IMPROVING THE HARVESTING AND TRANSPORT OF WHOLE CROP HARVESTED SUGAR CANE

By

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Abstract

WHOLE CROP (WC) HARVESTING involves the collection and transportation of the entire sugar cane crop including trash/extraneous matter to the sugar mill. The sugar cane and trash are then separated and the trash used for other revenue streams such as an additional fuel source for cogeneration. Harvesting whole crop results in a significant increase in the total mass of product to be harvested and transported. Additionally and more significantly, it also results in a considerable decrease in the bulk density of the transported material. Strategies to improve the WC harvesting and transportation efficiency have been identified, tested and costed. These strategies included trash particle size reduction (shredding), billet length reduction, vibration, compaction/compression and crop topping. Shredding trash resulted in good increases in transportation bulk density. However, because of harvester extractor cane losses, the cost of this strategy was very high. A modified fan and hood arrangement was tested and reduced the losses. Billeting losses were significant when reducing billet length. Compaction is a promising strategy because there is no cane loss and topping erect crops where possible was a simple way of improving bulk density and trash fuel quality.

Introduction

Sugar cane trash is an energy resource that is increasing in value and in use. Its use as fuel is increasing worldwide with the move to renewable energy resources. The NSW Sugar Milling Cooperative built electricity cogeneration plants at Condong and Broadwater (Palmer et al., 2009) with the aim of using sugar cane trash as a supplementary fuel for the plants.

The crop was to be harvested ‘whole crop’ (WC), with both the cane and trash transported to the sugar mill. Harvesting WC results in a significant increase in the total mass of product to be harvested and transported (McGuire et al., 2010). Additionally and more significantly, it also results in a considerable decrease in the bulk density of the transported material.

The bulk density of the cane/trash mix has a significant impact on WC harvest and transport costs and so strategies were identified which would increase bulk density. The main strategies identified include:

- shredding of trash
- billet length reduction
- compaction
- vibration
- topping.

These strategies were investigated and costed to identify the most cost effective way of increase WC transportation bulk density.
Shredding trash

Trials were conducted to quantify the impact and feasibility of reducing the trash particle size and its impact on increasing the transportation bulk density of WC harvested sugarcane. A modified primary extractor fan was tested to assess the impact on shredding the trash and then reintroducing it into the harvester elevator to be transported with the cane. Shredding trash using the primary extractor has been demonstrated previously (Spinaze et al., 2002); however, little data on cane losses were collected.

A shredder fan was designed and tested. Key design considerations for the shredder fan were:

- It should be a simple, robust and low-cost design.
- It should be a simple modification to existing harvesters.
- The number of fan blades should be maximised to maximise shredding capability.
- The fan speed should be maximised while maintaining current ‘Harvest Best Practice’ (Whiteing, 2002) extractor fan airflow.
- It should discharge the trash into the elevator.

The shredder fan was manufactured and fitted to the existing primary extractor fan mount (Figure 1) and trials were conducted. Improvements to the harvester hydraulics were required because of the high power requirement of shredding trash.

![Fig. 1—Initial shredder fan designs; note machined leading edge both flat (L) and serrated (R).](image)

Trials in 2010 resulted in increases in bulk density of between 12% and 22%. Samples were collected during trials for both shredder fan on and fan off treatments to determine the level of extraneous matter. Samples were hand sorted into billets and extraneous matter and weighed. Extraneous matter samples were then mulched and sub sampled and frozen (Figure 2).

![Fig. 2—Sorting, weighing and processing of extraneous matter samples.](image)
These subsamples were used later to determine the level of pol in the trash (Table 1) (Sichter et al., 2005). The difference between the levels of pol in the trash can be attributed to cane loss through the shredder fan and is thus a measure of sugar lost, as it is unrecoverable.

<table>
<thead>
<tr>
<th>Trial date</th>
<th>Fan off</th>
<th>Fan on</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/06/2010</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>7/07/2010</td>
<td>1.1</td>
<td>–</td>
</tr>
<tr>
<td>15/07/2010</td>
<td>1.6</td>
<td>–</td>
</tr>
<tr>
<td>26/07/2010</td>
<td>1.6</td>
<td>–</td>
</tr>
<tr>
<td>17/08/2010</td>
<td>2.8</td>
<td>–</td>
</tr>
<tr>
<td>9/08/2010</td>
<td>2.4</td>
<td>4.4</td>
</tr>
<tr>
<td>8/09/2010</td>
<td>1.9</td>
<td>–</td>
</tr>
<tr>
<td>17/09/2010</td>
<td>2.2</td>
<td>4.0</td>
</tr>
<tr>
<td>19/10/2010</td>
<td>1.4</td>
<td>4.2</td>
</tr>
<tr>
<td>3&amp;4/11/10</td>
<td>2.7</td>
<td>5.2</td>
</tr>
<tr>
<td>5/11/2010</td>
<td>2.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Average</td>
<td>1.9</td>
<td>3.8</td>
</tr>
</tbody>
</table>

A financial analysis of the 2010 season results determined that the transportation savings from the increased WC bulk density were less than the value of sugar lost due to the shredder fan.

These results highlighted the need to reduce cane loss in any effort to increase bulk density by shredding trash. A modified prototype hood and fan was designed (Figure 3) and constructed with the aim of reducing cane loss.

The key design considerations for the prototype hood and fan were as follows:

- The fan should be raised higher in the hood to allow separation of cane and trash in the cleaning chamber with the aim of reducing the amount of cane drawn into the fan and thus reducing cane loss.
- The overall harvester height should be equal to or below the existing harvester height.
- The modified and existing hoods should be easily interchangeable for trials.
- Trash should be shredded and discharged back into the elevator.
- If should fit within existing harvester space constraints.

Key features of the manufactured prototype hood and fan are:

- the fan runs approximately 500 mm higher than the standard fan in the cleaning chamber
- a spiral volute around the outside of the hood to convey material around and out to where it is discharged at the rear of the hood
- a hole in the top of the hood to reduce fan backpressure
- 18 serrated hardened steel blades
- a nose cone to improve aerodynamic performance
- fixed blades to improve shredding.

The prototype hood was manufactured and fitted to a harvester for trials during 2011 (Figure 4) Like the shredder trials in 2010, improvements to the primary extractor hydraulics were required because of the high horsepower requirements of shredding the trash.
Trials conducted with the new prototype hood and shredder fan resulted in an average increase in haulout bulk density (Figure 5) of 14%. Billet length in all trials was kept constant and was on average approximately 180 mm. All trials were conducted in 2-year-old lodged cane. Average extraneous matter levels were 25%. This is typical for lodged 2-year-old cane.
Average pol in trash results for 2011 prototype hood and shredder fan trials (Table 2) show a reduction in pol in trash for the fan on treatments in comparison to the 2010 trial results. This is also true when the individual samples are presented as a function of the fan speed (Figure 6).

**Table 2** — Pol in trash (%) for 2011 trials with prototype hood and shredder fan.

<table>
<thead>
<tr>
<th>Trial date</th>
<th>Fan off</th>
<th>Fan on</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/08/2011</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>9/08/2011</td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>15/08/2011</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>18/08/2011</td>
<td>1.5</td>
<td>2.7</td>
</tr>
<tr>
<td>17/09/2011</td>
<td>2.2</td>
<td>2.0</td>
</tr>
<tr>
<td>17/09/2011</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Average</td>
<td>1.9</td>
<td>2.2</td>
</tr>
</tbody>
</table>

The reduction in trash pol from 2010 to 2011 shows that, based on limited data, the prototype hood has reduced cane loss. Raising the fan in the cleaning chamber has resulted in a reduction in cane loss. Further trials are required to support these findings.
The optimum operating speed for the shredder fan was found to be 1400 r/min (unloaded – no material flow). Figure 7 shows the approximate fan power for both harvesting and unloaded states for various trials.

The average fan power at 1300 r/min (harvesting) was 58 kW. A speed of 1400 r/min was the optimum for good trash extraction without blocking the outer volute of the fan. Material build up in the volute occurred with maximum fan speed (1600) and with very high levels of material extraction. The level of trash extracted was variable, depending on field conditions and crop. Separate trials showed that at approximately 1300 r/min, the fan separated approximately 60% (by mass) of the extraneous matter.

![Fig. 7—Prototype hood and shredder fan power requirements.](image)

**Billet length**

A trial was conducted in 2008 at Broadwater using two similar harvesters in the same field, one with four chopper blades per drum and other with six blades per drum.

Both machines harvested WC and the transportation bulk densities were compared. For this trial an increase in bulk density of approximately 13% was achieved using a six blade per drum chop.

Subsequent bin weight data collected from these two harvesters over an extended WC harvesting period confirmed that the increase in bulk density was approximately 13%.

Based on billeting loss data from the BSES chopper test rig (Hockings et al., 2000), the cost of sugar loss due to the additional billeting losses from the six blades per drum machine was determined as greater than the transportation savings gained from improved bulk density.

**Compaction**

Compaction was identified as a good strategy to increase WC bulk density. To quantify compaction pressure versus WC bulk density a small test rig was constructed consisting of a sample drum and hydraulic ram.

Samples were taken and compressed in the rig and hydraulic force recorded. Compaction pressure was then calculated. Tests were repeated for varying samples.
Test rig results (Figure 8) show that compaction pressure on average of greater than 20 kPa would be required to achieve the target bulk density of 250 kg/m$^3$.

Figure 8 also shows the effect of shredding the trash on bulk density and compaction. Less compaction pressure is required to achieve the target bulk density when the trash particle size is reduced.

Compaction was used extensively during WC harvesting by some harvesting groups to increase road bin weights (Figure 9) and various compaction/levelling machines were developed by groups and trialled. Field data collected from one of these compaction machines support the test rig data (Figure 10).
Other issues associated with compaction of the WC in the multi-lift road bins are the spillage caused by heaping material in the bin prior to compaction and, significantly, the labour cost associated with a dedicated machine for compaction.

This strategy improves the road transport bulk density but does not address the infield haulage bulk density.

**Vibration**

The effect of vibration on WC bulk density is commonly observed during transportation. To quantify the effect of additional vibration a small test rig was constructed and WC samples vibrated using small pneumatic vibrators.

Results showed that an increase in bulk density between 9% and 13% was achievable however the use of vibrators on the bin was considered to have less of an effect on bulk density than would be possible if the material in the bin was directly vibrated.

Another small test rig was constructed with a moving partition wall that oscillated (Figure 11) to achieve this.

Fig. 10—Compaction data from test rig together with field compaction rig.

Fig. 11—Oscillating wall test rig (L) and conducting a trial with the test rig (R).
Trials conducted with this test rig showed an increase in bulk density of 21% when vibrating the material while filling the bin in comparison to no vibration when filling. Additionally, the moving partition had the effect of aligning billets, thus also contributing to the improvement in bulk density.

The test rig demonstrated on a small scale that vibration of WC in the infield haulout while filling the bin was effective, however, in a practical sense, vibration of this kind on a full scale could be difficult and potentially very costly both in capital and maintenance. Scaling up the oscillating wall could also be problematic.

**Topping**

Topping of one-year-old erect crops is an excellent strategy for improving transportation bulk density. While topping isn’t always possible it does result in the majority of the wet green leaf and top, which has little fuel value, being left in the field (to leave a trash blanket) and only the dry dead leaf/trash being harvested.

Trials were conducted to evaluate what increase in bulk density could be achieved by selectively removing the top. One-year-old erect cane was harvested WC with and without the topper and results compared.

On average, the WC haulout bulk density was 226 kg/m³. When topping, this increased to 241 kg/m³, an increase of approximately 7% (Figure 12). Average billet length for Trial 1 was 135 mm and 180 mm for Trials 2 to 5.

![Fig. 12—WC topping trials; haulout bulk density.](image)

Topping reduced the average moisture content of trash from 58% to 53%. Extraneous matter decreased from 35% to 28% with topping. On average, topping removed approximately 20% of the extraneous matter (wet weight).

**Financial analysis**

A financial model was created to assess the relative costs and benefits of various strategies to increase whole of crop harvesting transportation bulk density. The model considers the following bulk density improvement options:
In option 6, the trash is transported in bales by truck to the mill, separately from the cane billets. The topping of cane was considered and was modelled separately. The option of vibration was not considered for the financial model.

The key assumptions used to construct the model are listed in Table 3.

**Table 3—Key assumptions used in the financial model.**

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average yield</td>
<td>141 t/ha (Broadwater Mill 5-year av)</td>
</tr>
<tr>
<td>Average burnt cane pol</td>
<td>11.2 % (Broadwater Mill 5-year av)</td>
</tr>
<tr>
<td>Pol lost due to burning</td>
<td>0.5 units</td>
</tr>
<tr>
<td>Harvest group crop size</td>
<td>80 000 tonne cane</td>
</tr>
<tr>
<td>Trash available additional</td>
<td>24.5% on burnt cane tonnes</td>
</tr>
<tr>
<td>Trash moisture content</td>
<td>55%</td>
</tr>
<tr>
<td>Diesel price</td>
<td>$1.18/L</td>
</tr>
<tr>
<td>Current burnt cane harvest price</td>
<td>$7.50/t of cane</td>
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<tr>
<td>Current road transportation price</td>
<td>$1.64/m</td>
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<tr>
<td>Current WC transportation bulk density</td>
<td>200 kg/m³</td>
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<tr>
<td>Target WC Transportation bulk density</td>
<td>250 kg/m³</td>
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<tr>
<td>Sugar price</td>
<td>$450/t</td>
</tr>
<tr>
<td>Electricity income</td>
<td>$70/MWh</td>
</tr>
</tbody>
</table>

The financial analysis in Figure 13 shows a reduction in costs for whole of crop collection (harvesting + transportation to the mill gate), when using trash shredding and/or compaction of product in the multi-lift bin. Strategies where there is no improvement in collection costs are: shorter billets (due to cane loss), low speed fan operation (because of the reduction in tonnes of trash collected), and GCTB and hay baling, (due to the high baling costs and extractor cane loss). The model does not consider the cost of separation of trash at the mill, nor the cost of handling and processing hay bales.

![Fig. 13—Trash cost from different whole crop harvesting strategies.](image-url)
A financial analysis of topping one-year-old crops suggests the dry trash collection costs could be reduced from the WC base case cost of $52 (one-year-old cane) per dry tonne of trash to approximately $45 per dry tonne of trash, despite the reduction in tonnes of dry trash collected.

**Conclusions**

Harvesting whole crop is problematic and difficult, particularly in large two-year-old lodged crops. Low product bulk density makes harvesting and transportation costly.

Shredding trash is an effective way of increasing transportation bulk density however the impact on cane loss must be considered.

A modified shredder fan and hood was tested and the results showed that the prototype hood and shredder fan increased transportation bulk density by 14% and that raising the fan is a sensible approach to reducing cane loss.

A significant reduction in cane loss was measured due to the use of a shredder fan and prototype hood in comparison with the shredder fan and standard extractor hood. Cane loss from primary extractors is a significant cost to the sugar industry and further research is required to validate these results.

Compaction is a simple strategy to increase bulk density. There is no cane loss associated with this strategy if spillage from tipping on the pad is avoided.

Topping one-year-old erect crops is a simple and practical strategy to improve bulk density and trash quality. Topping erect cane resulted in an average increase in WC bulk density of 7%, reduced the amount of wet trash collected by approximately 20% and reduced the trash moisture content by approximately 5 percentage points. Topping one-year-old erect cane has also shown to be an effective way of increasing WC bulk density while increasing trash fuel quality.

**Acknowledgements**

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**REFERENCES**


