Final Report - SRDC Research Project
NSC 019

IMPROVING THE HARVESTING AND
TRANSPORT OF BIOMASS FOR SUGAR AND
POWER PRODUCTION IN NSW

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TERMINOLOGY

1YO – 1-year-old
2YO – 2-year-old
BD – Bulk Density
EM – Extraneous Matter
GCTB – Green cane trash blanket
GPS – Global Positioning System
Ha – Hectare
HBP – Harvest best practice
in – inch
kPa – kilopascal
psi – pounds per square inch
WC – Whole Crop
1 Executive Summary

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.

The NSW Sugar Milling Cooperative, in a joint venture, invested in cogeneration plants with the intention of using trash collected from WC harvesting as additional fuel for the plants. WC harvesting was attempted but with limited success. A significant problem with WC harvesting was the reduction in bulk density of the cane/trash mix.

This research project aimed to identify, test and cost strategies to improve the transportation of whole crop harvested cane. The strategies identified fall into the following broad categories:

- Particle Size reduction
- Compaction
- Vibration
- EM reduction (Topping, low fan speed)

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 during the 2010 harvesting season to assess the impact of shredding the trash and then reintroducing it into the harvester elevator to be transported with the cane. Good increases in bulk density were achieved with the use of the shredder fan.

A financial analysis of the 2010 season results determined that the transportation savings from the increased WC bulk density were less then the value of sugar lost due to the shredder fan. A new hood was designed and tested with the fan located approximately 500mm higher in the chamber. The aim of this design was to reduce cane loss by allowing more time for the cane/trash to separate and thus drawing less cane into the fan.

The use of the new hood and shredder fan resulted in an average increase in transportation bulk density 14%. Cane loss data collected showed a reduction in cane loss with the use of the prototype hood. Further research is required to support these findings.

Field trials conducted with a standard 4 blade per drum chopper system and a 6 blade per drum chopper system, to achieve a shorter billet length, resulted in an increase in transportation bulk density of approximately 13%. Additional billeting losses, due to the shorter billet, were calculated to be greater then the transportation savings.

Test of compaction was conducted using a small test rig. Using this test rig, the relationship between compaction pressure and bulk density was determined for WC harvested sugar cane. The impact of shredding the trash and billet length was also...
investigated. Data collected during a field trial of a compaction machine was consistent with the test rig data.

Financial modeling of a compaction machine suggest that compaction of material on the loading pads would be a cost effective strategy. Improvements to the compaction machine design would be required. Issues such as spillage and labour still need addressing.

The testing of vibration to accelerate the consolidation of the WC material was conducted using small test rigs. Both pneumatic vibrators and a swinging wall vibrator were tested. The swinging wall rig proved to be more successful because of the direct movement of the material in the test bin. Vibration, while being very effective, has limited practical application. This is due to the high cost of installing vibration equipment and the potential damage to haulout equipment.

The final strategy field-tested was topping while harvesting WC. Topping cane trials were conducted in one-year-old, erect cane to assess the impact on transportation bulk density of removing the green and wet plant top. Topping erect cane resulted in an average increase in whole crop bulk density of 7%. Topping 1-year-old erect cane has also shown to be an effective way of increasing whole crop bulk density while increasing trash fuel quality.

2 Background

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 billets and trash are then separated and the trash is used as an additional income stream, most commonly as a fuel source for cogeneration of electricity and process steam.

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 efficiency of WC harvesting and transportation have been identified, tested and costed. These strategies included trash particle size reduction (shredding), billet length reduction, vibration, compaction/compression and crop topping.

The NSW Sugar Milling Co-operative constructed cogeneration plants at Condong and Broadwater Mills. The aim of the project was to cease infield burning of sugar cane trash and use the trash as supplementary fuel for the cogeneration plants. Whole crop harvesting & milling was attempted in 2008 and briefly in 2009 and 2010, but with limited success. In addition to significant issues within the factories, the bulk density of the harvested product was a major issue (and cost) both in the field and on the road. This report aims to provide a detailed summary of the research conducted on strategies to improve the transport bulk density of whole crop harvested material for the New South Wales sugar industry.
2.1 Whole Crop Harvesting

Whole crop harvesting can be described as the removal of both cane and extraneous matter from the field with the additional EM associated with WC harvesting typically consisting of dry and semi-dry leaf, tops, green leaf and usually, a higher level of additional soil. The WC harvesting of large 2-year-old (2YO) lodged crops (Figure 1), predominately in the Broadwater Mill area, has significant impacts on the harvesting operation.

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. The forward speed of the harvester is reduced when harvesting whole crop thus reducing harvester pour rate (tonnes of cane / hour).

2.2 Whole Crop Yield

Whole crop harvesting trials were conducted and data collected on crop yield, as well as the crop composition, cane and extraneous matter (EM) or Trash.

During these trials cane yields of approximately 50 to > 150 T cane/Ha (Figure 2) were recorded and WC yields of approximately 70 to > 210 T WC/Ha. It is noted that crops larger (in yield) are known to occur within the mill areas however these were not harvested during these trials.

Significant variation in both cane yield and trash yield per hectare was found during the trials with both variety and crop yield having a significant impact on the amount of extraneous matter.
An average of approximately 28% EM was recorded during the trials. It can therefore be expected that whole crop harvesting will result in greater than 25% extra mass being both harvested and transported to the mill.

Figure 4 shows the whole crop yield and dry ash free fibre yield for whole crop harvested cane.
2.3 Equipment/Capital

Whole crop harvesting requires the modification of existing equipment and/or the purchase of additional harvesting equipment. Equipment modifications were made to both the harvester and infield haul-outs in preparation for whole crop harvesting in 2008. A summary of harvester configurations and modifications is detailed Appendix A – Harvester Survey 2009.

Modifications to the Harvester that were undertaken to assist whole crop harvesting include the following changes:

- Large Knockdown Roller
- 12 Blade Chop (6 blades per drum)
- Large side-knives
- Aggressive gathering teeth fitted to the base-cutter legs
- Foam discharge fire protection equipment
- Primary extractor directed into elevator to clear boot and prevent ‘boiling’ of material
- GPS guidance auto-steer
- Elevator enclosure

Modifications to the infield haul-outs included:

- Extending bin length to increase volume
- Extending bin height to increase volume
- Flipper rollers to aid control of tipping
- Moving sidewalls (chain) to aid control of tipping
- Levelling arms/rotors to level product in road transportation bin
As well, some groups purchased additional haul-outs with larger bins and also manufactured/modified specific pieces of stand alone plant to compact/level the whole crop in the road transportation bin.

The additional capital requirements were specific to each harvesting group’s management and strategy. When considering the additional costs of whole crop harvesting, a significant proportion of these costs are capital. The effective and efficient use of capital is critical in minimising WC harvesting costs. The financial model discussed in chapter 7 used harvesting costs based on the 2009 WC harvesting trial and approximate capital expenditure by Broadwater growers in preparation for WC harvesting.

### 2.4 Forward Speed

Harvester ground speed data collected during a WC trial during 2009 shows a significant difference between average harvester ground speeds for WC harvested and burnt cane harvested crops. This data was collected harvesting 2YO crops.

Whole crop harvesting results in reduced harvester forward speed due to the additional crop throughput and subsequent feeding issues (in comparison to burnt cane) but also due to reduced operator visibility and limited elevator capacity resulting in elevator overflow.

GPS data collected from harvesters during the trial period showed an average reduction of harvesting speed of 35% from an average of 6.9 km/h in burnt cane to an average of 4.4 km/h when harvesting WC. The difference between the two harvesting scenarios can be clearly seen in Figure 5.

**Figure 5 Average Harvester Forward Speed – WOC Trial July 2009**
From field data gathered during the trial, it was also possible to determine the difference in fill times of the haul outs between whole crop and burnt cane. The time to fill each haul-out was recorded and averaged. Figure 6 and Figure 7 below give a good graphical representation of the difference between whole crop harvesting and burnt cane harvesting.

On average, whole crop harvesting resulted in a 23% reduction in time under the elevator for Group 1 and a 40% reduction in time under the elevator for Group 2. It is
important to consider these fill times in conjunction with the reduction in ground speed of the harvester. This reduction in fill times is related to the haulout capacity and crop yield, but it demonstrates a significant reduction in fill time due to the additional biomass harvested, and thus the most likely need for an additional haulout.

### 2.5 Fuel Usage

Harvesting whole crop results in increased fuel usage for both the harvester and haulout equipment. The increased fuel usage is due to the increased tonnes harvested (harvester throughput) and the additional fuel required to haul the crop (increased mass & increased volume) to the pad for loading into the multi-lift bins.

Figure 8 shows data collected for both burnt and WC harvested crops, (L/t) and crop yield. The data shows the change in fuel usage per tonne cut as crop yield increases. It also shows that the change in harvester fuel usage per tonne of crop cut is generally independent of whether the crop is burnt or green.

![Figure 8 Fuel usage for a modern sugar cane harvester as a function of crop yield](image)

Haulout fuel usage is harder to represent graphically as many factors impact on it. These include:

- Type of haulout (size, horsepower)
- Field Layout
- Crop yield
- Distance to loading pad
- Operator

Increased haulout fuel usage is closely related to the increased crop harvested and hauled due to WC and the reduction in crop bulk density. WC trials in 2009 found that on average fuel costs per tonne of cane for harvesting and hauling WC increased by 47% in comparison to burnt cane harvesting.
2.6 Labour

Whole crop harvesting requires additional labour. It involves both longer hours to achieve the same tonnes of crop cut (both cane and total crop) and in most cases, an additional infield haulout operator.

To quantify this, data was collected during the 2009 WC trial (Table 1). Detailed labour records were kept for both WC harvesting and burnt cane harvesting sections of the trial. A comparison between man-hours per tonne of cane, and man-hours per tonne of crop harvested can be made. Note that man-hours per tonne of crop and man-hours per tonne of cane for burnt cane are the same.

<table>
<thead>
<tr>
<th></th>
<th>Man Hours / T Crop</th>
<th>Man Hours / T Cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average WC</td>
<td>0.082</td>
<td>0.102</td>
</tr>
<tr>
<td>Average Burnt Cane</td>
<td>0.068</td>
<td>0.068</td>
</tr>
</tbody>
</table>

From this trial it was found that man-hours per tonne of cane when harvesting WC increased by 50% to that of the average burnt cane man-hours. An increase of 20% in man-hours per tonne of crop was also recorded. This increase was due both to the increased labour required for the harvesting crew but slower pour rates due to harvester feeding issues, waiting for haul-outs etc. This highlights not only the reduction in tonnes of cane cut per man-hour when harvesting WC but also the increased labour requirements.

3 Whole Crop Bulk Density

There are many factors that influence whole crop bulk density. These factors include crop variety, age, class, yield, trash moisture content, billet length and billet length. Investigating the individual influence of all of these factors has not been considered in this project.

The most significant of these factors is the level of extraneous matter (EM) or trash. Increasing levels of EM result in a reduction in bulk density.
The data in Figure 9 has been collected from a range of sources but highlights the fact that there is a significant variation in whole crop bulk density even at fixed levels of EM.

The data shows reasonable bulk densities even at higher extraneous matter levels. This can be explained by the fact that high extraneous matter levels can be recorded in 1-year-old varieties with high levels of trash, where the wet, green trash is a high proportion of the mass but occupies a smaller volume than the same mass of dry trash.

The road transportation bins are 90 m$^3$ in volume and have a 22.5 tonne net target load. Based on these figures, the target bulk density for whole crop harvesting is 250 kg/m$^3$. The data also shows that for WC harvested cane with extraneous matter levels between 20% and 30% (majority of fan off trials); very few trials resulted in bulk densities greater than 250 kg/m$^3$.

Average bulk density in 2YO cane at Broadwater from a large trial in 2009 was approximately 200 kg/m$^3$. Trials in 2010 and 2011 also found the average WC bulk density to be approximately 200kg/m$^3$ in 2YO crops.

This highlights the need to use alternative strategies to increase the transportation bulk density to the target bulk density of 250 kg/m$^3$.

### 4 Strategies to Increase Transportation Bulk Density

The strategies considered to increase the transportation bulk density focused on the following broad principles:

- Reducing particle size (both cane and trash)
- Vibration
- Compaction/Compression
• Trash Reduction (reducing the amount of trash collected)

These strategies were tested and costed to determine the relative benefit of each.

4.1 Cane Loss

Whole crop harvesting aims to increase sugar recovery per hectare by minimising sucrose loss from burning and harvester losses\(^1\). Cane loss is critical in harvesting and any strategy used to increase transportation bulk density must consider not only the savings due to bulk density improvements but also the cost of cane/sucrose loss associated with the strategy.

Harvester cane loss through the primary extractor and choppers are of most significance. BSES research documents the losses that can be expected from the primary extractor and from the choppers\(^2\). Applying this research knowledge is important when testing strategies to improve bulk density.

4.2 Billet Length

Reducing billet length is a well-known and commonly practised strategy to increase bulk density. It is practised in both burnt and green cane harvesting. The reduction of billet length allows the cane billets to pack more densely, reducing air void size, thus increasing bulk density.\(^3\)

Most groups, when harvesting whole crop, used billet length reduction to increase bulk density. The first method of reducing billet length is the billet length control on the harvester. This negatively affects the harvester feeding and billet quality. Several harvester groups installed 12 blade choppers (6 blades per drum) to achieve a shorter billet length and thus greater bulk density. The average billet length with a 12-blade chop was approximately 130mm. The average billet length with a standard 8-blade chop was approximately 180mm.

Trials conducted during 2008 compared a standard 8-blade chop harvester with a 12-blade chop harvester in the same block at Broadwater. Both machines harvested WC and the transportation bulk densities compared. For this trial an increase in bulk density of approximately 13% was achieved.

Subsequent bin weight data collected from these two harvesters over an extended WC harvesting period confirms these results to be approximately 13% (Figure 10).

\(^{1}\) McGuire et. al. (2010)  
\(^{2}\) Whiteing (2002)  
\(^{3}\) Vitale M, Domanti S (1997)
Additional billet losses as a result of the additional cuts must be considered when evaluating the effectiveness of shorter billets as a means to increase bulk density. Trials conducted with the BSES chopper test rig data found losses were approximately 0.6% per cut per m under ideal conditions with sharp blades. These losses double when the blades are blunt. These losses only consider the actual cutting losses. Deterioration losses under normal cut to crush delays would also increase.

Using this chopper loss data in a financial model shows that additional billeting losses from a 12-blade chop system result in losses greater than the transportation savings gained from improved bulk density.

### 4.3 Trash Particle Size Reduction (Shredding Trash)

Like reducing billet length, reducing trash particle size will increase bulk density. Reducing trash particle size by shredding/attrition was trialled. The primary recommendations from the SRDC travel and learning project CNSW01, was to shred the trash and remix with the sugar cane for transportation.

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Shredded trash shed tests were conducted to evaluate the theoretical improvement in bulk density from reducing the trash particle size. To conduct the tests, a large cylindrical drum was constructed and filled with whole crop harvested crop from the harvester elevator. This mass of this material was recorded and then the billets and trash separated. Billets and trash were weighed individually and trash samples taken for moisture content.

The trash was then shredded with the use of a small garden mulcher (Figure 12). The trash and billets were then mixed and returned to the cylindrical drum for weighing and measurement. From this the bulk density before and after trash shredding could be calculated. Also recorded and calculated was the bulk density after travel, which simulates the vibration the infield bins would experience whilst filling.

Results indicated that a bulk density improvement of between 6 and 20 % was achievable by shredding and the vibration associated with travel (Figure 13). However, it was found that the samples were variable with poor repeatability due to
the impact of crop size, variety and extraneous matter levels influencing the bulk density.

![Figure 13 Shed test sample bulk densities (BD)](image)

The variation between samples meant that a better method of testing was required. To compare unlike samples, the use of a consistent force was applied in a Compaction test rig. This is covered in detail in the next section.

Practical considerations for shredding the trash on the harvester include; safety, increased cane loss, power consumption, maintenance, available space, weight, trash moisture content and shredding effectiveness.

A ‘shredder fan’ to shred the trash in the primary extractor was designed constructed and tested. This is reported in detail in Chapter 5 - Trash Shredder.

### 4.4 Compaction/Compression/Levelling

Compaction is a practical way of increasing the bulk density of WC sugar cane. Because of the high level of EM and low bulk density, WC responds well to compaction.

A test rig was constructed to test the compaction of whole crop sugar cane. Additionally, the variable nature of WC sugar cane makes comparing different samples (i.e. billet length, trash composition) difficult and the use of the compaction test rig enabled a standard way of comparing treatments/samples. The use of a compaction test rig enables a reasonable comparison between treatments to be made by comparing bulk density at a certain compaction pressure.

#### 4.4.1 Compaction Test Rig
To quantify the compaction of whole crop sugar cane, a test rig was constructed. The test rig consisted of a frame, sample drum, a hydraulic cylinder to compress the sample and pressure gauges (Figure 14). The test rig was powered by oil supplied from tractor hydraulic remotes.

WC sugar cane compaction trials were conducted to observe the bulk density of WC sugar cane with respect to compaction and to determine the relationship between compaction pressure and bulk density.

Hand cut sugar cane samples were collected, stripped and cut into billets. The billets and trash were separated and each portion was weighed. From these segregated portions, the sample mass and crop composition (% trash) was determined. A billet sample was taken and billets were measured and size distributions determined. The samples were then mixed and put into test rig drum.

Static weights were applied to the cane/trash mixture to measure compaction at lower pressure levels. The mixture was then compacted with a hydraulic cylinder and the oil pressure was recorded against cylinder displacement.

From the cylinder size and test rig size, both compaction pressure and bulk density were calculated. Sample composition was then altered and the effect of this investigated. Several different combinations of billet lengths and trash shredding were tested. Generally the following was investigated:

- Effect of billet length on WC bulk density
- Effect of % trash on WC bulk density
- Effect of shredding trash on WC bulk density

For each treatment the test was repeated. Details of each trial are presented in the table below:
Table 2 - Compaction test rig Trials

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Ave Billet Length</th>
<th>Sample % Trash</th>
<th>% Trash Chopped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>170 mm</td>
<td>19%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 2</td>
<td>170 mm</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 3</td>
<td>265 mm</td>
<td>21%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 4</td>
<td>170 mm</td>
<td>21%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 5</td>
<td>170 mm</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>Trial 6</td>
<td>135 mm</td>
<td>28%</td>
<td>100% (shredder fan sample)</td>
</tr>
<tr>
<td>Trial 7</td>
<td>180 mm</td>
<td>23%</td>
<td>50%</td>
</tr>
<tr>
<td>Trial 8 (a)</td>
<td>180 mm</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 8 (b)</td>
<td>180 mm</td>
<td>15%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 8 (c)</td>
<td>180 mm</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 8 (d)</td>
<td>180 mm</td>
<td>25%</td>
<td>0%</td>
</tr>
<tr>
<td>Trial 9</td>
<td>180 mm</td>
<td>20%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Billets were cut by hand, but were cut as close as possible to the average billet length from a standard commercial harvester (170 –180 mm).

A summary of trials having similar sample characteristics of approximately 170 –180 mm billet length and approximately 20% trash is presented below. As can be seen there is some variation between samples, which highlights the difficulty in quantifying specifics of material behaviour of whole crop harvested sugar cane. The data does however follow a consistent trend and so a line of best fit is presented in Figure 16.

Figure 15 WC Bulk Density vs Compaction
The relationship between compaction and bulk density of whole crop sugar cane can be represented by the general formula:

$$y = C \times x^k$$

Where:

- $c =$ constant
- $k =$ constant

This is consistent with the compaction of other biomass products.\(^5\)

The difference between long and short billets was also investigated in Trial 3 and Trial 6. The billet length distribution is presented in Figure 17. The effect of varying billet length on compaction bulk density can be seen in Figure 18.

Longer billets required significantly more compaction pressure to achieve the same bulk density and are more susceptible to billet damage. For example, the application of approximately 5 kPa of compaction pressure in the short billet trial resulted in a bulk density of 250 kg/m\(^3\), however in the long billet sample the application of this compaction pressure resulted in a bulk density of only slightly more than 160 kg/m\(^3\).

At high compaction pressures (> 30 kPa) billet failure and damage was observed in the sample. This damage was in the form of splitting, squashing and local deformation of the billets.

\(^5\) Pelt T, (2002)
Figure 17 shows the billet length distribution for compaction trials. Figure 18 shows the characteristic curve of compaction for these billet lengths.

![Figure 17 Compaction test rig trials billet length distribution](image)

Trial 8 involved varying the amount of trash in the sample. Compaction trials were conducted with the following levels of trash:

- 0%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
Table 3 - Trash Level Compaction Trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>% Trash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 8 (a)</td>
<td>10%</td>
</tr>
<tr>
<td>Trial 8 (b)</td>
<td>15%</td>
</tr>
<tr>
<td>Trial 8 (c)</td>
<td>20%</td>
</tr>
<tr>
<td>Trial 8 (d)</td>
<td>25%</td>
</tr>
</tbody>
</table>

Results of the trials are presented in Figure 19. A significant difference between 10%, 15% and 20% trash is observed however, the 25% trash result is very similar to 15% and 20% results. Possible reasons for this are: a) as testing continued dry trash broke up resulting in reduced trash particle size, b) there is little difference in compaction pressure between 15% and 25% trash.

Further trials were conducted to determine the effect of shredding/conditioning the trash to simulate the effect of any harvester modification that would reduce the trash particle size. The procedure for these trials was similar to the previous trials. Cane samples were cut by hand and stripped and then cane cut into 180mm billets. The trash was also cut into approximately 180mm lengths and the cane and trash mixed into the test drum. Static weights were applied to get data points at lower compaction levels and then the hydraulic ram used to determine bulk densities at higher compaction pressures.

Half the trash (by mass) was then removed and chopped into approximately 60mm lengths and then remixed and the compaction tests repeated. Figure 20 illustrates the trash before and after conditioning.
A difference in bulk density between the chopped and un-chopped samples can be seen in Figure 21. All un-chopped test results are reasonably consistent with a clear increase in bulk density due to 50% of the trash being shredded/chopped.

Bulk density compaction trials provide some insight into the bulk material properties of whole crop harvested sugar cane under compaction. Whilst there is some variation within each trial, a trend is present which enables some conclusions to be drawn. From field trials the average WC bulk density is approx 200kg/m3. This coincides with a compaction pressure of approximately 5 kPa.

Billet length has a clear impact on bulk density. The pressure to compact the long billet mixture to the same bulk density as the short billet mixture was significantly higher. The table below illustrates that increasing the billet length from 180mm to 265mm decreased the WC bulk density by 22%.
Table 4 - Billet Length Compaction Trials Summary

<table>
<thead>
<tr>
<th>Compaction (kPa)</th>
<th>180mm Billet</th>
<th>265mm Billet</th>
<th>% BD decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>205</td>
<td>160</td>
<td>-22%</td>
</tr>
<tr>
<td>10</td>
<td>227</td>
<td>178</td>
<td>-21%</td>
</tr>
<tr>
<td>15</td>
<td>241</td>
<td>190</td>
<td>-21%</td>
</tr>
<tr>
<td>20</td>
<td>252</td>
<td>199</td>
<td>-21%</td>
</tr>
</tbody>
</table>

At high compaction pressures billet damage occurred. This damage was more noticeable in the long billet sample. This is an important consideration when looking at compaction however it is not expected that compaction forces high enough to cause billet damage could be applied in the field with existing compaction machines.

A difference in compaction pressure was observed for variations in sample trash content. The difference from sample to sample was observed however test consistency was poor. A explanation for this could be the breaking up of trash particles due to repeatedly separating and mixing as testing went on from 10% trash to 25% trash.

Shredding trash resulted in an obvious increase in bulk density. By using the equation for the line of best fit, the potential increase in bulk density can be determined. The potential bulk density increase at 5 kPa by shredding 50% of the trash is approximately 9% and from shredding 100% of trash it is approximately 16%.

Table 5 - Trash Shredding Compaction Trials Summary

<table>
<thead>
<tr>
<th>Compaction (kPa)</th>
<th>Bulk Density (kg/m3)</th>
<th>% BD Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0% Shredded</td>
<td>50% Shredded</td>
</tr>
<tr>
<td>5</td>
<td>205</td>
<td>223</td>
</tr>
<tr>
<td>10</td>
<td>227</td>
<td>246</td>
</tr>
<tr>
<td>15</td>
<td>241</td>
<td>260</td>
</tr>
<tr>
<td>20</td>
<td>252</td>
<td>271</td>
</tr>
</tbody>
</table>

4.4.2 Field Compaction – Road Transportation Bins

Compaction of the WC material in road transportation bins is an effective way of increasing transportation bulk density. Many harvesting groups used compaction to increase bulk density during WC harvesting. The following pieces of equipment (Appendix B – Levelling/Compaction Equipment 2009) were used for compaction:
- A specifically modified/constructed piece of mobile plant
- From the haulout – extended arm
- Excavator
To improve the understanding of compaction at the pad, a trial using a compaction machine was performed. The aim of the trial was to quantify how much compaction force the compaction rigs could deliver and the cycle time between bins.

Several harvesting groups used compaction of the WC material into road transportation bins during WC harvesting periods in 2008 and 2009. The ‘BTN’ Compactor was used for trials in 2011.

The ‘BTN’ compactor (manufactured by BTN harvesting group) consists of a full track infield haulout with the bin removed and in its place, a compaction frame. This compaction rig was used during the 2009 WC harvesting period and during previous whole crop trials with good success. Its advantages are that it is robust, effective for both levelling and compacting and has good visibility into the bin. Its major limitation is that it is on tracks; so transportation between loading pads is inefficient.

Data collected during the 2009 WC trial shows the effectiveness of the compactor. Early in the trial, excellent results were achieved which dropped away later in the trial. An average bulk density of 236 kg/m3 was achieved using the BTN compactor during this whole crop harvesting period.
Cycle time measurements taken on the 11/11/11 with the BTN compactor demonstrated that it was possible to level and compact a multi-lift bin filled with WC in less then two minutes. This rate is more then sufficient to keep up with the harvester.

Hydraulic cylinder pressure measurements and calculations show that the BTN compactor is able to deliver a compaction pressure of approximately 13 kPa (calculated using compaction surface area of 4m * 1.5m). The graph below shows the compaction pressure vs. bulk density data collected from the BTN compaction rig with data collected from the WC compaction test rig (presented in previous milestone reports). This shows that to achieve the target bulk density, greater compaction pressure is required.
An issue with filling the bins to capacity is the inherent difficulty in filling all the space. Typically there is unused space at the front and the rear of the bin. When attempting to tip more material into the bin to fill these voids, the load is heaped on top and then levelled. This results in spillage.

Spillage is also a significant problem associated with using a compaction machine. Again due to the need to ‘heap’ the whole crop material in the bin so it is above the top of the bin. This causes a significant amount of spillage. In attempting to heap more material on top of the bin cane/trash is spilt over the far edge of the bin (furthest from the haulout) and onto the ground. Improved vision with the use of camera and increased operator skill would go some way to reducing the amount of spillage however it will never be avoided using the current side tipping rigs which offer little control over the WC material when tipping.

A potential solution to this problem would be the use of elevating haul-outs to top up the bins. The use of one elevating haulout per harvest group would allow two tips with the regular side tipping haul-outs and topping up with the third elevating haul-out.

The additional labour requirement for any compactor is assumed to be the same hours that the harvesting crew would work and at the same hourly rate.

The BTN compactor machine effectively and efficiently demonstrated levelling and compacting the whole crop product to below the tarp line. The machine is fast and operator visibility from the cab is good. Importantly, the compaction rate is sufficient to keep up with commercial harvesting however the filling of bins with additional crop is problematic with excessive spillage over the sides of the bins.

Any future designs for compaction machines should aim to have the following features:

- Good visibility in the field
- Easy to operate
• Manoeuvrable on the pad and fast between loading pads (rubber tires)

Levelling and/or the compaction of Multi-lift bins in most cases will be required when harvesting WC. Most importantly, individual harvesting groups will determine what works best for them in terms of levelling and compaction, but it is essential that a financial incentive is paid to harvesting groups to ensure bin weights are achieved and provide reasonable compensation for the additional cost of compaction and levelling.

4.5 Vibration

Consolidation of harvested cane material due to the movement in transportation equipment is well observed particularly in whole crop harvesting. The use of vibration to accelerate this consolidation has been investigated.

Vibration is another strategy used to increase the bulk density of biomass. Others have tested the effect of vibration on specific biomass samples previously6, but no specific literature relating to the vibration of whole crop sugar cane could be found. On this basis a simple vibration test rig was constructed to determine the impact of vibration on whole crop sugar cane. This strategy is being considered and investigated by engineers at CTC in Brazil7.

Samples were collected weighed and cut up into billets, the trash was also cut up into billet size lengths. The trash and billets were mixed and put into a container. This container was then vibrated using small pneumatic vibrators and results collected.

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 then 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 26) to achieve this.

Figure 26 Oscillating wall test rig (L) and conducting a trial with the test rig (R)

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6 McDonald, T., Stokes, B., McNeel, J. (1995)
7 Brod pers comm (2010)
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. Some compaction of the material also occurred due to the oscillating wall.

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.

### 4.6 Trash Reduction – GCTB (Low Fan Speed)

The reduction of trash levels increases transportation bulk density and the simplest way of achieving this is increasing the primary extractor fan speed. This strategy was used extensively at Condong Mill while whole crop harvesting. Limited bulk density field data has been collected using low fan speed, however, based on data collected and presented in Figure 9, EM levels would need to be reduced to approximately 15% to consistently achieve a bulk density of approximately 250 kg/m³.

The following issues present themselves when using this strategy:

- The primary fan removes drier/lighter trash in preference to green trash, thus preferentially removing the dry trash with higher fuel value.
- Primary Extractor cane loss – although low at low fan speeds, cane loss levels due to the primary extractor could be expected in line with BSES research.
- Green Cane Trash Blanket – This strategy would in many cases result in the use of a post harvest burn in many parts of the NSW industry, depending on location and the amount of trash being left in the field due to wet, cold conditions.8

This strategy, whilst suiting some growers, will not suit others and doesn’t result in the harvesting of the greatest tonnage of high value fuel. Selectively removing the green leaves is proposed as a better option.

### 4.7 Trash Reduction – Topping

The sugarcane plant top (green leaf) has a higher moisture content than the dry lower dry (brown) leaves. Because of this higher moisture the green top has a lower fuel value.

WC harvesting topping trials were conducted in the Condong Mill area during the 2010 and 2011 harvesting seasons. These trials were aimed at determining the bulk density

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density improvement achieved by leaving the cane plant top in the field by topping, thus recovering only the dry leaf and in doing so, improve the transportation bulk density. The use of topping as a bulk density improvement strategy is usually only possible while harvesting 1YO cane due to high prevalence of crop lodging with 2YO cane. However, where possible it is a simple way of improving bulk density.

The trials consisted of WC harvesting 1-year-old cane with and without the topper operating. Samples were collected to determine the level of extraneous matter for each treatment as well as the average trash (EM) moisture content.

Haul-outs were filled to a consistent level and payload recorded. From the known volume of the haulout, the bulk densities were calculated. Figure 28 shows the average haulout bulk density for both topper off and topper on treatments for the trials.

On average the WC haulout bulk density was 226 kg/m³. When topping, this increased to an average haulout bulk density of 241 kg/m³, an average increase of approximately 7%.
Figure 28 Topping Trials – Haulout bulk density

The average level of extraneous matter in the crop harvested of 35% when not topping was reduced to 28% when topping. On average, topping removed approximately 1/5 of the extraneous matter (wet weight).

Figure 29 Topping Trials – Average % EM

The average moisture content of the extraneous matter harvested is presented below. Topping reduced the trash moisture content from an average of 58% to 53%.

34
In summary, whole crop harvesting 1-year-old cane and topping increased whole crop transportation bulk density by 7%, reduced the amount of wet trash collected by approximately 20% and reduced the trash moisture content by approximately 5 percentage points.

Topping of the crop is considered an effective way of increasing bulk density and increasing trash fuel quality. This strategy would obviously only be able to be used where 1-year-old cane is erect and the grower is able to leave the tops and not use a post harvest burn.

Whilst not as effective as running the primary extractor to reduce trash levels, topping results in the harvesting of trash of a higher fuel value.

### 4.8 Other Strategies

Other Strategies were considered to improve the harvesting/transportation of WC sugarcane and are included in Appendix C – Other Bulk Density Improvement / Trash harvesting and Transport Concepts. Notes, calculations and general concepts are included in this appendix for completeness.

### 5 Trash Shredder

The trash shredder concept was to reduce the trash particle size, and thus increase the transportation bulk density. The concept was to use the existing primary extractor fan to extract the trash in the cleaning chamber, and then direct the trash back into the harvester elevator where the whole crop would be delivered into the haulout.
5.1 Concept

The design requirements for the extractor shredder fan were as follows:
- Extract trash whilst minimising cane loss
- Reduce trash particle size by shredding/cutting/attrition
- Discharge shredded trash back on to elevator

Design factors considered for the extractor shredder fan were:
- Safety
- Simple design
- Low cost - simple modification to harvesters
- Robust – good service life
- Maximising the number of blades to maximise shredding capability
- Maximise fan speed whilst maintaining current Harvester Best Practice (HBP) extractor fan air flow
- Minimise weight
- Modular design with the following benefits:
  - Minimise overall cost of manufacture and cost to modify during testing
  - Maximise flexibility for testing by interchangeable blades and adjustable blade pitch
  - Incorporation of fixed blades to maximise trash shredding
  - Raise fan higher up in the extractor hood to assist in evenness of air-flow

The shredder fan design was required to be an addition to an existing modern sugar cane harvester. It therefore must be designed in consideration with the following constraints:
- Fit into existing extractor hood of either a Austoft 7000 series harvester (4’6”) or a Cameco 3510 (5”) harvester primary extractor
- Hydraulically powered
- Limited hydraulic power is available
- Weight

5.2 Initial Design - Cameco

Based on the design requirements an initial shredder fan was designed to suit a Cameco 3510 harvester that was available for testing. Initial flow calculations of the 3510 harvester primary extractor were made in an attempt to match the fan airflow at maximum speed of the shredder fan with the airflow of a commercial harvester at harvester best practice speed.

A model was developed that considered the number of blades, blade surface area, blade length and blade pitch. The model contained several simplifying assumptions. With these limitations in mind, a design was developed which would hopefully satisfy the key requirements. The design had a stepped hub to increase the height of the fan in the cleaning chamber.
The design drawings and calculations were sent to a consulting engineer to conduct a formal design review on the basis that the fan is a potentially hazardous piece of high speed rotating plant. The consulting engineers design review identified some concerns with the design and made a series of recommendations. Of concern was the stress on the stepped hub design at full fan speed. Table 6 lists the design review recommendations and the action taken in response to the recommendations:

Table 6 - Consulting Engineers Shredder Fan Review Summary

<table>
<thead>
<tr>
<th>Action to Consider from Consulting Engineers</th>
<th>Action Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Rotational Mass</td>
<td>Total Mass of fan reduced from approximately 130kg to less than 85 kg.</td>
</tr>
<tr>
<td>Pressure Relief in Hydraulic Circuit</td>
<td>Hydraulic Circuit has pressure relief system</td>
</tr>
<tr>
<td>Provide a Hard Barrier</td>
<td>Designed a hard barrier to be fitted on extractor hood to provide additional protection in the event of failure.</td>
</tr>
<tr>
<td>Use Symmetric Mounting</td>
<td>Redesigned hub so no longer offset. Reduced blade mass. Blades will still be mounted offset to hub plate however hub is no longer welded design. Unable to use symmetric blade mounting with current blade holder design. Manufacturing issue.</td>
</tr>
<tr>
<td>Reduce number of independent connections</td>
<td>Hub redesign includes reduction in number of blades.</td>
</tr>
<tr>
<td>Bolt checking procedure</td>
<td>Procedure to be developed to torque nuts to specified tension and to check regularly.</td>
</tr>
</tbody>
</table>

Based on the recommendations from the consulting engineers the design was simplified to a flat hub design. This simplification meant that the fan was not higher in the chamber. This design was then installed on a 3510 harvester at Condong (Figure 32).
The design featured an inlet cone and fixed blading with the aim of guiding material into the fan blades and maximising trash shredding. For this initial test, the fan blades were manufactured from mild steel and had a straight machined leading edge. This fan was trailed in early 2010 both pre-season and one trial at the beginning of the season. The fan was effective in shredding the trash and results are presented in section 5.

### 5.3 Initial Design - Austoft

A similar design to the Cameco design was manufactured for an Austoft 7700 harvester with which the majority of the remaining trials were conducted. This design included 16 blades with the blade now featuring a serrated leading edge. The blade was manufactured from a heat-treated spring steel to improve wear properties. Fixed blades were included in the fan barrel to improve shredding and a nose cone was fitted to the fan hub to improve aerodynamic performance.
Remaining trials during the 2010 season were conducted with this shredder fan fitted to the Austoft harvester.

Improvements to the hydraulic system of the Austoft harvester were necessary due to the high operating hydraulic pressure. Operating pressures exceeded the working range for the standard Austoft configuration, which included a gear motor driving the shredder fan. An additional piston pump was fitted to the harvester (tandem pump on one of the traction pumps) and a piston motor fitted to the primary extractor fan. The piston pump/piston motor combination has a higher allowable operating pressure. This system resulted in higher fan speeds being achieved.

5.4 2010 Trials

To increase the transportation bulk density of whole crop cane, the design, construction and testing of a shredder fan has been undertaken. The ‘shredder’ fan aimed to extract the trash as per a standard extractor fan but in doing so, reduce the trash particle size by the action of the aggressive multi blade fan. The trash is then returned to the elevator for whole crop delivery to the infield haul outs.

Trials of the shredder fan were conducted during the 2010 season at both Condong and Broadwater Mill areas.

Table 7 - 2010 Shredder Trials

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-1-10</td>
<td>Condong</td>
</tr>
<tr>
<td>15-4-10</td>
<td>Condong</td>
</tr>
<tr>
<td>21-5-10</td>
<td>Condong</td>
</tr>
<tr>
<td>20-6-10</td>
<td>Condong*</td>
</tr>
<tr>
<td>5-7-10</td>
<td>Pimlico</td>
</tr>
<tr>
<td>14-7-10</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>21-7-10</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>22-7-10</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>23-7-10</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>9-8-10</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>12-8-10</td>
<td>Pimlico</td>
</tr>
<tr>
<td>9-9-10</td>
<td>Pimlico</td>
</tr>
<tr>
<td>13-9-10</td>
<td>Pimlico</td>
</tr>
<tr>
<td>17-9-10</td>
<td>Woodburn*</td>
</tr>
<tr>
<td>19-10-10</td>
<td>Empirevale*</td>
</tr>
<tr>
<td>3-11-10</td>
<td>Teven*</td>
</tr>
<tr>
<td>4-11-10</td>
<td>Teven*</td>
</tr>
<tr>
<td>5-11-10</td>
<td>Teven*</td>
</tr>
<tr>
<td>22-11-10</td>
<td>Wardell</td>
</tr>
<tr>
<td>4-12-10</td>
<td>Mullumbimby</td>
</tr>
<tr>
<td>9-12-10</td>
<td>South Ballina</td>
</tr>
</tbody>
</table>

* Bulk Density Data collected
Trial procedure included the running of the shredder fan whilst harvesting whole crop and comparing data collected with ‘fan off’ treatments. Data collected during the trials included:

- Haul-out bulk density
- Multi-lift bulk density
- Primary extractor fan speed
- Primary extractor fan oil pressure
- Extraneous matter samples
- Trash samples
- Billet length
- Cane analysis data including Pol

Trials showed that the bulk density of whole crop harvested cane can be increased significantly by the use of a shredder fan. Cane loss was observed to be significantly higher whilst taking samples and the samples were analysed to quantify the level of loss.

Additional benefits to the shredded trash treatments were the improved ‘flow’ characteristics of the material when being tipped. The shredded trash treatments tipped in a more controlled manner from the haulout into the multi lift bin, thus reducing spillage and allowing product to be tipped to where it was required in the bin.

**Figure 34** Haul outs being tipped with material that has been harvested without (pictured on the left) and with the use of the shredder fan. Note trash particle size in shredded treatment.

**Trial 1 – Condong – 20/6/10**

The first full trial of the shredder fan following preseason testing was carried out in 1-year-old (1 YO) cane at Condong Mill. The fan was fitted to a 2007 John Deere 3510 harvester. The shredder fan was the first fan manufactured and included a fabricated inlet guide section to force the material through the blades. 16 * 100 mm wide mild steel blades were used for this trial.

Testing was carried out using 4 treatments:
• Shredder Fan Off (baseline Whole Crop Bulk Density)
• Shredder Fan On
• Shredder Fan Off – Topper On (Bulk density of topped crop)
• Shredder Fan On – Topper On

A temporary shroud was constructed to catch the trash from the primary extractor hood and direct it onto the elevator. The inlet guide ring with fixed blading was also fitted inside the primary extractor to assist shredding. This harvester was fitted with a 12-blade chop (6 blades per chopper drum).

Table 8 - Trial 1 2010 - Bulk Density Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Haulout BD (kg/m³)</th>
<th>Bulk Density Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>236</td>
<td></td>
</tr>
<tr>
<td>WC with Shredder (1220 rpm)</td>
<td>274</td>
<td>16%</td>
</tr>
<tr>
<td>Topping</td>
<td>252</td>
<td>7%</td>
</tr>
<tr>
<td>Topping with Shredder (1220 rpm)</td>
<td>283</td>
<td>20%</td>
</tr>
</tbody>
</table>

The average bulk density improvement using the shredder fan was 16%. Using the topper alone an increase in bulk density of 7% was achieved. Using both the shredder fan and the topper resulted in an increase in transportation bulk density of 20%.

Hydraulic oil pressure whilst harvesting was approximately 3100 psi and whilst the fan was not loaded it was approximately 2200 psi.

Trial 2 – Pimlico – 14/7/10

This trial was conducted at Pimlico using the 2003 Austoft 7700 that was used for the majority of all subsequent trials. This harvester was fitted with a permanent hood to collect trash as it left the primary extractor hood. The hood was also locked to the elevator so that it would slew with the elevator. The fan configuration consisted of 16 * 100 mm wide mild steel blades. The fan was powered using the standard Austoft gear motor and had a maximum unloaded speed of 1050 r/min.

Table 9 - Trial 2 2010 - Bulk Density Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Haulout BD (kg/m³)</th>
<th>Average Multi BD (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>244</td>
<td>216</td>
</tr>
<tr>
<td>WC with Shredder</td>
<td>273</td>
<td>241</td>
</tr>
<tr>
<td>Improvement from Shredding</td>
<td>12%</td>
<td>11%</td>
</tr>
</tbody>
</table>

The trial resulted in an average bulk density improvement of 12% and 11% for the haul out and multi lift bins respectively. Of note is the fact that only two haul out tips per Multi lift bin made thus leaving some spare room in each Multi for additional crop. Billet fragments were observed in the samples.

The primary extractor oil pressure was relieving at 3200 psi (Austoft design relief 3500 psi). The maximum continuous rating for the hydraulic motor is 2500 psi and the relief is to protect the motor. Continuous operation at the pressure relief point is not desirable and would result in elevated oil temperatures and potential motor failure.
Trial 3 – Pimlico – 22/7/10

Following the trial at Pimlico on the 14/7/10, the standard primary extractor motor (8.1 in³) was replaced with a smaller 6.4 in³ gear motor with the aim of increasing fan tip speed. Concern over high oil pressure in the primary extractor also led to the replacement of the 100mm wide mild steel blades with 75 mm wide blades. These new blades were hardened spring steel blades with machined serrations. Different numbers of blades were tested to assess the impact on reduced blades on fan running pressure.

Table 10 - Trial 3 2010 - Bulk Density Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Haulout BD (kg/m³)</th>
<th>Average Multi BD (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>212</td>
<td>188</td>
</tr>
<tr>
<td>WC with Shredder</td>
<td>260</td>
<td>222</td>
</tr>
<tr>
<td>Bulk Density Improvement</td>
<td>22%</td>
<td>18%</td>
</tr>
</tbody>
</table>

The trial wasn’t large enough to have sufficient data to determine variations in bulk density from different treatments, so an average increase in bulk density for the ‘fan on’ treatment is presented. Again, only two tips of the haulout per multi were done for the trial so each multi did have additional capacity.

Although variation in primary extractor oil pressure could be seen, all treatments resulted in the system running at relief for some period of time.

Trial 4 – Pimlico – 9/8/10

The next trial at Pimlico was conducted with 12 fan blades. This trial aimed at finding a compromise between lowering fan oil pressure whilst maintaining effective extraction. 12 serrated 75mm blades were used with the fan operating at 1500 r/min unloaded.

Table 11 - Trial 4 2010 - Bulk Density Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Haulout BD (kg/m³)</th>
<th>Average Multi BD (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>204</td>
<td>163</td>
</tr>
<tr>
<td>WC with Shredder</td>
<td>238</td>
<td>190</td>
</tr>
<tr>
<td>Bulk Density Improvement</td>
<td>16%</td>
<td>16%</td>
</tr>
</tbody>
</table>

An increase in bulk density of 16% was achieved in the haul out and a 16% increase in the multi lift bins. Again only 2 haulout tips per multi lift bin were made, thus leaving some additional capacity in the multi bin and the very low apparent bulk density in the multi bin. Like previous trials, the primary extractor fan was operating at relief whilst harvesting.

Trial 5 – Woodburn – 17/9/10
Following previous trials, the hydraulic system on the harvester was upgraded so that the primary extractor was powered by a separate piston pump and piston motor. This modification was made to the Austoft harvester to allow the fan to run safely at higher hydraulic oil pressures.

This trial was the first full data collection trial with the new pump/motor combination. The trial was conducted with 2 * 45m³ tractor-trailer infield and the fan was operated with both 16 and 8 blades. Crop variation across the paddock resulted in the 8 blades outperforming the 16 blades in bulk density improvement so an average of the two treatments is presented.

**Table 12 - Trial 5 2010 - Bulk Density Results**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Haulout BD (kg/m³)</th>
<th>Average Multi BD (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>181</td>
<td>178</td>
</tr>
<tr>
<td>WC with Shredder (average)</td>
<td>218</td>
<td>213</td>
</tr>
<tr>
<td>Improvement from Shredding</td>
<td>20%</td>
<td>19%</td>
</tr>
</tbody>
</table>

In addition to bulk density data, a short period of trash extraction onto the ground was done to determine the extraction efficiency of the fan. This was done for both 8 and 16 blade configurations. Bulk density improvement of 20% and 19% was achieved for the infield haul-outs and multi-lift bins respectively. Hydraulic oil pressures were able to be logged for their full range without the system relieving and average running pressure for the 16 blade configuration was 4800 psi whilst the average running pressure for the 8 blades was 3800 psi.

**Trial 6 – Empirevale – 19/10/10**

This trial was attempted after a prolonged period of wet weather. Field conditions were still very wet and muddy. The attempt to conduct the trial under these conditions highlighted the significant issues with harvesting whole crop in the wet. Field damage, mud and harvester performance issues were made worse by trying to harvest whole crop under these conditions.

The wet weather ultimately resulted in the trial being abandoned. The data collected indicated very good bin weights and excellent bulk density for both fan on and fan off treatments. The fan was operated with only 8 blades. 2.5 tips per multi were made which, along with good yielding cane and wet muddy conditions, resulted in high multi lift bin weights/bulk densities.

**Trial 7 & Trial 8 – Teven – 3-5/11/10**

This trial was conducted in good conditions. Some light showers occurred during the trial but generally conditions were good in good cane. The first day of the trial was aimed at collecting more data using the existing fan configuration. The latter days of the trial (Trial 8) looked at the impact of longer billets on bulk density.

The fan on / fan off treatments were tested with the standard chopper blades. Then 2 chopper blades per drum were removed to assess the impact of long billets. Fan on
and fan off treatments were tested to obtain base case versus shredder fan data. The billet length dial in the harvester cab was then adjusted down to short chop to obtain data for another billet length. The results are presented below for all treatments.

Table 13 - Trial 7&8 2010 - Bulk Density Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Haulout BD (kg/m³)</th>
<th>Average Multi BD (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC - 8 Blade Chop</td>
<td>218</td>
<td>204</td>
</tr>
<tr>
<td>WC with Shredder - 8 Blade Chop</td>
<td>262</td>
<td>246</td>
</tr>
<tr>
<td>Bulk Density Improvement</td>
<td>20%</td>
<td>21%</td>
</tr>
<tr>
<td>WC - 4 Blade Chop</td>
<td>185</td>
<td>172</td>
</tr>
<tr>
<td>WC with Shredder - 4 Blade Chop</td>
<td>225</td>
<td>210</td>
</tr>
<tr>
<td>Bulk Density Improvement</td>
<td>22%</td>
<td>22%</td>
</tr>
<tr>
<td>WC with Shredder - 4 Blade Chop - Short Chop</td>
<td>241</td>
<td>221</td>
</tr>
</tbody>
</table>

5.5 2010 Trial Results

Shredder fan trials conducted in 2010 resulted in an average increase in haulout bulk density of 18%. Bulk density improvements for the trials ranged from 12 to 22% (Trial 6 has been omitted due to the data inconsistency).
Actual bulk densities achieved in the multi-lift bins were not always representative of the product bulk density because in many trials, only 2 haulout tips per multi were made to eliminate the error found in partially tipping bins. Actual bulk densities that could be achieved would be slightly higher for some trials if the material in the bin were levelled.

The trials did demonstrate the continued need for some form of levelling of the multi-lift bin at the pad despite having the trash shredded.

Whilst good improvements in bulk density were achieved with the use of the shredder fan, a significant amount of billet chips where observed in samples taken. To quantify the cane loss due to the shredder fan, trash samples were collected for both the fan on and fan off treatments. These samples were then mulched in the field, sub-sampled and frozen for later analysis.
A direct cane analysis was then performed on the trash samples to quantify the additional juice in the trash as a result of the operation of the fan. The graph below shows the trash analysis results with the average level of pol for both fan on and fan off treatments. It can be seen that the average level of pol in trash increases from approximately 2% to approximately 4%.

Table 14 - 2010 Trials Average Pol % Trash Results

<table>
<thead>
<tr>
<th>Trial Date</th>
<th>Average Pol in Trash % - Fan Off</th>
<th>Average Pol in Trash % - 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><strong>Average</strong></td>
<td><strong>1.9</strong></td>
<td><strong>3.8</strong></td>
</tr>
</tbody>
</table>

Also recorded was an increase in extraneous matter for the fan on treatments as well as an increase in trash moisture content, which indicate the loss of cane.

Figure 38 Average %EM content – 2010 Trials
The pol in trash results for the 2010 season demonstrated that cane loss was high. When a financial analysis of the results was performed (Chapter 7), it was shown that the harvesting and transportation savings as a result of increased bulk density were less than the value of cane lost due to the shredder fan.

On this basis a modified shredder fan and hood was designed with the aim of reducing cane loss.

### 5.6 Modified Design - Prototype Hood

Cane loss through the shredder fan was identified as the key issue in any attempt to increase transportation bulk density. In an effort to reduce the amount of cane drawn into the fan, a new prototype hood was manufactured. The fan in this hood was higher above the discharge of billets from the choppers.

In order to raise the fan and not increase fan-operating pressure due to it discharging against the top of the hood, the prototype hood has a hole in the top. The concept relies on the trash being thrown outwards by the fan blades and exiting the hood at the rear outlet, whilst primarily clean air exits the top of the hood. The fan is similar in design to the fan trialled on the Austoft harvester.
The sale of the test harvester mid November 2010 stopped the trial of this hood however it was installed briefly on another harvester at Broadwater in late November. A small trial was conducted between the commercial harvesting of cane. During the trial, samples were taken to determine the amount of trash being extracted and air flow.

Generally the principle of the hood worked however excessive trash was exiting at the top of the hood and wet material was building up in the ‘volute’ area of the fan hood.

Visually it appeared that approximately 2/3 of the trash extracted was discharging at the rear and approx 1/3 of the trash leaving the hood at the top outlet.

The following changes were made to the fan following this trial:
- Smaller hydraulic motor – Fan operating faster
- Ring fitted to top hole to reduce diameter
- Section of inner ring removed to allow trash to clear easily
- Larger blades (longer and wider) fitted to increase extraction.
Another trial with these modifications (with exception of smaller motor) was conducted on the 4th of December at Mullumbimby. The top outlet hole was reduced in diameter from 1000 mm to 800 mm. The 75 mm wide blades were replaced with 100 mm wide blades and some of the inner ring was removed.

Reasonable trash/air separation occurred however with the dry conditions, more dry trash exited through the top hole than the previous trial. The extraction efficiency of the fan still needed improving. Structurally the hood also needed improvement and the motor mount required redesigning to reduce vibration. The volute remained clean despite the reasonable amount of mud due to the very wet ground conditions. Air/trash separation within the hood was observed to be good during 2010 trials however some trash was still exiting via the top outlet.

Design changes to the prototype hood were undertaken to improve the fan performance. These changes were aimed at addressing the issues observed during 2010 tests. The changes made to the fan included:

- New blade holders were manufactured to ensure blade pitch uniformity and thus improve fan balance
- A ‘trash finger hub’ was manufactured with the aim of removing any trash from top outlet air stream and directing it towards the rear outlet
- Modified fan mounts to reduce vibration
- Increased number of fan blades to increase extraction

![Figure 42 Trash Finger hub to reduce the amount of trash exiting the hood via the top hole](image)

Testing of these modifications during the non-crush period was made on a test frame powered by a hydraulic power pack. Testing using the power pack was performed to quantify airflow, pressure, airflow split between the rear outlet and top outlet as well as air flow visualisation. The modifications made following the 2010 season resulted in a significant reduction in fan vibration. New, longer serrated blades were also manufactured for the 2011 season.
5.7 2011 Trials

For the 2011 season, the prototype hood was fitted to a 2007 Austoft harvester. Trials with the prototype hood were conducted in the Broadwater Mill Area. Modifications to hydraulics made in 2010 were repeated for 2011 season.

Table 15 - 2011 Prototype Hood and Shredder Fan Trials

<table>
<thead>
<tr>
<th>Trial Date</th>
<th>Trial Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>29/6/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>30/6/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>8/7/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>11/7/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>13/7/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>14/7/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>4/8/2011</td>
<td>Pimlico</td>
</tr>
<tr>
<td>9/8/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>10/8/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>15/8/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>17/8/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>18/8/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>17/9/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>18/9/2011</td>
<td>Pimlico*</td>
</tr>
<tr>
<td>25/10/2011</td>
<td>East Wardell*</td>
</tr>
<tr>
<td>26/10/2011</td>
<td>East Wardell*</td>
</tr>
</tbody>
</table>

* Bulk Density Data Collected

Early season tests focused on understanding the fan airflow, extraction and optimising the outlet sizes. Testing done from the 29th of June until the 14th of July involved changing the rear and top outlet size and optimising the fan speed.

Full trials were conducted with both fan-on and fan-off treatments and directing trash back into the elevator to determine the increase in WC bulk density. Some trials involved varying fan speed to determine the effect of fan speed on both bulk density and cane loss.

In the initial tests the fan did not extract sufficient trash. To address this, the rear outlet, previously 450 mm * 700 mm, was replaced with a 600 mm * 700 mm outlet. Additionally, the deflector plate was moved upwards to direct the material up into the cleaning chamber. A 100 mm annular ring was removed from the top outlet however this resulted in very high extraction to the point where cane was observed going through the fan and the outer spiral of the hood blocked due to high material flow rates. The blocking of this spiral resulted in trash exiting the fan though the top outlet.
The top annular ring was replaced and fan speed limited to approximately 1400 r/min (unloaded) to address the blocking in the spiral. In good, dry conditions, it was found that the extraction at 1400 r/min (reducing to approximately 1300r/min while harvesting) was sufficient.

The finger wheel trash wiper at the top of the hood required some changes; the attachments of the fibreglass rods to the aluminium hub were pinned. The fibreglass rods were robust and none broke or showed signs of significant wear after the 2011 trials. The trash finger wheel’s effectiveness was not quantified however it did make access from the top down to the fan spiral difficult. Specific trials with and without the finger wheel would be required to ascertain how effective it is.

5.8 2011 Trial Results

Airflow measurements of the shredder fan were undertaken during the season following the change in fan outlets. Fan inlet velocity measurements confirmed field observations, that at 1600 r/min, the inlet air velocity (under dry field conditions) is sufficiently high that a significant amount of cane would be drawn into the fan.
Figure 44 Prototype hood and shredder fan inlet air velocity – Approx 600 mm below fan

Of note, is the split in airflow from the rear and top fan outlets. Measurements of the fan air flow at the rear and top outlets show a significant volume of air is discharged from the fan via the top outlet.

Figure 45 Prototype hood air split

Like previous trials, a hydraulic pressure data logger was fitted to the harvester to record the hydraulic pressure of the shredder fan. With this information and the fan speed, it is possible to calculate the fan power. The graph below shows the fan power for both harvesting and unloaded fan operation. The harvesting fan power is approximately 58 kW at 1300 r/min.
For each trial conducted, the bulk density of the material in the haulout was recorded. When the haulout is filled consistently between treatments, this measurement gives the best representation of the improvement in bulk density due to the shredding of the trash. Whole crop haulout bulk densities for the fan off treatments ranged from $173 \text{ kg/m}^3$ to $234 \text{ kg/m}^3$ with an average of $204 \text{ kg/m}^3$. This is consistent with 2010 trial results. Figure 47 shows the average fan on and fan off bulk densities for the 2011 trials.

Haulout bulk densities with the shredder fan operating at 1300 r/min (harvesting) ranged from a minimum of $167 \text{ kg/m}^3$ to a maximum of $290 \text{ kg/m}^3$ with an average of $233 \text{ kg/m}^3$. These results show the significant variability of results encountered with whole crop.
Operating the shredder fan and directing the trash back into the elevator increased the haulout transportation bulk density on average by 14%.

Average whole crop extraneous matter (EM) was 25% of total crop harvested and had an average trash moisture content of 42%.

Both fan on and fan off treatments were sampled to determine the level of extraneous matter. The extraneous matter samples were then mulched and sub sampled using the same methodology detailed in previous milestone reports.

The samples were then tested to determine the level of pol in the trash. The graph below shows the average pol in trash results for both the fan on and fan off treatments.
for each trial. The difference between the two can be attributed to cane loss through the shredder fan.

Table 16 - 2011 Trials Average Pol % Trash Results

<table>
<thead>
<tr>
<th>Trial Date</th>
<th>Average Pol in Trash - Fan Off</th>
<th>Average Pol in Trash - 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><strong>Average</strong></td>
<td><strong>1.9</strong></td>
<td><strong>2.2</strong></td>
</tr>
</tbody>
</table>

These results are a significant improvement on the results from the 2010 season. While there is still an increase in pol in trash between the two treatments the difference is significantly less than that found during the 2010 season using the shredder fan with the standard extractor hood (Figure 50).

Figure 50 2011 Comparison between 2010 and 2011 results – Pol % Trash

Trash sampling and testing methods were identical in both years. These results confirm that the prototype hood has reduced cane loss.

The results, when calculated back to a tonnes of cane/hectare, appear to be too low despite efforts made to ensure all small cane particles would be caught by the elevator. These efforts included sheeting of the harvester elevator floor to ensure no small particles could fall through, and trialling the collection of samples from the haulout as opposed to the multi-lift bins (this method resulted in no difference).

Mass balance trials were attempted but significant variation in the extraneous matter levels of samples resulted in the trials not providing clear results. Unfortunately, further trials were not possible due to the unavailability of the harvester.
6 Additional Tools to Improve Whole Crop Harvesting

This section aims to highlight some additional improvements that harvesting groups have implemented that have made the harvesting of WC easier.

6.1 Bin Mounted Camera

The use of a bin-mounted camera assists the haulout driver to both fill and empty the haulout bin when harvesting WC. Good vision of what the material is doing in the bin assists the operator in controlling tipping. Mounting a camera on the rear of the bin allows the haulout driver to maximise the payload from the field by being able to see the rear of the bin easily when filling.

Cameras are cheap, relatively reliable and assist the operator to tip the load into the road bin. If the camera is located correctly, the operator can see both into the road bin and into the haulout making transferring the load to the correct part of the bin easier. Additionally, and more importantly the camera allows the operator to tip the load with greater control, reducing spillage and waste.

![Figure 51 Haulout with a bin mounted camera](image)

6.2 Flipper Rollers

Flipper rollers are commonly used in burnt cane harvesting on side tipping haul-outs to control the tipping. They perform this function in WC harvested cane as well but not as effectively. They are however very effective when used in conjunction with a bin mounted camera. The combination of these two features gives the operator good vision and control whilst tipping.
**6.3 Matching of Haulout Capacity to Road Transportation Bin Capacity**

Controlled tipping of WC harvested cane is difficult, and partial tipping is even harder. To avoid part-tipping haul-outs, the matching of the haul-out capacity to road bin capacity is important if the road bin payload is to be maximised.

For the 90m$^3$ road bin the use of 3 tips from a 30 ± m$^3$ haulout or 2 tips from a 45 ± m$^3$ haulout is the ideal scenario. Because during transport to the loading pad the material in the haulout will consolidate, it will require some levelling/compaction when tipped into the multi-lift bin.

**6.4 GPS**

Harvester and haulout operators have reduced visibility when harvesting WC, which makes staying on the row difficult. This is especially true where the crop is large and lodged. Staying on the row is especially critical in controlled traffic systems to avoid field damage.

Fitting the harvester with GPS guidance assists the harvester operator find the row in whole crop, and stay on the row. Despite some initial issues, those harvester operators that have persevered with GPS auto-steer consider it to be an excellent tool.

The benefits of a controlled traffic farming system with GPS guidance were well demonstrated in SRDC Research Project NSC 005 – Implementing an Integrated Farming System in NSW $^9$.

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$^9$ Ensbey et al, 2008
7 Outputs - Financial Model and Analysis

A financial model was created to analyse the results from the 2010 and 2011 seasons. An initial analysis following the 2010 season trials showed that the savings in transportation and harvesting were less than the value of the cane lost due to the shredder fan (see Milestone 5 report). On this basis a prototype hood was developed with the aim of reducing cane loss.

The analysis conducted for this report includes the results from the 2011 season trials using the prototype hood. The analysis considers the following whole crop harvesting/trash recovery strategies:

- Whole crop harvesting – No Fan
- Whole crop harvesting – Shredder Fan with prototype hood
- Whole crop harvesting – No Fan – Mobile Compaction of product in multi-lift bin.
- Whole crop harvesting – Combined Shredder Fan with prototype hood and compaction of product in multi-lift bin.
- Whole crop harvesting – Shorter Billets (12 Blade Chop)
- Green cane trash blanket – Fan Low Speed

The model relies on certain assumptions to allow a reasonable comparison between strategies to be made. The assumptions are based on harvesting 2-year-old cane. The majority of these assumptions are outlined in Appendix D – Financial Model Assumptions, however the key assumptions are listed below in Table 17.

<table>
<thead>
<tr>
<th>Table 17 - Financial Model Assumptions 2YO cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average yield (burnt cane)</td>
</tr>
<tr>
<td>Average burnt cane Pol</td>
</tr>
<tr>
<td>Pol lost due to burning</td>
</tr>
<tr>
<td>Harvest group crop size</td>
</tr>
<tr>
<td>Trash available additional</td>
</tr>
<tr>
<td>Trash moisture content</td>
</tr>
<tr>
<td>Diesel price</td>
</tr>
<tr>
<td>Interest rate</td>
</tr>
<tr>
<td>Current burnt cane harvest price</td>
</tr>
<tr>
<td>Current road transportation price</td>
</tr>
<tr>
<td>Current WOC Transportation Bulk Density</td>
</tr>
<tr>
<td>Target WOC Transportation Bulk Density</td>
</tr>
<tr>
<td>Sugar price</td>
</tr>
<tr>
<td>Electricity income</td>
</tr>
</tbody>
</table>

Harvesting cost information is based on data collected during the whole crop trial in 2009.

Strategy 1 is the harvesting of the whole crop with no extraction fans running. During trials this strategy was rarely used in practice due to capacity issues at the harvester elevator boot and bulk density issues in the haulout. To alleviate the issue at the elevator boot, many groups began to operate their primary extractor fan to clear the elevator boot and then directed trash back into the elevator. Additionally, some
groups operated the primary extractor fan at low speed to improve bulk density. Despite these limitations this strategy is treated as the ‘base case’.

*Strategy 2* is the use of the modified shredder fan and prototype hood to shred the trash and then direct it back into the haulout. This strategy has been the focus of trials during the 2011 season.

*Strategy 3* is harvesting the whole crop as per strategy 1 but then compacting the material into the road transportation bins with a piece of mobile plant.

*Strategy 4* is the combination both strategies 2 and 3. The use of the shredder fan to shred the trash and then the use of a compaction rig on the pad to compact the material into the multi-lift bin.

*Strategy 5* is whole crop harvesting but with shorter billets. This strategy illustrates the impact of cutting shorter billets by way of a 6 blade per drum chop on bulk density and sugar loss.

*Strategy 6* is operating the primary extractor fan at low speed to remove some trash. This strategy allows improved bulk density however results in cane loss and a reduction in fibre recovery. No consideration is given to the agronomic costs of this strategy and it is noted that leaving trash in the field is not an option for many growers.

*Strategy 7* is full Green Cane Trash Blanket (GCTB) harvesting and the trash recovery by baling. Contract hay baling rates were used to determine the cost of trash recovery. It should be noted that this strategy relies on weather conducive to hay baling and for this reason; it is an ‘opportunity’ strategy only.

The financial model aims to calculate the relative financial cost of the strategies trialled to increase whole crop bulk density during transport. The impact of cane loss on this financial analysis is significant.

Trials from the 2011 season with the new prototype hood fan have significantly lower losses than the shredder fan used in the 2010 season. The reduction in cane loss has resulted in a positive net benefit when operating the shredder fan. The model suggests that trash costs per dry tonne with the ‘base case’ (whole crop harvesting with no fan) is approximately $60. This cost could be reduced to approximately $55 per dry tonne of trash with the use of the shredder fan and prototype hood.

The model calculates that for pad compaction alone the cost per dry tonne of trash would be $53 per dry tonne. This is based on the assumption that bulk densities of greater the 240 kg/m$^3$ could be consistently achieved. The combination of shredding trash and compacting on the pad is similar to shredding alone because of the additional capital, but apparent minor increase in bulk density on the pad between shredded and shredded & compacted.

Only extended periods of whole crop harvesting could confirm if this is the case however it should be noted that some form of levelling in the bin will be required, so while performing the levelling, it would be possible to do some compaction.
The model shows that WC harvesting, based on current costs is marginal with increased gross value per hectare (at mill gate) between burnt cane harvesting and WC harvesting with the shredder fan of approximately $300/Ha. These costs rely heavily on the harvesting costs inputs and the cane loss data collected during trials. These values do not consider the costs associated with separation or processing at the sugar mill. They represent only the value of the product once harvesting and transportation costs are deducted.
Shredding trash is a good strategy if extractor loss can be maintained at a low level. Further research is required to confirm cane loss data from the prototype hood. The model also shows that compaction is a good strategy despite high labour costs.

A separate financial analysis has been done for topping of 1-year-old cane. Key assumptions are outlined in Table 18. The model calculates the relative benefit of harvesting whole crop 1-year-old cane with the topper operating. It accounts for the reduction in tonnes of trash harvested and the reduction in the trash moisture content.

**Table 18 - Topping Financial Model Assumptions**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average yield</td>
<td>90 T/Ha (Condong)</td>
</tr>
<tr>
<td>Average burnt cane Pol</td>
<td>12.0% (Condong)</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 Tonne</td>
</tr>
<tr>
<td>Trash moisture content pre topping</td>
<td>55%</td>
</tr>
<tr>
<td>Trash moisture content post topping</td>
<td>50%</td>
</tr>
<tr>
<td>Current burnt cane harvest price</td>
<td>$8.00/t of cane</td>
</tr>
<tr>
<td>Current road transportation price</td>
<td>$1.64/m²</td>
</tr>
<tr>
<td>Current WOC transportation bulk density</td>
<td>220 kg/m³</td>
</tr>
<tr>
<td>WOC transportation BD – topped improve.</td>
<td>7%</td>
</tr>
<tr>
<td>Target WOC transportation bulk density</td>
<td>250 kg/m³</td>
</tr>
<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 of topping shows a positive result if topping is undertaken. Again it should be highlighted that the ‘base case’ scenario is presented for comparison only, and was not widely practiced (if at all).

**Figure 55 Financial Model – Value per hectare – topping 1YO cane**

Topping is a practical way of improving whole crop harvesting in year old cane. The model suggests that crop value per hectare could increase by approximately $250
(based on assumptions) if whole crop harvesting and topping was performed (value is gross and at mill gate).

Further large-scale trials are required to validate the initial topping trials.

8 Intellectual Property and Confidentiality

There is no intellectual property associated with this project that requires protection.

9 Conclusions and Recommendations

Harvesting whole crop is problematic and difficult, particularly in large two-year-old lodged crops. Low product bulk density makes harvesting and transportation costly. Increased harvesting costs are a result of increased man-hours per tonne of cane harvested, additional fuel usage for harvesting and hauling the whole crop, and the increased capital due to the larger capacity hauling equipment and harvester modifications.

Whole crop harvesting results in approximately 25% additional mass harvested and a reduction in transportation bulk density by approximately 50%. Due to the high biomass yield per hectare in large 2YO crops and low transport bulk density, whole crop harvesting results in reduced harvester throughput (t cane/hr), increased harvesting costs and increased field traffic.

This project has identified, tested and costed various strategies to improve the transportation of WC harvested cane. These strategies included:

- Particle size reduction
- Compaction
- Vibration
- EM reduction (topping, low fan speed)

The impact on cane loss must be considered with any strategy to increase transportation bulk density. As such, measuring cane loss and quantifying the cost of cane loss in the bulk density improvement was an important aspect of this project.

The project has demonstrated that shredding trash is an effective way of increasing transportation bulk density however this method increases loss of cane. Initial testing of the shredder fan concept resulted in excellent bulk density improvements however high cane loss results were also measured. The shredder fan also had higher power requirements to the standard primary extractor and a higher operating oil pressure. Modifications to the pump and motor on the Austoft test harvester were required. The use of the shredder fan also prevented elevator overflow by clearing the elevator boot of trash.

In an attempt to reduce cane loss a modified shredder fan and hood were designed and tested. These tests showed that the use of the prototype hood and shredder fan resulted in an increase in transportation bulk density of 14%. The prototype hood also
demonstrated that raising the extractor fan/shredder fan in the primary extractor hood is an effective and sensible way of reducing cane loss. A reduction in cane loss was measured due to the use of a shredder fan & prototype hood in comparison with the shredder fan & standard extractor hood.

The compaction of WC cane was found to be effective. Shed tests were conducted to quantify WC compaction and a relationship between bulk density and compaction pressure was determined. Field testing of a compaction machine supported the shed test data. Cost models suggest that despite the high labour cost, this strategy could be cost effective. Improved compaction machine designs are required that enable quick effective compaction with good operator visibility and machine manoeuvrability. Ultimately, compaction, without trash shredding, may achieve target bulk density levels without the inherent risks (cane loss, maintenance costs, reliability) of the trash shredding process.

Topping trials were conducted in one-year-old, erect cane to assess the impact of topping the crop on transportation bulk density. Topping 1-year-old erect crops is a simple and practical strategy for both improving bulk density and trash quality. Topping erect cane resulted in an average increase in whole crop 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 1-year-old erect cane has also shown to be an effective way of increasing whole crop bulk density while increasing trash fuel quality.

Vibration tests conducted on WC harvested sugar showed good improvement in bulk density. Where the product was vibrated directly using the swinging wall test rig, the improvement in bulk density was greater than when the test bin was vibrated using small pneumatic vibrators. In fact the use of small bolt on vibrators, would appear to be less than the settling/consolidation of the material that is observed in transit. Care should be taken in any attempt to vibrate the material, as excessive vibration would most likely cause damage to transportation equipment.

The ultimate solution is likely to be a combination of strategies and is likely to evolve to become mature technology only after there is an improved market for the trash with a strong incentive for growers and harvesting groups to participate.

This research project has resulted in a greater understanding of WC harvesting and strategies to improve transportation bulk density. Based on this knowledge, the following recommendations are made:

- Further research should be conducted using the prototype shredder to confirm the magnitude of the reduction in cane loss. The suggested methods for testing for cane loss should include the use of the BSES ‘infield sucrose loss’ rig and mass balance trials. Additional data would support the concept of raising the fan in the hood.

- Based on cane loss data, the prototype hood should be refined further to allow trouble free operation under most operating conditions. Dimensional and material changes should be considered.
• Blade life assessments should be conducted after an extended period of operation to determine the probable life of shredder fan blades and whether the current blade material is suitable.

• This project primarily focused on whole crop harvesting two-year-old crops. This was a conscious decision based on the principle of “if it will work in 2YO cane then it will work in 1YO cane”. Specific whole crop harvesting with the shredder fan, topping and other trash reduction strategies, should be carried out in 1YO crops.

• Further trials should be conducted in 1 year old erect cane with both topper and shredder fan (with prototype hood) operating to collect additional data on bulk density improvement achievable with both strategies. Additionally, cost data on 1YO WC harvesting should be collected.

• Any future move to WC harvesting should be done in a staged approach, with data collected, analysed and acted on after each stage. This could be facilitated using a small, transportable, basic trash separation plant. The use of a small trash separation plant would enable additional data to be collected without having an impact on mill recovery. Cost data could be collected from many harvesting groups over an extended period.

• A wet weather harvesting strategy needs to be developed for WC harvesting. Whole crop harvesting of large two-year-old lodged crops in very wet conditions is not recommended or considered to be cost effective due to the subsequent field damage resulting in reduced ratoon crop yields. Controlled traffic farming would reduce the field damage, but a strategy that includes burning cane where required needs to be developed if WC harvesting is to be considered.

• Field trials should be conducted that assess the agronomic and financial impacts of WC harvesting right through the crop cycle. This data could be collected by splitting a block into two, harvesting one half WC and the other burnt. These trials could be repeated right through the crop cycle to enable a good comparison. The agronomic impacts of topping the crop or retaining small amounts of trash in the Condong Mill area should also be investigated.

• Further investigation of compaction is required. Because there is no cane loss associated with it (apart from spillage, which would need to be addressed), compaction and suitable compaction machines should be developed further.

• The concept of extracting less trash with the harvester and then pulverising that portion of trash before reincorporation should be investigated further. This concept may address cane loss while still resulting in a reasonable increase in bulk density.
10 List of Publications

11 References


Chevanan N, Womac A, and Bitra V. Loose Filled and Tapped Densities of Chopped Switchgrass, Corn Stover and Wheat Straw, Biosystems Engineering and Soil Science, University of Tennessee, Knoxville, ASABE PAPER TN084085

Davis RJ, Norris CP (2001) Impact of chopper harvesting on the translation of field CCS to factory realised CCS. SRDC Final Report BSS244, Sugar Research and Development Corporation, Brisbane.


Appendix A – Harvester Survey 2009
Appendix B – Levelling/Compaction Equipment 2009
Appendix C – Other Bulk Density Improvement / Trash harvesting and Transport Concepts
Appendix D – Financial Model Assumptions

Key Assumptions: 2YO Cane Model

- Average yield: 141 T/He Cane (Bwr 5 Year Ave)
- Average Burnt Cane Pol: 11.2 % (Bwr 5 Year Ave)
- Pol Lost Due to Burning: 0.5 Units
- Harvest Group Crop Size: 80 000 Tonne Cane
- Trash Available: Additional 24.5% on Burnt Cane Tonnes
- Trash Moisture Content: 55%
- Diesel Price: $1.18 / L
- Burnt Cane Harvest Price: $7.50 / T of Cane
- Road Transportation Price: $1.64 / m3
- Current Whole crop Road Transportation Bulk Density: 200 kg/m3
- Current Whole crop Infield Transportation Bulk Density: 212 kg/m3
- Target Whole crop Road Transportation Bulk Density: 250 kg/m3
- Sugar Price: $450/T
- Electricity Income: $70/MWh
- Contract Baling and Haulage Price: $100/ Tonne @ 15 % Moisture delivered to Mill
- Where cane is delivered with trash – use of Trash Separation Plant to clean cane before milling.
- Capital Financed @ 10% over 5 years.
- Mill Efficiency: 86% - Broadwater
- Sugar: 99.2 Tonnes Sugar/Tonne Pol
- Variable cost hauling cane (non Capital) as percentage of Total Harvesting Cost: 30%
- Sugar loss during harvesting burnt cane is not considered as %Pol for burnt cane is Pol at the mill.
- All trash is collected when shredding trash on harvester

Key Assumptions: 1YO Topping Model

- Average yield: 90 T/He Cane (CDG)
- Average Burnt Cane Pol: 12% (CDG)
- Pol Lost Due to Burning: 0.5 Units
- Harvest Group Crop Size: 80 000 Tonne Cane
- Trash Available: Additional 24.5% on Burnt Cane Tonnes
- Trash Moisture Content: 55%
- Trash Moisture Content Post Topping: 50%
- Diesel Price: $1.18 / L
- Burnt Cane Harvest Price: $8.00 / T of Cane
- Road Transportation Price: $1.64 / m3
- Current Whole crop Infield Transportation Bulk Density: 220 kg/m3
- Target Whole crop Road Transportation Bulk Density: 250 kg/m3
- Sugar Price: $450/T
- Electricity Income: $70/MWh
- Bulk Density Improvement due to Topping – 7%
- Where cane is delivered with trash – use of Trash Separation Plant to clean cane before milling.
- Capital Financed @ 10% over 5 years.
- Mill Efficiency:
- Sugar: 99.2 Tonnes Sugar/Tonne Pol
• Variable cost hauling cane (non Capital) as percentage of Total Harvesting Cost: 30%

• Sugar loss during harvesting burnt cane is not considered as %Pol for burnt cane is Pol at the mill.