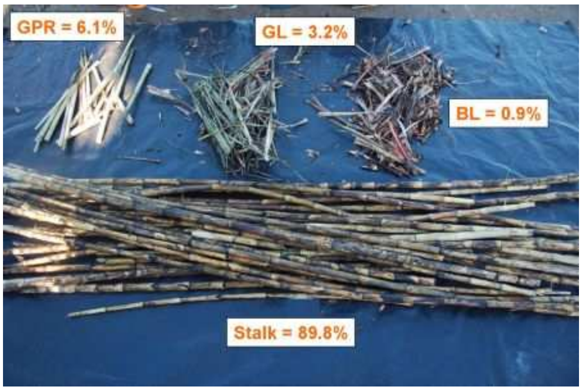

Figure 9. FX N27 burnt whole-stalk and GPR.

Trash expressed on a dry mass basis

The use of sugarcane trash as a biomass source is heavily dependent on the amount of dry mass available for energy or bio-product production. For this reason, the average % materials on a dry mass basis were also calculated. Results for the N12 variety (NB and UCL) are shown in Table 3 and for the N27 variety (FX) are shown in Table 4.

Table 3. Trash levels of cane of N12 trial cane on a dry material mass[*] basis (%).

Trash Material	Field Cane	NB 1 Green billets	NB 2 Burnt billets	NB 3 Burnt whole-stalk	UCL 1 Green billets	UCL 2 Burnt billets
Stalk	58.9	75.0	83.7	95.3	80.9	86.1
BL	22.4	15.2	9.3	4.3	13.4	5.7
GL	13.6	4.5	3.5	0.4	2.7	4.8
GPR	5.2	5.3	3.5	0.0	2.9	3.4
Total Trash (BL+GL+GPR)	41.1	25.0	16.3	4.7	19.1	13.9
GL/BL ratio	0.6	0.3	0.4	n/a	0.2	0.8

[*] *Percent mass of dry material was calculated as Wet Mass × (100 – % Moisture Content)/Total Plant Dry Mass × 100. Average moisture contents for the N12 whole-stalk field cane were: Stalk=73.4%, BL=15.2%, GL=66.7% and GPR=81.3%.*

When calculated on a percent dry mass basis (Table 3) it was observed that a large portion of the field cane total dry mass (41.1% for N12 and 33.2% for N27) was, in fact, trash. This percentage will vary with variety and age (Eggleston *et al.*, 2009a), but were similar to results reported for South African sugarcane by Purchase *et al.* (1990).

Table 4. Trash levels of the N27 trial cane on a dry material mass[*] basis (%).

Trash type	Field Cane	Green billets	Burnt whole-stalk
Stalk	66.8	83.4	89.0
BL	16.6	9.9	2.4
GL	12.0	3.2	3.7
GPR	4.5	3.5	4.8
Total Trash (BL+GL+GPR)	33.2	16.6	11.0
GL/BL ratio	0.7	0.3	1.5

[*] *Percent mass of dry material was calculated as Wet Mass × (100 – % Moisture Content)/Total Plant Dry Mass × 100. Average moisture contents for the whole-stalk field cane were: Stalk=69.2%, BL=12.1%, GL=63.5% and GPR=75.7%.*

The dry mass associated with trash that was delivered to the factories with green billets (25.0% for NB, 19.1% for UCL and 16.6% for FX) was still considerable and higher than in some other cane producing countries, particularly those harvesting 12 month old cane (Eggleston *et al.*, 2009a). Moreover, these results highlight the abundance of dry mass that South Africa is not currently using for cogeneration or production of biomass products such as bioethanol. Results from Tables 3 and 4 also show that the GL/BL ratios were always lower than when calculated on a wet mass basis (Tables 1 and 2). These results are mostly explained by the low BL moistures.

Contribution of trash to fructose, glucose, sucrose and colour loads – N12 and N27 cane

The main sugars (sucrose, fructose and glucose by GC) and colour at pH 7.0 of the N12 cane material extracts, quoted on a sample basis, are listed in Table 5 (UCL cane).

Table 5. Sucrose, fructose, glucose and colour quoted on a sample basis[*] of N12 sugarcane material (UCL).

Type	Material	Fructose (%)	Glucose (%)	Sucrose (%)	ICUMSA Colour (IU)
Field cane	Green leaves	0.79	0.65	0.42	189,400
	Brown leaves	0.00	0.00	0.08	nd[†]
	GPR	0.72	0.63	1.26	123,430
	Stalk	0.18	0.18	14.55	11,830
Green billets	Green leaves	0.79	0.56	2.04	178,530
	Brown leaves	0.91	0.74	2.64	161,120
	GPR	0.93	0.75	2.55	132,250
	Stalk	0.18	0.12	16.80	13,720
Burnt billets	Green leaves	0.69	0.46	6.90	174,350
	Brown leaves	0.50	0.41	8.59	105,520
	GPR	0.60	0.45	4.71	70,320
	Stalk	0.12	0.09	18.15	16,730

[*] *Brix from each sample was extracted by cold digestion; sugar results are expressed on the original sample and not on the extract*

[†] *nd = not determined*

On a sample basis, generally, the GL had the highest colour, followed by BL, GPR and the stalks with the lowest colour. In contrast, when colour was further calculated on a % wet material mass basis, which better reflects the actual load of colour deliverable to the factory (Table 6), the colour loads by the different materials were much different. In particular, the stalk contributed much more to colour at the factory than either GL or BL, just because of the much greater mass of stalks. Table 6 also shows the main sugars expressed on a % wet material mass basis, indicating relative contributions to the consignment.

Table 6. Sucrose, fructose, glucose and colour loads[*] of N12 trash quoted on a % wet material mass basis – indicates load delivered to factory (UCL).

Type	Material	% on wet material mass basis			
		Fructose	Glucose	Sucrose	Colour load[*]
Field cane	Green leaves	0.10	0.08	0.05	22,260
	Brown leaves	0.00	0.00	0.01	nd[†]
	GPR	0.06	0.05	0.11	10,860
	Stalk	0.13	0.13	10.20	8,280
Green billets	Green leaves	0.02	0.01	0.05	4,230
	Brown leaves	0.04	0.03	0.12	7,400
	GPR	0.04	0.03	0.12	6,000
	Stalk	0.16	0.11	14.87	12,140
Burnt billets	Green leaves	0.03	0.02	0.27	6,840
	Brown leaves	0.01	0.01	0.16	1,950
	GPR	0.03	0.02	0.24	3,640
	Stalk	0.11	0.08	16.19	14,930

[*] *Colour load = ICUMSA colour × % wet material mass*

[†] *nd = not determined*

Similarly, the main sugars (sucrose, fructose and glucose) and colour of the N27 cane material extracts, quoted on a sample basis, are listed in Table 7 (FX cane).

Table 7. Sucrose, fructose, glucose and colour quoted on a sample basis[*] of N27 sugarcane materials (FX).

Type	Material	Fructose (%)	Glucose (%)	Sucrose (%)	ICUMSA Colour (IU)
Field cane	Green leaves	0.56	0.51	2.04	296,650
	Brown leaves	0.33	0.33	0.00	1,208,470
	GPR	0.36	0.36	4.44	65,510
	Stalk	0.21	0.21	15.39	11,530
Green billets	Green leaves	0.37	0.51	0.05	226,240
	Brown leaves	0.74	0.74	0.00	469,780
	GPR	0.81	0.87	1.56	84,670
	Stalk	0.15	0.21	15.69	15,460
Burnt whole-stalk	Green leaves	0.51	0.51	3.75	153,530
	Brown leaves	0.50	0.66	5.12	173,850
	GPR	0.63	0.60	3.96	44,290
	Stalk	0.33	0.36	14.70	12,330

[*] *Brix from each sample was extracted by cold digestion; sugar results are expressed on the original sample and not on the extract*

Results were similar to those observed for the N12 variety (Tables 5 and 6). Generally, on a sample basis (Table 7) the BL had the highest colour, followed by GL, GPR and the stalks with the lowest colour. In contrast, when colour was calculated on a % wet material mass basis (Table 8), the stalk from the burnt whole-stalk cane contributed much more to the colour load at the factory than the GL or BL, because of the much greater mass of stalks. The contribution of colour from stalks to delivery of colour to the factory should, therefore, not be underestimated. With the green billeted cane, the green leaves also contributed significantly to the colour load. This approach also clearly shows the larger contribution of reducing sugars by the GPR and stalk than previously considered. Table 8 also shows the main sugars expressed on a % wet material mass basis, indicating relative contributions to the consignment.

Table 8. Sucrose, fructose, glucose and colour loads[*] of N27 trash quoted on a % wet material mass basis – indicates load delivered to factory (FX).

Type	Material	% wet material mass basis			
		Fructose	Glucose	Sucrose	Colour load[*]
Field cane	Green leaves	0.06	0.06	0.23	34,060
	Brown leaves	0.02	0.02	0.00	79,280
	GPR	0.02	0.02	0.29	4,250
	Stalk	0.16	0.16	11.61	8,700
Green billets	Green leaves	0.01	0.01	0.00	6,420
	Brown leaves	0.03	0.03	0.00	17,350
	GPR	0.04	0.04	0.07	4,020
	Stalk	0.13	0.19	13.92	13,710
Burnt whole-stalk	Green leaves	0.02	0.02	0.12	4,890
	Brown leaves	0.00	0.01	0.04	1,500
	GPR	0.04	0.04	0.24	2,720
	Stalk	0.30	0.32	13.20	11,070

[*] *Colour load = ICUMSA colour × % wet material mass*

It is interesting to note from Tables 6 and 8 that the transport and processing of the additional trash materials resulted in a 1.9 and 4.0% increase in the actual mass of sucrose that was delivered to the UCL factory for green and burnt billeted cane, respectively, and a 0.5 and 3.0% increase in the mass of sucrose that was delivered to the FX factory for green billeted and burnt whole-stalk cane, respectively. This increase is due to the sucrose present in the GL, BL and GPR and is often overlooked when considering these issues. Despite this increase in sucrose content, factory DAC and MJ purities are still negatively affected by the presence of trash, also bearing in mind the considerable amount of non-pol associated with the trash. (This is clearly shown in the next section, Table 9.) In the field cane, the trash would have caused a 1.6% and 4.3% increase (relative, not absolute) in mass of sucrose received at UCL and FX respectively, had all of it been delivered to the factory.

Direct analysis of cane (DAC) – N12 variety

NB cane – comparing green and burnt billeted and burnt whole-stalk cane

Results from the analyses of different DAC samples collected continually over the three trials at NB are listed in Table 9.

Table 9. Average NB DAC results for green and burnt billets and burnt whole-stalk cane (CTS laboratory results).

Trial cane (n)	Quantifier	Pol (%)	Brix (%)	Purity (%)	Fibre* (%)	Moisture (%)
Green billets (15)	Average	13.36	15.20	87.84	14.28	70.52
	SD	0.49	0.36	1.36	0.69	0.50
	RSD (%)	3.67	2.34	1.54	4.85	0.70
Burnt billets (15)	Average	13.66	15.42	88.58	14.37	70.21
	SD	0.27	0.22	0.79	0.74	0.73
	RSD (%)	1.96	1.40	0.89	5.13	1.04
Burnt whole-stalk (8)	Average	15.91	17.27	92.12	15.76	66.97
	SD	0.10	0.14	0.33	1.68	1.62
	RSD (%)	0.66	0.83	0.35	10.66	2.42
F-tests	P1 (0.05)	0.04	0.05	0.08	0.74	0.18
	P2 (0.05)	0.00	0.00	0.00	0.01	0.00
	P3 (0.05)	0.00	0.00	0.00	0.01	0.00

n ≡ number of samples; SD ≡ standard deviation; RSD ≡ relative standard deviation
P1 ≡ probability that values for the green and burnt billets differ significantly
P2 ≡ probability that values for the green billet and burnt whole-stalk differ significantly
P3 ≡ probability that values for the burnt billet and whole-stalk differ significantly
($P<0.05$ indicates a significant difference at the 5% level)
**Calculated values*

There was a significant difference for pol and Brix values between the green and burnt billeted cane, with the values for burnt billets being higher, as expected due to the lower trash levels. The purity values calculated from the same pol and Brix values were not significantly different, indicating that the ratio between pol and non-pol in the samples remained similar. However, this lack of a significant difference may also be due to the larger standard deviation associated with the purity calculation. Calculated fibre and moisture levels between the billet trials were, most unexpectedly, not significantly different.

In comparison to the billet trials only, there were significant differences for all the measured parameters between the billeted and whole-stalk cane. The DAC moistures of the burnt whole-stalk were significantly lower than for the billeted cane resulting in higher fibre values, which may be due to a number of reasons. Note that the total trash levels between the NB green (17.4%) and burnt (11.3%) billets differed markedly, while the GL/BL ratios were of the same order (0.8-0.9) (Table 1). The wet conditions at NB most likely decreased the combine harvester throughput rate which increased the trash amounts delivered to the factory.

The analyses of DAC samples taken continually over the two trials are listed in Table 10.

Table 10. Average UCL DAC results for green and burnt billeted cane (factory laboratory results).

Trial cane (n)	Quantifier	Pol (%)	Brix (%)	Purity (%)	Fibre* (%)	Moisture (%)
Green billets (15)	Average	13.88	15.32	90.56	16.50	68.18
	SD	0.38	0.33	0.78	1.86	1.82
	RSD (%)	2.74	2.14	0.86	11.24	2.66
Burnt billets (9)	Average	14.28	15.72	90.82	14.49	69.79
	SD	0.27	0.29	0.86	0.37	0.50
	RSD (%)	1.91	1.82	0.95	2.56	0.72
F-test	P (0.05)	0.02	0.01	0.51	0.01	0.02

n ≡ number of samples; SD ≡ standard deviation; RSD ≡ relative standard deviation

P ≡ probability that values for the green and burnt billets differ significantly (P<0.05 indicates a significant difference at the 5% level)

**Calculated values*

The pol, Brix, moisture, and fibre values were significantly different between the green and burnt billets, while the purities of the samples did not differ significantly. As indicated earlier (Table 1), the GL to BL ratios between the green and burnt billets were 0.5 and 2.1 even though the total trash was around 10.8-11.5% (GPR levels were similar). These results suggest that the types of trash (specifically GL or BL) rather than total trash amount had an effect on the pol, Brix and purity values.

Combined NB and UCL DAC results

To assess the effect of the trash on the quality parameters of the N12 DAC samples, the NB and UCL results were combined and evaluated for trends against the total trash values. Thought it is recognised that the five sets of cane were from three different fields with the associated limitations in terms of cane quality variations which are well established, trends are nonetheless informative. The trash levels of the billeted cane are shown in Figure 10 with the GL/BL and GL/GPR ratios shown in Figure 11.

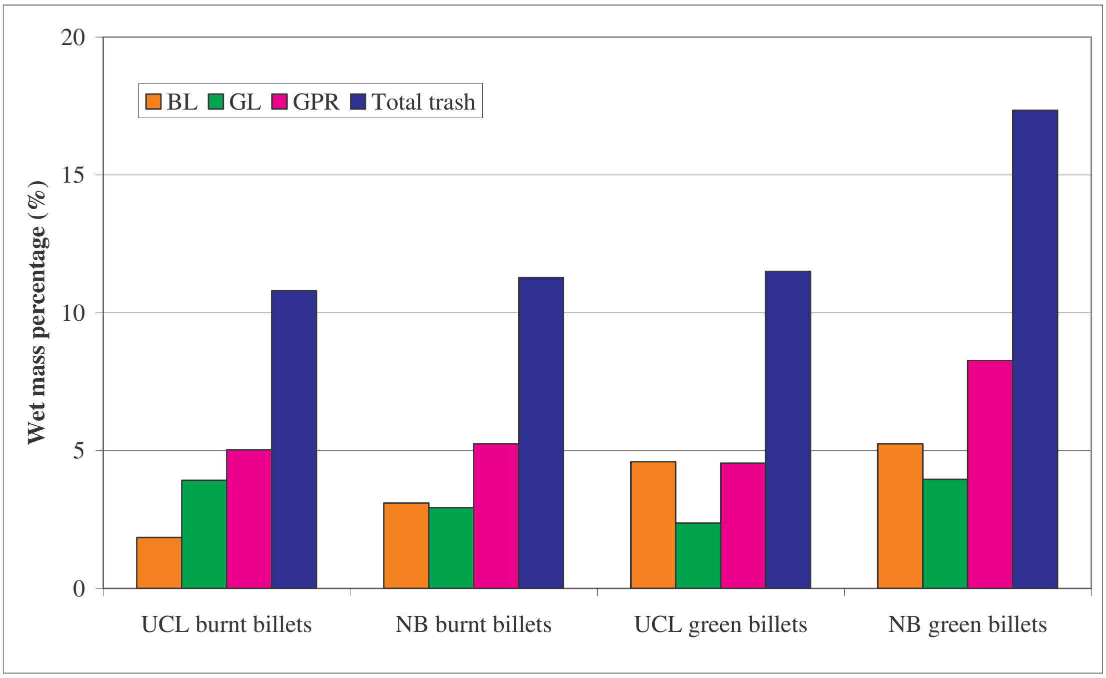

Figure 10. Trash levels of N12 billeted cane.

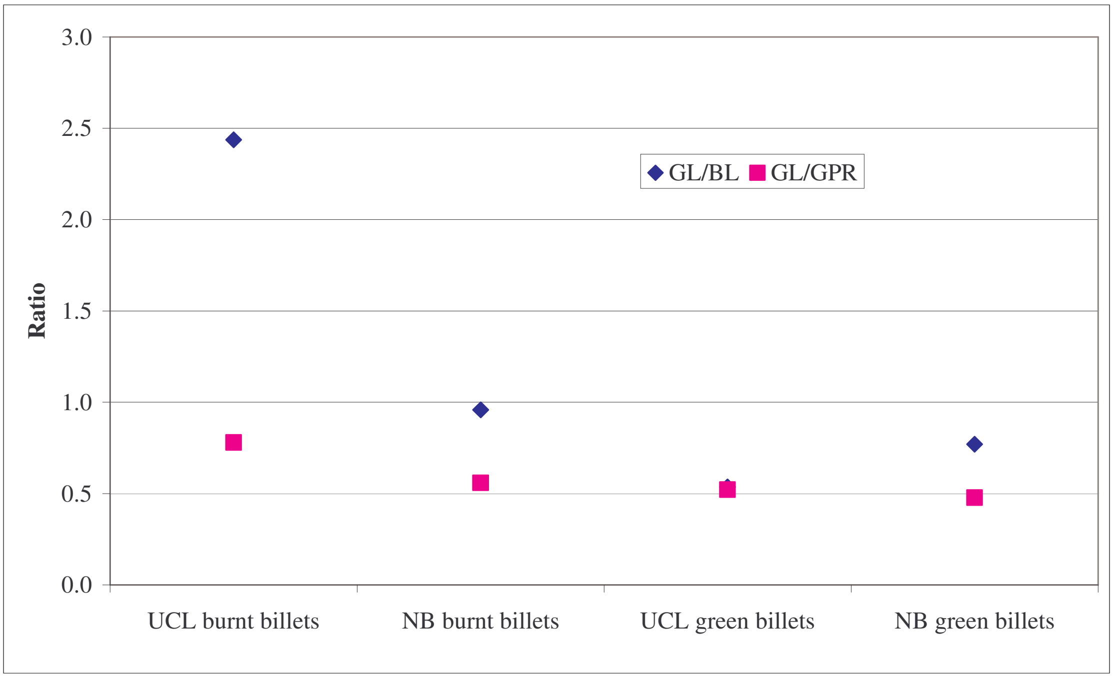

Figure 11. GL/BL and GL/GPR ratios of N12 billeted cane.

The total trash levels for each DAC sample were then compared to the pol, Brix and purity values to define relationships, as illustrated in Figure 12.

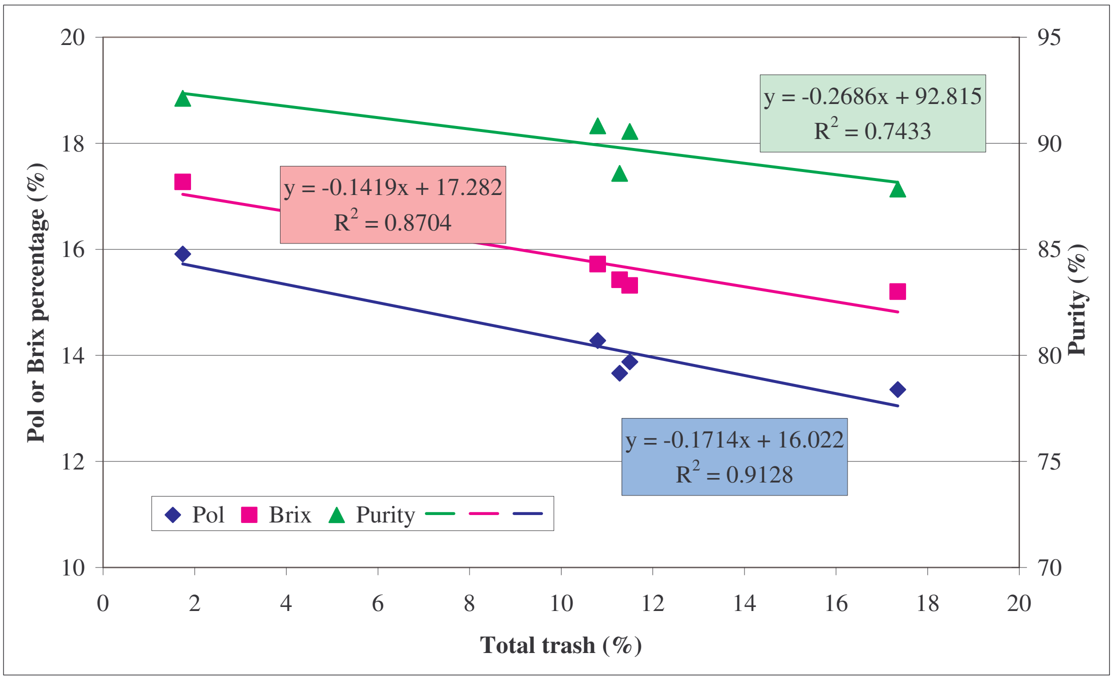

Figure 12. The effect of total trash on pol, Brix and purity of DAC samples.

The average DAC pol and Brix values were strongly correlated with total % trash levels while the purity values were only moderately correlated. Apart from the trash causing lower pol masses, the trash also increased the non-pol impurities as indicated by the decreased purities. The Brix values decreased with increased trash levels which is most likely because of the lower Brix levels in the leaves than stalks.

The total trash levels for each DAC sample were then compared to the moisture and fibre values to define relationships, as illustrated in Figure 13. No significant correlation was observed between DAC fibre and total trash, even when each factory was considered individually. When these results were compared against the different types of trash (GL, BL and GPR) to evaluate if the nature of the trash has a more profound effect on the DAC properties, some trends were evident but the correlations were weak (not shown).

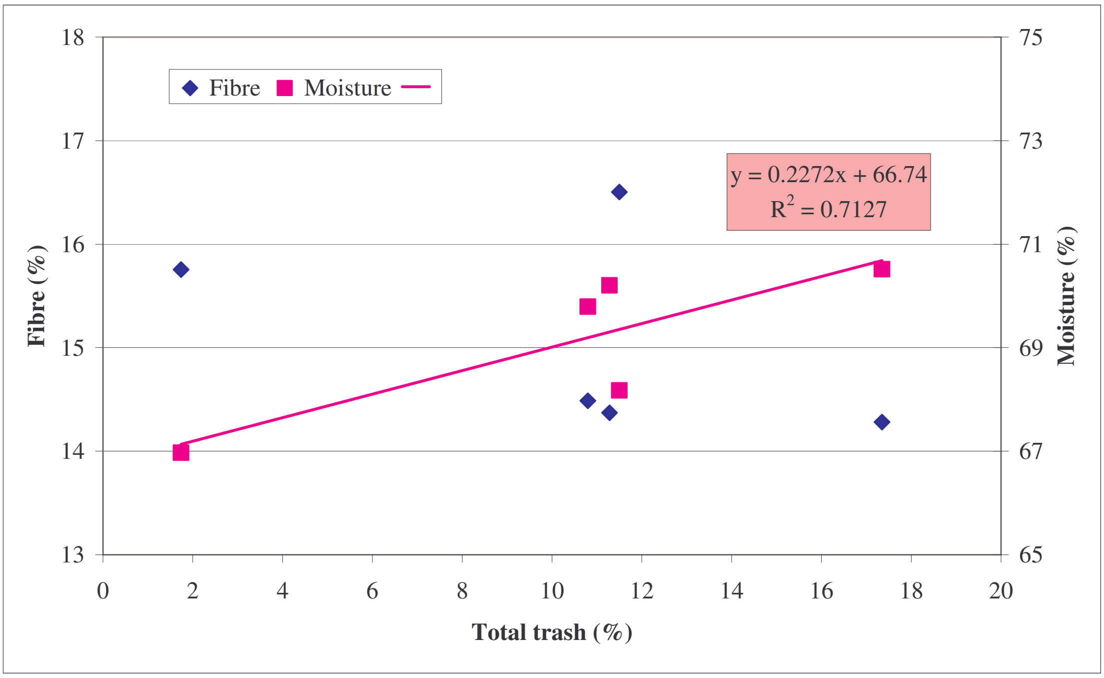

Figure 13. The effect of total trash on fibre and moisture of DAC samples.

The estimated recoverable crystal (ERC) formula is a cane quality index that estimates the percentage of crystal recovery that is possible from a given sample of cane (SASTA Laboratory Manual, Chapter 1: 6-7). ERC values were calculated from the DAC results for the NB and UCL trial cane and compared to the total trash levels as shown in Figure 14. A clear correlation is evident with a 1% increase in trash generally resulting in a 0.2% drop in ERC.

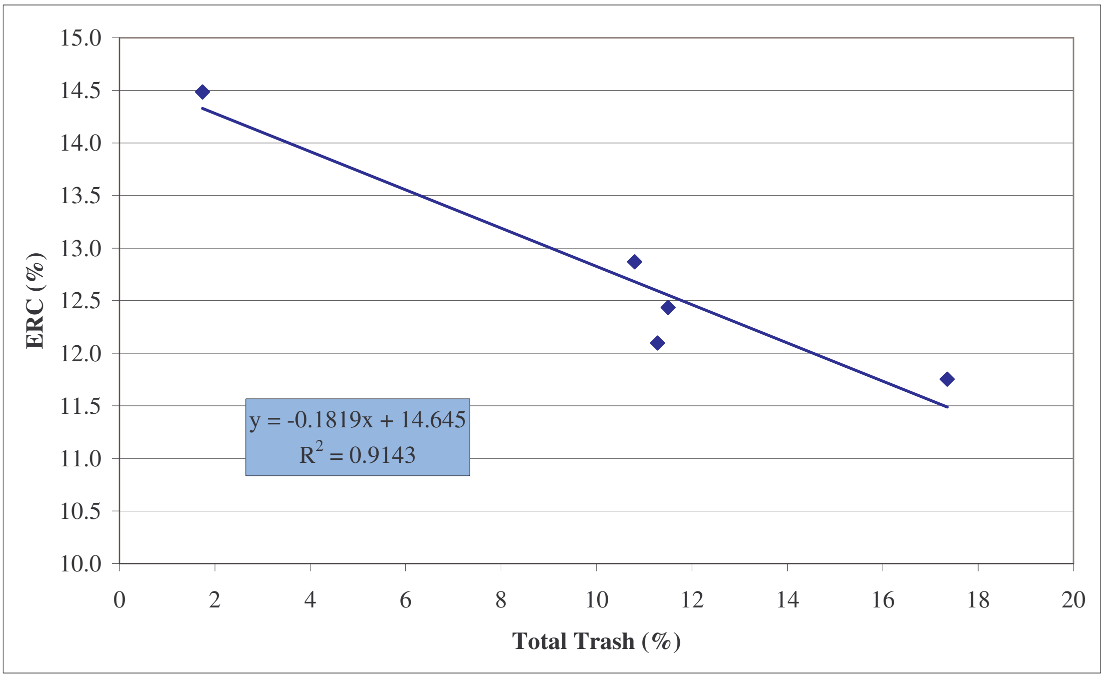

Figure 14. The effect of total trash on the estimated recoverable crystal (ERC).

Bagasse – N12 variety

A composite bagasse sample was analysed for pol, Brix and moisture at NB and UCL on each day. At both factories, there were no significant differences in the average bagasse moisture, pol or purity values for the green billets compared to the burnt billets or between billets and burnt whole-stalks. These results indicate that the harvesting methods had no effect on the quality of the bagasse produced. The average pol in bagasse was 1.5% at NB and 1.5% at UCL. The average purity of bagasse was 58.5% at NB and 57.8% at UCL. The average moisture in bagasse was 51% at NB and 49% at UCL.

Mixed juice collected from the factories

The mixed juice (MJ) samples collected from the factories allowed for a direct comparison of the physico-chemical properties of the MJs from the different trials (Table 11).

Table 11. Total trash levels and mixed juice (MJ) analytical results.

Factory	**NB**			**UCL**	
Trial type	**Burnt whole-stalk**	**Burnt billets**	**Green billets**	**Burnt billets**	**Green billets**
Total Trash (%)	*1.74*	*11.28*	*17.35*	*10.81*	*11.50*
MJ Pol (%)	15.46	11.40	11.68	11.51	11.26
MJ Brix (%)	16.80	13.02	13.66	12.83	12.54
MJ Purity (%)	92.02	87.56	85.51	89.71	89.79
MJ Sucrose (%)	15.43	11.50	11.69	11.58	11.31
MJ Fructose (%)	0.19	0.27	0.35	0.16	0.17
MJ Glucose (%)	0.20	0.25	0.38	0.12	0.13
MJ Colour (IU)	14,500	19,900	20,300	23,200	19,100
MJ Conductivity Ash (%)	0.45	0.44	0.45	0.43	0.42

The Brix levels in MJ are generally determined by operational factory settings (such as the imbibition water to cane ratio) and *not* by the cane type or quality. Comparisons can suitably be made on results expressed on a Brix basis. Results were compared with the total trash levels to assess the effect of trash on the MJ quality. Note that the highest and lowest (as well as one of the three intermediate) trash levels were obtained at NB factory (refer to Table 1).

Figure 15 illustrates the effect of total % trash levels on the MJ apparent purity (based on pol) and true purity (based on GC sucrose) values for both NB and UCL factories. A difference of more than 6.5% units was observed due to an increase in trash from 1.7 to 17.4% (Δ=15.7%). Therefore, for every 1% increase in trash there was an approximate 0.4% decrease in MJ purity. Furthermore, the 17.4% trash level is not that unusual for total trash levels delivered to South African factories: at another factory near the coast, up to 25% trash levels were measured in random delivery loads. This is the first time that actual trash levels delivered to a factory have been related directly to MJ parameters in South Africa.

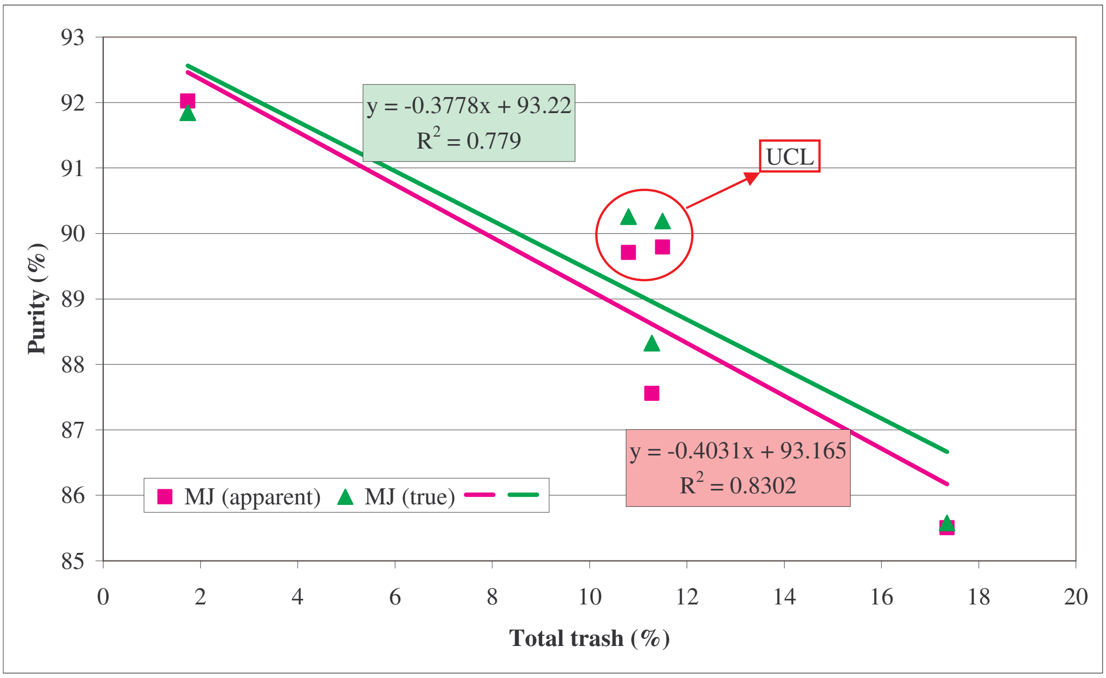

Figure 15. MJ purities *versus* total trash levels.

Correlations between the MJ fructose and glucose and the trash levels (Figure 16) were not as strong when combining data from the two factories. However, a quantitative difference in fructose and glucose was discernable between the two factories, which may be either due to differences in the cane quality, differences in the extraction rates of the reducing sugars between the milling tandem at NB and the diffuser at UCL or possibly differences in enzymatic inversion rates between the two factories. When the NB factory results were evaluated separately the correlation coefficient (R^2) values were more than 0.99 (not shown). Nevertheless, increased trash levels typically caused an increase in the reducing sugars levels in the MJ. This result was expected since the GL and GPR contribute significantly to the reducing sugars in the cane (Tables 5 and 7).

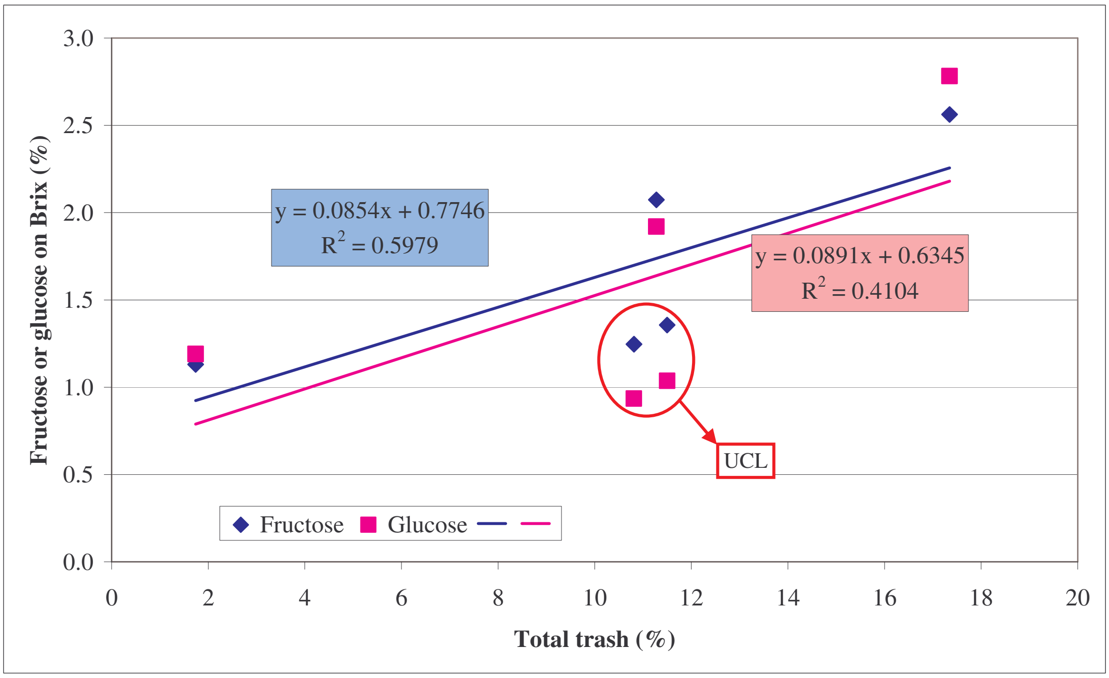

Figure 16. Fructose and glucose versus total trash levels in mixed juice (NB and UCL).

Comparisons of the MJ colour contents with the total trash levels (Figure 17) indicated moderate polynomial correlations. However, the linear correlation was strong when comparing NB data alone. These differences may be due to differences in the original cane quality, but is more likely due to the different factory extraction processes, i.e. diffusion (UCL) versus milling (NB). Diffusion extracts more colour from trash than tandem mills (Rein, 1995). The results confirm previous reports that increased trash levels generally result in increased juice colour at the factory (Scott *et al.*, 1978; Rein, 2005; Kent, 2007) and indicated a 400 MJ ICU colour unit increase per 1% total trash.

In strong contrast to the colour results, the MJ conductivity ash levels were not significantly related to the total trash levels (Figure 17).

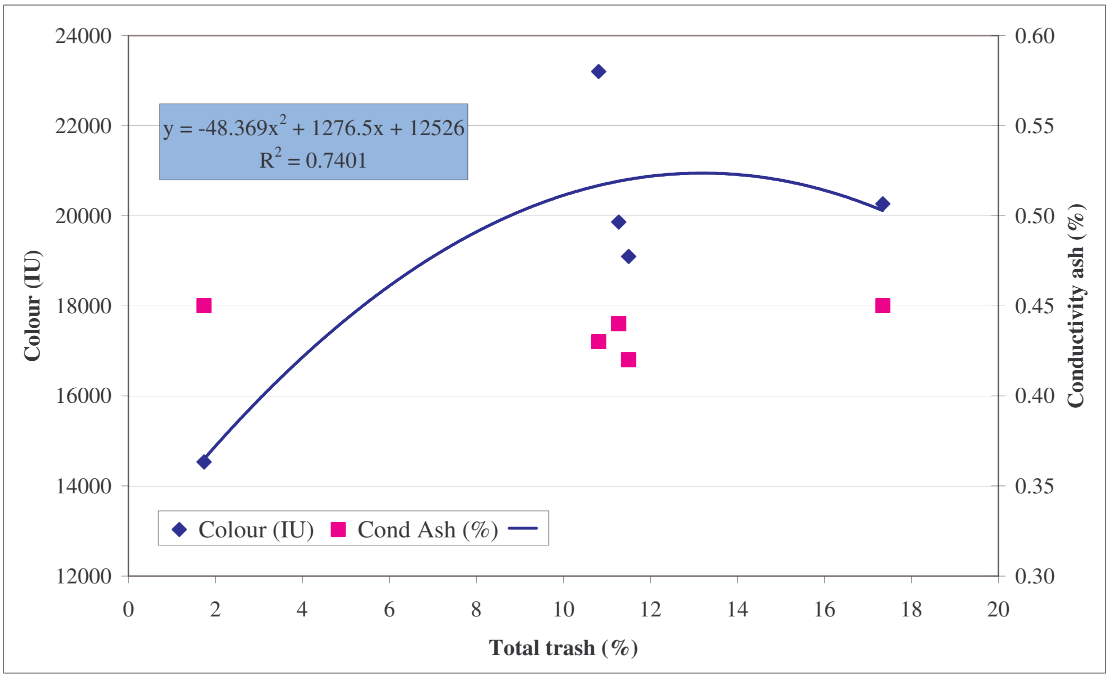

Figure 17. Colour and conductivity ash versus total trash levels in mixed juice.

Mixed juice laboratory settling tests

The natural phosphate levels (measured as P_2O_5) of the MJs for four of the five MJs from the trials were ~260 mg/kg (NB burnt billets was 166 mg/kg). Douwes Dekker (1953) indicated that phosphate levels of 300-350 mg/kg are generally sufficient for successful clarification (i.e. formation of calcium phosphate flocs) and that levels of 100-150 mg/kg require the addition of phosphoric acid. Laboratory clarification and settling experiments were, therefore, done to determine the effect of adding phosphoric acid to the mixed juice prior to clarification, and to compare the settling performances and final mud volumes for the various MJ samples from the NB and UCL trials. For the NB samples no difference could be observed in the clarification when phosphoric acid was added to the MJ. In contrast, for UCL juice without additional phosphoric acid, the mud settled initially but started rising to the surface of the settling tubes within 5 min, suggesting that the density of the secondary flocs was too low. The UCL juice with added phosphoric acid settled well and quickly. These observations were confirmed in repeat experiments.

The settling and mud volume results for the NB samples are listed in Table 12. The mud volumes expressed per unit Brix after 18 and 30 min settling were compared to total trash levels in Figure 18. Excellent correlations were observed particularly after 30 min settling. It is clear from the correlations, that increased trash caused a marked increase in the mud volumes per unit MJ Brix. Furthermore, a 1% increase in trash caused an approximate 0.0125% increase in mud volume % per unit Brix after 30 min settling. (Note that laboratory scale equipment gives an indication only.) Moreover, initial Brix of the MJ was not correlated with actual mud volumes, which is in agreement with results recently reported on the clarification of juices obtained from separated trash and stalk cane materials (Eggleston *et al.*, 2009a).

Table 12. NB laboratory clarification test results.

Cane type	Burnt whole-stalk	Burnt billets	Green billets
Total Trash (%)	*1.7*	*11.3*	*17.3*
MJ Brix (°Bx)	17.0	12.8	13.7
MV_{18} (%)	18.4	14.7	17.6
MV_{30} (%)	17.5	14.3	17.2
CJ Brix (°Bx)	17.3	13.2	13.9
MV_{18}/Bx (% per unit Bx)	1.08	1.15	1.28
MV_{30}/Bx (% per unit Bx)	1.03	1.12	1.26
Breakpoint (s)	48.0	21.0	16.1
Initial settling rate (ml/min)	168.5	376.3	470.5

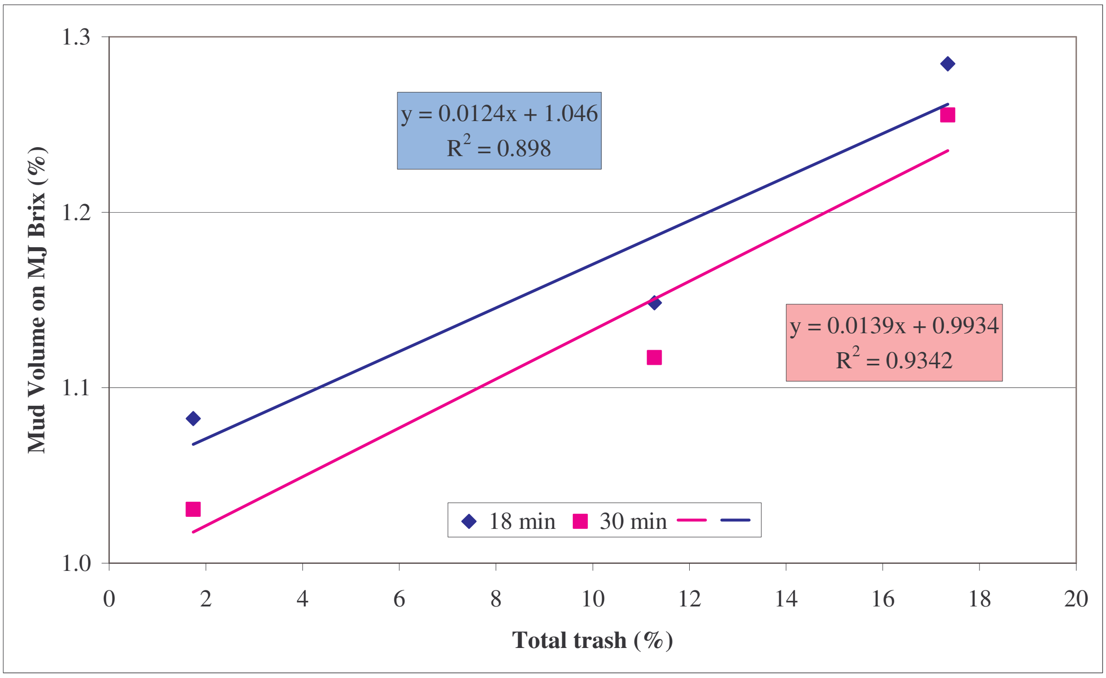

Figure 18: Mud volumes on Brix against total trash levels for NB juice

Settling performances of the MJ were measured as the breakpoint (BP) and initial settling rate (ISR) (Table 12). As expected, there was an excellent correlation (R^2=0.97) between the BP and ISR. Increased initial Brix of the juice had only a mild effect on increasing the breakpoint and, therefore, reducing the settling rate. However, the total trash levels had a much more dramatic effect on the settling rate with excellent relationships between total trash and ISR (R^2=0.99) and BP (R^2=0.94). Overall, the higher the trash amount the faster the settling but the higher the mud volumes per unit MJ Brix. Eggleston *et al.* (2009a) recently reported that the growing point region (GPR) was critical to sugarcane juice clarification and that mud settling was extremely poor where GPR was completely absent in the juice. The increase in GPR in the total trash was, therefore, most likely responsible for faster settling rates. However, the trash was detrimental to the mud consistency and may be detrimental to the turbidity and colour of the clear juice. This issue warrants further investigation.

The main differences observed in the laboratory scale clarification tests between the mill juice from NB and diffuser juice from UCL were in the settling rates and mud volumes. The mill juices settled gradually (typical breakpoints of 20 s were observed) whereas the diffuser juices settled too quickly and with no clear settling line to determine a breakpoint. The typical diffuser juice low mud volumes (Koster, 1995; Rein, 1995) were observed.

The separated muds from all samples were evaluated using digital micrographs. The NB billeted cane muds, both green and burnt, clearly contained pieces of fibre and cellulosic material as well as large dark flocs as can be seen from the micrographs in Figures 19 and 20. In contrast, the mud particles from the burnt whole-stalk were much smaller and uniform, indicating consistently well-formed flocs as shown in Figure 21. No differences could be seen in any of the mud samples where phosphoric acid was added prior to clarification.

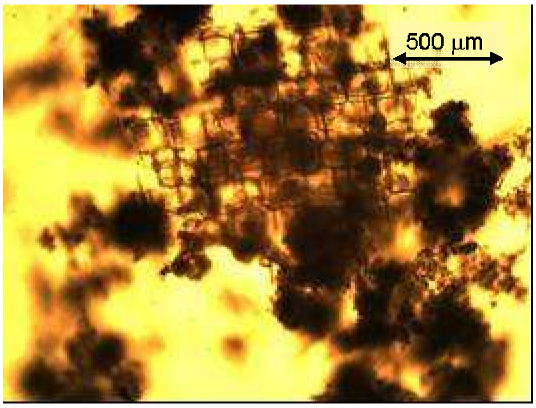

Figure 19. Mud - NB green billets.

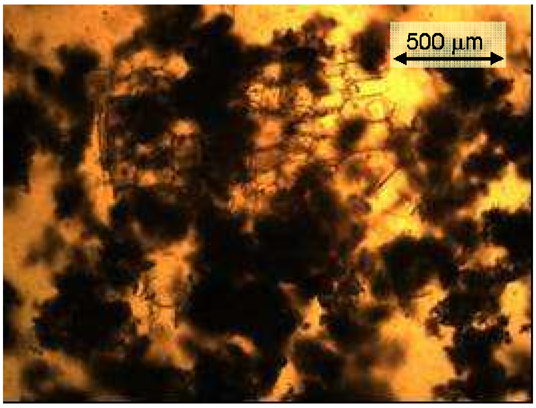

Figure 20. Mud - NB burnt billets.

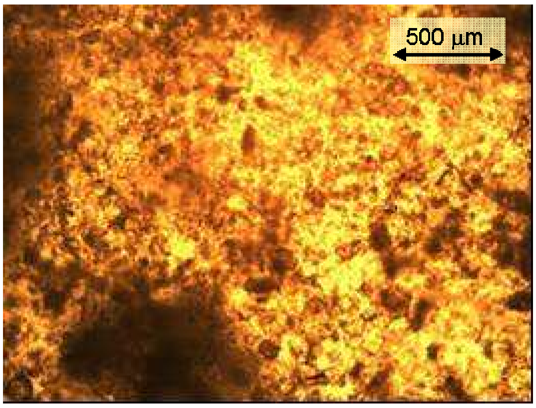

Figure 21. Mud - NB burnt whole-stalk.

The UCL green and burnt billeted cane muds are shown in the micrographs in Figures 22 and 23. Both muds contained pieces of fibre and cellulosic material. For the diffuser juice, the addition of phosphoric acid did not cause any observable change in the mud consistency at the same magnifications, despite the clear differences observed in the volumes and settling behaviour of the muds during the clarification tests. During pilot plant processing, the NB juices were, therefore, clarified without the addition of phosphoric acid, whereas phosphoric acid was added to the UCL juices, according to normal factory practices.

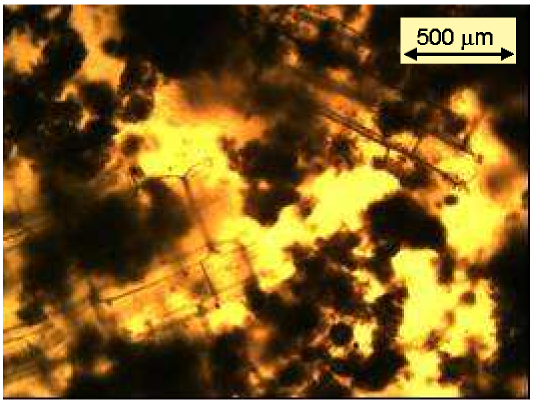

Figure 22. Mud - UCL green billets.

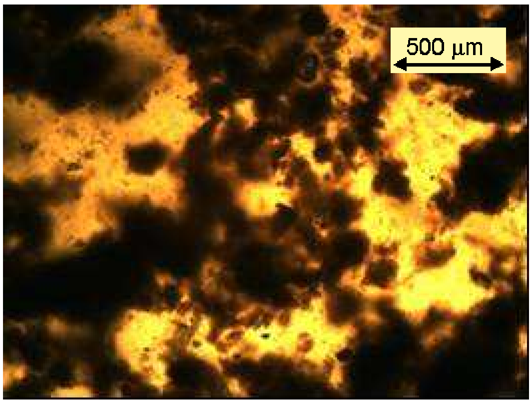

Figure 23. Mud - UCL burnt billets.

Pilot plant processing of mixed juice into A-sugar

The mixed juices from each trial were processed in the SMRI pilot plant and samples of clear juice (CJ), evaporator syrup (FES), A-massecuite, A-molasses, A-sugar and affinated sugar were analysed for a range of physico-chemical properties. All results are shown in Tables A1 and A2 in the Appendix. Note that the average particle size of the A-sugar is typically less than 100 µm and that this sugar therefore does not resemble A-sugar from a factory. Trends are nonetheless informative.

Figure 24 shows the apparent (based on pol) and true (based on sucrose) purity values for the pilot plant samples of the three different types of cane from the NB trials. Both purity values showed a clear subsequential ('knock-on') effect across factory processing, following the order, from worst to best, of green billets < burnt billet < burnt whole-stalk all the way to the massecuite products. This is the first time in South Africa that an unequivocal effect due to the trash levels has been shown on downstream processing using a pilot plant. It also confirms observations made by Kent *et al.* (2003) in syrup. To have demonstrated this effect successfully across a factory would have been practically unfeasible as at least three-day loads of exactly the same cane would have been required. Differences in purities between burnt and green billets at UCL did not differ as much as at NB because of their very similar trash levels (results not shown).

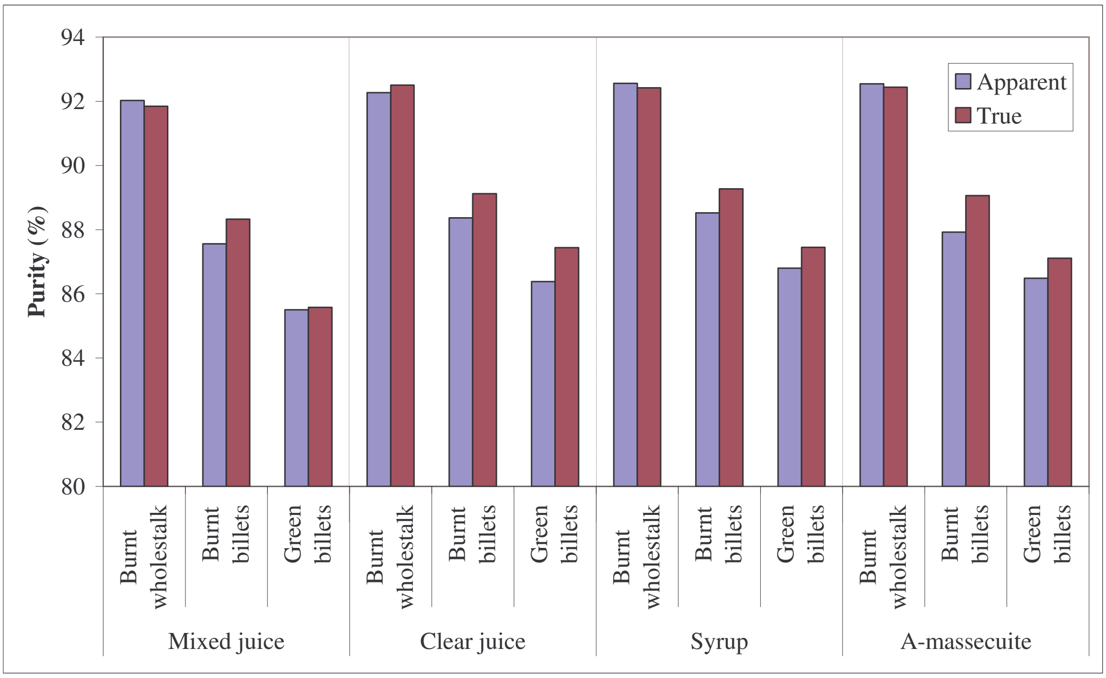

Figure 24. Purity levels in NB pilot plant samples.

The reducing sugars (Figure 25) throughout the pilot plant for the NB samples showed a clear trend following the order, from highest to lowest, of green billets > burnt billets > burnt whole-stalk. This ranking carried through the subsequent processing stages.

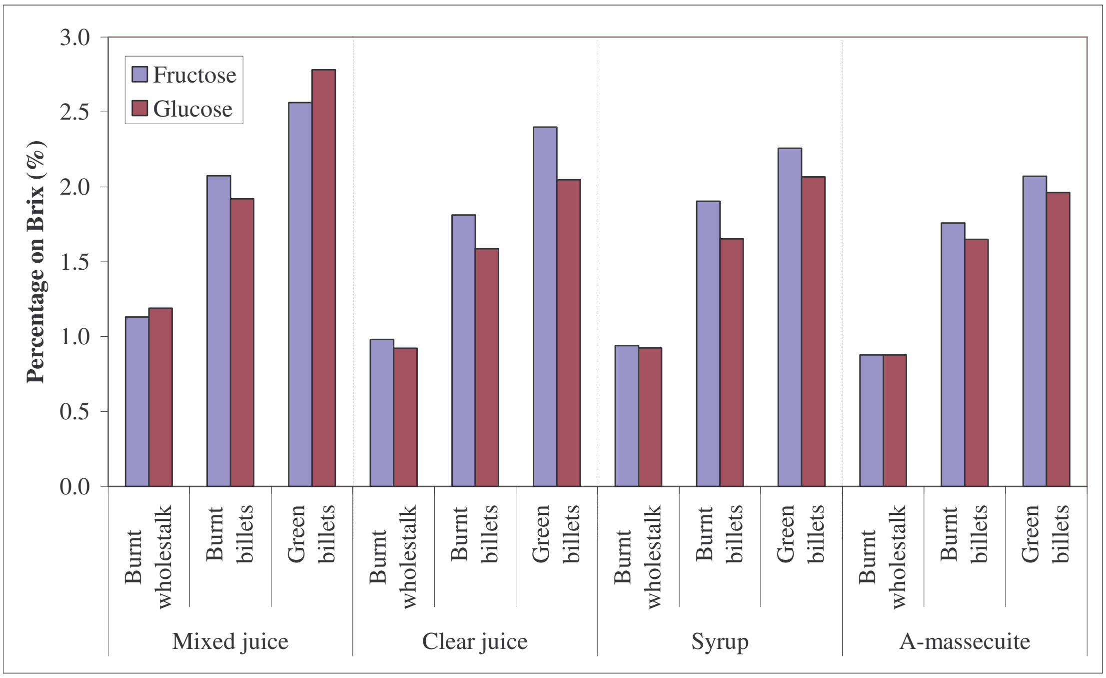

Figure 25. Reducing sugars on Brix in NB pilot plant samples.

The reducing sugars (Figure 26) for the UCL cane were slightly higher in the green compared to the burnt billets. Since the total trash levels delivered to UCL on the two trial days were very similar, this effect is believed mostly due to the type and not the amount of trash delivered, with the green billets having higher GL and lower BL levels compared to the burnt billets (Table 1). While the total trash and GPR levels of these samples were similar for both billet types, the RS/ash ratio trend shows a clear correlation with the GL/BL ratios that were substantially higher in the burnt billets compared to the green billets, being 2.4 and 0.5 respectively.

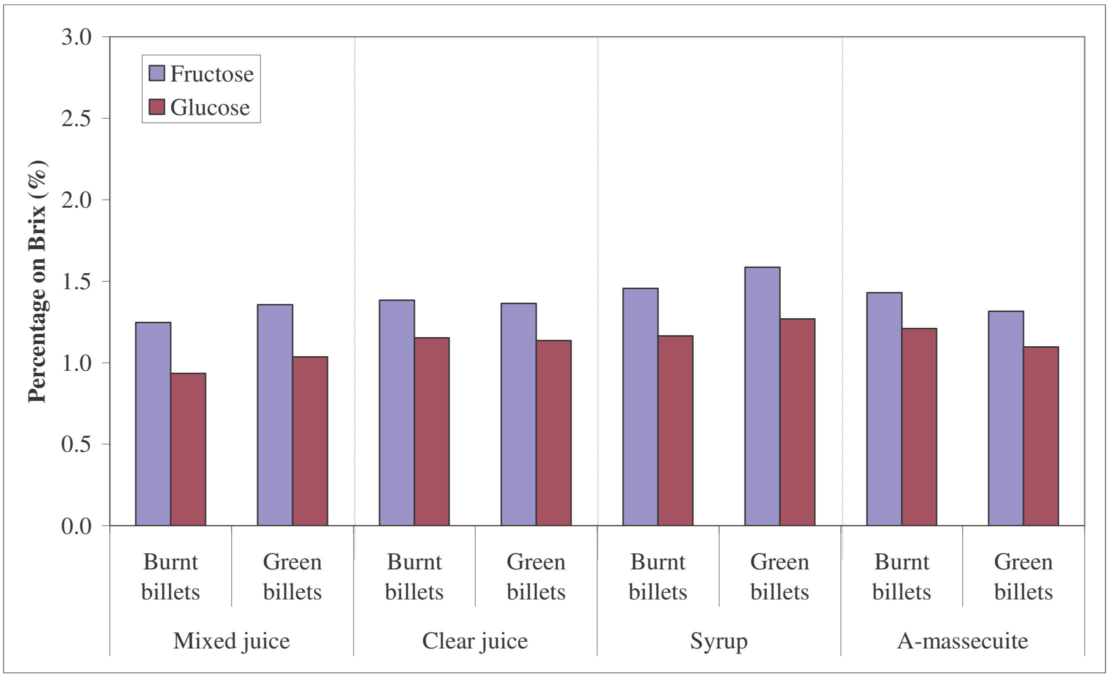

Figure 26. Reducing sugars on Brix in UCL pilot plant samples.

The NB colour results are shown in Figures 27 and 28, and values showed the same trend as the juice was processed across the pilot plant. The final affinated sugar colours were well correlated (R^2=0.98) with the total trash levels indicating that increased trash caused a linear increase in colour. The colour transfer from syrup to affinated sugar was generally ~5% for all of the samples, and although this is higher than the expected 3% (syrup to VHP is 6%; VHP to affinated is 50%), it is consistent for all of the samples and subject to the specific affination procedure used in the pilot plant.

Figure 27. Colour in NB pilot plant samples.

Most of the colour entered the factory with the cane since there is only a small increase in colour from MJ to massecuite. The burnt whole-stalk MJ had markedly lower colour than the two billet types and, generally, green billets exhibited slightly more colour than burnt billets. Furthermore, the pattern of differences in colour for the MJ governed the differences in the other samples formed across the process (Figure 27).

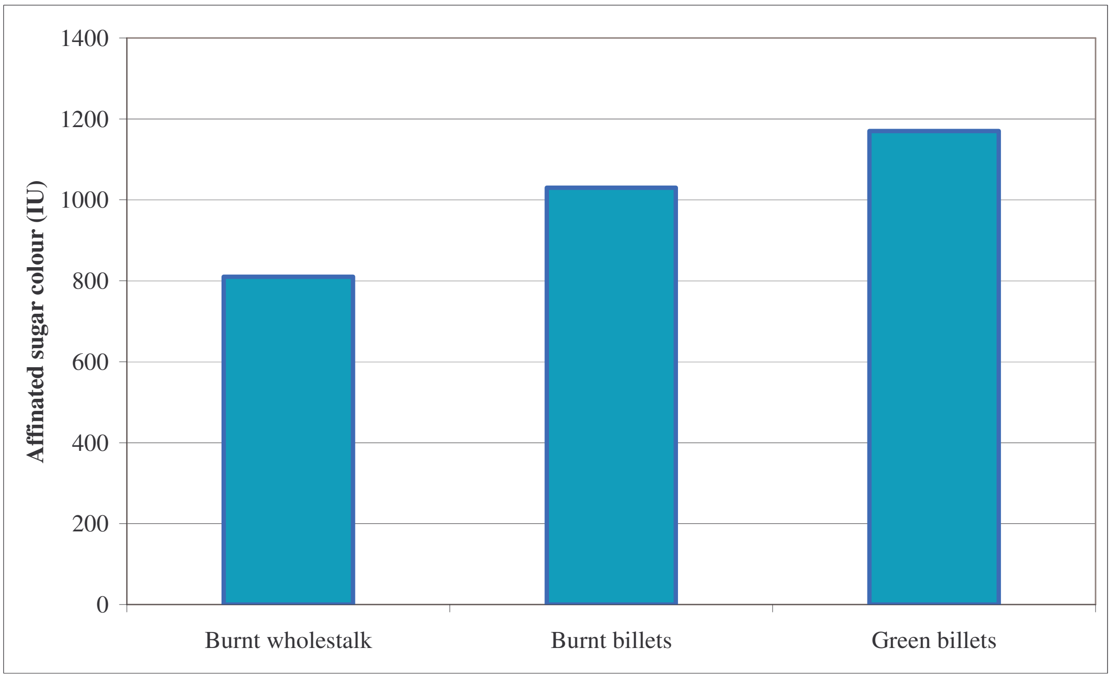

Figure 28. Colour of NB pilot plant affinated sugars.

The drop in colour over clarification from MJ to CJ for the burnt billeted cane may indicate that the colour bodies particular to this harvesting method are most likely more easily removed during clarification (burnt billets contained predominantly more GL compared to green billets which contained more BL). However, since some of this colour reappeared in syrup it may be indicative of analysis errors in either mixed juice or clear juice. The results do emphasise that most of the colour in the factory comes from the cane and very little, comparatively, is formed and degraded across the factory. Molasses colours (not shown) also followed the subsequential effect.

The UCL colour results in Figures 29 and 30 are different to those for NB factory (Figures 27 and 28). There was more colour at UCL, particularly with burnt billets, despite the total trash not being higher. UCL operates a diffuser which is known to produce more colour, especially from GL, than tandem mills (Rein, 1995). This fact most likely explains why the colour of burnt billets was higher than green billets at UCL as they contained more GL (Table 1). Furthermore, unlike NB, the total trash and GPR levels of the UCL samples were similar but the GL/BL ratios were much lower for the green than for the burnt billets, at 0.5 and 2.4, respectively (Table 1). The colour differences may, therefore, also be due to the GL/BL ratios. This hypothesis suggests that the type of trash, as well as the amount of trash, has a much greater effect on the colour of juice and downstream products than previously considered, particularly for diffuser factories (Eggleston *et al*, 2009b). The colour transfer from syrup to affinated sugar in the pilot plant was ~4%.

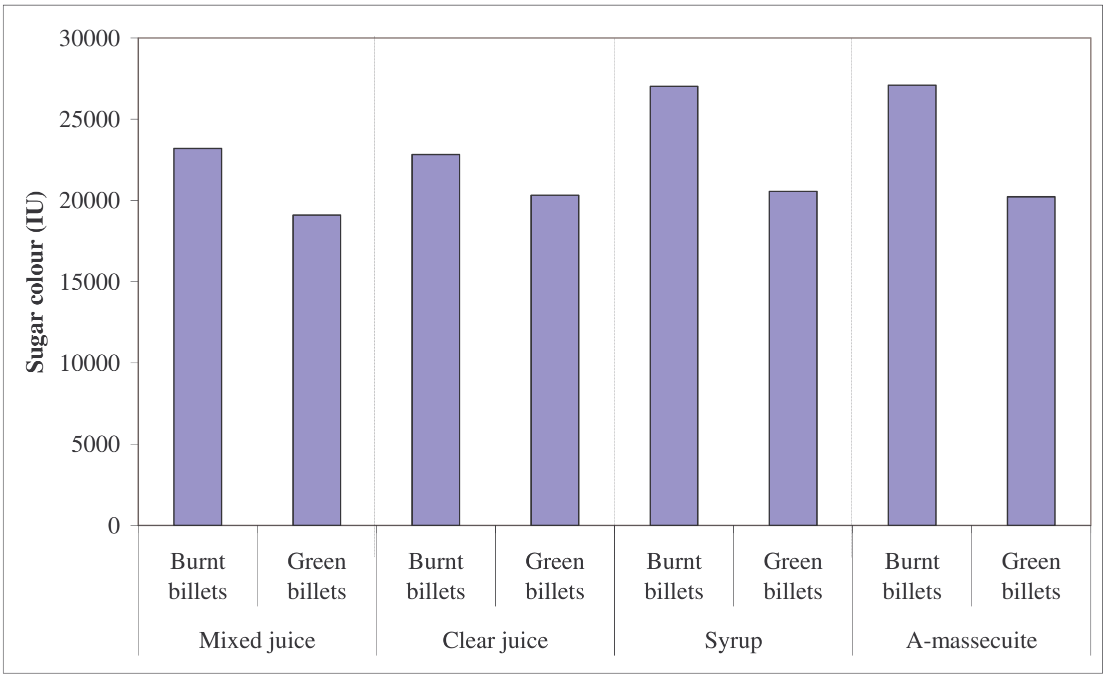

Figure 29. Colour in UCL pilot plant samples.

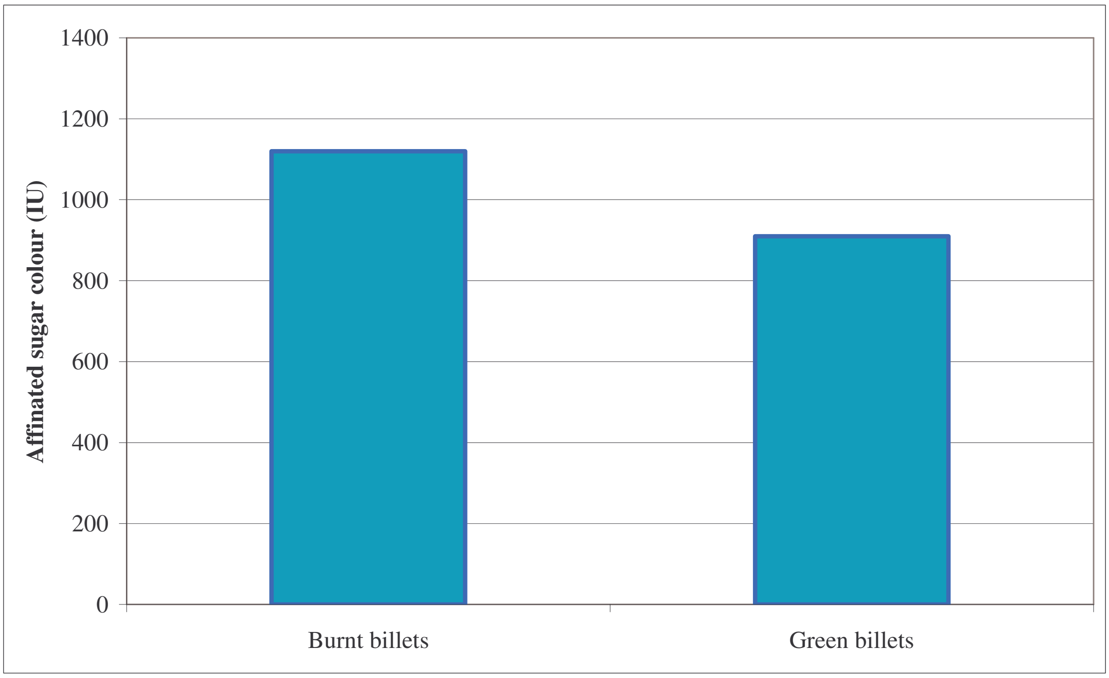

Figure 30. Colour of UCL pilot plant affinated sugar.

Since the trial occurred during the cold and dry winter season, and under strictly limited burnt/harvest to crush delays, gums due to poor cane quality and delays should have been negligible. There was no observable increase in the gums levels due to the increased trash levels. Gum levels in the massecuite and molasses samples did not show any significant trends in either factory (levels in NB molasses were around 10,000 mg/kg on sample) (not shown).

Rheological properties of syrups and A-massecuites

Rheological properties were measured using an Oscillatory Deformation Rheometer (ODR). This technique is different from rotational viscometers of the Brookfield type, more commonly used in the sugar industry, and provides more information about viscosity and intermolecular network associations within the sample (Eggleston and Côté, 2009). A mild correlation (R^2=0.72) was found between dynamic viscosity of massecuite and total trash, indicating that the viscosities did tend to increase with increased trash levels (Figure 31). This result warrants further investigation. However, all of the samples behaved like typical concentrated solutions, confirming that the trash did not cause any gel-like networks which are now associated with the Louisiana hard-to-boil massecuites phenomenon which occurs after severely deteriorated cane has been processed (Eggleston and Côté, 2009). Very concentrated solutions can also markedly increase viscosity and reduce heat transfer properties of molasses. The viscosity ranking at MJ did not carry through to subsequent stages, suggesting that factors other than trash level dominated at these later stages, such as process control and operation.

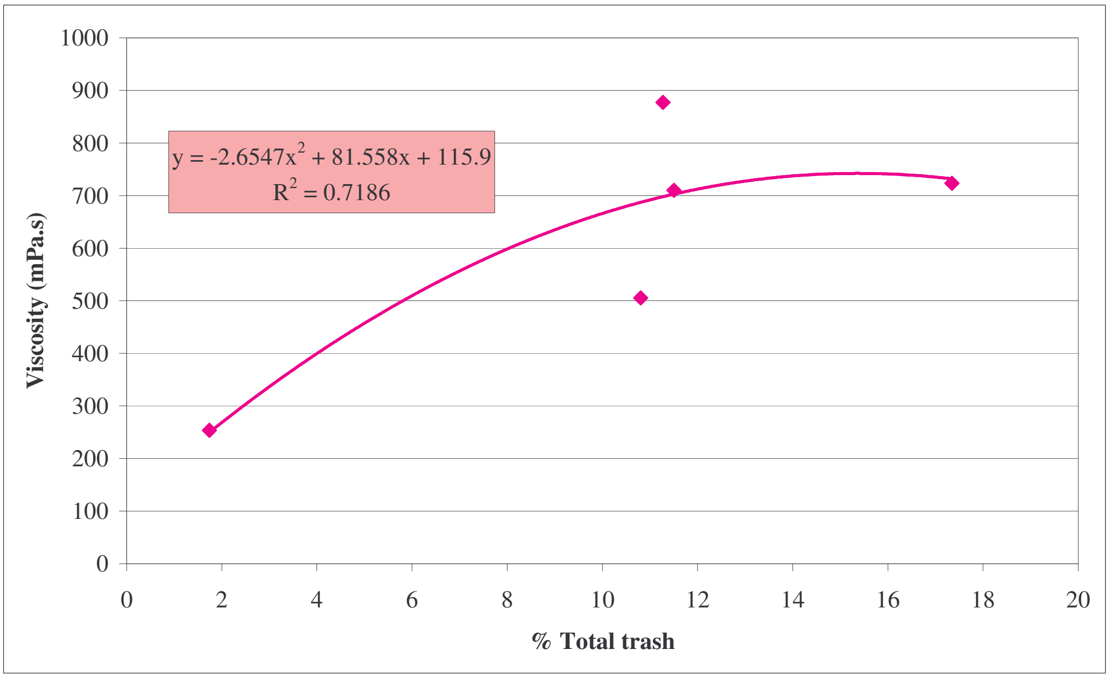

Figure 31. Effect of total trash on the viscosity of massecuites. Viscosity was measured at 2.5 rad/sec using Oscillatory Deformation Rheology.

Conclusions

Processing of green compared to burnt cane did not necessarily imply a predetermined change in the trash levels, but was dependent on the exact conditions and practices during harvesting, although increased total trash levels can be expected in green cane. Moreover, burnt cane is more susceptible to deterioration than green cane, while billeted cane (green or burnt) is more susceptible to deterioration than whole-stalk cane (Eggleston *et al.*, 2008).

A large portion of the dry mass in the field cane was derived from the total trash which was similar to results reported for South African sugarcane by Purchase *et al.* (1990). Dry mass associated with trash delivered to the factories when practising green harvesting, was considerable and higher than in some other cane producing countries, particularly those harvesting 12 month old cane (Eggleston *et al.*, 2009a). This result highlights the abundance of dry mass that South Africa is not currently using for cogeneration or production of biomass products such as bioethanol.

Stalks generally contributed more to the load of colour delivered to the factory than the trash materials because of their higher mass. While trash increases colour in a factory, the contribution of colour from stalks to delivery of colour to the factory should, therefore, not be underestimated.

Increased trash levels resulted in decreased DAC purities, and physical sucrose losses to bagasse due to increased trash were significantly higher than was previously considered. An increase in total trash of 1% resulted in a 0.2% drop in ERC.

The effects of increased trash on factory front end processes, i.e. mill chokes, slower crushing rates, as reported by others, were confirmed. Increased trash levels resulted in decreased MJ purities in the factories. For every 1% increase in trash there was an approximate 0.4% decrease in MJ purity.

An increase of 400 IU colour units in MJ was measured per 1% increase in total trash delivered. The green leaves have a greater impact on the colour produced at a diffuser than at a tandem mill factory. The increased trash levels also caused an increase in the colours of affinated sugar of 25 IU (equivalent to 50 IU in VHP sugar) per 1% trash.

The consistency and sizes of the floc particles in the clarifier mud changed dramatically due to the presence of more trash. An increase in trash, generally, caused a corresponding increase in the settling rate but also significantly higher mud volumes per MJ Brix unit. It is still not yet clear what the practical implications of trash on clarification are. Clarification is reportedly the one place where trash has a major and often catastrophic impact on the raw sugar factory (personal communication[1]). This issue warrants further investigation. It is expected that the effect with diffusers will be less than with mills because of the partial clarification that takes place in diffusers.

The effect of trash on processing of the mixed juice in the pilot plant was a reduction in purity all the way through to A-massecuite. Viscosities of downstream products, i.e. syrups, massecuites and molasses tended to increase with increased trash levels but this result needs further investigation.

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Appendix: Pilot plant samples analytical results

Table A1. NB sample results from pilot plant processing of mixed juice.

Product	Trial type	Pol (%)	Brix (%)	Purity (%)	Sucrose (%)	Fructose (%)	Glucose (%)	Colour (IU)	Cond Ash (%)	Gums (mg/kg)
Mixed juice	Burnt whole-stalk	15.46	16.80	92.02	15.43	0.19	0.20	14,500	0.45	-
	Burnt billets	11.40	13.02	87.56	11.50	0.27	0.25	19,900	0.44	-
	Green billets	11.68	13.66	85.51	11.69	0.35	0.38	20,300	0.45	-
Clear juice	Burnt whole-stalk	16.00	17.34	92.27	16.04	0.17	0.16	16,100	0.41	-
	Burnt billets	11.70	13.24	88.37	11.80	0.24	0.21	15,800	0.45	-
	Green billets	12.24	14.17	86.38	12.39	0.34	0.29	20,400	0.49	-
Syrup	Burnt whole-stalk	64.07	69.22	92.56	63.97	0.65	0.64	16,600^{a}	1.05	-
	Burnt billets	59.98	67.76	88.52	60.49	1.29	1.12	18,400	1.40	-
	Green billets	58.79	67.73	86.80	59.23	1.53	1.40	22,100	1.49	-
A-massecuite	Burnt whole-stalk	84.35	91.15	92.54	84.26$^{\alpha}$	0.80	0.80	17,100	2.25	6,000
	Burnt billets	79.97	90.95	87.93	81.00$^{\alpha}$	1.60	1.50	18,800	3.33	7,200
	Green billets	79.35	91.75	86.49	79.92$^{\alpha}$	1.90	1.80	21,700	3.40	6,200
A-molasses	Burnt whole-stalk	65.00	79.95	81.30	64.30	1.60	1.60	60,700	4.83	11,000
	Burnt billets	61.16	82.15	74.45	61.30	3.20	3.00	41,700	6.45	10,500
	Green billets	57.28	82.90	69.10	57.40	4.00	3.90	49,700	7.12	10,000
A-sugar	Burnt whole-stalk	-	-	-	-	-	-	4,920	-	-
	Burnt billets	-	-	-	-	-	-	8,770	-	-
	Green billets	-	-	-	-	-	-	8,590	-	-
Affinated sugar	Burnt whole-stalk	-	-	-	-	-	-	810	-	-
	Burnt billets	-	-	-	-	-	-	1,030	-	-
	Green billets	-	-	-	-	-	-	1,170	-	-

$^{\alpha}$ *Values adjusted due to analytical error*

Table A2. UCL sample results from pilot plant processing of mixed juice.

Product	Trial type	Pol (%)	Brix (%)	Purity (%)	Sucrose (%)	Fructose (%)	Glucose (%)	Colour (IU)	Cond Ash (%)	Gums (mg/kg)
Mixed juice	Burnt billets	11.51	12.83	89.71	11.58	0.16	0.12	23,200	0.43	-
	Green billets	11.26	12.54	89.79	11.31	0.17	0.13	19,100	0.42	-
Clear juice	Burnt billets	11.63	13.01	89.39	11.71	0.18	0.15	22,800	0.45	-
	Green billets	11.86	13.20	89.85	11.94	0.18	0.15	20,300	0.45	-
Syrup	Burnt billets	61.56	68.68	89.63	62.30	1.00	0.80	27,000	1.50	-
	Green billets	56.35	63.04	89.39	56.90	1.00	0.80	20,600	1.26	-
A-massecuite	Burnt billets	81.50	90.95	89.61	82.03$^{\alpha}$	1.30	1.10	52,100	3.24	5,800
	Green billets	81.92	91.20	89.82	82.54$^{\alpha}$	1.20	1.00	44,500	3.16	7,100
A-molasses	Burnt billets	63.14	81.50	77.47	63.10	2.20	2.00	27,100	6.47	9,800
	Green billets	62.60	81.30	77.00	62.20	2.50	2.30	20,200	6.73	10,700
A-sugar	Burnt billets	-	-	-	-	-	-	7,770	-	-
	Green billets	-	-	-	-	-	-	5,610	-	-
Affinated sugar	Burnt billets	-	-	-	-	-	-	1,120	-	-
	Green billets	-	-	-	-	-	-	910	-	-

$^{\alpha}$ *Values adjusted due to analytical error*