BUREAU OF SUGAR EXPERIMENT STATIONS

QUEENSLAND, AUSTRALIA

HARVEST AND TRANSPORT CONSIDERATIONS FOR WHOLE-CROP HARVESTING IN THE CONDONG MILL AREA

by

C P Norris CPEng*, B G Robotham RPEng*
and Dr N J Tudroszen**
**BSES Bundaberg*
***NJT Consulting Pty Ltd*
CO00016

BSES Publication
Consultancy Report CO00016 **August 2000**

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1. EXECUTIVE SUMMARY

This report was commissioned by NSWSMC to provide an independent review of a number of issues relating to the supply of trash to Condong Sugar Mill for co-generation purposes.

In addition to addressing the amended terms of reference, this report has further defined additional issues such as probable trash levels and probabilities of achieving necessary product packing densities for efficient transport.

This report illustrates the relative differences between selected cane/trash and burnt cane harvest and transport options. The costing of all systems is based on the estimated cost of purchasing a full suite of equipment for each scenario, including the burnt cane reference cases~~..~~. Due to the specific machinery currently used by the various harvesting groups within the Condong Mill area, and the mode of operation of this equipment, many potential pathways exist for adoption of a cane and trash ("whole-cane") harvesting system. As the adoption phase is considered transitory, it is not addressed in this report. The adoption options must be considered on an individual group basis, in order to optimise the process for that particular group. The groups' current machinery type and age as well as their debt/equity levels will influence this process. The adoption phase may occur over a period of several years and involve the temporary use of mismatched bin volumes.

The agronomic consequences of retaining or removing the trash are not considered in this report. Future limitations imposed on pre-harvest burning, to facilitate crop harvesting, may transfer additional costs to the grower and harvesting contractor. The effects of infield trafficking of current and proposed machinery on soil structure and crop production must be considered before new machinery systems are determined.

The three overriding issues addressed in this report are:

- The probable crop composition of whole crop harvested cane in the Condong Mill area.
- The potential of the harvester to operate in unburnt crops at acceptable harvesting rates. The potential to transport the harvested material to the mill economically. Issues relating to transportation include:
  - bulk densities of the cane-trash product
  - maximum allowable axle loads for haulout vehicles used on public roads
  - physical constraints to infield haulouts and transport equipment design that may limit the potential to achieve maximum allowable loads with the product bulk density.
- The impact of increased mass and reduce bulk density of harvested material on the relative cost of both the harvest and the transport operations.

Crop Composition:

Limited relevant data is available to quantify the expected composition of material to be transported to the mill from whole crop harvested cane in the Condong Mill area. After reviewing data from a number of sources, the authors believe that:

- Typical compositions of components of whole crop harvested cane, ie dry leaf, green leaf and tops will generally have similar moisture contents and chemical compositions, irrespective of the crop variety or condition.
- Trash/total biomass, leaf and tops/total biomass and cane/total biomass ratios will be determined by crop variety, yield crop class and crop age, as will the relative billet weights. These will impact critically on final bulk densities of harvested material.

Harvesting:

The authors believe that, with appropriate modifications, harvesters will be able to achieve similar whole-cane harvesting rates (tonnes of actual cane/h) in unburnt crops to that currently achieved by harvesting "average" one year and two year cane burnt, providing no processing of trash is undertaken on the harvester. Additional considerations are:

- In heavier crops, machine productivity will fall, but will remain significantly greater than the productivity of current machines when "green cane" harvesting.
- The greatest impact on harvesting costs in the proposed systems are external factors such as time lost waiting for haulouts to turn at the end of rows, and time lost waiting for the return of haulouts from delivering product to the pads.
- Fuel costs and maintenance costs are estimated to be similar to current practice.

This option is only viable if the product produced is of an appropriate bulk density for efficient transport. It is believed by the authors that strategic trash level reduction, eg topping of light standing crops and operation of the extractor system at low extraction rates, will allow the optimum compromise between trash collection and harvesting and transport costs.

It is argued that processing (separation and shredding) of trash on the harvester should only be undertaken as a last resort to achieve acceptable product bulk densities for efficient transport, unless other very significant advantages for field shredding of trash can be identified. The proposed shredder system is not considered a desirable option as:

- Harvesting rate will be severely compromised, with the projected pour rate being between 55 and 60% of pour rates currently achieved in burnt cane.
- Repairs, maintenance and fuel consumption of the harvester will all be significantly greater than for current practices.
- Even at the reduced pour rates, any trash shredder system based on the current primary extractor system on the harvester will have cane losses that can be conservatively estimated at 5-15 t ha^{-1}. Whilst this shredded cane will be transhipped to the mill for fuel, its value is severely reduced relative to that of cane billets.

The option of separation of trash on the harvester and separately transporting it to the mill is considered to have very significant logistical difficulties and is economically not attractive.

Harvesting costs in the Condong Mill area are adversely affected by relatively small field sizes, with the subsequent time lost in turning and "cutting in" to new blocks severely reducing field efficiencies and increasing harvesting costs. This constraint also impacts on haulout design options.

Despite these constraints, the current relatively low harvesting and infield transport costs in northern NSW can be seen to be a result of:

- burnt cane harvesting, with the corresponding increases in harvester productivity
- larger crops (high yielding one year cane and two year cane crops)
- comparatively short field to "pad" haul distances
- well organised harvesting units and mill transport systems, limiting the time lost by the harvester in waiting for a haulout to receive the harvested cane

Transport:

The objective of this section of the consultancy was to propose methods to minimise the costs of transporting the cane-trash product from the field to the multi-lift bin pad. Key considerations relating to the transport of the cane-trash product to the mill include:

- The mass of product to be carried will increase by about 20%, and consists of cane of high value per m^3, along with trash and leaf with relatively low value per m^3. The variability of product density, relative to that of billeted burnt cane, will be a significant issue. Initial trials conducted by NSWSMC indicate the bulk densities for billeted "whole-cane" range from >0.2 t m^{-3} to <0.3 t m^{-3}, relative to about 0.38 t m^{-3} for billeted burnt cane. However, strategies are available to reduce this variability and maximise typical product densities.

- If shredding of trash on the harvester were undertaken, bulk densities of 0.3 t m^{-3} should be achievable.

- On the basis of a limited data set from NSWSMC and other available information, it is believed that, with appropriate attention to billet length as well as strategic reductions in trash levels to be transported to the mills, product densities of 0.250 t m^{-3} can be reliably achieved. This can be achieved without additional processing of the trash on the harvester.

- The current multi-lift bin has a volume of 65 m^3 and the maximum allowable payload (RTA NSW axle loading regulations) is achieved with burnt product with less than 100% volume utilisation. Modification of current bins to increase the volume to 82 m^3 results in maximum allowable loads being achieved at a bulk density of approximately 0.3 t m^{-3}. A bin design (95 m^3) is available to carry the maximum allowable load at 0.250 t m^{-3}. Due to design improvements giving reductions in tare weight, this unit offers similar payload to the current system.

- All harvesting groups in the Condong Mill area presently have some operational time with loaded infield haulout equipment on public roads. Compliance with RTA regulations is mandatory for this equipment. There could also be a significant issue with maximum axle load compliance on a proportion of the current wheeled haulout fleet. Some large capacity wheeled haulouts currently only comply with RTA allowable axle load limits when filled with product density not greater than 0.250 t m^{-3}. Designs of infield transporters to carry product of this density are therefore currently available, however the development of more efficient designs giving higher payload/tare ratios is clearly possible.

- Rubber tracked transporters appear to have considerably greater load carrying capacity than conventional wheeled units, however the maximum pavement load limits have not, as yet, been determined by RTA. On the basis of current information, viable designs for haulouts can be developed that achieve the assumed maximum allowable loads, at a product density of 0.250 t m^{-3}.

An analysis undertaken on the impact of alternate haulout options on harvesting efficiency of whole-cane and the current burnt cane system indicates that:

- The most cost-effective approach for efficient whole-cane harvesting is the use of increased haulout volume to carry the maximum allowable payload. Haulouts of sufficient capacity to ensure the number of haul trips does not increase are, however, not permitted, as axle loading would significantly exceed allowable limits. Physical size and infield manoeuvrability could also be issues with haulouts of this size.

- Haul distances from field to pads currently can cause significant waiting periods by the harvester. If an increased number of haulouts of the current bin size (carrying significantly reduced mass due to the lower bulk density) are used to service a harvester, then harvesting and haulout costs will increase. Despite this increase in cost, the most cost effective method to achieve cane and trash transport to the mill may be to subsidise the use of this equipment until the industry gains confidence in equipment of more appropriate design.

- The use of alternative systems, typically incorporating trailers of different designs (eg B-Double configuration), were generally not considered cost effective because of the Condong Mill situation of narrow headlands. Considerable time would be lost turning at ends of rows and difficulties in reverse towing the trailer for “breaking in” to the numerous small blocks was considered a major issue. Unacceptable increases in unloading times were also seen to be exacerbated by the design and location of current pads. High capital costs also limit the applicability of these options.

Costs of Harvesting and Transport:

The basis for costing all options has been the use of “burnt cane equivalent”, ie the total mass of available cane and the typically associated extraneous matter of approximately 6%, made up of leaf, tops and dirt. The actual trash levels and composition of the trash when whole-cane harvesting will vary. It is assumed that the recommended modifications have been made to the harvester for harvesting whole-cane.

A harvesting system which transports whole-cane at the same "burnt cane equivalent" cost as a burnt cane system is effectively delivering the trash to the multi-lifts at no cost.

It is believed that the cost of a harvesting and transporting system for whole-cane product, relative to the costs associated with the current system, and on the basis of "burnt cane equivalent product" will indicate that:

- The best available rubber tracked haulout option (47 m^3 haulout) on the shortest haul (0.75 km), will increase the harvest and transport costs by 4.3%. As the haul distance increases to 2 km and 5 km respectively, the costs of whole-cane harvesting increase by 6.0% and 9.4% relative to the burnt cane system. By comparison, the increase in costs associated with green cane harvesting over burnt cane harvesting for the three haul distances are 9.4%, 11.1% and 16.5% respectively.

- The next most viable option is to accept a longer day length and use the current haulouts. Over the three haul distances, this would result in an increase in total harvesting costs of 9.4%, 16.8% and 33.1% respectively relative to the current burnt cane harvesting system. Some modification of the haulouts will be required.

- Increasing the number of current haulouts is not a viable option when capital costs are considered. Even if three units were presently available, this is a more expensive option than operating only two units of current design.

- Similar trends occur with wheeled haulouts, with the most economical whole-cane system (2*32 m^3 bins) delivering whole-cane product for about 5% more than burnt cane over the three haul distances.

- Large capacity specialist haulout equipment was generally not competitive relative to enlarged units of current design (47.5 m^3 tracked and 32 m^3 wheeled) primarily because of increased fixed costs.

An additional significant consideration is the effect of haul distance on total harvest and transport costs.

- For the rubber tracked burnt cane system, increasing haul distance from 0.75 km to 2.0 and 5.0 km increases total harvest cost by 9.3% and 33.6% respectively.
- The increased haul distances for the lowest cost whole-cane tracked option increased costs by 10.9% and 40.6% respectively.

- For the wheeled options, the increasing haul distances increased costs by 6.2% and 28%, and by 7.1% and 28% for the burnt cane system and best green cane systems respectively.

Conclusions:

With respect to the terms of reference of this report, and on the basis of current knowledge:

- It is believed that existing and new harvesters can be modified to efficiently "whole crop" harvest most crops which are likely to be encountered in the Condong Mill area, at rates equivalent to that currently achieved by harvesters operating in burnt cane.
- Assuming a product density of 0.250 t m^{-3} can be achieved, RTA allowable axle loadings rather than product bulk densities will limit the payload of cane-trash product that can potentially be hauled from the fields.
- It is believed that product densities of 0.250 t m^{-3} are achievable if a strategy of billet length reduction and strategic rejection of trash and/or tops is undertaken in some crops. The potential variability in product density will be substantially greater than that currently encountered by the industry. The use of load cells on haulout equipment to determine load mass will be essential to assist operators achieve target product bulk densities in low density material and minimise overloading with other product of higher inherent density.
- The most significant variable impacting on harvesting and haulage costs of both whole-cane and burnt cane is field to pad distances. Increased haul trip time with the associated cost also result in greater harvester waiting times. The increase in costs associated with whole-cane harvesting can be minimised by attention to field to pad distances.

2. TERMS OF REFERENCE

The initial terms of reference for this report were determined by NSWSMC and recorded in the Work Program of the Consultancy Agreement. During the consultancy the terms of reference were expanded by the mutual agreement of both parties.

2.1 Amended Terms of Reference

1. To investigate and document the cane/trash and leaf mixtures, and resulting bulk densities to be expected from whole crop harvesting in the Condong Mill area.
2. Nominate necessary and justifiable changes to cane harvesters to facilitate green cane harvest with collection of the total crop (cane and trash). This should include any changes to elevators that are necessary to handle the additional volume or accommodate larger capacity infield units.
3. Determine probable harvesting rates and harvester input costs for this mode of operation.

4. To investigate and document the advantages and/or limitations of large capacity infield units carrying a cane/trash mixture of agreed bulk density in the Condong Mill area. *The bulk densities to be assessed are 200, 250 and 300 kg/*m^3.

5. Liaise with equipment manufacturers to determine the viability and cost of:

- modifying existing units to carry the increased volume of low density material
- designing and building a new large volume unit

6. Compare the costs (capital and operating costs) of the current burnt cane harvesting system with potential whole-cane harvesting systems based on:

- large capacity infield units
- extra units of current design

7. Examine the advantages and/or limitations of alternate methods such as on-harvester shredding and infield units that have the capability to compact the cane/trash mixture.

8. Compile a concise, self-contained report that documents the issues, the options and the recommended solutions.

2.2 Initial Terms of Reference

The initial terms of reference, as forwarded by NSWMC in the initial briefing paper were:

1. To investigate and document the advantages and/or limitations of large capacity infield units carrying a cane/trash mixture of nominated bulk density in the Condong Mill area.

2. Liaise with equipment manufacturers to determine the viability and cost of:

- modifying existing units to carry the increased volume
- designing and building a new large capacity unit

3. Compare the costs (capital and operating costs) of large capacity infield units with the alternative of extra units.

4. Investigate the options, feasibility and cost of adapting or building infield units that have the capability to compact the cane/trash mixture.

5. Nominate necessary and justifiable changes to cane harvesters to facilitate green cane harvest with collection of the total crop (cane and trash). This should include any changes to elevators that are necessary to handle the additional volume or accommodate larger capacity infield units.

6. Determine probable harvesting rates and harvesting costs of this mode of operation.

7. Compile a concise, self-contained report that documents the issues, the options and the recommended solutions.

It was believed that strict adherence to these terms of reference would not result in the outcome requested by NSWSMC.

3. GENERAL RECOMMENDATIONS

The recommendations of this report are that:

- Discussions be initiated with representatives of RTA NSW to determine allowable pavement loadings for rubber tracked sugarcane haulage vehicles. The wheeled and tracked haulout recommendations from this report should be discussed with representatives of RTA NSW to ensure all options conform to the appropriate guidelines.

- A cane/trash mixture of bulk density 0.250 t m^{-3} is assumed as the achievable bulk density and all bins, infield and multi-lift be sized to suit. A program of vehicle weighing should be undertaken during this harvest, to determine the axle loadings of current infield haulout units. The axle loading used in calculations within this report are based on recent weighing of equivalent sugarcane haulouts and estimates from manufacturers and owners. Weighing of the vehicle is the only method of accurately determining axle loadings.

- To minimise the capital investment during transition, modified current haulouts with an additional haulout be considered as a possible solution. This is not the lowest cost option but with subsidisation of the haul component, this should be acceptable to all parties.

- Based on the results of discussions with NSW RTA, tenders be called for the construction of one 47.5 m^3 tipper bin to carry a cane/trash mixture load of 12.5 t (as described in Rubber Tracked Option T47). This infield bin would be used by the appropriate harvesting groups to trial the harvesting of cane/trash mixtures. The bin would be equipped with load weighing cells and have a tipping height to suit the appropriate multi-lift bin. Although based on the current design, engineering consideration must be applied to reduce vehicle tare mass where appropriate. Field trials with this vehicle would examine in field maneuverability (ease of end towing, etc), cane/trash mixture unloading from the bin (optimum bin floor/side angle to be determined during this harvest), ease of filling of the multi-lift bins and issues such as material spillage and tarping. This would also enable the need for enhanced material flow control to achieve safe unloading and minimise spillage to be evaluated.

- The commercial partners should determine if the purchase of a wheeled 32 m^3 tipper bin for demonstration purposes is required. The option of limited utilisation of the current 32 m^3 tipper bins constructed by the Morrin Harvesting Group should be considered. These units are of the desired volume and although bin tip height does not suit proposed multi-lift bins, should be suitable for field testing purposes.

- Consideration be given to the use of improved weight transfer systems on all trailed infield bins. Significant gains in load carrying capacity are achievable with an efficient weight transfer system as gross vehicle mass can be shared in the desired proportions by all prime mover and trailer axles. The ideal system would be a dynamic system with feedback from the bin load.

- The location and number of multi-lift bin pads in the Condong Mill area be examined with the aim of reducing haulage distances and times. The interaction of pad design and multi-lift bin layout be examined for the selected transport options. On-farm considerations such as size and condition of headlands, type of roads and limitations to use of the shortest direct route field to pad (inappropriately placed culverts etc) should also be examined. Where possible, pads should be positioned to minimise the need to travel on public roads thus avoiding issues such as mud and cane on roads. The hauling of all harvested cane on farm roads may be a future goal for this mill area.

- Researchers monitor the composition of harvestable biomass in the NSW mill areas during the current harvest period(s). This should include samples from crops of different varieties, crop class, age and relative yield to give an appropriate cross section of probable biomass composition.

- A harvester be setup with all proposed modifications to quantify the ability to harvest whole-crop at the projected harvesting rates. Trials should then be undertaken to determine the relationship between crop size, trash levels and achievable bulk densities for different crop varieties. The effect of billet length on the bulk density of whole-cane product should also be quantified under NSW conditions.

- BSES be commissioned to undertake comparative testing of the 5-blade chopper system. This work would be undertaken on the chopper test rig at BSES Bundaberg and would determine billet damage and loss parameters for this system. This would allow the real costs associated with manipulating billet length as a strategy to maximise bulk density to be determined.

- Sampling strategies used in the determination of trash levels in whole-cane product be reviewed. There appears to be considerable error in the measurement of EM levels in the NSWSMC data, particularly in measurements undertaken on unshredded loads. Through consultation with other sugarcane research groups, a standardised sampling methodology be determined and this methodology be applied to all further testing. A relationship between trash/EM and cane versus bulk density could not be determined from the NSWSMC data, primarily because of apparent error in the measurement of EM.

- A review be undertaken into harvester and haulout ‘track’ spacing and its interaction with the current crop row spacings. The review should consider the current best practices from other agricultural industries. This review would examine systems in use in other sugar industries with adverse harvesting conditions eg Louisiana.

4. ANALYSIS AND DISCUSSION OF FINDINGS WITH RESPECT TO AMENDED TERMS OF REFERENCE

4.1 To investigate and document the expected cane/trash and leaf mixture and resulting bulk densities to be expected from whole crop harvesting in the Condong Mill area

This phase of the investigation requires the determination of:

1. Typical cane/EM (particularly trash and leaf) ratios expected in the harvested material under NSW conditions.
2. Relationships between cane/EM ratios and bulk densities that could be expected in the Condong Mill area.
3. If a density of 0.250 t m^{-3} is achievable for whole crop harvesting without additional processing of trash.

4.1.1 Determine the typical cane/EM ratios expected in the harvested material under NSW conditions

EM is typically defined as all material other than millable cane in the product supplied to the mill, and thus typically includes green leaf, tops ("cabbage billet"), trash and definable sucker billets as well as dirt and root material. This loose use of the term presents significant problems in the determination of the usefulness of material for combustion.

The key issues for this phase of the investigation include:

- To determine typical values for field extraneous matter (EM), and it's composition, from NSWSMC trials and compare these values with data from other areas.
- Assess the usefulness of the recorded EM levels in harvested material for NSW trials.

4.1.1.1 Pre-harvest EM levels and EM composition

The ratio of trash and leaf to cane is generally accepted to be affected by variety, growing conditions and final crop yield. A given variety can display significantly different characteristics, depending on the environment in which it is grown[1]. In an assessment of the transport logistics of whole crop harvesting for co-generation, the breakdown of the characteristics of the total biomass is of critical importance, ie EM levels alone are of limited value unless the components of the EM are known. Similarly, the calorific values of the different components EM is of significant value when determining the value of EM as a fuel. The dirt component of EM is an additional significant consideration. Furthermore, the bulk density of the cane trash mixture is important and the most critical crop factors impacting final bulk densities will be cane density, leaf and trash to cane ratios and leaf and trash characteristics.

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[1] King *et al.* (1965), Manual of Cane Growing. Angus & Robertson.

NSW data

Limited data is available on cane trash levels in the Condong Mill area. Figure 1 presents data derived from trials undertaken in NSW (Nielsen, Beattie, Watts) and by Ridge (Qld BSES).

The Pimlico, Harwood and Condong data details tops and trash only as a percentage of total harvestable material. The levels of these components are indicated to be in the order of 12-16% trash and tops of 4-12%. The data from Nielsen, Ridge and Beattie indicates EM levels of approximately 24-28%. As per accepted research guidelines, these results probably include suckers as EM. For the purposes of this exercise, it can be argued that suckers should not be included as EM as they have a density approximately equal to that of cane billets. Similarly, Edwards[2] argues that tops, when defined as the "top" piece of billetable material, typically incorporating the "cabbage" has densities and characteristics closer to that of billets than of trash and leaf. It is therefore highly probable that tops will remain in the cane supply after passing through a pneumatic cane cleaning plant.

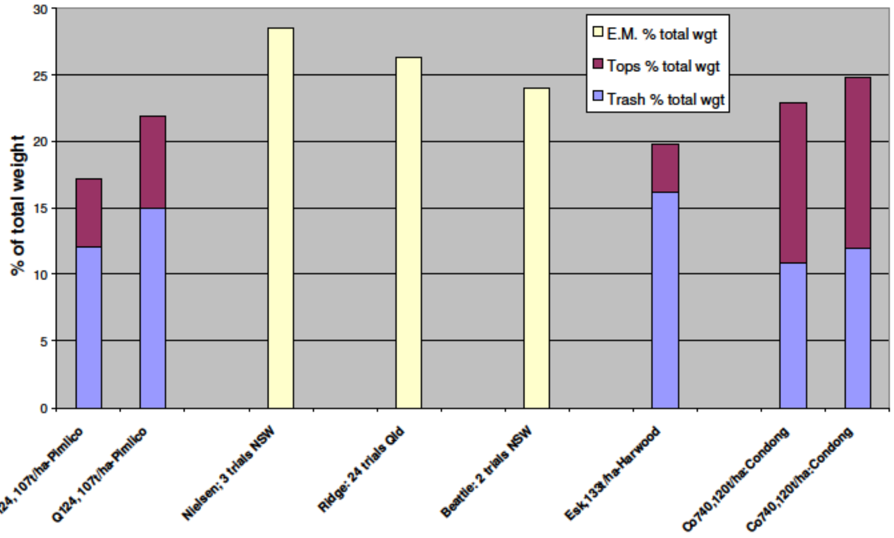

Figure 1 - Typical field crop compositions, NSW trials[3]

In these data sets, dirt in cane has not been included as EM (as it would hopefully be close to zero in hand cut samples).

The available data sets for NSW were unrealistically small to assess probable available trash levels. Additional data was then sourced from trials conducted in Far North

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[2] Edwards B P, 1994 *Trials on the effect of Trash on Factory Operations in 1991 and 1992* SRI Technical Report No. 8/94

[3] Source: Tables and Data from Internal Correspondence, from Dick Watts to Cam Palmer 29/12/99 and 11/01/00

Queensland and elsewhere. Although from a very different environment, it was believed that this data could be used as a broad reference.

North Queensland data

The results[4] from a series of trials undertaken by BSES and Mulgrave Mill are summarised in Figure 2. For these data sets, extraneous matter is calculated as tops and trash and excludes suckers.

The results for trials 12, 18 and 26 are for burnt crops. Trial averages (Figure 2) for EM, trash and tops are 17.12%, 13.60% and 3.52% respectively after removing data from the burnt trials. EM ranged from 12% to 26.2% as a percentage of total sample weight. Sucker content averaged 7.45% on cane.

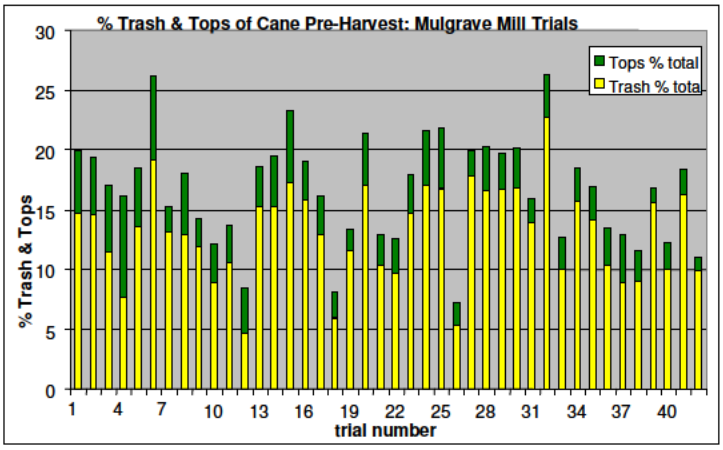

Figure 2 - Typical field cane compositions, north Queensland

A source of error in this data is the potential under-estimation of field trash levels. The experimental protocols involved gathering all plant components, including trash, for determination of pre-harvest Pol and Brix. The aim was typically to collect all the trash on the stalk, however little attempt was made to collect trash from the ground. This inconsistency may have biased some samples more than others, depending on the condition of the crop.

Colombian data

Further reference data is available from the Colombian Industry, where significant research has been undertaken on trash levels for co-generation and fundamental research on sugar accumulation. Data on the EM (defined as tops <including leaf> plus trash) for a range of Colombian varieties is presented in Figure 3[5].

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[4] Crook *et al.* (1999). A Survey of Field CCS versus Mill CCS. Proc ASSCT 21: 33-37.

[5] Amaya *et al.* (1999). Progress in Varietal Selection for Green Cane Harvesting in Colombia.

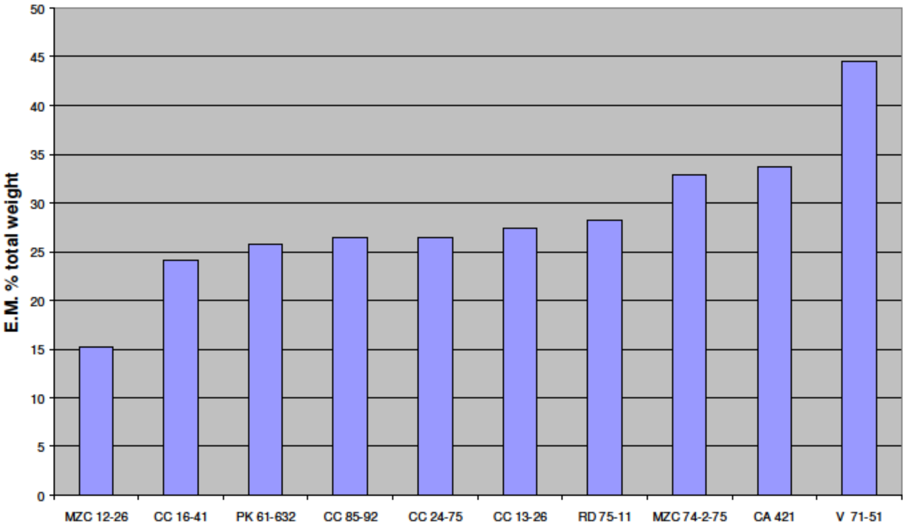

Figure 3 - EM (trash plus tops <including leaf>) levels for a range of Colombian cane varieties

Colombian varieties are characterised by high trash/cane ratios. Varieties MZC 74-2-75 and V71-51 are most common varieties currently grown but the industry is now targeting varieties with less than 30% trash plus tops <including leaf>: cane ratio (23% trash plus tops <including leaf>: total weight) to enhance machine harvestability[6].

Brazilian data

Further data is available on Brazilian varieties from Engineering staff at Copersucar[7]. Data from harvester testing trials undertaken by Copersucar indicate typical levels of trash % cane at harvest range from 13% to 20%, with a mean of 16.5%. This equates to 11.5 to 16.7 trash % total weight, with a mean of 14.2%.

Crop condition

Available NSWSMC data (Watts data, Harwood trials) indicates that very light crops may have higher trash, tops and leaf levels than high yielding crops. This is consistent with other data, eg:

- M.F. R&D files[8] indicate, that on the basis of a limited program of field measurements:

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[6] Bricenco,C., Cock, J,Torres, J., (1999) Electric Power from Green Harvesting Residues of Sugar Cane in Colombia. Final report on a pre-feasibility study. Cenicana.

[7] Joao da Silva, Pers Com during visit to Colombia by C Norris, Nov 1999.

[8] Massey Ferguson R&D documents as held by BSES Bundaberg.

- Low yielding crops typically have both lower density billets and higher levels of trash.
- Typical composition of the cane plant varies between regions with crops in wetter areas of the Wet Tropical Coast having higher trash and tops levels by weight (cane: dry leaf: tops and green leaf 70: 10: 20) than crops in other environments, eg Mackay (84: 7: 9) by weight.

This information was of interest to M.F. engineers in the design of harvester cleaning systems.

- Pope[9] demonstrated increasing levels of EM in the cane supply as cane class moved from plant to fourth or older ratoon. This relationship was exacerbated by reducing billet weights and reducing derived "bin weights at 0% EM". This effect suggests increasing EM levels in the pre-harvest crop as the crop class "ages", as well as reduced density in "whole-cane" product.

- Mulgrave Mill "sugar balance" data[4] on tops and trash composition of unburnt cane in the field is presented in Figure 4. The data indicates that trash levels, as a percentage of total crop mass falls significantly as crop size increases (16% at 80 t/ha versus 10% at 160 t/ha). Whilst the percentage of tops also falls as crop size increases, it is not as dramatic (4% at 80 t/ha versus 3% at 160 t/ha.). A potential source of error in this data is the failure to collect at least a proportion of the trash on the ground during sampling. Notwithstanding this error, the data strongly indicates the reduction in trash levels as crop size increases.

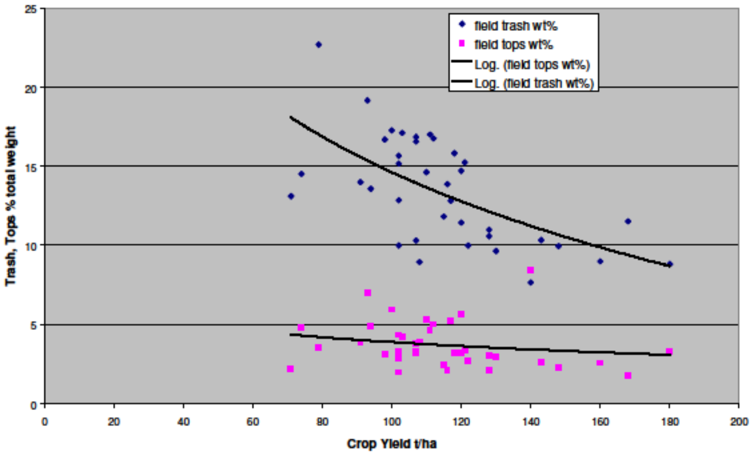

Figure 4 -Relationship between trash and tops (as % of harvestable biomass) as crop size increases

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[9] Pope, G M (1998) Effect of Cane Factors on Bin Weights. Proc ASSCT, 20:22-27

Summary of data on cane characteristics

On the basis of limited data sets and available information from other cane growing regions, indications are that:

- Higher yielding crops will have lower trash levels than poorer crops of the same age, however the relationship between trash levels of the same varieties and yield of two different ages is not known ("well grown" one year cane versus "poorly grown" two year cane).

- Under NSW conditions, and for "well grown crops" it is unlikely that total plant material EM will exceed 25% "in the field".

- "Trash plus green leaf " will probably be in the range of 12% to 17% for "high yielding crops", in particular high yielding one year cane.

Whilst it can be reasonably assumed there will be a difference in absolute trash and leaf levels, between different regions in Australia, even for the same variety, these variations will not be extreme. The magnitude of difference noted in the M.F. data appears greater than that noted elsewhere. In Colombia, which is noted for high trash levels, newer varieties are typically in the range of 24-27% "trash plus green leaf plus tops" % total weight, which is less than the levels quoted in the M.F. documents.

Recorded EM levels in harvested material for NSW trials

As previously noted, the NSWSMC data is too limited to provide accurate indications of field EM values, or to define the relative proportions of the components of the EM. Similarly, significant problems appear to exist with the determination of total levels of EM material in samples taken from the harvested material. This is well demonstrated in Table 1, which presents data from the Pimlico trials reported on December 29, 1999.

TABLE 1
Extraneous Matter comparisons with field measurements - Pimlico trials, December 1999 (Q124, approx 107 t/ha, one year cane)

Bin No.	**Shredded**	**Billet cut**	**% EM duplicates**		**% EM (av)**	**Bulk density ($t\ m^{-3}$)**
268	Yes	Long	30.3	47.5	38.9	0.314
316	Yes	Short	32.0	49.8	40.9	0.318
304	No	Long	31.3	25.4	28.4	0.264
312	No	Short	28.0	37.1	32.6	0.305
Corresponding crop analysis - % EM			**23.2**	**24.9**		

Source: Internal correspondence from Dick Watts on December 29, 1999

The data demonstrates the variability between EM samples. *Importantly the data highlights the potential overestimation of EM levels in bin measurements compared with field values.*

Table 2 further explores the relationship between pre-harvest and post-harvest sampling and signals problems associated with post harvest sampling, particularly of unshredded cane. In the three cases where an assessment was made of the crop pre-harvest, the "unshredded" post harvest sample significantly over-estimates EM levels. The internal correspondence (*Watts*) clearly recognises and acknowledges all of these issues.

The material properties of shredded material should make it easier to achieve accurate sampling, of the proportion of shredded material. "Theoretically" the shredded material should be composed predominantly of shredded leaf, as pneumatic cleaning systems on harvesters are relatively ineffective at removing tops. Consequently, EM levels for shredded samples should be lower than the same crop when trash is unshredded, as the EM determination of unshredded material typically included tops.

TABLE 2
Comparison of pre-harvest and post-harvest EM levels for NSW trials

	Pre-harvest sample			**Treatment**	**Post-harvest sample**		
	Trash	**Tops**	**Total EM**		**Trash**	**Tops**	**Total EM**
Q124, 107 t/ha Pimlico	13.5	6	19.5	Shredded Unshredded			39.9 30.5
Q124, 68 t/ha Harwood				Unshredded	27.4		
Esk, 133 t/ha Harwood	16.2	3.6	19.8	Unshredded	25.3	6.2	31.5
Co740, 120 t/ha Condong	11.5	12.4	23.9	Shredded Unshredded			40.7 43.1

All data from internal correspondence from Dick Watts, December 1999, January 2000 and March 2000.

Whiteing, as part of BS189, has conducted significant numbers of trials assessing cane loss from harvesters. A "fans off" treatment was replicated in a large number of trials to determine total available cane (ie minimise harvesting losses). The bins for the "fans off" treatments were sampled "off the carrier" at Mulgrave Mill using the same system that was used for EM sampling of all other treatments. The trash and green leaf ranged from 12% to 21% (average 17.5% trash and green leaf) for the 1997-98 "fans off" treatments. This data can be related to the estimates of pre-harvest trash and leaf given in Figure 2 where trash levels pre-harvest averaged 13.6% (range- less than 10% to greater than 20%). The higher levels of trash in the Whiteing trials could be attributed to under-estimation of trash in the Mulgrave trials and bias towards the selection of lighter, standing crops by Whiteing. A key aspect of Whiteing's protocol is a large number of samples: typically approximately 4 kg of sample/tonne of product.

Composition of residues

Available data on the composition of residues, with respect to "fresh" moisture content, potential calorific value and composition of key chemicals is of interest. Table 3 summarises data from NSWSMC trials on trash composition.

TABLE 3
Trash composition, wet basis and dry matter basis

Component	**% by weight**			**% by moisture**			**% by wet EM**			**% DM of total EM**		
	Watts	Nielsen	Ridge	Watts	Nielsen	Ridge	Watts	Nielsen	Ridge	Watts	Nielsen	Ridge
Cane	80.2	71.5	73.7	-	-	-	-	-	-	-	-	-
Tops	3.6			78.6	84.6	82.6	18.2	28	-	7.7	10.6	-
Green Leaf	10.1	28.5	26.3	66.9	67.9	70.9	51.0	46	-	33.4	36.2	-
Dry Leaf	6.1			3.5	17.0	16.4	30.8	26	-	58.9	53.2	-

This data indicates that, although green leaf is the greatest component by mass of EM, dry leaf is a significantly greater source of dry-matter.

Table 4 presents data from Colombian[6] trials on the moisture content of wet trash and the analysis of dry trash.

TABLE 4
Analysis of residue samples of the MZC 74275 variety

Residue component	**Moisture % Initial**	**Moisture % residual**	**Volatile %**	**Ash %**	**Fixed carbon %**	**Sulfur %**	**Caloric value kcal/kg**
Tops	78.6	6.0	71.2	7.1	15.6	0.20	4 253
Green leaves	65.7	6.2	66.7	9.8	17.2	0.26	4 021
Dry leaves	11.9	5.9	68.6	11.6	13.9	0.22	3 993

The similarities in the data are encouraging. Most significant, however is the comment: “In general, the analysis is similar to that of cane residues analysis reported from Brazil and Florida. It appears that there is little difference between the composition of residues from widely different environments. Therefore, no additional effort has been made to characterise each of the local planted varieties.”

Conclusions

On the basis of limited available data:

- Tops and trash levels in NSW appear, on average, to be similar to or only slightly higher than cane grown in other districts.
- A relationship can be expected to exist between crop size and trash levels, with poorer crops having higher proportion of the total biomass as trash and leaf.
- There appears to be considerable error in the measurement of EM levels in the NSWSMC data, particularly in unshredded loads.
- Moisture contents and fuel quality indicators are unlikely to be different for trash from NSW relative to trash from other regions.

In order to maximise the value of analysis undertaken, sampling strategies used in the determination of trash levels in cane product should be reviewed.

4.1.2 Determine the relationships between trash/cane ratios and bulk densities which could be expected in the Condong Mill area

4.1.2.1 NSWSMC Trials

The original logarithmic curve detailing the relationship between EM levels and product bulk density, included in the Trash Position Paper (Cam Palmer) dated 10/12/99 is presented in Figure 5. The data set for this graph is tabulated in Table 5. Whilst the data set is limited, the bulk density value supplied for whole crop harvesting can be expected to be a very good representation of the bulk densities which were achieved under the conditions specific to that site. Given the discussion in Section 4.1 of this report, the greatest source of potential error in this data set will be the measurement of EM levels in the product. A second issue is how "representative" were crops chosen for trials, ie differences in characteristics between "average" and other crops may be significant.

TABLE 5
Initial data for NSWSMC density assumptions (Palmer)

Cane	**Harvester mode**		**Nett mass**	**CCS**	**EM**	**Bulk density ($t\ m^{-3}$)**
	Topper	**Extractors**	**Tonnes**	**%**	**%**	**65 m^3 basis**
Standard	On	On				
Florida 1YO 1st Ratoon	On	On	23.35	13.2	6.1	0.37
Florida 1YO 1st Ratoon	Off	Off	11.87	11.8	22.9	0.18
CP 1YO 1st Ratoon	On	On	24.46	13.4	10	0.38
CP 1YO 1st Ratoon	On	Off	13.92	13.15	23.7	0.21
CP 1YO 1st Ratoon	Off	Off	10.08	11.7	40.9	0.16
1 YO PN/BL trial (8/99)	Off	Off	16.4	??	20	0.25
Trash only trial	Off	On	3.93	N/A	100	0.06

The relationships between bulk density and extraneous matter shown in Table 5 is expressed as a logarithmic relationship in Figure 5.

The original logarithmic curve Figure 5 can be extended by including data from the unshredded Pimilico and Harwood Trials *(Internal correspondence from Dick Watts to Cam Palmer 29/12/99*) and additional Harwood Trials (unshredded) (*Internal correspondence from Dick Watts to Cam Palmer 11/1/00*). Individual EM measurements are included rather than averages. This data is presented in Figure 5a.

A regression analysis of the "whole-cane" data would probably indicate either no relationship or, potentially, a relationship indicating increasing bulk density with increasing EM. The variability of samples from the same load confirms the statistical in-validity of the data.

This variability presents major problems with the use of these data sets alone for further analysis.

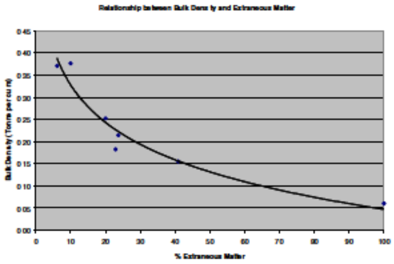

Figure 5 - Log relationship between EM and bulk density from initial NSWSMC data

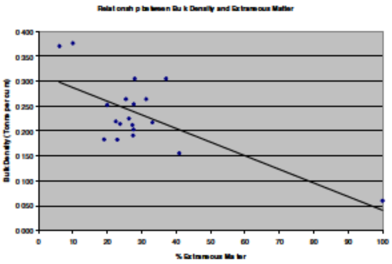

Figure 5a – Relationship between EM and bulk density with increased data set

The scatter of points probably reflects variations due to:

- Sampling error associated with sample size. This is strongly indicated by the differences in the EM levels in bins versus pre-harvested cane and the variability between samples from the same load.
- Differences in composition of samples for determination of EM ie presence and absence of tops and relative proportion of green and dry trash.
- Inherent bulk density differences of billets.
- Billet length differences.

The significant issues to come from this data are:

- EM measurements as supplied are unreliable.
- A significantly higher level of confidence can be given to the measurement of bulk densities. These values are "real', for whole-cane. Interestingly, a very significant number of data points indicate densities above 0.250 t m^{-3} whole-cane.
- Characteristics of the cane used are not fully known.
- Billet length not known in many trials, however useful data is available for some trials.

Attempts were therefore made to locate additional data sets to give a realistic relationship between EM, and components of EM and bulk density. A comparison between trials at CSR, Tully and Mulgrave are presented below.

4.1.2.2 Data from SRI Trials – Edwards 1994

Trash versus bulk density

Comprehensive trials have been conducted in the Herbert to establish the effects of trash % cane on bulk density. The results published by SRI in 1994[10] are based on 17 paired

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[10] Edwards B P, 1994 *Trials on the effect of Trash on Factory Operations in 1991 and 1992* SRI Technical Report No. 8/94

experiments of clean and dirty rakes. The outcome is expressed as changes in bin weights versus "dirty - clean cane trash content" to disguise the primary data at CSR's request[11].

The publication contains sufficient information to reconstruct the results in a format directly comparable to the NSWSMC trials[12]. A reasonable approximation of the effect of trash % cane on bulk density can be thus derived as shown in Figure 6. The linear relationship over this limited range is expressed by the equation:

Bulk Density = 0.3896 – 0.0107*Trash
The regression constant is –0.863

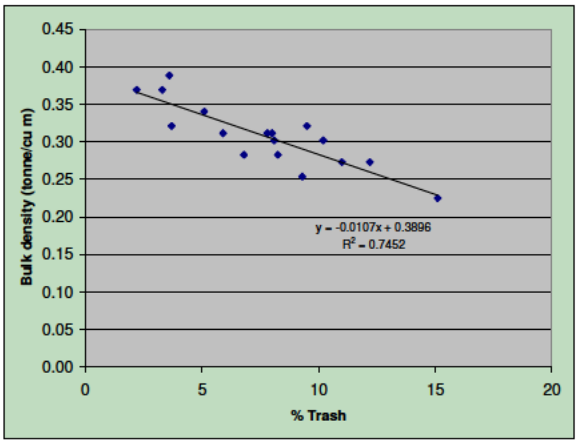

Figure 6 - Bulk density versus % trash (Edwards 1994)

Edwards discussed the significance between using trash versus EM (trash plus tops) as a key variable. He argued that trash alone should be employed since the bulk densities of tops and billets are comparable. NSWSMC's internal correspondence (*Dick Watts, Dec 29, 1999*) similarly argues for a narrowed definition of % EM to exclude fixed tops and suckers.

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[11] Personal communications between NJT and Dr Vic Mason May 31, 2000.

[12] The following method was employed to reconstruct the data:

- Read absolute levels of trash % cane from fig 2.2 for clean and dirty rakes for each of the 17 paired experiments.
- Calculate bin volume of 10.37 m^3 from dimensions.
- Average net bin weight of 3.83 tonnes for clean cane is given. Estimate the bin weights of dirty cane for each experiment based on "Average bin weight (clean)" + "Dirty-Clean net bin mass" for each pair as provided in (fig 3.1).
- Establishing the relationship between EM and bin weight is a little more tenuous. The average extraneous matter for clean rakes is given as 10.0% comprising 6.8% tops and 3.2% trash.
- The "dirty-clean tops % cane" is provided for each pair (figure 2.3). The tops content for each dirty rake can be approximated as "Average clean tops" + "dirty-clean tops % cane".

Appropriate "background data" from Edward's report is:

- The data sets used by Edwards approach 15% trash. This was achieved by "turning off the primary extractor to produce 'dirty rakes'". Treatments were generally topped.
- Average billet lengths for the period were 250-275 mm[13]
- The data sets would have encompassed a wide range of cane classes, impacting on billet density and initial EM levels
- The cane yield in 1991, when the trial was conducted was low.
- With respect to the sampling system for determining EM levels, Edwards states "The system installed for these experiments should be free from any questions of whether the sample is correct as it complies with the required characteristic of a good sampler".

EM versus bulk density

It is possible to establish a relationship between % EM (trash plus tops) from the SRI, using the methods footnoted. The comparative results are included in Figure 8. The linear relationship over this limited range of EM values is expressed by the equation:

Bulk Density = 0.411 – 0.0072*EM
The regression constant is –0.702

4.1.2.3 Mulgrave trials

The influence of EM on bin weight changes was assessed for the period 1989 to 1997 using data from 20 000 individual EM analyses. The following observations were made:

- EM was defined as including trash, green leaf, tops, definable suckers, root material and dirt. The rate at which bulk density reduces as EM increases will be less dramatic than if the definition was confined to trash and leaf or trash, leaf and tops.
- The relationship between bin weight and this measurement of EM was statistically significant and could for all years be described by linear regression equations for EM levels between 4 and 13%.
- The densities of crops varied between years, 1994 coincided with some of the lowest bin weights recorded.
- %EM increased significantly from the plant crop to 3rd and 4th ratoons. Corresponding declines in bin weights (Table 6) and average billet weights were observed across classes. The averaged billet weights for the 1997and1997 seasons were 118.5 g/billet for plant crop falling to 108 g/billet for third and subsequent ratoons.

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[13] (S Martin, CSR Macknade Mill *Pers Com 8/6/00.* C Norris)

TABLE 6
Effects of EM on bin weights and bulk density for plant and 3R crops

Year	**Plant crop**	**3rd Ratoon crop**
	Bin weights (tonnes) and bulk densities (t m^{-3})	
1992	4.10 (0.392)	3.88 (0.371)
1993	3.99 (0.381)	3.83 (0.366)
1994/95	3.89 (0.380)	3.70 (0.354)
1996/97	3.93 (0.376)	3.65 (0.349)

Source: Pope, G M, 1998 Proc ASSCT, 20:22-27

2994 data points are compared with the NSWSMC data in Figure 8. The linear regression equation so derived is:

Bulk Density = 0.371– 0.0029*EM
The regression constant is –0.98

Mill average billet length for the period can be assumed to be approximately 225 mm[14].

4.1.2.4 Tully trials

Comparable trials, conducted at Tully during 1993/94 for green and burnt cane have been analysed by Ridge and Hobson (1999)[15]. The authors observe a lower correlation between %trash and bin weights (r = 0.423) compared with those cited above. The effects of trash (and EM) on reductions in bin weights are also lower. The regression line for Tully for trash levels of 2-14%, based on 190 measurements is:

Bin weight = 3.83 – 0.04 * Trash

Equally significant from the Tully trials was the relationships observed between dirt levels in cane and trash (and leaf) levels.

This indicates a trend towards increasing dirt levels in the cane supply as trash levels increase. It also indicates that dirt levels contribute 1.5 to 2% to the total E.M under normal harvesting conditions. Under "high dirt" harvesting conditions dirt levels as a proportion of delivered cane may well increase.

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[14] G. Pope, Mulgrave Mill *pers com*.)

[15] Ridge, D.R. & Hobson, P.A., 1999 *Removal of extraneous matter in sugar mills for co-generation of power and reduction of cane loss* BSES Publication SRDC Final Report SD99005.

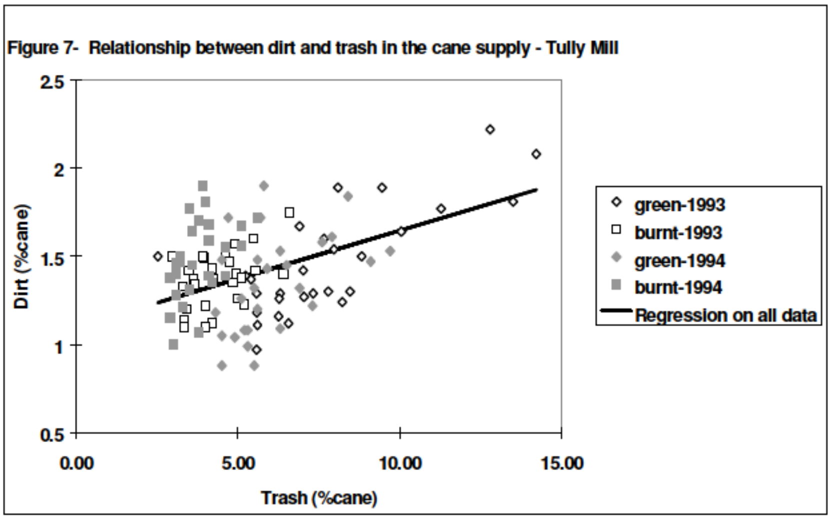

Figure 7- Relationship between dirt and trash in the cane supply-Tully Mill

4.1.2.5 EM versus density determination

Figure 8 presents a comparison of Condong, Pope and Edwards data for the estimation of the effect of EM on bulk density.

Because the Pope data includes identified sucker billets and dirt in the EM determination, the reduction in bulk density with increasing EM will not be as dramatic as where EM is defined as leafy material only.

The relationships developed by Edwards can be expected to be relatively pessimistic with respect to achievable EM levels because:

- the long billet lengths of the period (250-275 mm)
- the poor crop when the trial was undertaken (1991 season)

No attempt was made to target a particular cane class or crop size by Edwards, so it can be assumed that all crop classes were included in the trials. The relatively high levels of trash in some treatments relative to expected trash levels confirm the probability of low yielding crops and therefore low billet densities.

Despite these constraints, the model proposed by Edwards is the preferred model as it will be “pessimistic” with respect to achievable bulk densities at given levels of trash or EM.

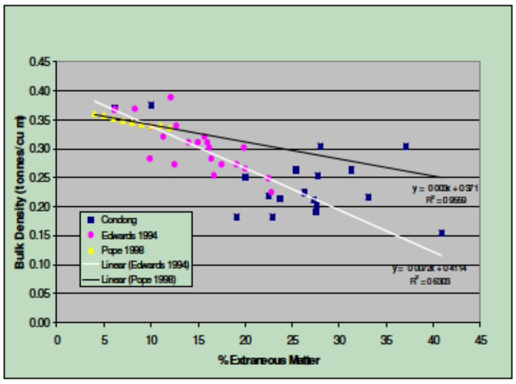

Figure 8 - Comparison of Condong, Pope and Edwards data for the estimation of the effect of EM on bulk density

The preferred relationship as a “worst case scenario” is therefore:

Bulk Density = 0.3896 – 0.0107*Trash

This relationship assumes a billet length of 250-275 mm.

4.1.2.6 Conclusions

A relationship between trash/EM and cane versus bulk density could not be determined from the NSWSMC data, primarily because of apparent error in the measurement of EM.

Whilst the trials at Macknade, Tully and Mulgrave have all led to the conclusion that bulk density is linearly related to %trash and/or % EM on cane, none of the data deals with EM levels comparable to harvested whole-cane, eg trash levels approaching 20%. It is conceivably possible that trash may physically interact with billets at above say, 15-20% EM to exacerbate decreases in bulk density.

Nevertheless, the best available relationship appears to be the linear relationship developed by Edwards during research in the Herbert Mill area. This data is very conservative because of the long billet length in use at the time and the poor crop.

4.1.3 Determine if a density of 0.250 t m^{-3} achievable for whole crop harvesting without additional processing of trash

From the analysis of potential haulout and transport options, bulk densities of 0.250 t m^{-3} or greater are required to minimise haulage costs. Failure to achieve this density will result in an increase in haulage costs. Of concern is the significant number of bulk densities near or below 0.20 t m^{-3}, evident in the NSWSMC data (Figure 8).

It is therefore essential to determine:

- the probability of achieving these bulk densities in the Condong Mill area
- the potential to manipulate the bulk density of the product to achieve the required minimum density under the widest range of crop conditions.

Both questions are pertinent to adopting a strategy of operating harvesting equipment to deliberately control bulk densities above a minimum threshold, below which haulout and transportation costs become uneconomic.

Figure 9 presents data on the bulk densities achieved in a number of different trials conducted by NSWSMC with whole-cane and unshredded trash. In a number of the trials, one variable was altered to assess its impact on bulk density of the product.

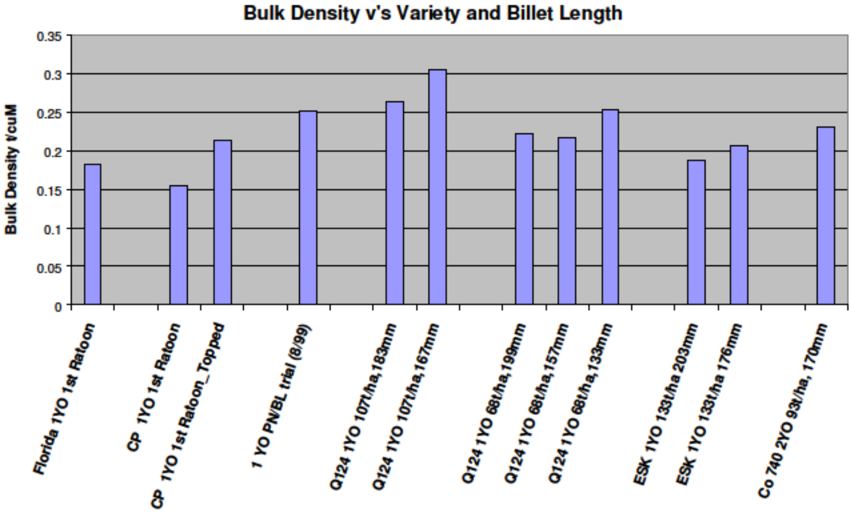

Figure 9 - Bulk densities of whole-cane, MSWMC data

Analysis of this data indicates:

- The mean bulk density for all data sets is 0.224 t m^{-3}
- Under the given test conditions, a number of varieties achieved bulk densities well below the desired 0.250 t m^{-3} .
- The higher yielding crop of Q124 had higher densities than the lower yielding crop, and achieved 0.250 t m^{-3} at both billet length settings.
- Billet length reduction in all cases gave a useful increase in bulk densities. In the case of the low yielding Q124, the short billet length setting allowed the targeted 0.250 t m^{-3} to be achieved.
- The crop of CP 1YO 1st Ratoon had a very low bulk density. The yield or condition of the crop is not known. The use of the topper significantly enhanced the bulk density of the product. Given the high water content of tops and green leaf, a reduction in the proportion of tops and green leaf could be advantageous, as their nett energy value relative to their weight is small in comparison to dry trash.

- The variety ESK, despite having a high yield had a poor packing density. This is attributed to the characteristics of the leaf (*Watts, internal correspondence*).

On the basis of the above discussions, it is evident that:

- With many varieties, a product density of 0.250 t m^{-3} could be achieved, provided a hierarchal strategy was adopted, including:
  - Reduction in billet length to the minimum practical length.
  - Strategic reduction in trash/leaf/tops levels to achieve the required bulk densities.

- With some varieties and crop classes, significant difficulties may be encountered in the achieving of the required bulk densities unless more aggressive methods are employed, eg more aggressive removal of trash or trash shredding etc.

Table 7 presents data on the Varietal Composition Condong Mill area, 1999 season[16].

TABLE 7
Varietal composition Condong Mill area, 1999 season

Variety	% of tonnage harvested
Q124	20.2
CP44-101	15.5
Co740	13.9
Delta	10.3
Dart	7.4
Concord	6.6
Encore	4.1
Q137	4.0
Other	18.0

Reviewing data from trials in the light of this information, the following comments apply:

- The most common variety in Condong Mill area is Q124. This variety is typically grown as a one-year cane. From the available data the target product density should be easily achieved in the majority of cases.
- CP44-101 may present significant problems, particularly in lighter crops and older ratoons. With current green cane harvesting systems, bulk densities of approaching 0.250 t m^{-3} can be encountered with this variety[17].
- Esk is a major crop in other NSW Mill areas (17% of NSW crop) but not a significant variety in the Condong Mill area. Available data indicates this variety may well present significant problems at full trash levels.

No data is available for other varieties.

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[16] *Varietal Composition and Distribution, 1999 season. BSES Publication ST00003, May 2000*

[17] J Budd, Central Tweed Harvesting, pers com.

Strategies to manipulate bulk densities are therefore critical, and include:

- Reduction in billet length to the minimum practical length.
- Strategic reduction in trash/leaf/tops levels to achieve the required bulk densities.

4.1.3.1 Billet length manipulation

Reducing billet length accepted way of increasing weight of material can be carried in a nominated bin. Similarly, there has been continual pressure by transport related sectors of the industry to reduce billet length to compensate for increasing levels of EM in the cane supply.

The two factors which impact on the optimum billet length for "whole-cane" harvesting are losses during billeting and the achievable changes in bulk density by the billet length manipulation.

Billeting losses:

Losses during billeting are composed of both juice and fibre losses at the site of each cut in the cane stalk. The losses per cut with current design rotary pinch chop system is minimised when an optimum relationship is achieved between the speed the cane is fed into the chopper drum by the feed train and the chopper blade tip speed. Currently all harvesters offer the option of variable chop length, which is achieved by reducing feedroller speed (to sub-optimal speeds). This increases the losses associated with each cut. This effect is illustrated in Figure 10, where the losses for a sample of chopper systems tested in the BS188 testing program are plotted against billet length achieved (in the relevant series of tests).

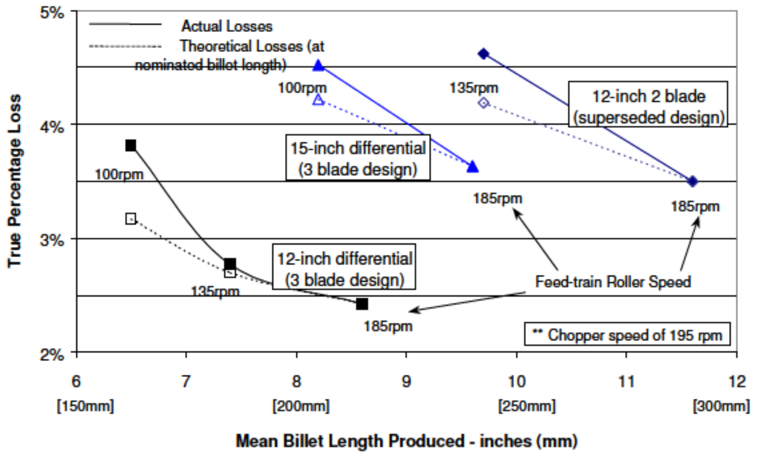

Figure 10 - Effect of chopper system and billet length setting on billeting losses[18]

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[18] BS165 data sets.

For each chopper system, billeting losses are minimised at the maximum billet length setting tested. The theoretical losses at the shorter billet length assume the same loss per cut as for the longer billet length setting.

From this data:

- To achieve minimum losses at any nominated billet length, the chopper drum must be optimised for that billet length (correct number of blades) and the peripheral speed also optimised. It is believed the poor relationship between the chopper peripheral speed and the feedtrain speed is the primary reason for the high relative losses of the 15 inch system.
- Losses increase as billet length is reduced. Even with a well designed chopper system (eg the "12 inch differential in the current example), losses climb significantly as billet length approached 150 mm. (because of the rapidly increasing cuts/metre of stalk).

Given the increase in billet damage which occurs as billet length is reduced (BS188 data), billet lengths below approximately 140-150 mm can be expected to suffer higher levels of mutilated and split billets.

The practical minimum limit for billet length will vary with cane variety and other factors, however industry experience would indicate 140-150 mm to be a practical minimum with well designed and setup chopper systems.

Bulk density:

Significant resources have been applied to the issue of empirically determining the effect of billet length on bin weights in chopper harvested cane. Initial work was done by Frost and Stevenson[19] who developed relationships for bin weight over a range of billet lengths and at up to 15% EM.

More recently, Vitale and Domanti[20] investigated the effect of billet length on bulk density by using a model developed by Parkhouse and Kelly, which predicts packing densities of long straight fibres. The model cannot be used to predict the effect of non-homogeneous materials (eg billets of different lengths) on final bulk density. Assuming homogeneous material (low levels of EM), the model predicts a simple geometric non-linear relationship between billet length and packing density. When calibrated for typical billet dimensions, the model predicts approximately a 0.5% increase in density for each 1% reduction in billet length[20], which the authors claimed agreed well with empirical observations in billeted cane. Whilst the model cannot predict the effect of EM on the bulk density achieved at a specific billet length, the approach was seen to offer some potential to investigate the effect on bulk density of relatively small changes in billet length at constant levels of EM.

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[19] Frost, M B and Stevenson, D M (1980). Cane Quality In The South Johnstone Area. Proc of ASSCT

[20] Vitale,M M and Domanti,S A (1997) An Investigation into the Optimal Length of Sugar Cane Billets. Pp 170-178 Proc of ASSCT.

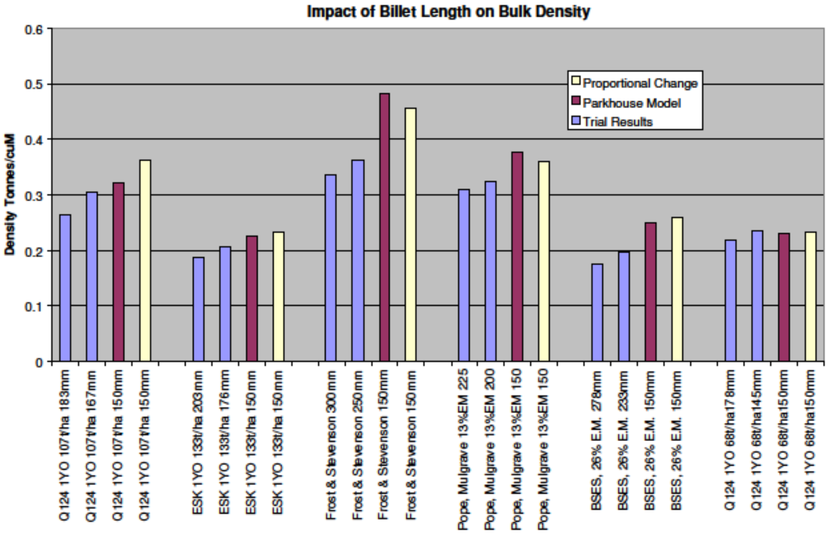

Figure 11 - Effect of predicted changes in billet length on bulk density

Figure 11 presents estimates of the impact of changing billet length to 150 mm on the bulk density of data sets where changes in billet length are evaluated. The trial data sets used include those data sets from Figure 10 which have billet length as a variable, as well as additional data sets from Pope's data (Mulgrave, 13% EM), data from Frost and Stevenson and results of the limited trial program undertaken at BSES Bundaberg.

The reference billet length and EM data was taken from the shortest billet length for each data set. For the Parkhurst data set, it is assumed the bulk density changes 0.5% for each 1% change in billet length (as nominated by Vitale and Domanti). For the "proportional change" scenario, it is assumed that the change in bulk density as billet length is changed will be proportional to the change in bulk density which occurred as the billet length changed from the longer length to the shorter length in the field trial. Of interest is the fact that the scaling factor was lower for low yielding light crops (0.32 for the 68 t/ha Q124) and higher for heavier crops (0.7 for the Esk crop).

Because of inconsistencies in the EM – billet length relationship for the Harwood Q124 trial, the results for the long and medium and medium and short billet lengths were averaged to give two data points. This ensured a conservative outcome.

From Figure 11, observations can be made that, at a billet length of 150 mm:

- The Q124 1YO at Pimlico (107 t/ha) would probably increase from a bulk density of 0.305 t m^{-3} at 167 mm to a bulk density of between 0.322 and 0.361 t m^{-3} at 150 mm.
- The ESK 1YO (133 t/ha) would probably achieve a bulk density of 0.225-0.232 t m^{-3} at 150 mm.
- The BSES trial (unknown variety, 26% EM) would probably increase from 0.196 t m^{-3}, at 233 mm to 0.250-0.260 t m^{-3} at 150 mm.

- The Q124 at Harwood (68 t/ha) would reduce in bulk density to 0.231-0.232 t m^{-3} at 150 mm as the billet length was increased from 147 mm.

From this analysis, changing billet length appears to offer a significant gain in bulk densities of the product, to the extent that 0.230-0.250 t m^{-3} appears achievable in most situations where "average" or "above average" yields are encountered.

4.1.3.2 Controlled reduction in % EM

Strategic reductions in EM levels are potentially a method to increase bulk densities of product at minimal cost. It obviously involves "sacrificing" a proportion of the trash to allow loading of transport equipment to be optimised.

This approach can potentially be achieved in two ways:

- Removal of the tops in standing crops
- Removal of limited amounts of material by the primary extractor system.

Topping:

Because of their high moisture content (lower net calorific value) and adverse sugar quality implications, the selective removal of tops and green leaf from the product could be advantageous.

The "loose" link between lower product bulk densities and lighter (standing) crops would indicate this may be a useful approach. This is further supported by the useful increase in bulk density achieved when the 1YO CP 1st ratoon crop (Figure 9) was topped.

Selective extraction:

Selective extraction of a small proportion of the leaf material can be seen to significantly impact on the bulk density of the cane trash product.

Given the Edwards equation of:

Bulk Density = 0.3896 – 0.0107*Trash

Applying the Parkhurst correction for billet length, an approximation for the bulk density at 150 mm billet length would be:

Bulk Density = 0.51-0.014*Trash

Whilst this would appear to give a high value for bulk density at 0% trash, it is more relevant than the original data sett for 255-275 mm billet length.

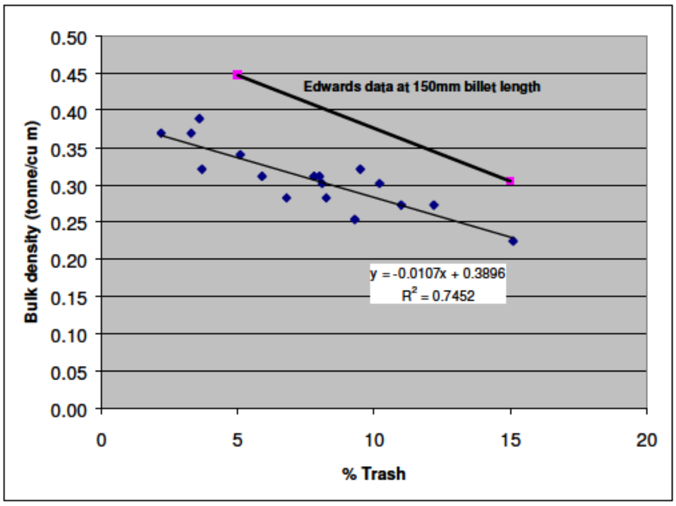

Figure 12 - Estimated bulk density versus trash corrected for 150 mm billet length

To illustrate this effect, assume a product with a density of 0.235 t m^{-3}. It would nominally have a trash level of 20%. The haulout payload would be 94 % of maximum allowable load.

A reduction of 1.1% in the leaf and trash level (ie from 20% to 19% trash) will give an increase in bulk density to 0.250 t m^{-3}, with a loss of 5% of total trash.

The relative value of transport costs and the loss of trash must then be assessed.

4.1.3.3 Conclusions

Arguing from these data and the regression equation established in Edwards' (1994) trials it may be possible to regularly achieve a bulk density of at least 0.250 t m^{-3} with harvested whole-cane. This is particularly so if trash and leaf levels of less than 20% are realistic. Similarly, the reduction in billet length to 140-160 mm will dramatically improve the proportion of crops, which can be whole-cane harvested and achieve bulk densities of 0.250 t m^{-3} without further manipulation of the product. Selective reduction in tops and/or trash will further enhance the probability of achieving the goals, particularly in lighter crops.

Different varieties, growing conditions, crop class and age will all potentially change the bulk densities achieved.

Further extensive trailing must be conducted at Condong Mill to validate these assumptions.

4.2 Nominate necessary and justifiable changes to cane harvesters to facilitate green cane harvest with collection of the total crop (cane and trash). This should include any changes to elevators that are necessary to handle the additional volume or accommodate larger capacity infield units.

This will incorporate:

- An overview of the current knowledge and experience elsewhere with harvesting of large unburnt crops.
- A discussion on constraints to harvester performance in large unburnt crop situations.
- Recommended modifications to maximise the potential of current harvesters to achieve required performance in large unburnt crops.

4.2.1 NSW industry background

Tables 8 and 9 present a generalised overview of average crop sizes and harvesting situation in the Condong Mill area.

Average crop size for one year cane approximates the Australian Industry average, and accounts for approximately 60% of the harvested tonnage. The average yield for two year cane, at approximately 150 t/ha, is substantially higher than the average yield Queensland mill areas and is also substantially greater than the mean yield for the Colombian Industry (117 t/ha). The ability of current harvesting equipment to harvest crops of this size unburnt is a major consideration.

TABLE 8
Differences in harvesting issues, one year versus two year cane

	One-year cane	Two-year cane
5 year average yield	98.9 t/ha	152.2 t/ha
% by area	70	30
% by tonnage	62	38
% harvested green	10-15%	<5%

Harvesting group sizes in Condong are large compared with average group sizes in Queensland, although not as large as harvesting groups in the other MSW Mill areas and some Queensland Mills (eg Tully). Similarly, harvester utilisation, in terms of harvested tonnes/engine hour is higher than all mill areas, which predominantly harvest unburnt crops, and similar to harvester utilisation for the Burdekin Region, where crops are typically harvested burnt. The pour rates quoted, however, appear high relative to published data[21] on typical harvesting rates in burnt cane.

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[21] Ridge *et al.* (1996). Factors influencing Industry Harvest Transport Performance. Proc ASSCT, pp 6-13.

TABLE 9
General statistics for harvesting groups in Condong Mill area (from discussions with harvester operators)

Average group size	60 000 + tonnes per year, 1999
Average harvester utilisation	60-65 tonnes/engine hour
Typical harvesting rate, 1 year crop	8-9 kph, 120-140 t/h pour rate
Typical harvesting rate, 2 year crop	6-7 kph, 140-160 t/h pour rate
Typical fuel consumption	0.7-0.8 L/ton, harvesting burnt
Typical harvester age	<5 years

An initial overview of crop size and harvesting conditions suggests that:

- Harvesting one year crops unburnt should, typically, pose few problems for current harvesting equipment in the majority of situations. The pour rates at which the harvesting operation occurs will significantly impact on the economics of the industry.
- Harvesting two year crops unburnt, particularly two year crops of greater than “average’ size or which are heavily lodged can be expected to present major problems with current harvesting equipment.

4.2.2 Machine performance when harvesting large green crops, issues raised in NSW

Harvesting crops green seen as more difficult than harvesting same crop burnt. This becomes particularly evident as crop size increases, and as such is of particular interest in northern NSW.

Issues identified in NSW relating to harvesting crops green:

- achieving feed in large green crops
- tearing cane stool from ground during the gathering process
- increased pickup losses, in large green crops
- guidance and ability to find the row
- basecutter height control
- volumetric capacity of feedtrain
- elevator capacity for “whole-cane” harvesting

One operator commented that his maximum operating speed whilst harvesting a block of heavy two year cane had been 3 km/h (60-70 t/h). If the crop had been burnt, his operating speed would have been in the order of 7-8 km/h (140-160 t/h).

Austoft[22] believe the ability of the harvester to gather and feed large unburnt crops is seen as the primary impediment to whole crop harvesting, with elevator capacity being an impediment to achieving necessary harvesting rates.

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[22] Mal Baker *pers com, telephone, 11/5/00, C Norris*

There was a universal view amongst machine operators that acceptable harvesting rates in large green crops could only be achieved if the cleaning function on the machine was not operating because:

- Power consumption of primary and secondary extractors: if this was not needed, more power available for other functions, and power consumption will increase if cleaning is necessary.
- Pour rate is limited if effective cleaning is to be achieved.

4.2.3 Experiences harvesting large green crops: Australia and overseas

The experience of the difficulty of harvesting heavy lodged crops, and in particular unburnt heavy lodged crops is not unique to the New South Wales Industry.

The most recent definitive data on harvesting rates was undertaken by Ridge *et al.*[21] in 1994-95 as part of an SRDC funded survey to validate the BSES Harvest and Transport model. Figure 13 presents information on the effect of crop size on typical pour rates for tracked harvesters. In small crops, pour rate is typically limited by maximum forward speed, however as crop size increases, a range of other factors control the typical maximum pour rates.. The difference in performance when harvesting green versus burnt crops is clearly evident.

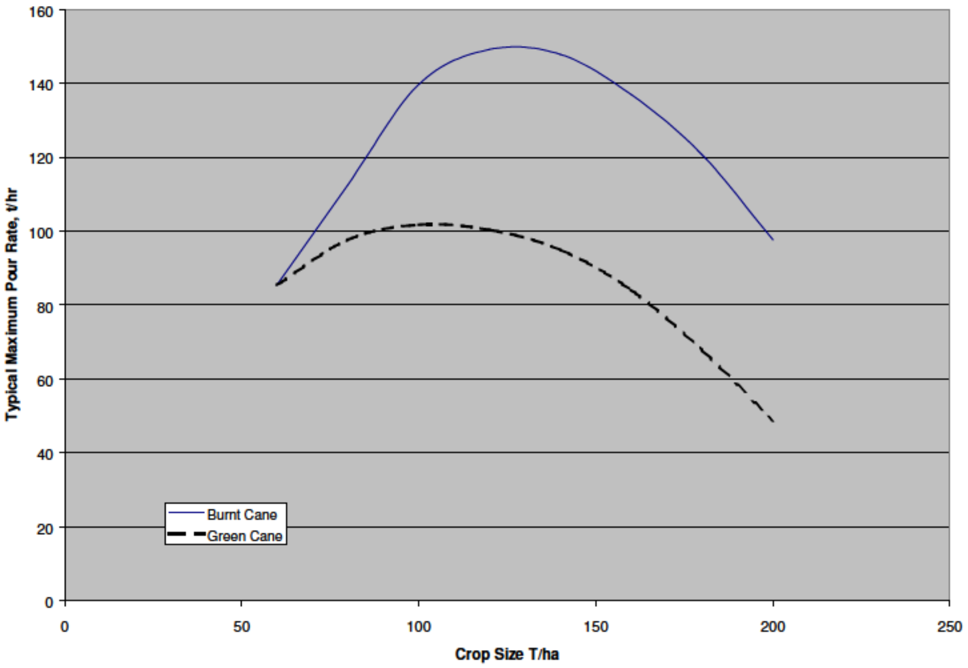

Figure 13 - The effect of crop size on maximum harvester pour rate (tracked machines), in burnt and green cane (Ridge *et al.*)

Since the period of the survey, developments have been made in harvesters which have increased capacity in both burnt and unburnt crops. These developments have included more engine power, substantially greater power available to key functions such as the choppers and larger primary extractors to enhance cleaning.

As a result of these changes, typical pour rates have increased[23], with the differentiation between green and burnt harvester performance being reduced in the 80-120 t/ha crop size range. The ability of machines to operate in large tangled crops has also improved because of the enhanced ability to process the large gluts of cane which occur as feed control mechanisms fail.

A substantial difference still exists, however, between the ability of current harvesters to harvest large crops burnt versus unburnt. At the end of the 1998 season, harvesters were taken into the Burdekin district from the Herbert and other districts, to assist with salvage of the crop. Most operators were experienced at harvesting green in their own districts. Because of wet conditions, harvesting green was seen as the preferred option. Whilst in lighter crops this was successfully achieved, in heavier crops significant reductions in harvester output were noted, eg:

- 400-500 tonnes/day cutting green
- 1200 tonnes/day cutting same crop burnt.[24]

This reduction in machine throughput was significantly greater than the reductions noted by Ridge[21] and probably relate to the size and state of the crops at the time (end of very wet harvesting season). In the current debate on harvesting costs in the Burdekin region, it is accepted by both the harvesting contractors and growers that, with typical Burdekin crops, harvesting rates will, on average be 30% lower for green cane harvesting than for burnt crops[25], which would appear to be a reasonable estimate based on average crop size in the region.

The industry in Florida has similar problems[26]. Average crop size in new varieties is in the order of 150 t/ha, with crops to 200 t/ha not uncommon. Currently almost the entire crop is burnt before harvest. Single row harvesters average 60 000-70 000 tonnes/year and have a productivity of 57-62 tonnes/engine hour.

US Sugar in Florida is currently running 60 trial sites evaluating agronomic and economic aspects of green and burnt cane production systems.

- In burnt cane, a unit of five harvesters will normally cut 3 600 t/day.
- Cutting 180-190 t/ha plant cane unburnt, the machines could only output 1 200 ton in same time, ie 33% of the productivity for the same machines in burnt cane.

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[23] Norris, C P, unpublished survey data, 1997-98

[24] John Powell, *pers com*, May 2000.

[25] The Caneharvester, April-May 2000.

[26] Woodroe W Storey,JR, US Sugar, *pers com during visit by C Norris*, November 1999.

- In lighter crops, the loss in productivity suffered when harvesting unburnt cane was less dramatic. Figures quoted were that in a 130 t/ha unburnt crop, machine productivity was 60-70% of burnt cane productivity/machine.

Pulling of stool from the (soft peat) soil was a major problem when harvesting green and a significant problem at higher harvesting rates in burnt cane.

Colombia has legislated phase out date for pre-harvest cane burning of 2005[27], and significant problems have to be overcome before chopper harvesters can offer a viable alternative to the high cost of hand cutting large green crops.

- Machines (near new Austoft 7700's and Cameco CH2500's) seen attempting to cut large green crops in Colombia (200+ t/ha) were suffering the same problems of low productivity caused by inability to feed and constant choking that are experienced in high yielding areas in Australia. Some mills have tried harvesters but reverted to hand cutting[7].
- Central Costilla Mill[28], which was reintroducing machines for the 2000 harvest was anticipating the output of machines to be 22 t/engine hour. Operating in the same field conditions but in burnt cane, the anticipated harvesting rate is well over twice this, and similar to Australian expectations of machine performance in large burnt crops.

The Brazilian industry is moving towards the elimination of cane fires by 2008, and as such is moving into green cane chopper harvesting. Sao Marthine Mill currently harvests 6M tonnes of its 7.5M tonnes with a fleet of 40 chopper harvesters (average 150 000 t/machine/year). Whilst most machines are recent model Austoft/Braztoft 7700's harvesting green cane, some harvesting "fronts" operate older Brazilian copies of Toft 6000's in burnt cane. Average yields for Sao Marthine mill are typically 100-120 t/ha. Fuel consumption and tons/engine hour are both significantly lower in green versus burnt crop[29] conditions:

- "6000" harvesters operating in burnt cane, fuel usage: 0.6-0.7 L/ton, average productivity of fleet is 52-57 tonnes/engine hour, calculated on a weekly basis.
- "7700" harvesters operating in green crops, fuel usage: 0.95-1.1 L/ton, average productivity of fleet is 42-47 tonnes/engine hour, calculated on a weekly basis.

The current series of harvesters does not offer an appropriate solution to the problems of harvesting large green crops anywhere in the world. Whilst increasing engine power and the power available to various systems has allowed harvesters to achieve some improvement in the ability to process these crops, it has not been the solution. Harvesting rates remain significantly lower than in burnt crops and damage to the cane stool is a major issue. Fuel consumption is typically also significantly higher.

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[27] Cock, J. *pers com during visit by C Norris,* November 1999.

[28] Milton Swares, Manager, *pers com during visit to Colombia*, November 1999.

[29] Mario Gandini, Gerente Agricola, Sao Martinho, *pers com. during visit to Brazil,* November 1999

4.2.4 Factors determining machine performance in large green crops

Initial work by Garson and Schembri, and further quantified by BSES research, identified that harvesters typically operate in a “glut-starve” feed pattern, which became more extreme as harvesting conditions became more adverse. Under burnt cane conditions, the feed of cane through the machine is significantly more even.

Factors which impact on the ability of a harvester to effectively harvest a large crop unburnt include:

- Capacity to gather and align the cane as the machine moves forward.
- The ability to feed the cane across the basecutters and into the feedtrain as evenly as possible.
- Volumetric capacity of the feedtrain and chopper system.
- Cleaning capacity.
- Elevating capacity.
- Side issues, guidance, basecutter height control to assist the operator because of limited visibility.

4.2.4.1 Gathering and aligning the cane

NSW growers and contractors identified gathering and stool pull-out as major potential issue when harvesting large crops unburnt. As part of a project BS165 (Improved feeding of large green crops), the processes involved in the gathering and alignment of the cane stalks by the gathering spirals have been investigated. This research clearly indicates that the current twin, counter rotating spiral system is not appropriate for gathering large lodged crops. Whilst the relatively low friction between stalks of burnt cane somewhat mitigates the problem of poor design, the significantly higher friction between unburnt trashy stalks results in difficulty in feeding large green crops and typically results in high forces being exerted on the cane stool during the gathering process. This can often result in pulling of stool from the ground, an effect which is clearly visible in video footage of trials associated with the research[30].

Apart from issues relating to stool damage, analysis of data clearly demonstrates that the design of the current gathering system is responsible for the initiation of the glut-starve feeding pattern which characterises harvesters operating in lodged unburnt crops.

Trials associated with this research program have clearly indicated that the design of gathering spirals can be optimised to enhance the gathering of lodged cane whilst minimising tension on the cane stool.

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[30] Davis, R.J. *pers com.*

4.2.4.2 Feed into feedtrain

Quick[31] identified both volumetric capacity of the feedtrain and chopper system and evenness of feeding as primary determinants of the achievable pour rates associated with any harvester design. Cleaning capacity was also an issue when determining the maximum viable pour rates in unburnt cane.

The determining issues are therefore:

- the bulk density of the material being processed
- the volumetric capacity of the feedtrain, which is the product of the effective cross sectional area and the velocity of cane along the feedtrain (as determined primarily by feedroller speed).

***Material bulk density*:**

Cane stalks traversing the feedtrain of a harvester are aligned and mildly compressed, and as such, have different density to random containerisation of billets. Billet densities as such, are of limited use in predicting the theoretical capacity of the feedtrain of a harvester.

Considerable amounts of data can be sourced from Massey Ferguson R&D files looking at the theoretical packing densities of a wide range of cane compositions, typical of canes from various regions of Australia, which were used in determining required feedtrain capacity of the 405 prototype. For the purposes of this exercise however, the SRI data by Schembri and Garson (Table 10), gives an adequate indication of the relative density of burnt and unburnt cane in the feedtrain of a harvester. Data for erect cane used topped stalks whereas untopped stalks were used for the lodged crop simulation. The cane was compressed with a pressure of 2 kPa, to simulate the loading of feedtrain rollers.

TABLE 10
Bulk densities of cane stalks and trash under simulated feedtrain conditions (Schembri and Garson, SRI)

Variety	Description		Density kg/m^3 (cane loaded to 2 kPa)	Density ratio, green/burnt
Q135	Erect	burnt	493	
Q135	Erect	green	323	0.65
Q124	Erect	burnt	680	
Q124	Erect	green	448	0.66
Q124	Lodged	stripped	430	
Q124	Lodged	green	375	0.87
Q136	Erect	stripped	519	
Q136	Erect	green	350	0.67
Q136	Lodged	green	346	0.66

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[31] D Quick, formerly Engineering Manager, MF Canehervester operations, *pers com.*

As expected, burnt erect cane has the highest packing density, with lodged green cane having the lowest density. On the basis of these results, the theoretical maximum pour rate of a harvester operating in green cane should be in the order of 66% that for the same crop burnt.

Volumetric capacity:

The volumetric capacity of the feedtrain is the product of the effective cross sectional area and the velocity of cane along the feedtrain (as determined primarily by feedroller speed). Both these factors are important as documented below.

Feedroller speed:

Feedroller speed on cane harvesters is a compromise between a range of factors including dirt rejection, machine capacity and billet length. The scientific research on which current settings are based was conducted in the early 1970's. On most harvesters, the feedtrain rollers are run in two distinct groups (see Figure 17). The first group (group 1) includes the buttlifter and first four (two top, two bottom) rollers, and the second group (group 2) are the remaining rollers which convey the cane to the choppers. The feedrollers have a nominal diameter of 215 mm.

On most recent model harvesters, the group 1 rollers operate at differing speeds in the range of 90-147 rpm (giving a peripheral speed of 3.7-5.14 km/h) and 90-245 rpm on 1999-2000 machines. This is nominally to agitate the cane bundle and maximise dirt rejection by the feedtrain. The group 2 rollers operate at a range of speeds, depending on harvester make and model. The adjustment in speed available in the group 2 rollers is to adjust billet length. Typical group 2 roller speed ranges are 100-150 or 120-190 rpm, depending on model and options. The maximum theoretical capacity of the feedtrain is therefore determined by the peripheral speed of the slower group 1 rollers (3.7-5.14 kph), and the cross-sectional area of the rollertrain at this site (900*150 mm). This equates to a theoretical capacity of:

- 380-500 t/h in erect, burnt or stripped cane (app 500-660 kg/m^3)
- 320 t/h lodged burnt or erect green cane (app 440 kg/m^3)
- 255 t/h in lodged green cane (app 350 kg/m^3)

Effective cross-sectional area:

Effective cross-sectional area is the width of the roller train multiplied by the feedroller opening. Current harvesters have a feedtrain width of 900 mm and a maximum roller opening of 150 mm. Figure 14 gives a profile of the roller opening (60 second sample interval, mean value recorded) for a harvester operating in an unburnt crop (90 t/ha) and large burnt crop (140 t/ha) at Mackay during the 1999 harvest season. The logging system conditionally logs to eliminate effects of turning, etc on roller opening. A value of 1000 equates to the last top feed roller being fully closed (minimal cane in the roller train) and a value of 2400 equates to the roller being fully open. Because the recorded number is the average value for a 60 second period, the recorded number indicates the gross variability in loading and does not reflect the incidence of near-choke events.

In the green cane harvesting blocks (7th, 8th and 10th June), the mean effective roller opening indicated in Figure 14 is approximately 1500mV, equating to 36% maximum opening. Results from BS165 indicate that with current harvesters, maximum sustainable mean roller openings range from greater than 40% in erect green crops to less than 30% in heavy, lodged green crops. At mean roller openings above this, the cyclic glut-starve feed pattern characteristic of current machine designs means that there is a high probability of feedtrain/chopper stall-out as the system processes the cyclic glut feeding events. In this example, assuming a product density of 400 kg/m^3, the pour rate would be 105 t/h. Observations under BS165 and BS189 indicate that, when harvesting unburnt crops, pour rates in excess of 140 t/h are difficult to maintain.

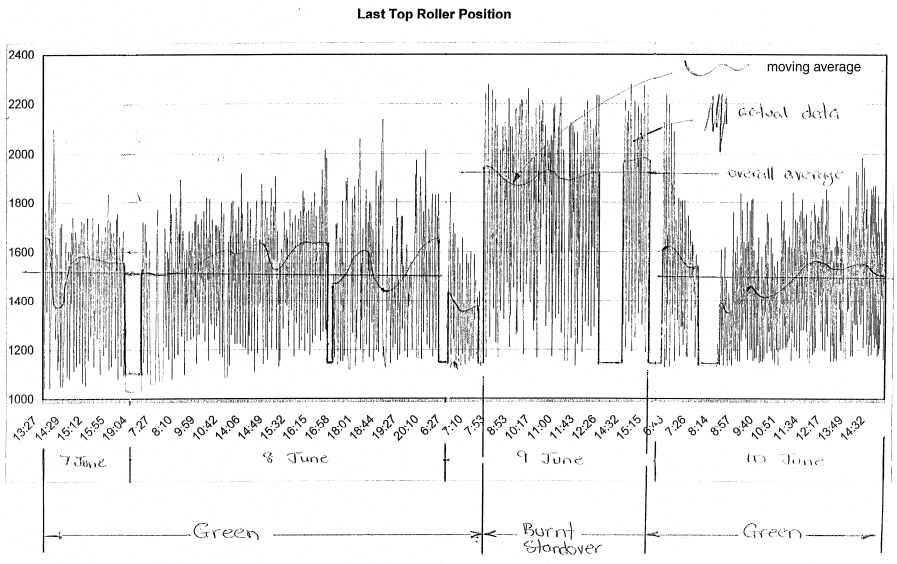

Figure 14 - Roller opening (60 second sample interval, mean value recorded) for a harvester operating in an unburnt crop (90 t/ha) and large burnt crop(140 t/ha)

By comparison, in the heavy burnt crop (to be ploughed out), the mean roller opening indicated across the full day was approximately 1920 mV. This equates to a mean roller opening of 66%, and a theoretical pour rate of approximately 200 t/h, while actually harvesting. This is a very high figure to maintain across the full day, however pour rates of 300 t/h have been recorded for extended periods in burnt cane.[32]

4.2.4.3 Chopper performance

The design of chopper systems fitted to modern harvesters is typically capable of processing all the material which can be processed by the feedtrains. Increased fibre in green cane associated with green cane harvesting increases the effort of the choppers to process the cane, which impacts on power consumption and chopper blade wear rate.

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[32] J Doore, Tully 1997 pers com

The chopper pressure data associated with the data presented in Figure 14 indicates mean chopper power consumption (as measured by chopper pressure) was only 25-30% higher in the burnt crop (1600 psi versus 1250 psi), despite the 100% increase in cane processing rate. The maximum chopper pressure was only 10% higher in the burnt crop than in the unburnt crop.

Wear rates on chopper blades is linked to pour rates, nominal billet length setting (lower feedtrain speeds increase induced tension in the cane bundle by the choppers and forces on the blades) and trash and dirt levels (fibre and fibre composition)[33].

4.2.4.4 Elevator capacity

Elevators are essentially volumetric conveying systems, and as such, capacity is impacted on by bulk density of material being conveyed. Issues such as % fill of the conveying "chambers" are impacted on by billet length and the geometry of the "boot" area of the elevator. In an open flight design, the maximum volume which can be conveyed on a flight will be dependent on the physical properties of the material, the height of the flight and the angle at which the unit is operating.

Whilst designs are generally similar, subtle changes in design of Austoft and Cameco elevators do impact on the capacity of the respective designs, with the capacity of the Austoft 7000 unit generally considered to have a capacity of 240 t/h in clean burnt cane (Austoft[2]) and the Cameco unit a capacity of approx 300 t/h under the same conditions[34].

Under green cane conditions (10-15% EM), the capacity of both units are in the order of 140-160 t/h for the respective units, but the actual capacity is impacted on by a range of factors as indicated above (BS189, BS165 and BS227).

Trials with "whole-cane" ("fans off" treatments in BS189 and 227), capacities are in the order of 70-90 t/h, again depending on the characteristics of the material.

4.2.4.5 Cleaning system performance

The ability of current concepts in cane harvester cleaning systems to effectively clean cane is typically a major constraint on the maximum pour rates achievable when harvesting unburnt cane. The cleaning system is the largest single consumer of power on the harvester. Typically, the total oil flow to the primary and secondary extractors is 45 gpm and 30 gpm respectively. Typical operating pressures are in the range of 2500-3500 psi for the primary extractor and 2000-3000 psi for the secondary extractor (Austoft [35]). This equates to an oil power of 49-69 kW and 26-39 kW respectively. The installed engine power to operate the extractors (assuming 90% efficiency) is 83-120 kW. Current

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[33] Hockings, P R, Davis, R J, & Norris C P, Chopper Systems in Cane Harvesters, B: Results of a Test Program, Proc of ASSCT. 22: 250-255.

[34] E Simms, EHS Machinery, *pers com.*C.Norris.

[35] M Baker, Austoft, *pers com.* C Norris

harvesters have an installed engine power of 243-270 kW, so the extractor system is capable of absorbing up to 50% of the available engine power.

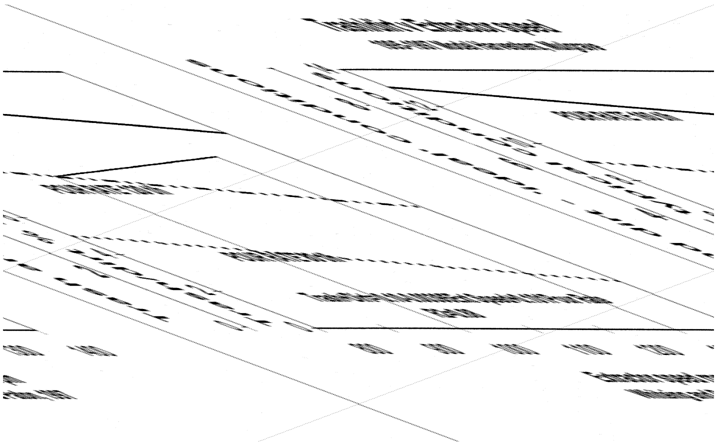

Figure 15 - The effect of extractor fan speed and pour rate on trash and dirt levels in harvested cane

Figure 15 illustrates the effect of pour rate on cleaning system performance, based on a series of trials undertaken in north Queensland in 1997. A criteria of output product quality is typically trash and dirt levels and, as such the most effective method of meeting a particular level product quality with current harvester cleaning systems is to manipulate pour rate. This effectively limits harvester capacity in when harvesting unburnt crops.

4.2.5 Potential modifications to harvesters to enhance performance

4.2.5.1 Crop size requirements

The goal of being able to harvest the majority of Condong crops unburnt, requires the systematic analysis of the performance of the harvester, and the options available to enhance the performance in large green crops.

Figure 16 illustrates a crop size distribution for two year old cane to be harvested in the Condong Mill area during the 2000 harvest. The estimated average yield for this cane is approximately 140 t/ha which is below the 5 year average of 150 t/ha. The crop size distribution would, however be expected to be similar. Approximately 38% of the tonnage harvester will be two year cane. The five year average yield for one year cane is 100 t/ha.

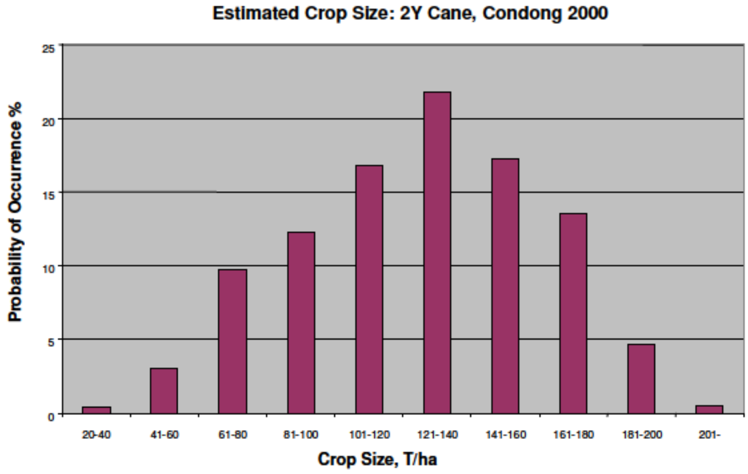

Figure 16 - Estimated crop size distribution two year cane 2000, Condong

For cost-effective harvesting of two year cane and trash for biomass, the harvester must be able to achieve effective crop removal rates in ha/h equivalent to that currently achieved by harvesters harvesting burnt cane, over most of the crop. Given an "average" crop size distribution, effective harvesting of crops up to 200 t/ha is desirable.

4.2.5.2 Harvester modifications to whole crop harvest large green crops

Gathering and feeding have been identified as major issues to the adoption of green cane harvesting in regions of Australia with higher than average yields. It was also identified as a significant issue by harvesting groups in the Condong area.

An SRDC funded project to investigate ways to enhance the ability of harvesters to harvest large unburnt crops has recently been completed by BSES, and the results of the project would appear relevant to the NSW situation. A brief outline of the results of the project is given in an article in "Caneharvester" magazine[36]. The original text of this article is given in Appendix 4. The project demonstrated that, with appropriate redesign of the gathering and feeding sections of he harvester, dramatic improvements are possible in the ability of harvesters to harvest large unburnt crops. The research also demonstrated a number of modifications which can be made to a harvester which will significantly enhance its performance in large unburnt crops.

The recommendations for modifications to current harvesters to enable them to affectively harvest large unburnt crops is based on this research, and knowledge of other options which may be available. These options are detailed in Table 11.

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[36] "The Caneharvester", April/May 2000, pp31-37

TABLE 11
Recommended modifications to enhance harvester performance for whole crop harvesting

Component	Recommended modifications	Supplier and cost
Gathering Fronts and Spirals	Fit spirals similar to BSES developed design.	EHS Manufacturing App $13 000
Row Guidance system incorporating gathering front & basecutter height control.	System approaching commercialisation by SRI. Works particularly well as row guidance in green crops.	SRI, approx price $12 500 (three units undergoing commercial evaluation in 2000, one on Austoft prototype)
Feed train.	Modify feed roller train to run all rollers at same peripheral speed, and at between 60% and 70% of the peripheral speed of the chopper blade tips.	Modifications range from App $5 500 on 1999 Austoft with "15 inch" choppers to changing all feedtrain motors (app $9 000) on 1997 Austoft machines.
Choppers.	Modified five blade design	Trail brothers. App $6 000
Elevator.	Modified design incorporating increased delivery height and higher volumetric capacity.	EHS Manufacturing. App $26 000

Desirable Modifications

Component	Modifications	Supplier and cost
Variable Speed Gathering Components	Operating basecutters and gathering components at speed proportional to groundspeed enhances evenness of feed and reduces stool damage.	App Cost $6 000

4.2.5.3 Improve gathering and feeding

These improvements essentially relate to improving the way the harvester manipulates the cane as it gathers it and feeds it into the harvester feedtrain. Improved gathering and feeding aims to reduce the magnitude of the "gluts", thus allowing the average feed rate to more closely approach the potential feed rate of the harvester feedtrain.

BSES gathering spirals and croplifters

The gathering spirals and crop divider fronts developed by BSES appear to offer incremental but significant improvements to the gathering and feeding of recent model harvesters. During the 2000 season at least one set will be on trial in Northern NSW. They will also be fitted to the Austoft prototype harvester being field tested during the 2000 season.

Supplier after market fitting	EHS Manufacturing, Mackay.
Cost - approximately	$13 000

They will probably be offered either as standard equipment or as a no cost option in 2001 on new Austoft harvesters.

Basecutters

The majority of recent model harvesters are sold with "Leg" basecutter arrangement, because of the better reliability and lower maintenance of this arrangement.

Data from BS165 trials, along with anecdotal evidence indicates that, in large crops, the "underslung" basecutter systems encourages more even feed of cane into the feedtrain.

Whilst it is impractical to change basecutter boxes on a harvester, for whole-crop harvesting in large crops, the underslung basecutter box should be considered. Several operators in the Condong Mill area expressed a preference for "underslung" basecutter boxes.

Proportional speed control: basecutters and gathering components

Kroes and Harris (1997) concisely demonstrated the advantage with respect to cane damage and stool damage of operating basecutters at an optimised rotational speed with respect to forward speed. Similarly, performance of the gathering components are optimised only when their characteristics - rotational speed, angle of inclination and spiral characteristics (major and minor diameter and lead of the spital) are matched to a selected, fixed forward speed. In large crops, it can be strongly argued that:

- linking basecutter speed and the rotational speed of forward feed and gathering components to ground speed, and,
- optimising the setup of these components to suit this relationship would significantly enhance machine performance. The geometry of the BSES fronts have has been optimised for a forward speed of approximately 3.5 kph.

The approximate cost to modify the relevant harvester hydraulic circuits and install an appropriate controller would be approximately $6 000.

4.2.5.4 Guidance systems and basecutter height control

Guidance and basecutter height control have been recognised as significantly greater problem in unburnt crops than for burnt crops for many years, and the issue was recognised by NSW harvester operators.

Although considerable resources have been put towards the problem, no systems are currently commercially available. A system developed by SRI and based on ultrasonic distance measurement will be under commercial evaluation during the 2000 season. Two units are being fitted to commercial machines in 2000, and one to the Austoft 2000 prototype machine. The system gives basecutter height control, height control on both crop dividers.

Providing cane is planted on appropriate and consistently even mounds, from which the systems can monitor the harvester's position, the system also gives very effective guidance on the row. This feature is reputed to work particularly well in lodged cane (Schembri, SRI).

Supplier:	SRI Mackay
Estimated cost	$12 500

4.2.5.5 Feedtrain roller speed modifications

The feedtrain layout and feedroller speed for the 1995 Austoft model harvester is presented in Figure 17.

The lower feedtrain rollers operate at constant but differing speeds, the rationale of this is to agitate the cane bundle and enhance dirt rejection. The research on which this practice is based was conducted over 20 years ago, under burnt cane conditions and at much lower pour rates than are currently used by the industry.

In order to achieve adjustability in billet length, manufacturers setup the group of six rollers closest to the choppers in an adjustable speed arrangement.

The key issues:

- Trials undertaken under BS165 indicated that the unsynchronised feedroller speeds further deteriorated the evenness of feed between the first floating feed roller and the last floating feedroller before the choppers.
- Trials with the chopper test rig at Bundaberg confirmed that with all rollers operating at the same peripheral speed, evenness of feed was maintained from the entry of the feedtrain to the choppers.
- Trials with the chopper test rig demonstrated that operating the feed rollers at a low peripheral speed relative to the choppers has a relatively limited impact on billet length but significantly increases variability in billet length. Operation in this mode increases losses associates with the chopping process, increases power consumption and can be expected to reduce chopper blade life.

By modifying the feedtrain so all feedtrain rollers all operating at same rotational speed, with this speed optimised to minimise chopper loses, a number of advantages are gained:

- Enhanced feedtrain capacity because of higher peripheral speeds of rollers. A 50% increase in feedtrain speed approximates a 50% increase in potential machine capacity.

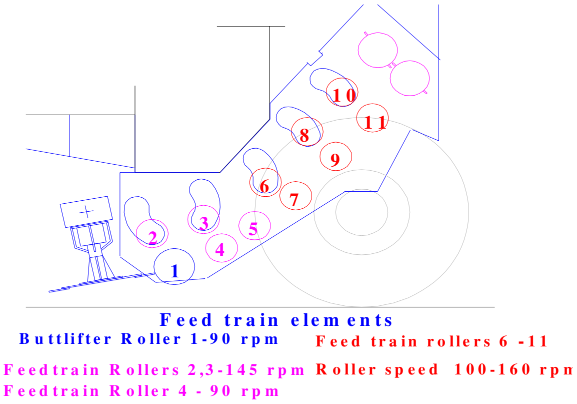

Figure 17 - Feedtrain layout and feedroller speed for 1995 model harvester

- Reduced soil in cane. Because the speed the cane enters the feedtrain more closely equates to the typical forward speeds, the cane is not being “baulked” as it enters the feedtrain, thus reducing the bulldozing of cane into the soil. A limited set of replicated field trials indicate a reduction of soil in cane levels of 15-20% relative to the standard machine setup.

- The BSES high density harvester has all rollers in its feedtrain operating at the same peripheral speed. This harvester has been demonstrated to substantially out-perform standard machines of similar specification (engine size, chopper drum configuration) with respect to feed capacity and maximum pour rate.

TABLE 12

Feedtrain roller speeds, 1999 Austoft (refer Figure 17)

Roller	Motor size and Configuration	Oil Circuit	Oil Flow/ motor	Roller speed	Roller surface speed
1 (Buttlifter)	2*24 gpm	basecutter	9.4	91	5.14
2 1st top	1*14.9	chopper (1)	15.5	240	9.7
3 2nd top	1*14.9	basecutter	9.4	147	5.95
4 1st bottom	1*24	basecutter	9.4	91	3.7
5 2nd bottom	2*24	Chopper (2)	10-15.5	96-148	3.88-6
6 3rd top	18.7	Chopper (2)	10-15.5	123-191	5-7.7
7 3rd bottom	18.7	Chopper (2)	10-15.5	123-191	5-7.7
8 4th top	18.7	Chopper (2)	10-15.5	123-191	5-7.7
9 4th bottom	18.7	Chopper (2)	10-15.5	123-191	5-7.7
10 5th top	18.7	Chopper (2)	10-15.5	123-191	5-7.7
11 6th bottom	18.7	Chopper (2)	10-15.5	123-191	5-7.7
Finn	2*24	Chopper (1)	15.5	148	8.4
Knockdown	2*24	Chopper (1)	15.5	148	8.4

TABLE 13
Recommended motor sizes, hydraulic circuit modifications and roller speeds 1999 Austoft for whole-cane harvesting

Roller	Motor size and configuration	Oil Circuit	Oil Flow/ motor	Roller speed	Roller surface speed (km/h)
1 (Buttlifter)	2*30 inch^{3} *	Chopper (2)	10-15.5	77-148	4.3-6.7
2 1st top	1*18.7**	Chopper (2)	10-15.5	123-191	5-7.7
3 2nd top	1*18.7**	Chopper (2)	10-15.5	123-191	5-7.7
4 1st bottom	1*18.7**	Chopper (2)	10-15.5	123-191	5-7.7
5 2nd bottom	2*18.7**	Chopper (1)	15.5	191	7.7
6 3rd top	18.7	Chopper (1)	15.5	191	7.7
7 3rd bottom	18.7	Chopper (1)	15.5	191	7.7
8 4th top	18.7	Chopper (1)	15.5	191	7.7
9 4th bottom	18.7	Chopper (1)	15.5	191	7.7
10 5th top	18.7	Chopper (1)	15.5	191	7.7
11 6th bottom	18.7	Chopper (1)	15.5	191	7.7
Finn	2*14.9***	Basecutter	9.4	145	8.2
Knockdown	2*24	Basecutter	9.4	90	5.1

*	Two new 30 inch^{3} motors
**	Five new 18.7 inch^{3} motors
***	Use motors replaced in roller positions 1 and 2
…	Motors to be changed

Table 12 presents data on the Austoft 1999 model feedtrain configuration and motor sizes (Austoft Service training manual, 1999). Table 13 gives recommended motor sizes and changes to hydraulic circuitry to achieve the desired effect of running the feedtrain at consistent peripheral speeds as well as achieving a better match to the chopper tip speed (section 4.2.5.6). The variable speed circuit (via the "Valvista" valve) should be connected to the lower feedtrain rollers, to reduce the aggressiveness of feed when operating at low speed "into" a lodged crop.

Cost:

Cameco harvesters:

The size of the buttlifter and lower group of rollers will have to be changed. This involves five rollers, at least one (depending on model) will have twin motors.

Austoft harvesters:

The cost of modifying the feedtrain on an Austoft 7000/7700 machine depends on the year model and chopper configuration. For example:

- 1997 machines with 12 inch choppers - change one chopper motor, chopper pump cartridge and most feedtrain motors

- 1999 machines, with 15 inch chop, involves changing seven feedroller motors and some re-plumbing of the hydraulic circuits.

Cost of new motors, approximately $650 each plus approximately $100/motor labour and incidentals.

The 2000 Wide front Austoft prototype will have feedtrain rollers operating at the same surface speed.

4.2.5.6 Chopper Systems

The functional requirements of the chopper systems to be fitted to harvesters for whole-cane harvesting are:

- Billet length of approximately 150 mm with high repeatability
- Minimum losses and billet damage during the billeting process
- Capacity to effectively process material at the pour rates required

The theoretical billet length achieved by a chopper system can be estimated from feedtrain speed, rotational speed of the choppers and the number of blades on the chopper drum, however a number of interactions occur which manipulate the actual billet length which will be achieved.

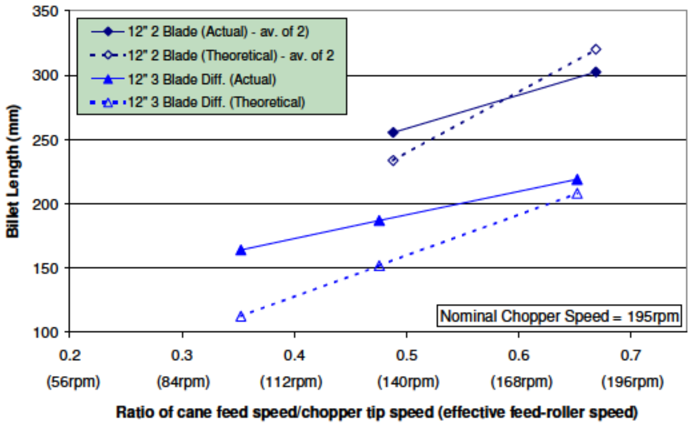

Figure 18 - The impact on billet length of the ratio of feedtrain peripheral speed to chopper peripheral speed

Figure 18 presents data from two chopper systems tested on the chopper test rig at BSES Bundaberg. From these results, as the number of blades per drum increases, the effectiveness of feedtrain speed as a method of controlling billet length reduces.

- For any chopper system, as the nominal feedtrain speed is reduced, the actual billet length achieved increases relative to the theoretical billet length. This is because the chopper system aggressively overrides the feedtrain with respect to the control of the speed of the cane along the feedtrain during the actual cutting phase of the chopper cycle. The greater the mismatch between feedtrain peripheral speed and chopper tip speed, the greater the potential billet length error.

- For chopper systems where the actual cutting phase of the chopper cycle is short compared with the total cycle time the effect is minimal (eg two blade 12 inch choppers), whereas Figure 19 presents data on the losses associated with the billeting process. For all chopper systems, there is a loss associated with the billeting process which is minimised at the optimum ratio of feedtrain speed to chopper tip speed. On choppers tested, the lowest losses occurred when the ratio of feedtrain speed to chopper tip speed is in the range of .6 to .7. Similarly, billet damage is minimised under these operating conditions.

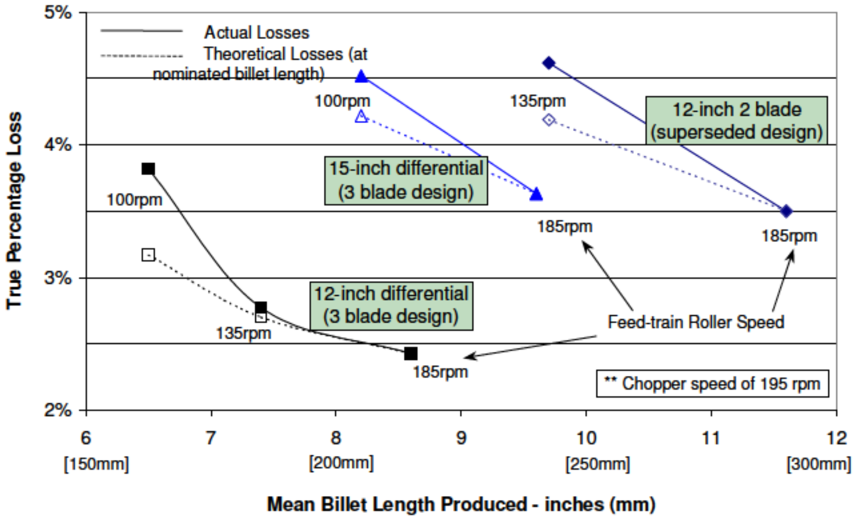

Figure 19 - Effect of feedtrain speed and chopper design on billet length and chopper losses

For each chopper system, data is given on the losses which would be achieved if the loss per cut remained constant as billet length was reduced (*Theoretical losses at nominated billet length*) versus the actual losses incurred by the chopper system. The increase in losses as billet length is reduced by manipulating feedtrain speed is evident.

To minimise billet damage and losses associated with the billeting process, whilst achieving the required billet length, the best approach is to increase the number of blades on the chopper system and run the feedtrain to achieve an optimal speed match.

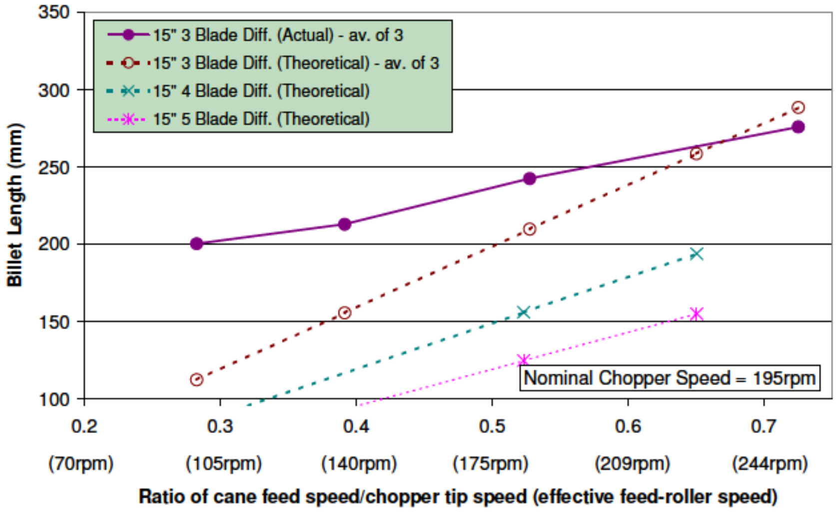

Figure 20 - Billet length versus feedtrain speed, 15 inch chopper drums

In order to achieve target billet length of 150 mm at an acceptable tip speed ratio. Figure 20 indicates that a five blade chopper would be appropriate. This is not a standard design.

Issues which may occur with this design may include billet damage due to constriction of billets during the billeting process and recirculation of billets if they are not adequately ejected from the choppers.

4.2.5.7 Cleaning system

The view of all operators in the Condong Mill area was that for efficient whole crop harvesting, it was not appropriate to operate the extractor systems on the harvesters. The strong preference was for a system where the entire product was taken “as is” by an elevator immediately after billeting.

Strategic trash removal may, however be required in some crop situations to ensure appropriate bulk densities can be achieved for optimisation of haulage costs. This would typically involve operating the cleaning system to achieve 5-20% extraction efficiency. Even with the limitations of current extractor system designs, this level of cleaning should be achievable with negligible cane loss.

These low levels of extraction cannot be achieved by reducing fan speed alone. At low fan speeds, particularly under damp conditions, trash build-up and wrap on the extractor fan blades could be anticipated to be a major problem.

The most cost effective solution would appear to be the fitting of “cut down” fan blades. The aim being to achieve an appropriate air flow to achieve low levels of extraction (eg 10-15 m/sec) at a fan speed of 1200-1300 rpm.

Cleaning would predominantly occur during periods of "reduced" cane flow through the cleaning system, however the potential for significant cane loss during these cyclic events will be dramatically reduced.

4.2.5.8 Elevators

The key requirements for an elevator for whole-cane harvesting include:

- capacity of 170-180 tonnes of cane and trash/h
- ability to deliver cane into haulout of 4.3 m height, operating in the same row as current haulouts (see Figure 21)
- no secondary extractor
- simple construction so whole of life costs are not significantly different to current designs

Discussions have been held with both EHS and Austoft about design concepts which may be relevant.

It is anticipated an appropriate design would be based on the primary elevator of the MF 405 prototype. The primary elevator on this machine was designed to carry full trash away from the choppers to the cleaning chamber up a steep incline.

Key features of design included:

- 1.0 m wide slats
- short/long slats at compressed spacing (7 inch and 4 inch high respectively)
- covered top over the elevator to prevent material falling from the flights

The anticipated cost of the elevator as a retro-fit would be approximately $27 000 (EHS).

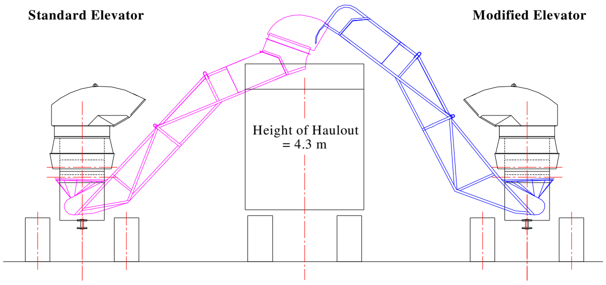

Figure 21 -Schematic of modified elevator to convey whole-cane

4.3 Determine probable harvesting rates and harvesting input costs of this mode of operation

To determine probable harvesting rates and harvesting input costs, estimates are made of three significant variables, viz:

- probable pour rate
- probable fuel consumption
- probable R&M

After determination of "reasonable" estimates, the information generated is used as inputs to and assess the outputs of the BSES Harvest and Transport model.

Options explored:

- burnt cane
- standard harvester in green cane
- modified harvester as whole-cane harvester
- modified harvester with shredder

Probable pour rates:

Pour rate is taken as the product of crop size and harvester forward speed, equating to the average instantaneous processing rate of the harvester.

A very high degree of variability can be expected "in the field". Identical harvesters can have dramatically different harvesting rates under identical field conditions, depending on the operators priorities, time pressures etc. Even with the same operator and machine, harvesting rate is not solely relates to crop size, as a 100 t/ha badly lodged cane can have a dramatically lower maximum harvesting rate than a 170 t/ha crop of standing cane[37]. The differences in productivity between green and burnt cane are well documented[21].

For the purposes of this discussion, however, the two "standard" crops are assumed to be a 100 t/ha standing crop and a 150 t/ha lodged crop.

Comments by Condong harvester operators, the 1994/5 survey data from Ridge *et al.*[21], experience gained during BSES green cane harvesting research and overseas data has been combined to determine values chosen. Similarly, where data is available on the effect of pour rate or crop size on power consumption of key harvester components or other harvester variables, this data has been incorporated.

To determine probable harvesting rates for different crop sizes and modes of operation for different machine configurations, the most likely performance limiting factors are assessed.

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[37] Trial results, BS165 (SRDC project "Improved Feeding of green Cane by Harvesters", Norris, Davis & Poulsen.)

Probable fuel consumption

Typically, harvester fuel usage is expressed as tonnes harvested/engine hour taken over an extended period. A potentially more useful approach is to calculate fuel efficiency as the harvester operates. Simple calculations of estimated "operating" fuel consumption versus pour rate result in very low fuel usage figures/tonne harvested, which the industry would consider nonsensically low. The discrepancy is primarily because of the percentage of time the engine is operating but the harvester is not actually processing cane, eg when turning at ends of rows, waiting for haulouts with the engine operating etc. Data from BS227[38], and Cameco[39] indicate that, on a season long basis, most harvesters actually harvest for significantly less than 50% of engine operating hours.

The impact of this on fuel usage can be illustrated by the situation when turning at end of rows. Typically, the engine is still at maximum rpm setting. All hydraulic circuits will still be absorbing power due to friction and other parasitic losses, eg:

- "No load" pressures are typically in the order of 10-15% of rated pressures for most circuits, equating to 10-15% of maximum power usage.
- The power consumption of engine driven (radiator fan) and hydraulically driven (oil cooling) fans is a significant component of total power usage which remains constant during turning etc. at ends of row.
- Extractor fans typically use up to 40-50% of maximum power under "no load" operating conditions at "harvesting" rpm settings (end of row) situations.
- Power consumption to the traction system typically peaks during turning at the end of the rows.

When turning at ends of rows or for short waits for haulouts, operators typically maintain the engine at full power setting, and throttle back for extended periods when waiting for bins etc. Clearly, factors such as row length, haulout waiting time and a range of external factors dramatically impact on fuel consumption/tonne harvested.

To generate reasonable estimates of fuel consumption for the various harvesting scenarios (for use in the BSES Harvest and Transport Model), the most logical approach is to estimate probable "instantaneous" fuel consumption. This allows realistic estimates of *relative* fuel consumption as key factors such as harvesting mode (burnt, green, shredding and "whole-crop") crop size and pour rates change. This information, along with estimates of engine partial load fuel consumption and an estimate of gross turning time can be used to give *relative* fuel consumption/tonne harvested.

In this exercise, the difference between pour rate and gross harvester productivity is calculated on the basis of 350 m row lengths and 60 second turn-around times at each end of the field. Both values considered "reasonable" for Condong Mill area.

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[38] BS227 "Improved harvest Efficiency", G Sandell *pers com.*

[39] N.Toft (*pers com*) fitted hour meters to elevators to a number of Cameco machines in 1998/1999 to assess % of total engine hours harvesters actually harvested cane.

Probable repairs and maintenance costs

Repairs and maintenance costs on a tracked harvester will vary widely, depending on soil type, class of cane etc, and can be sub-divided into track related maintenance and harvester system related maintenance (ie components interacting with the cane).

Track Maintenance Costs: Track wear can be demonstrated to be related to soil type and soil surface profile, total distance travelled, harvesting speed and the number of turns relative to travel distance. For logistic reasons, track maintenance on cane harvesters is usually undertaken on an annual basis rather than when optimally required for a "least cost" maintenance scenario. Under NSW harvesting conditions, it is assumed that the chain pins and bushes are "turned" every year and that the track chain and rollers are replaced every second season. Given a nominal contract size of 70 000 t, this equates to a track maintenance cost of approximately 10 ¢/t.

Burnt-cane Harvesting Maintenance Costs: On the basis of available data, the maintenance cost of non track components over a five year machine life, amortised per tonne of cane harvested can be estimated at 10c/t, giving a total maintenance cost of 20c/t.

Whole-cane and Green-cane Harvesting Maintenance Costs: Repairs and maintenance on the harvesting system components of a harvester operating in green cane are universally accepted as being substantially greater than for the harvester operating in the same crop harvested burnt. The primary component associated with this are the increased cost of maintenance of the extractor systems. Some estimates are that this can account for 50% of the total "harvesting system" maintenance costs[40] in green cane. Other estimates put the cost of maintenance of extractors at 20-25% of total maintenance costs in burnt cane[41]. On the basis of field survey data, Ridge uses an increase in total repairs and maintenance of 50% for green versus burnt cane in the BSES Harvest and Transport Model. This reflects the expected increase in repairs and maintenance on other harvester components such as chopper blades and general "wear and tear" because of the increased material being processed. The cost of track maintenance is not addressed in the model.

On the basis of available data, the maintenance cost of non track components over a five year machine life, amortised per tonne of cane harvested can be estimated at 15 ¢/t, giving a total maintenance cost of 25 ¢/t for green cane harvesting.

The repairs and maintenance for whole-cane harvesting, assuming either no extractor system is operating or "limited" extraction is occurring, can be assumed to be similar to or slightly less than the harvester operating in burnt cane with the extractor operating. As noted above, the reduction in costs associated with reduced extractor wear will be partially offset by increased chopper blade wear and increased wear on feedtrain components. It is therefore assumed that the maintenance cost of non track components over a five year machine life, amortised per tonne of cane harvested can be estimated at 10 ¢/t, giving a total maintenance cost of 20 ¢/t for green cane harvesting.

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[40] R Stiff, Austoft Confidential Internal Memo "Extraneous matter in Mechanical Harvesting", 1980.

[41] R Ridge, *Pers com*

Shredded-cane Harvesting Maintenance Costs: Estimated repairs and maintenance for a harvester fitted with a shredder can only be estimated. Given the shredder essentially replicates the extractor fan, it is reasonable to assume that the repairs and maintenance can be increased by this margin again to cover the costs of a harvester fitted with a shredder. On this basis, it is assumed that the total maintenance costs for the harvester fitted with a shredder will be 30 ¢/t.

Option 1 - Burnt cane harvesting, standard harvester

Estimated pour rates: Burnt crops are accepted the easiest crops to harvest, with even older machines being able to achieve ground speeds equating to high pour rates, providing the cane is not excessively lodged.

In lighter crops, the limit to achievable output of tracked type harvesters is typically harvester ground speed (although at high ground speeds considerable stool damage is done by the basecutters because of disc contact). As crop size increases, a number of potential factors limit pour rate, including operator visibility, guidance on the row, basecutter height control, ability of operator to react to changing conditions, quality of job, and eventually the ability of harvester to feed. Stool damage and other quality of job factors also become issues which determine maximum harvesting rate.

TABLE 14
Machine performance details - burnt cane harvesting

	Burnt-cane harvesting: Standard harvester							
Crop size (t/ha)	80	100	120	140	150	160	180	200
forward speed (km/hr)	9.00	9.00	8.00	6.75	6.25	5.60	4.60	3.50
pour rate(cln cane/hr)	108	135	144	142	141	135	124	105
effective speed after turns	4.38	4.38	4.07	3.64	3.46	3.20	2.77	2.24
harvesting rate (t/hr)	52.6	65.8	73.4	76.6	77.9	76.9	74.9	67.3
avg chopper pressure (psi)	1007	1196	1259	1243	1235	1192	1120	986
avg chopper power (65gpm)	32	38	40	39	39	38	35	31
extractor pressure (psi)	800	800	800	800	800	800	800	800
extractor power (kw)	18	18	18	18	18	18	18	18
avg basecutter pressure (psi)	600	700	750	850	900	900	900	800
basecutter power(85gpm)	19	22	24	27	28	28	28	25
Total component power (kw)	68	77	81	84	85	84	81	74
Additional Losses (kw)	80	80	80	80	80	80	80	80
Engine power useage (kw)	178	189	193	196	198	196	194	185
Total fuel useage (l/hr)	43.1	45.7	46.8	47.5	47.9	47.5	46.9	44.7
fuel/ton harvested (l/t)	0.82	0.69	0.64	0.62	0.62	0.62	0.63	0.66
Limit	harvester maximum speed	harvester maximum speed	quality & damage	quality & damage	quality & damage	quality & damage	machine feed	machine feed

Estimated Fuel Consumption: Typically, fuel consumption/hr is estimated from assessing power usage of various components across the range of crop conditions at the nominated forward speed. Fuel usage/tonne is then calculated, on the basis of effective harvesting rate. Relative fuel consumption/tonne can then be calculated across the range of crop sizes. Data from Condong, the Burdekin and Brazil indicates seasonal fuel usage/tonne is typically 0.6-0.7 L/tonne in 100-150 t/ha crops.

Comments:

- Forward speed estimates/limits based on comments from operators in Condong Mill area and trial results.
- Average chopper pressure and average basecutter pressure based on data from instrumented machines associated with BS165 and BS227 in typical crops at varying speeds.
- Extractor power is based on estimated extractor pressures in burnt cane conditions.

Estimated engine fuel usage is then calculated to give fuel usage/tonne.

Note: Forward speed is an indicative "probable maximum" only: actual harvesting rate is highly dependent on conditions and may vary up considerably from the nominated value.

Option 2 - Green cane harvesting, standard harvester

Estimated pour rates: Up to crop sizes of 80 t/ha there is usually little difference in the expected pour rates for modern harvesters between burnt and unburnt crops. As crop size increases, the difference in productivity between the two harvesting modes increases. Initially, the reduction in productivity is because of restrictions on cleaning system performance (product quality issues). Visibility, difficulty in assessing position on the row and basecutter height control issues also impact on the speed at which the operator is comfortable. As the crop size continues to increase, maintaining effective feed becomes the major issue, resulting in stool damage and increased levels of damaged billets in the cane supply.

Florida and Colombian data indicates that typical daily productivity in an unburnt crop of 180-190 t/ha is 33% of that in burnt cane and in 130 t/ha crops, 60-70%. In this exercise, and on the basis of trials under BS165 and Australian data, more optimistic values of 87% at 140 t/ha and 40% at 200 t/ha have been selected.

Estimated fuel consumption: Fuel consumption/hour is estimated from assessing power consumption of various components across the range of crop conditions at the nominated forward speed. Fuel usage/tonne is then calculated.

Comments:

- Forward speed estimates/limits based on overseas and Australian data.
- Average chopper pressure and average basecutter pressure based on data from instrumented machines associated with BS165 and BS227 in typical crops at varying speeds. Average chopper pressure in green cane is (12*pour rate+250psi). Basecutter pressure is observed values from instrumented harvesters. It is higher under green cane conditions than in burnt cane.
- Extractor power is based on estimated extractor pressures, M Baker, *pers com.*

TABLE 15
Machine performance details - green cane harvesting

	Green-cane harvesting: Standard harvester							
Crop size (t/ha)	80	100	120	140	150	160	180	200
forward speed (km/hr)	9.00	7.50	6.25	4.75	4.00	3.50	2.50	1.75
pour rate(cln cane/hr)	108	113	113	100	90	84	68	53
effective speed after turns	4.38	3.91	3.46	2.84	2.49	2.24	1.70	1.24
harvesting rate (t/hr)	52.6	58.7	62.3	59.6	56.1	53.8	45.9	37.4
avg chopper pressure (psi)	1547	1601	1601	1448	1331	1259	1061	881
avg chopper power (65gpm)	49	51	51	46	42	40	34	28
extractor pressure (psi)	2750	3000	3000	3000	3000	2750	2750	2500
extractor power (kw)	60	66	66	66	66	60	60	55
avg basecutter pressure (psi)	650	750	850	950	1000	1000	1000	1000
basecutter power(85gpm)	21	24	27	30	32	32	32	32
Total component power (kw)	130	140	143	142	139	132	125	114
Additional Losses (kw)	85	85	85	85	85	85	85	85
Engine power useage (kw)	258	270	274	272	269	260	253	239
Total fuel useage (l/hr)	62.4	65.4	66.3	65.8	65.2	62.9	61.1	57.9
fuel/ton harvested (l/t)	1.18	1.11	1.06	1.10	1.16	1.17	1.33	1.55
Limit	harvester maximum speed	E.M. in cane	E.M. in cane	Feed/ E.M.	Feed / E.M.	poor feed	poor feed	poor feed

Option 3 - Modified "whole-cane" harvester

It is assumed the harvester is modified with:

- "BSES" Modified gathering fronts
- feedtrain roller modifications
- basecutter and gathering front height control and row guidance
- modified elevator

Estimated pour rates: Because there is no, or limited, cleaning being undertaken on the machine:

- pour rate becomes limited primarily by machine feedtrain capacity during "glut feed" events.
- evenness of feed (which dramatically impacts on cleaning system performance) becomes much less significant as crop size increases
- .

At up to 150 t/ha crop size, it is assumed forward speed will be similar to that achieved by a harvester in burnt cane. The machine will be running "closer to the limit" than when operating in burnt crops because of the increased material mass and volume passing up the feedtrain and the fess even feed (even with the modifications) relative to the feed in burnt cane (BS 165 observations).

TABLE 16
Machine performance details - whole-cane harvesting

	Whole-cane harvesting: Modified harvester							
Crop size (t/ha)	80	100	120	140	150	160	180	200
forward speed (km/h)	9	9	8	7	6.5	6	5	4
pour rate(cln cane/h)	108	135	144	147	146	144	135	120
effective speed after turns	4.38	4.38	4.07	3.73	3.55	3.36	2.95	2.49
harvesting rate (t/h)	52.6	65.8	73.4	78.5	80.0	80.7	79.7	74.7
avg chopper pressure (psi)	1547	1911	1980	2016	2007	1980	1872	1691
avg chopper power (65gpm)	49	60	63	64	63	63	59	53
extractor pressure (psi)	0	0	0	0	0	0	0	0
extractor power (kw)	0	0	0	0	0	0	0	0
avg basecutter pressure (psi)	650	750	850	950	975	1000	1000	1000
basecutter power(85gpm)	21	24	27	30	31	32	32	32
Total component power (kw)	69	84	89	94	94	94	91	85
Additional Losses (kw)	80	80	80	80	80	80	80	80
Engine power useage (kw)	174	196	204	211	211	211	206	198
Total fuel useage (L/h)	42.2	47.5	49.4	51.0	51.2	51.1	49.9	47.8
fuel/ton harvested (L/t)	0.80	0.72	0.67	0.65	0.64	0.63	0.63	0.64
Limit	harvester maximum speed	quality & damage	quality & damage	quality & damage	quality & damage	quality & damage	machine feed	machine feed

Estimated fuel consumption: Fuel consumption/hour is estimated from assessing power consumption of various components across the range of crop conditions at the nominated forward speed. Fuel usage/tonne is then calculated, and predicted to be similar to fuel consumption for burnt cane harvesting.

Comments:

- Chopper pressure calculated as for standard harvester in green cane.
- Basecutter pressured increased because of increased pour rates.
- Fuel consumption estimates are similar to that for burnt cane. The increased power to the choppers and basecutters is compensated for by the reduced power for the extractors.

Option 4 - Modified harvester and shredder

Estimated pour rates: Two primary determinants of pour rate are the maximum capacity of shredder and maintaining a sufficiently even feed to minimise cane loss and maximise capture of trash. The power usage of the shredder will impact on the harvesting speed. It is assumed the harvester has all modifications as stipulated for the whole crop harvester**.**
On the basis of available information:

- In lighter crops (up to 100 t/ha,) pour rate will be limited by shredder capacity (tonnes/hour to be shredded and power availability) leading to stall-out if this is rate exceeded.
- As crop size increases, the improvements in feed reduce the deterioration in maximum feed rate, which would be expected with a standard harvester. It is assumed 75 t/h can be maintained up to 150 t/ha.

Estimated fuel consumption: Fuel consumption/hour is estimated from assessing power consumption of various components across the range of crop conditions at the nominated forward speed. Fuel usage/tonne is then calculated.

TABLE 17
Machine performance details - shredding trash

	Whole-cane harvesting & shredding: Modified harvester							
Crop size (t/ha)	80	100	120	140	150	160	180	200
forward speed (km/h)	6.5	5.5	4.5	4	3.5	3.2	2.6	2
pour rate(cln cane/h)	78	83	81	84	79	77	70	60
effective speed after turns	3.55	3.16	2.72	2.49	2.24	2.08	1.75	1.40
harvesting rate (t/h)	42.7	47.4	49.1	52.3	50.5	50.1	47.4	42.0
avg chopper pressure (psi)	1187	1241	1223	1259	1196	1173	1093	971
avg chopper power (65gpm)	38	39	39	40	38	37	35	31
extractor pressure (psi)	2500	2600	2750	2750	2750	2750	2500	2500
extractor power (kw)	55	57	60	60	60	60	55	55
Shredder Power (kw)	38	38	38	38	38	38	38	38
avg basecutter pressure (psi)	650	750	850	850	850	850	900	900
basecutter power(85gpm)	21	24	27	27	27	27	28	28
Total component power (kw)	151	158	164	165	163	162	156	152
Additional Losses (kw)	80	80	80	80	80	80	80	80
Engine power useage (kw)	296	307	316	317	314	313	304	298
Total fuel useage (L/h)	71.7	74.3	76.4	76.8	76.1	75.8	73.5	72.1
fuel/ton harvested (L/t)	1.68	1.57	1.56	1.47	1.51	1.51	1.55	1.71
Limit	shredder	shredder	shredder	shredder	shredder eveness of feed	shredder eveness of feed	feed	feed

Comments:

- Average chopper pressure in green cane is (12*pour rate + 250psi). Basecutter pressure is observed values from instrumented harvesters. It is higher under green cane conditions than in burnt cane.
- Shredder power is based on available data on pressures. (B Lamb NSWMC and J Budd, Central Tweed) and known information on hydraulic circuit capacities

4.4 To investigate and document the advantages and/or limitations of large capacity infield units, including units of "B-double" configuration, carrying a cane/trash mixture of nominated bulk density in the Condong Mill area

The bulk densities to be assessed are 0.2, 0.25 and 0.3 t m^{-3}. Issues considered will include:

- current infield sugarcane haulage equipment
- vehicle requirements to conform with NSW heavy vehicle regulations
- field factors affecting harvest and haulage
- proposed multi-lift bin and infield bin match

4.4.1 Current infield sugarcane haulage equipment

The eight harvesting groups in the Condong Mill area utilise about 26 haulout vehicles, if full-track infield units are not included. These vehicles vary in size from a nominal 8 tonne (21 m^3) unit to a nominal 14 tonne (33 m^3) unit with a total haulage capacity of about 280 tonnes. Wheeled equipment accounts for twice the capacity of the rubber-tracked vehicles (184 tonnes versus 92 tonnes). Full-track infield units, either self-propelled or trailed are currently considered essential for hauling cane during ‘wet’ harvests and only one group did not have this capability.

The steel tracked infield haulouts are built from ex-harvester components. These units are only used when wet harvesting conditions exceeding the capabilities of the conventional wheeled haulout equipment are encountered. Because of the unpredictable usage of these units, it is difficult to economically access these units. Assuming the proposed 95 m^3 multi-lift bin is adopted, all current steel tracked infield haulouts may require modification. Minimum modification would be to increase the lift/tipping height of these units to suit the new bins. Most units are of local manufacture and unique in design. The most common configuration consists of cab at the front and the engine at the rear and hence offers only limited potential to increase the bin volume. Bin length may be increased by about 1-2 metres but height appears to be the easiest dimension to increase. Current steel track units vary in size from 21 m^3 (2 off), 23 m^3 (2 off) or 28 m^3 (1 off). Any increase in bin volume must consider the need to match with the wheeled unit on the headlands that in turn match the new multi-lift volume. A steel tracked infield bin volume of 32 m^3 is the best match for the proposed system. The number of field trips required will increase proportionally depending on the current bin size and allowing for a 50% increase in crop volume. Should non-compliance of steel tracked units with RTA NSW guidelines be acceptable to harvesting groups, the bin widths greater than 2.5m may be possible. Steel tracked infield units are not used on public roads and are floated from site to site.

The concept of single, infield rubber track haulout of 32 m^3 as a replacement for current steel tracked wet weather buggy is also being considered by some harvesting groups. This unit could be used as a haulout under normal harvesting conditions and as an infield buggy emptying into wheeled haulouts on the headland during wet weather harvesting. The higher maintenance costs of this machine, particularly in situations of longer hauls would be a consideration.

Most haulout equipment used in the Condong Mill area is of local manufacture. The equipment is either made by local manufacturers or produced by the harvesting group outside the harvest period. All equipment is based on the single side tipping field bin. This option has been chosen as it is:

- simple and relatively inexpensive
- quick to unload (about one minute)
- when used with multi-lift bins does not have the bin size match problems of many Queensland tramway systems

The current equipment is assumed to have a turning time of 1.5 minutes for both rubber tracked and wheeled units. Average speeds for the rubber tracked machines are 25 km h^{-1}

unloaded and 20 km h^{-1} when loaded . The current tractors would have operating speeds of 40 km h^{-1} unloaded and 30 km h^{-1} when loaded.

Elevating tipper bins are popular in Queensland mill areas where the infield haulout must fill mixed bin sizes that may vary in size (eg 4 t and 10 t rail bins at the same siding). The infield tipping haulout and the multi-lift bin system currently used in NSW are quite efficient and generally well matched to other components. Elevating tipper bins have been trialed in NSW but were found to be more expensive, have higher maintenance costs and were slower to unload.

A review of haul distances of the different groups appears to justify the use of both rubber tracked and wheeled versions of infield haulouts. The rubber-tracked vehicles had lower maximum haul distances (2-4 km) than the wheeled units (5 km or greater). In general, the rubber tracked equipment is the newer equipment although the recent purchase of a ‘new generation’ (50 km h^{-1} + road speeds) tractor by a local harvesting contractor should significantly reduce haulage trip times. The rubber tracked infield units still have some limitations as trailer track life of less than one season has been reported. Improvements in rubber track design will increase life expectance but field testing is required to validate these design changes.

TABLE 18
Size specifications of current infield haulouts used at Condong

Nominal capacity (tonnes)	Nominal volume (m^3)	Number tips per 65 m^3 bin
8	21	3
9	23	2.5
12	28	2
14	31-33	2

Table 18 summaries the nominal bin sizes, mass carried and volume, for similar numbers of infield bin loads to fill a current multi-lift bin. Obviously, the current transport system must have:

- many haulout bins are crown filled to increase capacity from the field
- multi-lift bin filled to varying masses
- and/or highly variable crop densities

The current equipment matching results in a nominal 65 m^3 multi-lift bin being filled by two tips from a 28 m^3, 31 m^3 and 33 m^3 infield bins. Theoretical filling match using current multi-lift bin (assuming burnt cane of 380 kg m^{-3} bulk density) would require infield equipment of:

32.5 m^3 (12.35 t)	2 bin tips
26 m^3 (9.88 t)	2.5 bin tips
21.7 m^3 (8.25 t)	3 bin tips.

Not withstanding this mismatch error, it was assumed that the current burnt cane bulk density is 380 kg m^{-3}.

4.4.2 Vehicle requirements to conform with NSW heavy vehicle regulations

An examination of the differences between NSW and Queensland regulations that apply to road transportation of sugarcane is necessary to fully appreciate the current status of infield haulage vehicles in NSW. The road regulators from both States describe sugarcane as a divisible load and hence haulage operators are required to limit loads through adjusting the amount of material placed in the bin. Application for permits to operate over-mass would not receive favourable consideration.

In 1997, BSES researchers (Robotham and Geddes), together with officers from Queensland Transport, undertook a detailed survey of vehicles used for infield and on-road haulage of sugarcane. The survey examined the range of machinery used to haul sugarcane and their compliance with current regulations[42]. A significant level of vehicle non-compliance was identified mainly in the area of mass limitations. In NSW, a cane haulage vehicle is classified as a heavy vehicle and as such must satisfy the mass and dimension requirements of this vehicle classification[43]. The Queensland cane haulage trailers are defined by legislation and, when equipped with the appropriate tyres, these trailers have allowable axle loadings in excess of the heavy vehicle classification [44].

Two important points pertinent to this review are the levels of non-compliance identified from the Queensland survey and that allowable axle loadings for wheeled cane haulage vehicles in NSW are significantly less than those allowed on similar vehicles in Queensland. As some of the machinery used to haul sugarcane in NSW has been developed and/or manufactured in Queensland, load levels must be significantly lowered to ensure conformity to NSW regulations. An example of a commercially available haulout is the Case Austoft Powerhaul, as used by Brunswick harvesting group. This unit has a single steer front axle and a single rear axle. Both axles have tyres of width greater than 450 mm. Data supplied to this review indicates this machine has a useable loaded mass of about 8 tonnes. Based on Queensland survey data of similar vehicles, this type of vehicle can be legally loaded with up to 8.5 tonnes in Queensland but due to reduced allowable axle loadings can only carry a load of less than 3 tonnes in NSW.

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[42] Geddes, R, Robotham, BG, Berry R and Rieschieck, R. A comparative analysis of vehicles used for road transportation of sugarcane. Proc of ASSCT 20:17-21

[43] Discussions with NSW RTA staff (May, 2000)

[44] Anon. (1994). Information Bulletin. Queensland Transport, VSS .02.0/94.

TABLE 19
Theoretical axle loadings for current wheeled infield haulouts (assuming burnt cane at 380 kg m^{-3} and effective weight transfer of 2 t)

Group	Nominal capacity (t)	Nominal capacity (cu m)	Tips/65 m^3 Bin	Theoretical load (t)	Estimated bin weight (t)	Theoretical axle load (t)
A	12	28	2	11.8	8	17.8*
B	8	21	3	7.8	7.5	13.3
C	8	21	3	7.8	7.5	13.3
D	9	23	2.5	9.4	7.5	14.9*
E1	12	33	2	11.8	8.5	18.3*
E2	8	21	3	7.8	7.5	13.3
F	8	21	3	7.8	7.5	13.3

* indicates vehicle that is non-conforming with respect to axle mass.
(Allowable Mass Limit for tandem axles, 450 mm tyres is 14 tonnes)

The theoretical axle loads produced in Table 19 are based on an assumed effective weight transfer of 2 tonnes for all units. This weight transfer is the expected value for weight transfer hitches of the types examined but actual field weighings of trailed bins would be required before more accurate estimations of axle loadings can be determined. This table shows the nominal 8 tonne bins as the only units that conform to axle mass limits. These units may be only 0.7 tonne below the allowable limit and use of a hitch that does not transfer weight, different construction styles or use of heavier materials could result in bins of higher tare weight than estimated.

TABLE 20
Theoretical axle loadings for current wheeled infield haulouts at varying material bulk densities (assume weight transfer of 2 t)

Group	Axle load (t) @ 0.38 t m^{-3}	Axle load (t) @ 0.3 t m^{-3}	Axle load (t) @ 0.25 t m^{-3}	Axle load (t) @ 0.2 t m^{-3}
A	17.8	15.3	13.7	12.2
B	13.3	11.7	10.7	9.6
C	13.3	11.7	10.7	9.6
D	14.9	12.9	11.7	10.4
E1	18.3	15.8	14.2	12.7
E2	13.3	11.7	10.7	9.6
F	13.3	11.7	10.7	9.6

(Allowable Mass Limit for tandem axles with single 450 mm wide tyres is 14 tonnes)

Table 20 shows that the larger of the current bins using tandem axles will only conform to allowable axle mass limits at a material bulk density of about 0.250 t m^{-3}. The data presented shows that all NSW sugarcane haulage units are mass limited or close to mass limited at the expected range of material bulk densities (0.38-0.250 t m^{-3}). When using tandem axles with 4 tyres of width 450 mm or greater, bins can be constructed of sufficient volumes to exceed allowable axle loadings at material bulk densities greater than 0.250 t m^{-3}.

One solution to the current axle load limitation proposed by several sectors of the industry is the use of triaxle configuration (6 tyres) on the haulout trailers. A triaxle configuration using agricultural tyres (23.1 x 26) would result in a large spacing, in excess of 3.5 m, between the front and rear trailer axles. This axle option has been trialed by one Queensland haulout manufacturer. Stool damage caused during turning of the triaxle trailer was initially determined as a major issue. Damage to the tyre sidewall and/or tyre carcase may also result from excessive side loading on the tyres during turns. The Queensland built machine was designed with one axle, the forward axle, capable of being raised during turning. However, this resulted in the three axles not being load-sharing and hence all the potential allowable axle loads were not granted. This configuration has not be accepted by either growers or harvesting contractors.

Under guidelines of the National Road Transport Commission, a load-sharing triaxle has an allowable mass limit of 18 tonnes when fitted to a pig trailer and 20 tonne when configured as a semi-trailer. Steerable, load-sharing axles, in triaxle and quadaxle configurations, are used overseas on large agricultural effluent distributors. These axle configurations would be essential for large cane haulout vehicles but are very expensive and have yet to be proven in sugarcane haulage. Wheels of a steerable triaxle or quadaxle configuration would encroach on the bin space thus reducing the potential storage volume. This may not be critical as these designs may also be mass limited not volume limited. Advice from RTA NSW would be essential before further consideration be given to these axle configurations. The authors believe the simplicity of the tandem axle configuration and its compatibility with current headland widths will ensure its continued usage with limited adoption of alternative systems.

The use of rubber tracks on infield sugarcane haulage vehicles is a relatively new development. Public road use of rubber tracks is important, as their interaction with paved roads is significantly different to that of high flotation, low pressure tyres or high pressure, truck or industrial tyres. After considerable lobbying by state-based, sugar industry bodies, Queensland Transport has set a maximum allowable load for rubber tracked cane haulage vehicles of 28 tonnes (per track pair). This load is based on allowable bridge loadings. This loading is less than the manufacturers maximum allowable loading of 31.75 t (70 000 lbs for Caterpillar VFS-70 tracks as used on sugarcane haulouts).

Discussions with representatives of NSW Road Transport Authority and a NSW sugarcane haulout manufacturer, Mr Barry McLean, have indicated that a maximum allowable loading for public road usage of rubber tracks in NSW have not been determined. To date, compliance requirements of cane bins equipped with rubber tracked vehicles in NSW has been restricted to issues of dimensions, brakes and lights. As RTA NSW regulations do not allow concessional axle loadings for wheeled sugarcane haulouts fitted with high flotation, low pressure tyres, it is realistic to assume a maximum allowable pavement load for rubber tracks of significantly less than the 28 tonnes allowed in Queensland. An allowable pavement load of 24 tonnes is assumed for calculation purposes within this report.

The operation of over-dimension vehicles, particularly over-width, under permit is not considered a viable option. Width is a critical road dimension and discussions with RTA representatives have indicated that continuous operation of over-width cane haulout vehicles of public roads will not be permitted. Due to this limitation, the concept of a wide axle (spanning two rows) haulout was not pursed further.

This review has not attempted to undertake a detailed study of the axle loadings of current infield haulage vehicles in the Condong Mill area but based on machine weights supplied by manufacturers and haulout owners, a significant number of infield haulouts appear to be non-compliant with respect to axle loadings. Any modification to the trailer or bin to increase bin volume and/or to increase unloading height may increase vehicle tare weight and hence adversely impact on load carrying capability. BSES have recently purchased 4 electronic vehicles load scales similar to those used by state road regulators. A program of in field weighing of current haulouts during the harvest period would more accurately determine the level of vehicle mass compliance.

4.4.3 Field factors affecting harvest and haulage efficiency

Field efficiency of harvesting equipment can be calculated as the percentage of total operating time that the machine is achieving it's "target" output. In the case of sugar cane harvesting, the "target" output is the "steady state" operating speed and is primarily determined by crop conditions. The percentage of available time the harvester is achieving its target output is primarily determined by time lost:

- turning at end of rows
- waiting for haulouts to take the harvested crop from the harvester
- "cutting in" to new fields where harvesting rate is slow because the harvester reverse tows the haulouts into the field

Time lost turning obviously relates to both the time taken for the harvester and haulout to turn at the end of the row and achieve correct positioning to allow the harvesting process to re-commence. It is therefore effected by:

- manoeuvrability of the harvester and haulouts
- available space for this manoeuvring (headland width)
- length of row and crop size, therefore effecting the number of turns which must be executed in a days allocated harvested cutting

Time lost waiting for haulouts relates to haulout capacity, speed of travel to the pad, unloading time and return time to near the harvester. This is therefore effected by:

- haulout speed, loaded and unloaded on both field headlands and formed roads
- distance to the pad
- unloading time at the pad

The Condong Mill area has a mix of conditions under which the harvesting operation must be undertaken. A percentage of most harvests are undertaken in wet conditions.

Field drainage is essential for sugarcane production in northern NSW and open surface drains are the most commonly used system. The widespread use of drains has produced small paddock sizes. Data supplied by Condong Mill indicates 34% of the paddocks are less than one hectare and 72% are less than two hectares (see Figure 13). The large number of drains and water furrows surrounding paddocks has resulted in small headlands (4 m or less) with manoeuvrability limitations for infield haulouts. This is further exacerbated by the practice of the harvester only cutting on one face of the crop in a paddock. Under this harvesting system, all end turns of the harvester and the haulouts are very tight as machines must return on the adjacent row.

The drainage layout can also increase haul times as the absence of conveniently located culverts prohibits vehicles taking the shortest direct route to the pad. Several harvesting groups cited improved location of pads as one method of improving harvesting efficiency. The practice of using pads as temporary storage of full multi-lift bin was also believed to be as a constraint to improving harvesting efficiency. When all bins on a pad are filled, loaded haulouts must travel increased haul distances to access empty bins on adjacent pads. Harvesting groups believed these increased haul distances could significantly reduce harvesting rates.

The small and sometimes irregularly shaped paddocks require reverse driving of the haulouts to prevent consuming significant amounts of time turning. One contractor stated 20% of paddocks had significant components of reverse filling.

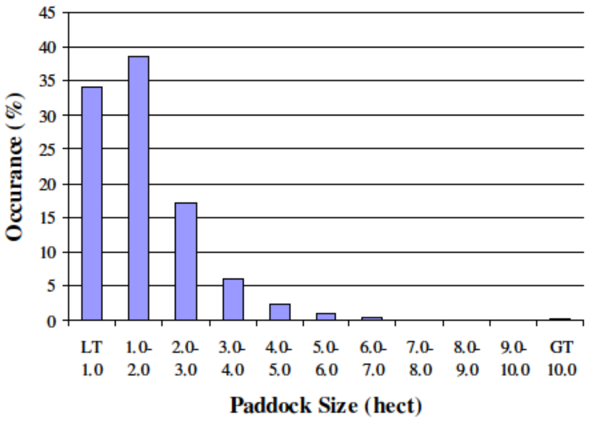

Figure 22 - Paddock size distribution for Condong Mill area

Paddock area data, similar to that shown in Figure 22, could not be obtained for the other NSW mill areas but discussions with Mr Ian Allan of Broadwater Mill, indicated the Condong area had the greatest number of small paddocks. The older Broadwater farms have paddocks in the 3 to 4 hectares while newer farms have 8 to 20 hectare paddocks. The largest paddocks in the Broadwater area are about 33 hectare.

When initially 'breaking into' a block of cane, reverse towing of the infield haulout with the harvester is commonly practiced. Under dry conditions, some harvester and haulout operators initially drive over the unharvested cane and then attempt to harvest this cane during subsequent passes. Due to the small paddock sizes, reverse towing of the haulout may be undertaken frequently. It is interesting to note that the practice on reverse end towing of haulouts by the harvester is not widely practiced in the other two NSW mill areas.

Representatives from all harvesting groups considered the B-double concept to be inappropriate for the current Condong cropping system. Perceived limitations discussed included:

- reduced manoeuvrability compared to present equipment (reversing on headlands and at the pad)
- inability to reverse fill
- inability to reverse tow when breaking into a block

Soil compaction was seen as an important issue but crop row spacing and the matching of machinery track widths was not viewed as the most practical solution. Improved vehicle flotation and the use of low ground pressure systems such as rubber tracks were the most commonly expressed solutions. Most harvesters and haulouts have track widths of 1.88–1.95 m. Crop row spacings as close as 1 270 mm (4'2") were reputedly used by some growers with 1 470 mm (4'10") considered an acceptable row spacing. The effects on row and machinery track mismatch are shown in Appendix 5.

4.4.4 Proposed multi-lift bin options

Multi-lift bin - option 1

This option considers the use of 95 m^3 multi-lift bins with no compaction of cane/trash mixture, either infield or at the pad.

Current 65 m^3 multi-lift bin tare mass = 3.8 t
Pro-rata mass for 95 m^3 bin = 5.5 t

Assuming the current bins are over-designed with respect to strength weight savings can be made through re-engineering of the bin design[45]. Weight saving could be in the range of 10–20%.

New 95 m^3 multi-lift bin tare mass = 4.5 t (5 t)

New trailers with dual tyres and air bag suspension have tare weight 1 tonne lower than original trailers (triaxle 12 tyres, 20 t mass limit)

Load carried by 65 m^3 multi-lift bin using old trailers = 23.5 t

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[45] Graham Dimes, Broadwater Mill *per coms* B Robotham

Therefore, load carried by 95 m^3 multi-lift bin using new trailer = 23.8 t (assume 23.75 t) (air bag type-1 tonne lighter)

To fill a 95 m^3 multi-lift bin with the required load of 23.75 t requires matching with material of a 250 kg m^{-3} bulk density. Infield bins to match the current 2, 2.5 and 3 tip scenarios will require volumes of 47.5 m^3, 38 m^3 and 32 m^3. This bin has a side height of 3.225 m.

Multi-lift bin - option 2

This option considers the use of 82 m^3 multi-lift bins with no compaction of material either infield or at the pad. A 82 m^3 bin comprises of the current 64.4 m^3 bin with about 700 mm height extensions. The effective unloading height for the infield haulouts would be 3.6 m.

Current 65 m^3 multi-lift bin tare mass = 3.8 t
Pro-rata mass for 82 m^3 bin = 4.8 t

The addition of height extensions or ‘hungry boards’ that are structurally sound is considered inefficient use of materials and hence a pro-rata mass increase is a reasonable assumption.

Load carried by 82 m^3 multi-lift bin using new trailer = 23.5 t

To fill a 82 m^3 multi-lift bin with a load of 23.5 t requires material with a bulk density of 286 kg m^{-3}. For a material bulk density of 300 kg m^{-3}, the multi-lift bin volume of 78 m^3 would achieve the required mass loading. Trials to date indicate that shredding on the harvester may achieve bulk densities within this range. Infield bin volumes to match the current 2, 2.5 and 3 tips will be 38 $m^{3,}$ 31 m^3 and 26 m^3.

Options considered but rejected

Using the current 65 m^3 multi-lift bins and compacting cane/trash mixture to a bulk density of about 365 kg m^{-3} was not considered a viable option. Reasons for rejecting this option include:

- the inability to achieve this bulk density under field conditions;
- the need for compacting machine either on-board multi-lift bin (additional tare weight) or discrete machine (requires separate operator and must be easily transportable from multi-lift bin to multi-lift bin and pad to pad);
- unloading problems and mismatch in volumes between infield bins and multi-lift bin (assume infield bin filled with material of lower bulk density (around 250 kg m^{-3});
- the capability to compact in the infield units would greatly increase the units tare weight and hence reduce the load carried. Discussions with operators suggested potential unloading problems due to ‘plug flow’ of the compacted material if tipping type unloading systems are used.

The options of separate multi-lift bins for cane and trash or a split cane and trash multi-lift bin were also rejected as impractical as:

- directing cane and trash into separate bins or separate areas within one bin would be unacceptable in the field;
- dividing the bin area would increase tare weight and hence reduce load carrying capacity;
- emptying a divided bin would require additional flaps or covers and hence increase tare weight;
- separate cane and trash infield bins and multi-lift bins would cause major logistical problems both in the field and at the pad.

Several alternate materials handling systems were considered such as the German, Fliegl Machinen Gigant push-off trailer (see Appendix 3). Whilst of interest, such units require a complete change in the materials handling equipment as they were not compatible with the current multi-lift bins. High capital cost and potentially greater unloading times were additional reasons for rejecting this option.

4.5 Liaise with equipment manufacturers to determine the viability and cost of:

(a) Modifying existing units to carry the increased volume
(b) Designing and building new large capacity units

The size of multi-lift bin used determines the size options of infield tipping bins to be used. All infield bins used in the Condong Mill area utilise side tipping unloading. These bins are used because of:

- speed of unloading (about 1 minute to unload)
- simple design
- low maintenance

Discussions with operators involved in shredding trials and with experience with other crops such as corn silage indicated side tipping bins to be the preferred unloading system option for the cane/trash mixture. Experience of BSES in northern Queensland indicates that bins with elevating conveyor unloading systems cannot easily handle cane with high trash levels. Tipping bins for cane/trash mixtures may require increased side/floor angles when tipped to ensure complete emptying. Times to empty are assumed to increase as more care may be required when unloading to prevent uneven filling of the multi-lift bins. Material may tend to ‘plug flow’ at high trash levels.

(a) Modifying existing units to carry the increased volume

Required modifications would include:

- increase tipping height from 2.9 m to 3.6 m (82 m^3 bin) 3.225 m (95 m^3 bin)
- increase bin volumes as required

A high lift bin option is currently available to fill road trailer bins, such as used in the Maryborough region. A number of surplus infield units from northern NSW have been re-worked and sold into this area. This market is limited and the current sugar price dictates that sales would only occur at the lower end of the market. Discussions with Mr Barry McLean, of McLean Agquip Pty Ltd, have questioned the economic viability of undertaking this modification. A commercial high lift option has a tipping height of about 4 m. When retrofitted to a current haulout, this option costs about \$10 000 and could add about 0.5 t to the tare weight of the trailer. Changing the end frames on the trailers and reusing the current lift cylinders would achieve a tipping height of about 3.05 m. Hence, increasing the lift height of the current bin fleet to suit the proposed 95 m^3 multi-lift bin will cost in excess of \$10 000 per unit.

Limited sales of surplus high flotation equipment have also occurred into the Mackay region but problems exist with the mis-match of the tipping bins to the 5-6 tonne rail bins used in that region. Three-year old, ex-NSW, 8 t side tipping bins have previously sold for about \$35 000 but the current market indications have reduced prices to the \$12 000-\$17 000 range maximum. Representatives from several harvesting groups estimated the disposal value of their current equipment at the sale value of the tractors alone.

The estimated axle loads of infield haulouts calculated in Table 20 indicates that additional data must be obtained before modifications to increase bin volumes are attempted. The program of vehicle weighing, as recommended in this report, would more accurately determine current axle loadings and hence the potential to increase bin volumes. The conformity of current 12 t nominal capacity, haulout bins is questionable and hence major structural modifications may be counterproductive due to the increase in tare weight. The wheeled unit designated E1 in Table 20, is an example of the upper load limit of wheeled haulout units. The smaller units of 21-23 m^3 volume would require modification to 26 m^3, 32 m^3 or 34 m^3 sizes. Increasing the bin volumes to the 26 m^3 may be mechanically feasible but this is part of the non-preferred B-double option. Altering bin volumes from 21-23 m^3 bins to 32 m^3 or 34 m^3 capacity is of questionable economics. Estimates of the conversion costs ranged \$40 000 to \$55 000 with a new unit costing about \$70 000. The smaller volume unit would have the greatest modification costs.

(b) Designing and building new large capacity units

This option was favoured by the majority of harvesting groups and, not unexpectedly, by the machinery manufacturers. The consultants have determined all the options listed and, for simplicity, these were the only options considered. The principals of McLean Agquip Pty Ltd and EHS Manufacturing Pty Ltd have however, reviewed these options and no additional configurations were suggested. Use of these manufacturers does not imply the exclusion of other manufacturers. The assistance of McLean Agquip Pty Ltd and EHS Manufacturing Pty Ltd, Mr Brian Cantrell, Omnitrac Australia, Hasting Deering Pty Ltd in preparing these options, is greatly appreciated.

Option 1 - Number of trips by infield bins remains the same for cane/trash as for current burnt cane when harvesting a given area.

- increased volume (182%) and mass increased (20%) per infield bin compared to burnt cane

Option 2 - Same bin capacity in tonnes but increased volume (20% more field trips)

- 50% increase in volume, same mass per infield bin compared to burnt cane

Option 3 - Current volume bins and the use of additional haulout(s)/trips (82% more trips)

- current volume, mass per bin decreases by 34%

Assume:

- 0.250 t m^{-3} material density in bin (66% reduction in bulk density compared to burnt cane with 6% EM – 0.38 t m^{-3})
- 20% addition mass of material (cane/trash mixture)
- current 65 m^3 multi-lift bins will be replaced by 95 m^3 multi-lift bins (Note: to correctly match the current road transport system – same number of multi-lift truck trips as currently would require multi-lift bins of approximately 118 m^3)
- increased unloading time (Present units with burnt cane have an unloading time of 1 minute. The estimated unloading time with whole-cane is 1.5 minutes or greater depending on the haulout option.)
- 3 current tipping options of 2, 2.5 and 3 infield bin tips per multi-lift are considered.

(Volumes rounded up to nearest 0.5 m^3, mass rounded up to nearest 0.5 t)

The number of acceptable configurations to carry cane/trash mixture was reduced due to most current NSW sugarcane haulouts being mass limited. Option 1 involved keeping the number of haul trips per area harvested the same for both burnt and cane/trash mixture. The load carrying capacity of infield haulage units would have to increase by 20% to satisfy these criteria. This is not practical due to the axle load limitations, previously discussed. Hence Option 1 was discarded.

Option 2 is only appropriate for wheeled haulouts of smaller bin volumes and assumes minimal increases in tare mass due to increases in bin volume and tipping height. This option would only be acceptable if sound engineering design were applied to the new bin and trailer designs. The current conformity of the wheeled haulout bins of 12 t nominal capacity to mass guidelines is questionable and hence any major modifications, with the load mass remaining constant, could be counterproductive due to the resulting increase in tare weight. The status of this option with respect to rubber tracked haulouts must be clarified before design concepts are developed further.

Option 3 may appear the simplest solution, but the current infield bins will not tip high enough to fill the proposed 95 m^3 multi-lift bin. The discussion used in Section 4.5 (a) then applies. Modification of the existing infield units to increase the tipping height but with no increase in bin volume could be an expensive option with questionable long-term benefits. In situations where two infield units are currently used, one additional infield unit of similar volume is a 50% increase in haulage volume. However as the total volume of material per unit area has increased by 82%, a fourth infield unit would be required to ensure harvesting rate was not reduced due to haulout capacity.

All haulout equipment considered is based on modern equipment and an amount of re-engineering to improve current designs would be incorporated, where possible. Additional methods of vehicle tare reduction through the use of alternate materials (aluminium and plastics) should be examined for future haulouts. Steel is currently the preferred construction material as it can be readily repaired or altered without special equipment.

All haulout options include load sharing hitches, split flipper rollers (for controlled unloading), load weighing cells, and ADR specification braking and lighting systems. Load cells on all infield haulout bins are essential to enable loads and hence density of the harvested product to be continuously monitored. Due to the mass limitations, it would be possible to exceed allowable pavement masses by filling the infield bin with material of a bulk density greater than 0.250 t m^{-3}.

Manoeuvrability of the haulout options is a function of hitch design, pull and axle geometry, tyre size, tyre spacing, turning circle of towing vehicle and field factors. Pull geometry has the greatest effect ability to turn. Considerable variation exists in the designs of pulls on the equipment currently used in the Condong Mill area. A superior pull design has been used on the trailed, wheeled bin manufactured by Mr N Morrin. The use of this gooseneck design enables the tractor rotate about 140^0 on the turning pivot point. With most other designs, interference between the pull frame and the tractor tyres or tracks restricts turning ability. Add-on features such as steerable pulls can also improve vehicle manoeuvrability but are as yet not commonly used in the sugar industry. Because of these factors, comments on the manoeuvrability of the haulout option are limited to better, similar or worse than current equipment.

For all vehicle options, operating speeds on headlands and on roadways were determined for both the loaded and the unloaded states. Speeds for the 0.75 km, 2 km and 5 km trips were calculated as composite headland and road travel. Table 23 details the derived speeds for the different haulout options.

Rubber tracked vehicle options

Burnt cane tracked option (T33)

Largest rubber tracked trailed bin currently in use is a 33 m^3 unit owned by Central Tweed harvesting group. For the purposes of identification, this bin arrangement is coded T33 in the costing analysis.

Bin tare mass = 11 t (10 t + 1 t weight transfer)
(nominal 33 m^3 crowned fill – manufacturers specification)
laden with 14 t cane (manufacturers specification) = 23.5 t + 2.5 t (weight transfer)

calculated cane density = 424 kg m^{-3} (unrealistically high cane density)
assuming cane density = 380 kg m^{-3}
Mass carried = 12.5 t (nominal 33 m^3 crowned fill)

Estimated Capital Costs:

Rubber tracked Tractor	=	$213 500
Trailed bin	=	$135 000
Total Cost	=	$348 500

Turning time	1.5 minutes
Unloading time	1 minute

For the optimised green cane harvesting system, it is assumed this bin can be manufactures in a capacity of 35 m^3 for the same price as the 33 m^3 units. Similarly, for the shredded cane option, it is assumed that the capacity can be expanded to 40 m^3 for no increase in cost.

Whole-cane tracked option 1 (T47)

Rubber tracked tractor and rubber tracked trailer (volume matched to fill multi-lift bin)
2 bin tips to fill 95 m^3 multi-lift bin.

Therefore infield bin volume = 47.5 m^3
Load carried (assuming crown fill) = 12.5 t

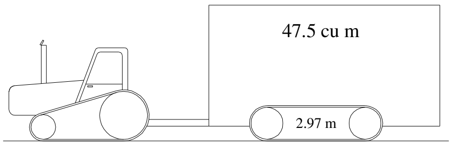

Figure 23 – Rubber tracked tractor and rubber tracked trailer

This option would involve an increase in bin volume of 14.5 m^3 with no increase in load carried. Increase in volume will be achieved by increasing bin height (from the current 3.35 m to 4.3 m, the maximum allowable) and bin length. Using the current McLean type side-tipping bin as an example, a bin length of 7.0 m (1.2 m increase) and height of 4.1 m (0.75 m increase) will result in a level fill volume of 47 m^3. The current width of 2.5 m, outside dimension, would not be altered. This trailed bin would have track pavement loading of about 24 tonnes, which is assumed the maximum load to be allowed by NSW RTA. RTA approval of this configuration must be obtained. Haulout operators and the manufacturers considered this bin size acceptable but have questioned the use of bins of greater volume. As the maximum allowable height for road usage is 4.3 m, there are many combinations of length and height increases that will fulfil this required volume.

Estimated bin tare mass = 11.75 t (manufacturers estimate)
Estimated total mass (laden) = 24.25 t (rubber track allowable loading not known)

Estimated Capital Costs:

Rubber tracked Tractor	=	\$213 500
Trailed bin	=	\$148 500
Total Cost	=	\$362 000

Turning time	1.5 minutes
Unloading time	1.5 minutes

This bin carries the same mass as the largest current tracked bin. Bin dimensions are larger but track type, pull geometry and prime mover would all be similar to the current tracked bin system. Hence the manoeuvrability of this option would be similar to the current 32 m^3 trailer bin combination.

(Note: Changes to allowable pavement loadings may result in this combination not conforming to RTA requirements.)

Whole-cane tracked option 2 (T64)

This option comprises of a rubber tracked self-propelled buggy with rubber tracked trailer. Several quotations for this combination were obtained. Two involved new components and one was based on a proposal to rework components from surplus Caterpillar Challenger 65 tractors (see appendix). The lowest cost of the new component was used in this estimate. The units would have tracks on both the prime mover and the trailer. On the Caterpillar Challenger 65 option, the size of the prime mover bin would be limited by the space requirements of the engine and manual transmission but a satisfactory tip match was still achievable.

The concept of a quad-track infield buggy was not pursued due to industry recommendations of excessive cost due to the requirement of four powered rubber track systems. Discussions have indicated that the quad-track concept as used on large broadacre tractors is not as yet fully proven in the field.[46]

The track length of Caterpillar Challenger 65 is 2.72 m centre to centre of track rollers which is slightly shorter than the currently used Caterpillar VFS 70 rubber track system (2.97 m). Replacement tracks would enable the track length to be increased.

Assuming 1.5 infield vehicle loads (3 separate bin loads) to fill 95 m^3 multi-lift bin and 2 equal sized bin (nominal 32m^3 capacity per vehicle.

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[46] Simon Zillman, CNH *per coms* B Robotham

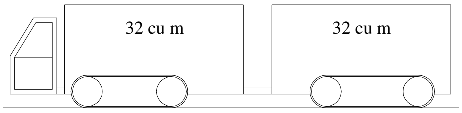

Figure 24 – Rubber tracked self-propelled unit with rubber tracked trailer

Therefore total infield bin volume = 2 x 32 m^3
Load carried = 2 x 8 t (16 t)

Estimated Cost:

Prime mover = $379 000
Trailed bin = $132 500
Total Cost = $1 023 000

Turning time 2 minutes
Unloading time 3 minutes

This rubber tracked infield transporter is a new concept for the sugar industry. Assuming appropriate track length is used, this machine is similar to Option 1 but with a greater mass on the prime mover. Selection of a rubber track drive system without the traction limitations of the current rubber tracked tractors may improve the manoeuvrability of this option. If used with the current rubber tracked system, manoeuvrability would be similar or perhaps slightly worst than the current system. Manoeuvrability limitations, particularly relating to steering the Caterpillar Challengers, were mentioned in discussions with several harvesting groups.

(Note: Changes to allowable pavement loadings may result in this combination not conforming to RTA requirements.)

Wheeled Infield Haulage Options

Burnt cane wheeled system (W21)

The “standard” wheeled haulout is considered to be a “standard” FWA agricultural tractor towing a trailed bin using a tandem axle with a 4 tyre configuration (tyres 23.1 x 26 or similar width greater than 450 mm). This allows a maximum axle load of 14 tonnes. After allowing for weight transfer, this design will typically allow a gross payload of 8 tonnes. The basket size will typically be 21-23m^3**.** For purposes of identification, this option is coded as W21, W23, etc.

Estimated Costs:

Tractor = $162 500
Trailer = $85 000
Total Cost = $247 5500

Turning time	1.5 minutes
Unloading time	1 minute

Whole-cane wheeled option 1 (W32)

A modern, high speed agricultural tractor with 50 km h^{-1} speed capability is used to tow a single, side tipping bin. The trailed bin uses a tandem axle with a 4 tyre configuration (tyres 23.1 x 26 or similar width greater than 450 mm) to allow a maximum axle load of 14 tonnes.

The bin has a tipping height in excess of 3.225 m for use with proposed 95 m^3 multi-lift bins. Three bin tips will be required to fill the 95 m^3 multi-lift bin.

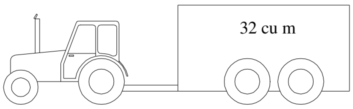

Figure 25 – Wheeled tractor with wheeled trailed bin

Estimated Costs:

Tractor = $185 500
Trailer = $85 000
Total Cost = $270 500

Turning time	1 minutes
Unloading time	1.5 minutes

This unit is identical to a trailed bin currently used in the Condong Mill area. This vehicle is of particular interest as the hitch and pull design allow considerably more turning movement than other designs. Future machine should included as much of this design as is possible. The only modification required would be to increase lift/tipping height to suit the proposed 95 m^3 multi-lift bin. Vehicle length and manoeuvrability would be as per the current machine.

(Calculations, based on trailer tare weights supplied to the authors, indicate the use of material with a bulk density greater than 0.250 t m^{-3} will result in this trailer configuration exceeding allowable axle loadings.)

Whole-cane wheeled option 2 (WBD64)

An agricultural tractor with 50 km h^{-1} speed capability would tow a B-double trailer configuration. Each trailer would use similar tyre configurations as in Option 1. The rear trailer uses a turntable similar to that used on a semi-trailer. Careful design will ensure both trailers track quite accurately to the wheel marks of the tractor. Most B-double configurations result in the rear trailer tyres running just outside the prime mover tyre tracks. Weight transfer considerations result in the different trailer bin sizes front and rear, with a total volume of 60 m^3.

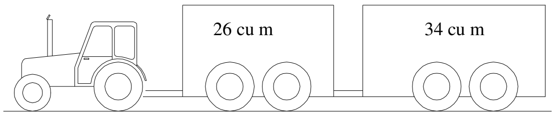

Figure 26 – Tractor and B-double trailer configuration

Estimated costs:

Tractor = $195 100
Front Trailer = $82 000
Rear Trailer = $85 000
Total cost = $362 100

Turning time	2.5 minutes
Unloading time	4 minutes

All harvesting groups considered this option to be inappropriate for the Condong area. Areas of criticism included:

- the inability to end tow when ‘breaking in’
- difficulty to reverse when turning on headlands
- the inability to reverse fill

All criticism of this configuration was related to manoeuvrability limitations. Of all the options, the B-double configuration is the least manoeuvrable. Tracking of the second trailer would depend on the position of the pivot point on the first trailer and the pull geometry of the second trailer. The second trailer on most B-doubles usually tracks just inside the track of the first trailer. Software is available from transport authorities to calculate vehicle swept paths. When used in conjunction with certain CAD programs, the effect of altering pivot point positions can be determined.

The concept was, however, considered acceptable in mill areas with large paddocks and without obstructions. Regions such as Broadwater may be suitable and the large paddocks of the Burdekin Irrigation Area would be worthy of consideration.

Whole-cane wheeled option 3 (WSP64)

This option comprises of a self-propelled prime mover with 32 m bin and trailed bin of similar volume. This option is based on a machine similar to a lightened version of a Case Austoft Maxi-Haul or the Cantrell or Greaves type haulout.

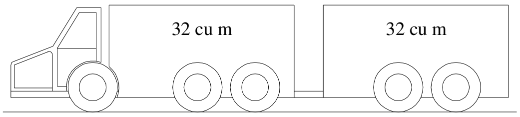

Figure 27 – Wheeled self-propelled with wheeled trailed bin

Estimated costs:

Prime mover and bin = $250 500
Trailed bin = $85 000
Total cost = $335 500

Turning time	2 minutes
Unloading time	3 minutes

Other considerations: A significantly greater unloading time has been allowed for positioning and unloading this double bin unit.

This configuration was quite well accepted by most harvesting groups. Tracking of the trailer would depend on the position of the pivot point on the prime mover and the pull geometry of the second trailer. The software previously mentioned would assist in determining vehicle swept paths. This vehicle option is not suitable for reverse filling or end towing when breaking into a block. Removing the trailer when undertaking these operations is an operational option but this appeared to unacceptable too most harvesting groups.

4.6 Compare the capital and operating costs of the current burnt cane harvesting systems with whole-cane harvesting systems incorporating:

- extra units of current design
- large capacity infield units

4.6.1 Methodology and assumptions

The basis of this comparison is the full cost of selected options. Each option is considered as a discrete operating system.

This section uses information obtained from harvesting groups in the Condong Mill area, as well as other industry data on harvest and transport costs, as inputs to the BSES Harvest and Transport Model. Although this is a relatively simplistic model, the outputs of the model have been demonstrated to be "close to reality" and are suitable for comparative purposes. Inputs to the model are based on:

- data on machine performance, cost, etc generated in this report
- discussions between the authors and members of different Condong harvesting groups
- data on harvesting costs supplied by MSWMC

On the basis of available data, assumptions made for inclusion in the model can be categorised as:

Capital and amortised (fixed) costs:

As the basis of this comparison is the full cost of selected options, each option is considered as a discrete operating system. Transition to that system has not been considered.

For the purposes of this exercise, the comparative costings contained herein are instead based on the assumption that all potential harvesting system options, including burnt cane, green cane and whole-cane options are to be financed in the same way.

All groups using wheeled haulouts will incur additional outlay due to the requirement of purchasing a steel tracked infield unit to ensure wet weather harvesting capability. This steel tracked unit has an assumed cost of $ 225 000. This costing assumes the unit to be manufactured using some second hand components.

The costings also assume that the capital requirement is funded by debt through a secured loan at an interest rate of 10%. Discussions with the different harvesting groups, indicated life expectancies of about 5 years for a harvester, 7 years for a haulout tractor and a somewhat longer life than this for the haulout trailer. For simplicity, a life of 7.5 years has been chosen for all haulout systems.

Based on these estimated life expectancies, the annualised amortisation is expressed on a per tonne of burnt cane basis, assuming 70 000 tonnes of burnt cane equivalent is each case. The unit amortisation per tonne cane will obviously vary with group size.

Season length:

Costings are calculated for a 175 day season length with the harvester operating for six out of seven days. This equates to 150 harvesting days for the exercise.

Wages and fuel:

- Infield drivers are paid award wages of $11.34 per hour for ordinary time based on a 38 hour week. Normal overtime rates apply. They are employed only during the crush.

- The harvester driver is a full time employee retained for pre-season maintenance. His corresponding hourly rate is $14.50 per hour for ordinary time, with normal overtime rates applying.

- Superannuation post July 1, 2000 is set at 8% on ordinary time. Annual leave loading of 17.5% for 4 weeks applies to the harvester driver. Workers compensation is included at 11% on total wages. An additional 2 hours per day per person in excess of actual harvesting time is included for fuel, servicing and lunch breaks.

- The net cost of diesel is included at 37 cents per litre.

Group size and product composition:

All costings are based on a base case for a group size of 70 000 tonnes of burnt cane equivalent, with a bulk density of 0.38 t m^{-3}. All costs for the cane/trash mixtures are presented as cost per tonne of cane burnt equivalent for ease of comparison. The relative compositions of burnt cane, green harvested cane and whole-cane are presented in Table 21. All calculations and outputs of the model are based on “burnt cane equivalent”.

TABLE 21
Relative product compositions and bin capacities

Product	Assumed EM %	Assumed density t m^{-3}	Nominal bin capacity, m^{-3}	Total payload tonnes	Burnt cane equivalent tonnes
Burnt Cane	6	380	21(Wheeled) 32 (Tracked)	8.0 12.0	8.0 12.0
Green cane	12	340	34 (Tracked)	12	11.25
Whole-cane	25	250	23 (Wheeled) 32 (Wheeled & Tracked) 47 (Tracked) 64 (Wheeled & Tracked)	5.8 8.0 12.5 16	4.7 6.5 10 12.8
Shredded trash and cane	25	300	40 (Tracked)	12	10

Harvester performance and cost:

- Harvester performance details (fuel usage/h, potential pour rates etc) are determined in section 4.3. and summarised in Table 22. It is assumed that the pour rates achieved on a day to day basis are 90% of the "nominal" or maximum pour rates.

TABLE 22
Harvester performance assumptions used in H&T model

Harvest Scenario	100 t/ha crop		150 t/ha crop	
	Fuel L/h	Pour rate t/h	Fuel L/h	Pour rate t/h
Burnt cane	46	121	46	131
Green cane	66	100	66	81
Whole-cane	47.5	121	51	131
Shredded trash and cane	74	74	74	66

- The cost of equipment is the replacement cost. Current replacement cost of a tracked harvester is approximately \$500 000. The additional cost of basecutter height control and guidance, the "optional fitting" of a high capacity elevator and optional fitting of five blade chopper drums are assumed to be \$20 000. It is assumed that modified gathering spirals, and modifications to the feedtrain motor sizings are no-cost options.

- It is assumed the shredder would cost an additional \$15 000. This is believed to be a conservative estimate. The cost of the primary and secondary extractor systems is approximately 25% of the cost of a harvester[47].

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[47] Stiff, R.A. Austoft internal documents.

Haulout specifications and assumed haul distances:

- The generic haulout options are described in section 4.3. Some leeway in actual capacity is assumed in the various model runs for different cane options so that the optimised multi-lift capacity is a multiple of the haulout capacity.

- Haul or cart distances of 0.75, 2 and 5 kms, each way, were examined. Haul speeds are dependant on vehicle type and the quality of roadway/headland surface. The model does not differentiate between headland and roadway travel, however the estimated travel speed is derived and input into the model. Key assumptions include:

  - The 0.75 km was assumed to comprise of 50% headland travel and 50% road travel. The other distances comprised of 0.5 km of 'headland travel' each way and the rest of the trip on good quality roadways.

  - The actual speeds achieved in each "leg" of the haul cycle will therefore be a function of the maximum speed on both the headland and the roadway, and the time involved in acceleration, braking and turning.

Table 23 details the assumptions made and the calculated speed for each haul leg for different machines and different haul distances.

TABLE 23
Derived speed assumptions for different haulout options

Haulout Configuration	Loaded Speed km/h					Unloaded Speed km/h				
	Headland	Roadway	Derived aggregate speed			Headland	Roadway	Derived aggregate speed		
			0.75 km	2 km	5 km			0.75 km	2 km	5 km
T31.7_Challenger	20	25	22.5	23.8	24.5	20	28	24	26	27.2
T31.7_Challenger WC	20	25	22.5	23.8	24.5	20	28	24	26	27.2
T47.5 Challenger	20	25	22.5	23.8	24.5	20	28	24	26	27.2
TSP63.3 (CH 75)	20	25	22.5	23.8	24.5	20	28	24	26	27.2
W21/23.5_FWA	20	30	25	27.5	29	25	38	31.5	34.75	36.7
W21/23.5_FWA_WC	20	35	27.5	31.25	33.5	25	38	31.5	34.75	36.7
W31.7_FWA_HT	25	40	32.5	36.25	38.5	30	48	39	43.5	46.2
WBD63.3_FWA_HT	20	30	25	27.5	29	25	42	33.5	37.75	40.3
WSP63.3 (MX HL)	25	40	32.5	36.25	38.5	30	48	39	43.5	46.2

Assumptions for determining haulout operating speeds include:

- ~~0~~ All tracked units are assumed to have maximum speeds of 32 km h^{-1} unloaded and 25 km h^{-1} loaded on good roadways and 20 km h^{-1} on headlands.

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- ~~0~~ The wheeled base case, the haul tractor is assumed to have maximum road speeds of 40 km h^{-1} unloaded and 30 km h^{-1} loaded, with headland speeds of 20 km h^{-1}.

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- ~~0~~Newer haul type tractors (FWA_H, as used in the whole-cane scenarios) are fitted with front axle suspension and high speed gearbox ratios, and are assumed to have unloaded speeds of 50 km h^{-1} and 35 km h^{-1} loaded, and 25 km h^{-1} on headlands. In the 'B-Double' configuration, these speeds are reduced to 45 and 30 km h^{-1} respectively.

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- ~~0~~The Wheeled, Self Propelled units (WSP) units are assumed to have speeds similar to the FWA_H unit.

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- The row length is assumed to be 350 m in all cases, as being generally representative of the district. Whilst a tracked harvester typically takes less than 45 seconds to turn, the rate determining procedure is the time taken for the haulout to exit the field and re-enter on the correct row. This ranges from 1.5 minutes to 3 minutes for the haulout options studied in this exercise (see Table 24).

TABLE 24
End of row turn times and pad unloading times – various haulout options

Haulout system	Turning time minutes	Unloading time minutes
T31.7_Challenger	1.5	Burnt cane 1.0 Whole-cane 1.5
T47.5 Challenger	1.5	1.5
TSP63.3 (CH 75)	2.0	3.0
W21/23.5_FWA	1.5	1.5
W21/23.5_FWA_WC	1.5	1.5
W31.7_FWA_HT	1.5	1.5
WBD63.3_FWA_HT	2.5	4.0
WSP63.3 (MX HL)	2.0	3.0

- Assumed unloading times based the number of bins and the manoeuvrability of equipment used. Current single bin units transporting burnt cane are reported to have an unloading time of 1 minute. Whole-cane haulage is assumed to increase single bin unloading time to 1.5 minutes.

- Haulout fuel-consumption is determined from estimated maximum fuel flow, estimated fuel flow under "gear up-throttle back" part load conditions and an estimate of engine load during each component of the haulout cycle. Details of fuel consumption estimates for the various haulout options are given in Table 25.

TABLE 25
Estimated fuel consumption - different haulout options

Haulout System	Maximum Speed km/h	Maximum Power (kW)	Maximum Fuel Consp'n L/h	Minimum Fuel Consp'n L/h	Estimated Cycle Fuel Consp'n L/h
T31.7_Challenger	32	180	43	10	26
T31.7_Challenger WC	32	180	43	10	26
T47.5 Challenger	32	180	43	10	26
TSP63.3 (CH 75)	32	260	63	16	36
W21/23.5_FWA	40	130	32	8	16
W21/23.5_FWA_WC	40	130	32	8	16
W31.7_FWA_HT	50	140	34	9	16
WBD63.3_FWA_HT	50	140	34	9	17
WSP63.3 (MX HL)	50	190	45	11	25

- Haulout Repairs and Maintenance is assumed to have a small time related cost (fixed component) and a more significant distance related cost associated with track and tyre wear. It is assumed that:

    - Rubber tracks cost $14 000/set and have a life expectance of approximately three seasons for two haulouts operating on a 0.75 km averaged haul distance (12 500 km track life for both haulout and tractor). Track idler bearings are assumed to have a life of approximately 8 000 km. The “fixed” component is assumed to be approximately $2 000/haulout/year.

    - Wheeled haulouts are assumed to have a tyre life expectancy of 15 000 km, with a similar “fixed” cost to the tracked units.

On the basis of these assumptions, R&M costs of the various options can be assumed, as listed in Table 26.

TABLE 26
Estimated R&M costs- various haulout options

Haulout Type	Bin Size Tonnes	Haul trips	Total km/year / haulout 0.75	2	5	Total Maintainence/year 0.75	2	5	R&M (cents/tonne) 0.75	2	5
T31.7_Challenger Burnt	12	5833	8750	23333	58333	9000	20667	48667	12.9	29.5	69.5
T31.7_Challenger WC	6.4	10938	16406	43750	109375	16875	41667	101167	24.1	59.5	144.5
T47.5 Challenger WC	10	7000	10500	28000	70000	10800	25467	60667	15.4	36.4	86.7
TSP63.3 (CH 75) WC	12.8	5469	8203	21875	54688	9450	21867	51667	13.5	31.2	73.8
W21/23.5_FWA Burnt	8	8750	13125	35000	87500	5863	9800	19250	8.4	14.0	27.5
W21/23.5_FWA_WC	4.7	14894	22340	59574	148936	9979	13345	26213	14.3	19.1	37.4
W31.7_FWA_HT	6.4	10938	16406	43750	109375	13588	18171	35694	19.4	26.0	51.0
WBD63.3_FWA_HT	12.8	5469	8203	21875	54688	7018	12880	26950	10.0	18.4	38.5
WSP63.3 (MX HL)	12.8	5469	8203	21875	54688	7000	12950	26950	10.0	18.5	38.5

Other model inputs and outputs:

Harvester and infield haulout fuel use is estimated both under load (*In-use*) and at idle.

Harvester Performance is defined from and by:

- TPH (t): tonnes of burnt cane per hectare (crop size)
- Tonnes per engine hour (t/h): total amount of cane harvested, in tonnes, divided by the total number of hours of engine operation, including 15 minutes/day for servicing and moving.
- Total harvest time (h day^{-1}): the number of hours the harvester engine was operating during the day.
- Harvester waiting time (minutes): the amount of time the harvester was available, engine running, but not harvesting. This time is assumed to be the time waiting in the field for haulouts.
- Harvester turning time. This is the non-productive time taken in turning the harvester and haulout at the end of each row, totalled for the day's operation.

Discussion:

The condensed model outputs are presented in Appendix 6 and is summarised in Table 27 and the data for tracked haulouts and wheeled haulouts is presented in Figure 28 and Figure 29 respectively.

These results can be used to show the relative cost of burnt cane harvesting and other options and effect of using strategies of

- extra units of current design
- large capacity infield units

to minimise the costs associated with whole-cane harvesting.

TABLE 27
Model output detailing estimated day length, fixed costs and variable costs for various harvesting options

System	Day	Fixed Costs c/t		Variable Costs c/t		Total Cost
	Length	Harvester	Haulout	Harvester	Haulout	¢/t
BC 2*T 31.5 .75	5.9	166	194	103	87	550
BC_2T* 31.5_2.0	7.7	166	194	115	126	601
BC_2*T 31.5_5.0	11.8	166	194	150	225	735
GC 2*T 35.5 .75	7	166	194	129	112	601
GC 2*T 35.5 2.0	8.6	166	194	141	167	668
GC 2*T 35.5 5.0	13	166	194	178	318	856
SC 2*T 39 .75	8.6	177	202	156	123	658
SC 2*T 39 2.0	9.9	177	202	167	162	708
SC_2*T 39_5.0	14.9	177	202	200	289	868
WC 2*T 31.7 .75	7.6	172	194	116	120	602
WC 2*T 31.7 2.0	10.9	172	194	142	194	702
WC 2*T 31.7 5.0	18.7	172	194	209	404	979
WC 3*T 31.7 .75	5.8	172	289	102	137	700
WC 3*T 31.7 .75	7.9	172	289	118	214	793
WC_3*T 31.7_5.0	13.1	172	289	160	410	1031
WC_2*T 47_.75	6.3	172	202	107	93	574
WC 2*T 47 2.0	8.4	172	202	122	141	637
WC 2*T 47 5.0	13.5	172	202	164	266	804
WC 2*TSP 63.5 .75	7	172	283	113	112	680
WC 2*TSP 63.5 2.0	8.6	172	283	125	153	733
WC 2*TSP 63.5 5.0	12.5	172	283	157	259	871
BC 2*W 21 .75	6.5	166	200	110	85	561
BC 2*W 21 2.0	8.6	166	200	122	108	596
BC 2*W 21 5.0	13.6	166	200	163	188	717
WC 2*W 23.5 .75	8.4	172	200	121	106	599
WC 2*W 23.5 2.0	12	172	200	150	157	679
WC 2*W 23.5 5.0	20.7	172	200	223	291	886
WC 3*W 23.5 .75	6.2	172	268	101	125	666
WC 3*W 23.5 2.0	8.6	172	268	123	164	727
WC 3*W 23.5 5.0	14.3	172	268	171	296	907
WC 2*W 31.7 .75	6.6	172	213	109	92	586
WC 2*W 31.7 2.0	8.6	172	213	123	120	628
WC 2*W 31.7 5.0	13.4	172	213	163	202	750
WC_3*W 31.7_.75	6.8	172	287	108	142	709
WC_3*W 31.7_2.0	7.6	172	287	113	155	727
WC 3*W 31.7 5.0	8.8	172	287	123	177	759
WC 2*WBD 63.3 .75	10.1	172	263	140	151	726
WC 2*WBD 63.3 2.0	11.1	172	263	147	166	748
WC 2*WBD 63.3 5.0	14.3	172	263	174	213	822
WC 2*WSP 63.3 .75	8.4	172	248	123	135	678
WC_2*WSP 63.3_2.0	9.2	172	248	127	147	694
WC 2*WSP 63.3 5.0	11.6	172	248	154	184	758

Current costs:

This section defines two base cases, operating in burnt cane:

- harvester and two rubber tracked haulouts (legal status cannot be confirmed)
- harvester with two wheeled haulouts estimated at maximum legal mass

Results:

The results of the model outputs for the tracked vehicle options are given in Figure 28.

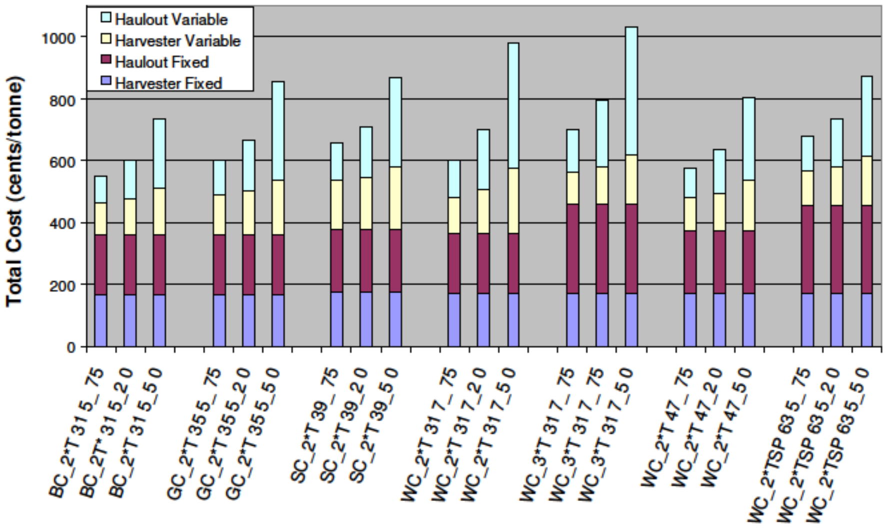

Figure 28 - Harvesting costs, tracked vehicle options

Tracked options

The burnt cane scenario total harvest/haul costs ranged from 550 ¢/t for a .75 km haul distance to 735 ¢/t for the 5 km haul distance.

By comparison, the most economical WC harvest/haul option was the 47.5 m3 single bin unit which had costs of 574 ¢/t for 0.75 haul and 804 ¢/t for 5 km.

The use current haulout fleet (2* 32 m^3) with WC had harvest/haul costs ranging from 602 ¢/t to 979 ¢/t respectively.

Increasing the number of haulouts from 2 to 3 caused an increase in harvest/haul costs. In this case harvest/haul costs increased to 700 ¢/t and 1031 ¢/t respectively, primarily because the cost of operating the extra machine were greater than the savings in labour. Even if the capital cost of the additional haulout is not considered, the haulout variable costs are higher when a third unit is operated.

The large capacity option (64 m^3) was always more expensive than the 47.5 m^3 option, primarily because of the high haulout fixed costs.

The harvest/haul costs associated with an optimised whole-cane harvesting system is believed to be marginally lower than that for an optimised green cane harvesting system, even without attributing a cost to the high levels of cane loss which will be suffered under a green cane harvesting system.

At 0.75 km and 2. km haul distances, it is interesting to note that largest haulouts (64 m^3) are a more expensive method of transportation than 2 of the 32 m^3 units. This results from the increased fixed costs associated with the larger units. This trend is reversed at the long haul (5 km) due to increases in day length and the repairs and maintenance component.

Wheeled system options

The results for the model simulations for the wheeled systems are given in Figure 29.

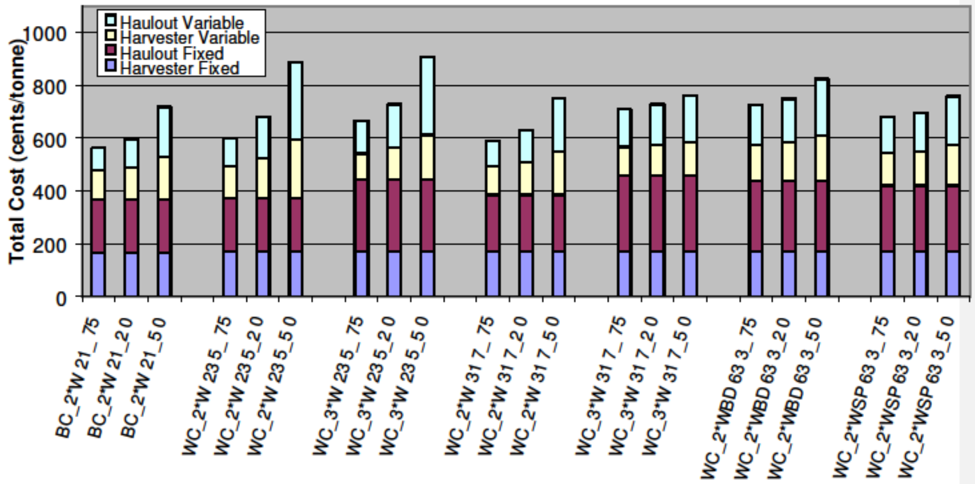

Figure 29 - Wheeled system options

The burnt cane scenario total harvest/haul costs ranged from 561 ¢/t for a 0.75 km haul distance to 717 ¢/t for the 5 km haul distance.

By comparison, the most economical whole-crop harvest/haul option was the 32 m^3 single bin unit which had costs of 586 ¢/t for 0.75 km hauls and 750 ¢/t for 5 km hauls.

The use of the current haulout fleet (2 of 23.5m^3) with whole-crop had harvest/haul costs ranging from 599 ¢/t to 886 ¢/t, respectively.

Increasing the number of haulouts to 3, resulted in increased harvest/haul costs. Harvest/haul costs increased to 666 ¢/t and 907 ¢/t respectively, primarily because the cost of operating the extra machine is greater than the savings in labour.

The large capacity ‘B-Double’ haulout options gave the highest harvest/haul costs, primarily due to increased day length, because of vehicle manoeuvrability limitations and high fixed costs.

The self propelled option had high fixed costs but its variable costs were competitive and day lengths were acceptable.

With the whole-crop options, due to the high volumes of material being handled and the 20% increase in mass associated with this mode of harvesting, the number of haulout trips and time per trip were critical in minimising cost.

The transport of cane or cane/trash mixtures is basically a materials handling exercise and this is clearly indicated by the model simulations. Transport also influences the harvesting cost due to factors such as harvester waiting time. The harvest/transport costs of wheeled haulouts were lower than those of tracked options, and the differences increased with greater haul distances.

4.7 Examine the advantages and/or limitations of alternate methods such as on-harvester shredding and infield units that have the capability to compact the cane/trash mixture, as ways to reduce the cost associated with the transport of trash

The principal ways to manipulate the bulk density of the cane/trash mix to potentially minimise transport costs include:

- Extracting and shredding trash and recombining the billets and trash in the load.
- Compacting of cane-trash or cane-shredded trash mixtures in transport equipment
- Separate transport of cane and trash/shredded trash.

A system of separation of the trash in the harvester cleaning system, shredding the trash and re-combining the billets and trash in the load has been under evaluation by NSWSMC. The concept being evaluated was that the smaller particle size of the trash would be less able to maintain large voids between billets and will allow higher packing densities to be achieved.

Similarly, limited trialing has been undertaken on compaction of billeted cane-trash mixtures and shredded trash and billet mixtures.

Figure 30 presents some data from trials undertaken by NSW Sugar and limited trials undertaken by BSES at Bundaberg.

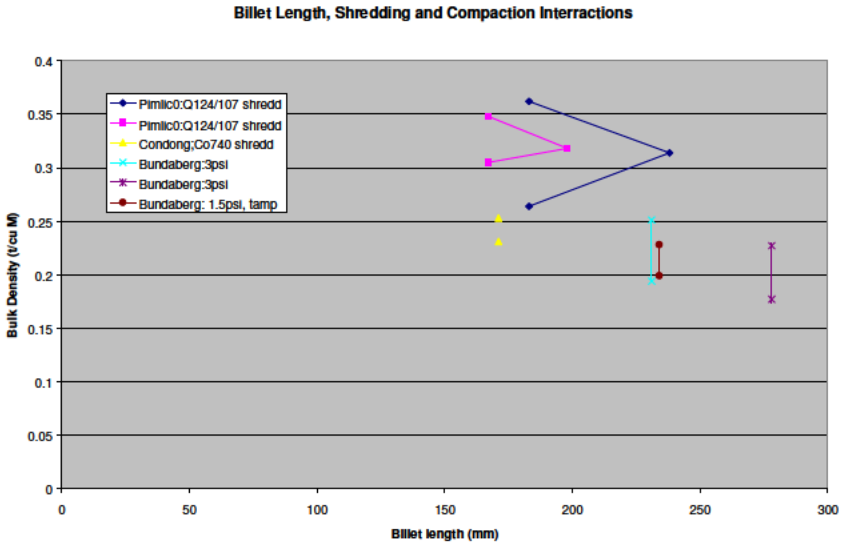

Figure 30 - Effect of billet length, shredding and compaction on bulk density

At the Pimlico shredding trials, the differences in billet length compounded the shredding effect, with the shredded treatments having longer billet length than unshredded treatments. A correction for billet length can be approximated (see section 1).

From this data:

- Useful changes in bulk density was achieved in one Pimlico trial 0.264-0.362 t m^{-3} (corrected for billet length).
- The gains in the second Pimlico trial were less dramatic although still encouraging (0.305-0.348 t m^{-3}).
- At the Condong trials, the gains from shredding were limited (0.231-0.253 t m^{-3}). Both treatments were compacted. The actual billet for this trial was not known, so a default value of 160 mm was used.
- The Bundaberg trials gave relatively consistent improvements for the 3 psi treatments and approximately half this effect from the 1.5 psi treatment.

Bulk densities at the Pimlico site were already in the target range >0.250 t m^{-3}. The effect gained from shredding is relatively inconsistent.

For reference, the packing pressures achieved by Cotton "Module Makers" is estimated to be in the range of 5-6 psi.

On the basis of available data no decision could be made on the performance of either compacting or shredding as a method to achieve increases in bulk density. It is appropriate to explore a number of significant relevant issues.

4.7.1 On-harvester shredding of trash

Shredding of trash and re-incorporation of it into the billet mass is a logical strategy to enhance bulk densities for transport of a billet trash mix. The execution of the proposal on current harvesting equipment presents some major problems. These are discussed under the following subject areas:

(a) The impact of ambient conditions and cane/trash characteristics on:

- trash extraction efficiency by the primary cleaning system
- resultant bulk densities of the cane-trash mixture

(b) Cane loss during shredding

- the typical cane loss relationships
- loss of value of billets when shredded
- increase in mass and volume of low density proportion of load

(c) Constraints to pour rate due to the shredding operation

- power consumption of the shredding operation
- shredder efficiency

(d) Repairs and maintenance of the shredder system

(e) Materials handling issues: haulout to multi-lift -flow characteristics of cane/shredded trash mixtures.

Each issue can be addressed:

(a) The impact of ambient and crop conditions

Ambient and crop conditions and cane/trash characteristics impact on:

- trash extraction efficiency by the primary cleaning system
- resultant bulk densities of the cane-trash mixture

Trials in north Queensland as part of a SRDC funded project characterised the performance of modern harvesters working under a range of crop, field and weather conditions. Figure 31 presents data from a series of trials undertaken in 1997 (Whiteing and Paton, BS189).

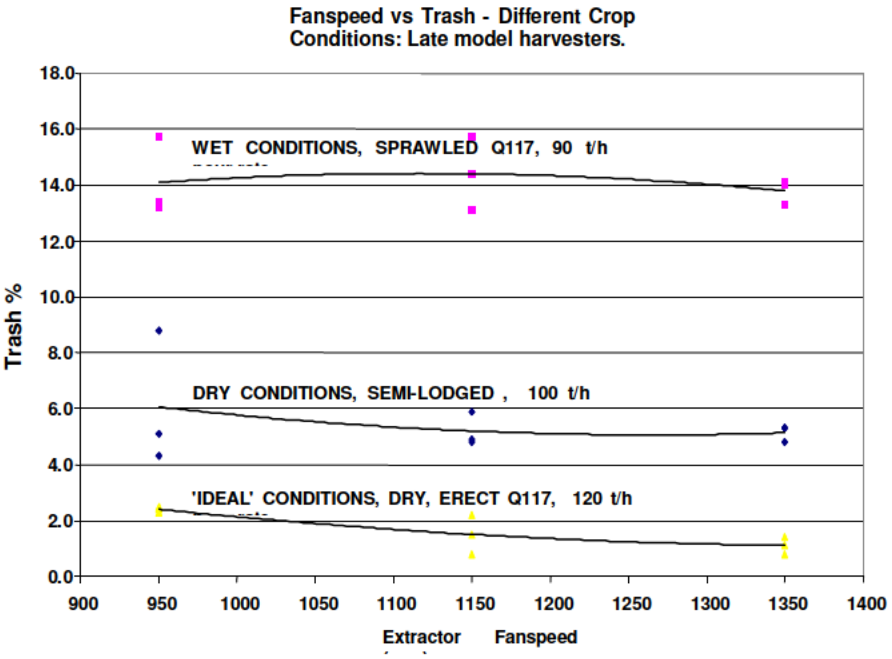

Figure 31 - The effect of fanspeed and harvesting conditions on trash levels

Under any given field conditions, pour rate has been shown to be the primary determinant of final product EM levels, as measured by trash and dirt levels[48]. As field conditions deteriorate, however, the extraction efficiency of current extractor system reduces dramatically despite the reduction in pour rate. Figure 31 demonstrates the dramatic impact of field conditions on the trash remaining in the harvested product.

Further trials carried out at Mulgrave Mill in 1998[49]. The trash levels in the delivered cane were compared to the trash levels in whole-cane taken from the field (as part of "sugar balance research"). Figure 32 relates extraction system efficiency to crop size.

Whilst in any crop size there will be a wide range of field conditions, harvesting pour rates, fan speeds and crop types, the impact of crop size on cleaning system trash removal efficiency is clearly evident, with the trend being towards sub 50% extraction efficiencies as crop size increased.

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[48] (Whiteing, BS189).

[49] Crook *et al.* (1999). A survey of field CCS versus Mill CCS, Proc of ASSCT, pp 33-37.

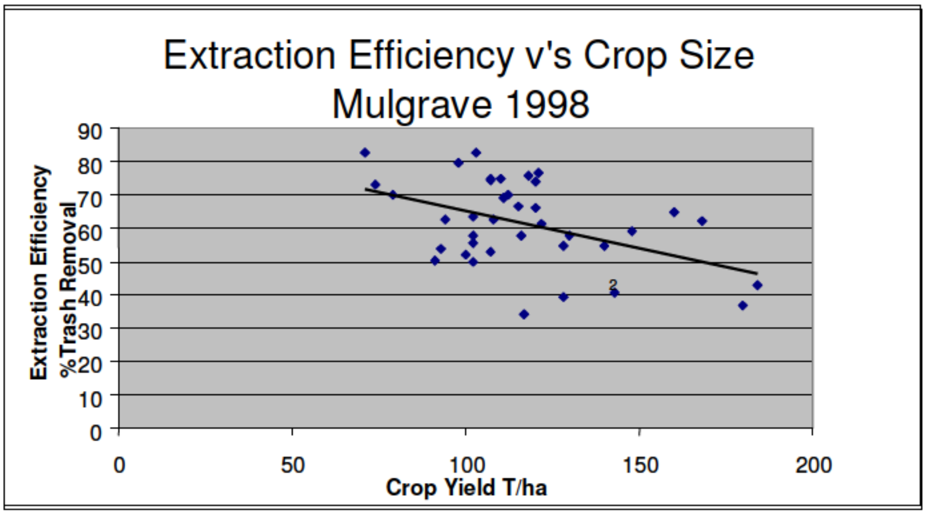

Figure 32 - Extraction efficiency versus crop size

Clearly, the harvester operator would have been attempting to maximise cleanliness of the cane supply. Whiteing (BS189 milestone reports) has recorded extraction efficiencies of 30% in both adverse harvesting conditions and when harvesting large lodged crops. The primary cause of the deterioration in cleaning system performance noted can be demonstrated as:

- in heavy lodged crops, the deterioration in evenness of feed through the machine (glut-starve feed) causes the cyclic overloading and under-loading of the extractor chamber[50].
- under damp trash conditions, the interactions between the billets and the trash, combined with the heavy "loading" of the chamber during glut feed events reduces the potential for cleaning to occur.

It can therefore be reasonably argued that under both adverse weather conditions and when harvesting large crops, the trash removal efficiency of the shredder system will be significantly reduced, resulting in a significant increase in the proportion of unshredded trash. This will result in a reduction in the final bulk density of the cane trash mix.

This effect has been demonstrated in the NSWSMC trials[51]. The EM of "cane only" in a trial where cane and trash were separated was approximately 21%. Interestingly, in other treatments in this trial, the cane plus shredded trash achieved only 0.253 t m^{-3} versus 0.231 t m^{-3} for cane and unshredded trash.

To mitigate this effect "in the field", it is probable the operator would increase shredder speed, with a direct effect on cane loss.

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[50] Norris *et al.* (1998). An investigation into the feeding of lodged cane by harvesters. Proc ASSCT, pp 224-231.

[51] Internal correspondence, Dick Watts, re Trash Trials, March 2000.

(b) Cane loss

The results of the trials undertaken in north Queensland under BS189 indicate that cane loss is primarily determined by fan speed, however under adverse harvesting conditions, operators almost universally increase fan speed in an attempt to reduce EM levels. Previous work by Ridge *et al.* (in-published data) demonstrates that at a given fan speed, cane loss was minimised at approximately 60 t/h (under controlled conditions) and increased both at lower pour rates and higher pour rates than this optimum. Hobson (Pers Com) has demonstrated that the aerodynamic configuration of the primary cleaning chamber is such that, at low pour rates conditions for high cane loss are exacerbated.

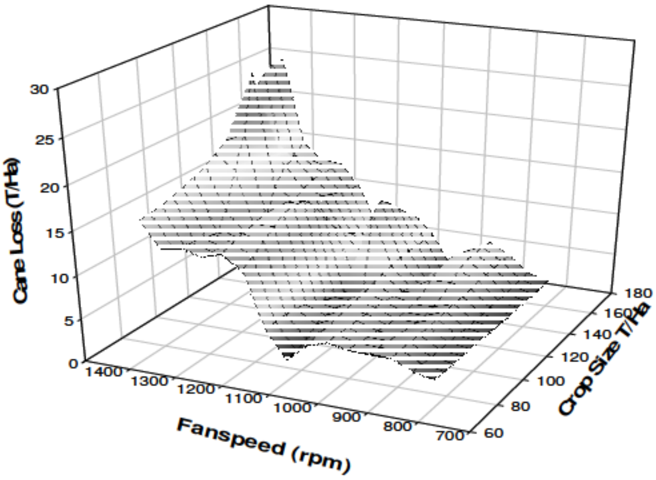

Figure 33 - The effect of crop size on harvester cane loss (Whiteing)

Cyclic glut-starve feeding patterns can therefore be expected to increase cane loss at any given pour rate, relative to even feeding at the same average pour rate. This effect is evident in Figure 33, which summarises the effect of crop size on cane loss[52]. The poorer extraction efficiencies generally achieved in large crops typically results in operators increasing fan speed, resulting in very high levels of cane loss. Both Whiteing (BS189)

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[52] Whiteing, 1997-98 data

and Fuelling[53] have recorded cane losses of over 30 t/ha on harvesters "as operated" when operating in large crops.

Cane loss during shredding:

Cane loss a major issue in green cane harvesting. With a shredder system based on the primary cleaning system, loss of significant quantities of cane billets during shredding is a real probability, if the shredder design is based on a modified primary extractor.

This effect could be difficult to detect, without proper replicated trials, using "mass balance" experimental techniques. The use of "blue tarp" systems (ie determining losses by measurement of mass of cane pieces) can be demonstrated to be totally inappropriate.

In the December shredded/unshredded trials at Pimlico, the increase in % EM from 30.5% average to 39.9% could probably at least partially be attributed to shredded billets being included as EM. This is appropriate, as once shredded, the billets are, in effect EM.

The cost of the lost cane must be factored into the cost of the shredding operation.

(c) Constraints to pour rate due to the shredding operation

Constraints to pour rate due to the shredding operation include:

- maximum pour rate of the shredder
- power consumption of the shredding operation

Available data (J Budd, pers com) indicates that:

- maximum pour rate of the harvester when operating in the Co740 crop at Condong was less than 80 t/h cane equivalent.
- The hydraulic pressures were in the order of 2000 psi for the extractor circuit (45 gpm) and 2200 psi for the shredder circuit (32 gpm). This equates to engine power input[54] of 44 kW for the primary extractor and 35 kW for the shredder, a total of 79 kW over the power consumption of a harvester operating in the "whole-cane " mode.

The reduction in pour rate and increase in power consumption can be shown to significantly increase harvesting costs (Terms of Reference 6).

(d) Repairs and maintenance of the shredder system

Repairs and maintenance on a harvester operating in green cane are substantially greater than for the same crop harvested burnt, and the primary components associated with this are the increased cost of maintenance of the extractors. This can account for 25-50% of the total maintenance costs. (Mal Baker (Austoft), pers com, R Stiff, Austoft internal Memo, R Ridge, pers com).

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[53] Cargnello,R. and Fuelling,T. (1998). Cane Cleaning Systems. Proc ASSCT pp 28-33.

[54] Assuming 88% hydraulic circuit efficiency, standard oil power formulae.

On the basis of field data, Ridge uses an increase in repairs and maintenance of 50% in his harvest and transport model for green versus burnt cane. Given the shredder essentially replicates the extractor fan, it is reasonable to assume that the repairs and maintenance can be increased by this margin again to cover the costs of a harvester fitted with a shredder.

On the basis of the above discussion, shredding the trash on the harvester is only a viable option if the advantages of the potential increase in bulk density, (allowing for recovery of all available trash and leaf) warranted the significant costs.

4.7.2 Compacting either the cane “whole trash” mixture or the cane-shredded trash mixture

The issues relating to compacting either chopped whole-cane or billets with shredded trash include:

- The allowable mass which can be carried from the field is limited by RTA restrictions on maximum axle loads.
- Increased bulk density allows smaller (volumetric) equipment to be used for a given total material mass.
- Compacting can potentially increase the probability of being able to transport all the available trash from the field.
- The potentially reduced tare weight of the smaller volume of haulout may be negated by the need to install moving floor systems in the haulouts to ensure reliable safe unloading of the compacted mixture. Limited experience, including trials at BSES Bundaberg, indicate that even at relatively low levels of compaction, the material will behave as a “block”. This would make unloading from tipper type bins difficult and potentially dangerous.
- Unless specifically designed systems such as the “Fiegl” (Appendix 3) system is used, any compaction achieved in the field will be reversed during the un-loading of the haulout into the multi-lift bins.

If billet length and other available variables can be manipulated so that all available trash can be collected in simple vehicles (ie a bulk density of 0.250 t m^{-3} can be achieved) there seems to be little advantage in compacting systems on infield haulouts.

Similar comments apply to compaction of the cane-trash product in the multi-lift transports.

4.7.3 Separating billets and trash on the harvester and:

- **Transporting it simultaneously, but in different equipment**
- **Depositing the trash on ground for pickup with balers**

Simultaneous transport:

Transporting trash simultaneously, but in different equipment is seen to have major logistical problems and issues. Key problems with this approach which are immediately evident are:

- The added complexity of equipment to transfer product from the harvester to the transport systems and the equipment needed to transport the product separately. Factors relating to optimisation of haulout size because of the changing cane/trash ratios become major issues.
- The issue of cane loss and shredder efficiency, as noted previously, become major considerations.
- Difficulty in the development of conveying systems which will not impede operations such as reverse filling and turning at the end of the row.

Given the logistics of the cane-trash collection program, including the small field sizes in the Condong Mill area, it is felt that separation of the components has little to offer in the Condong situation.

Given longer row lengths in other NSWSMC regions, systems may be developed to enhance the logistics of separate cane/trash transport. However, cane loss and other shredded performance issues would remain.

Drop and Retrieve trash:

Depositing trash on the ground (conventional green cane harvesting), for later retrieval has a number of very significant potential advantages:

- Conventional harvesting and haulout equipment can be used for the cane (conventional green cane harvesting).
- The trash can dry on the ground, significantly enhancing its usefulness as a fuel and improving storage properties.
- Separate specialist equipment can be used to collect the trash.

The proposal has a number of significant constraints, including:

- Cane loss issues, particularly in large crops.
- The issue of rain after harvest and re-wetting of trash. If wet conditions persist, significant agronomic issues emerge.
- Cost - available information suggests cost will be a major impediment to the commercial viability of this approach.

A number of studies have been conducted into this option (See Appendices 1A, 1B and 1C). The concept has been assessed in some detail by the Colombian industry (Appendix 1B, where analysis has been undertaken on baling and forage harvesting of residues.

Ridge[55] costed this option as part of a SRDC funded project. The summary of his findings under Australian conditions were: "Baling of trash and tops in the field did not appear to be an economic proposition compared to using current harvesting equipment for collection of trash in the field by reducing cleaning efficiency".

Summary of issues:

From investigations relating to transport from the field to the multi-lift and the subsequent haulage to the mill, the following premises apply:

- Providing a material bulk density of 0.250 t m^{-3} can be achieved, both infield and on-road transport systems are potentially mass limited, not volume limited, ie viable designs exist for haulouts and multi-lift bins which allow full rated load to be carried.
- The advantages of reliably achieving greater bulk densities than 0.250 t m^{-3} occurs only when the reduction in volume being carried gives some significant alternative advantage, eg the use of current equipment to reduce capital costs.

The concepts of shredding the trash, using a shredder system incorporating current harvester extractor technology does not appear to offer major advantages because of cane loss and trash extraction inefficiencies.

Similarly, the development of systems to compact the cane trash mixture as parts of the current system has limited advantage unless significant problems are encountered in collecting adequate levels of trash from the field.

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[55] D.R.Ridge and P.A.Hobson (1999) Final Report-SRDC Project BS157S "Removal Of Extraneous Matter In Sugar Mills For Co-Generation Of Power And Reduction Of Cane Loss"

5. APPENDIX 1A

CONFIDENTIAL PRELIMINARY DRAFT, *Sunshine Energy Condong Co-generation Facility:* Cane Trash as a Potential Fuel Source
Position Paper by Cam Palmer NSWSMC

Section 3 - Solutions

During the last twelve months there has been significant, albeit intermittent, activity within NSWSMC and the cane farming community, aimed at developing cost effective, feasible methods for the harvest and transport of cane trash. Broadly, there are three options:

- Field Separation of cane and trash (on the harvester), dump trash to ground, rake, bale and transport.
- Field Separation of cane and trash (on the harvester), possible shredding of trash (on the harvester), transfer of loose trash direct to infield transport and then to the cane pad and the road transport system.
- Harvest and transport the whole crop as a mixture in loose form, separate at the factory.

Section 4.1 - Baling Options

It is considered that any option involving baling is not considered viable for the following reasons:

- High cost of raking and baling. Although it has not been possible to gain a firm understanding of all costs that would reflect the likely economies of scale, several sources indicate that costs for raking and baling of approximately $33 per tonne, at 15-20% moisture ($39-$41 dry basis) are likely. Note that this does not include any transport, handling or debaling costs. Recent evidence of large scale baling and debaling of bagasse tends to indicate that it is preferable to handle such material in bulk form. This is the case even when transport cost issues are not relevant, eg bagasse handling at Invicta Mill, north Queensland.

- Baling is normally done after the material has dried to less than 20% moisture in the field. The risk of material becoming wet from rain between the time of harvest and the time of baling would be high. Also this risk would significantly reduce quantities harvested green.

- The amount of material able to be collected from the field even in good conditions without significant contamination problems, is reported to be no greater than approximately 60 % of the total potential trash. This problem is accentuated in wet field conditions where trash is often pushed into the ground by the movement of infield vehicles at the time of harvest.

The advantages of the baling option which need to be noted are:

- That the material needs to be relatively dry before baling (eg < 20% moisture) and this has obvious advantages during combustion.
- Bulk density is markedly improved such that achieving a satisfactory payload is much easier than for the loose options.

These benefits do not balance the above disincentives but the concepts need to be considered in the development of the best system.

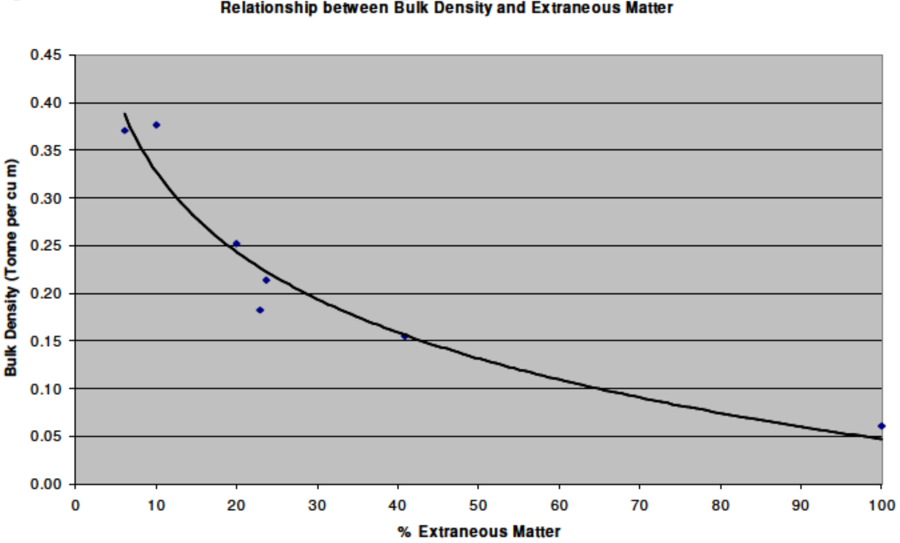
Another baling system that has been mooted is a system that involves baling direct from the harvester, eg with the baling machine being towed behind the harvester or infield transport bin. This option would need more thorough investigation and some rigorous development work before any proper assessment could be made. The following problems are envisaged:

- Increased complexity of harvesting operation and more opportunities for blockages etc.
- Harvesting speed is likely to be reduced significantly (cost ramifications).
- An extra machine and operator will be needed in the field at the time of harvest to collect the bales as they are produced, to clear the way for cane infield transporters (cost ramifications).

Section 4.2 - Loose options

Both of the options involving transport of trash or a cane/trash mixture in loose form or possibly using methods of enhancing the bulk density, are considered worthy of detailed analysis. The current status of this analysis is presented below.

Graph 4.1 - Cane and trash mixture - per cent extraneous matter versus bulk density



The dominant variable is bulk density. The most relevant data is from trials done in 1995 at Condong and in 1999 at Broadwater. The total number of samples is not large (7 bins) but this data is arguably more relevant than other reported data because it is based on trials using the 65 cubic metre containers used in the NSW industry. Other available data relates to much smaller, eg, 10-15 cubic metre rail bins etc. Refer to attached graph.

Section 4.2.1 - Field Separation of cane and trash, transported separately in loose form

For this scenario, it is proposed that the trash is separated from the cane on the harvester as at present and is then pneumatically conveyed to a separate compartment of an extended infield bin. The separate compartment could be adjustable in size to facilitate varying cane trash proportions and to achieve some compaction of the trash. The two materials are transported to the gravel pad and tipped separately into different multi-bins on the pad. The multi-bins for trash are 25% larger than the cane bins.

As most readers would be aware, there is an opportunity to improve the bulk density of the trash by shredding on the harvester. This issue is currently the subject of detailed development work being undertaken by the University of Southern Queensland with funding from SERDF and SEDA. This work is proceeding well and a prototype rig is being fitted to a harvester for trials in December 1999. In the absence of firm data relating bulk density to achievable particle size and the effect of the shredding device on harvester performance, the issue of bulk density has been examined by sensitivity analysis. At this stage it is not possible firm conclusions on this issue.

6. APPENDIX 1B

Electric Power from Green Harvesting Residues of Sugarcane in Colombia. A Pre Feasibility Study on it's Technical and Economic Viability.
Briceno, C.O., Cock, J.H., Torres, J.S.
February 1999. Cenicana, Cali, Colombia

CHAPTER TWO: THE RESOURCE BASE

The precise amount of fibre available from cane trash can be expected to vary with plant varieties, climate and soil conditions, cultivation procedures, and harvesting practices. Available evidence suggests that where the cane is hand harvested without burning, the fibre in the trash can be expected to equal or exceed that which reaches the mill in the harvested stalks (Alexander, A 1985).

The Cauca Valley of Colombia is a semi-humid region with mostly fined textured soils, on which cane is planted and harvested year-round. After green cane harvesting of commercial varieties, the amount of residue vary from around 50 to a maximum of 150 t/ha. These residues must be manipulated in order to avoid negative effects on the crop. An attractive option is to find alternative uses such as energy generation (Torres, J *et al.* 1998).

2.1 Quantity and Quality of Residues

The cane planted area in the Cauca Valley of Colombia is 185 000 ha with 75 to 80% harvested each year, with the harvest continuing throughout the year but with greater intensity in the two dry periods. The amount of vegetative material left after harvesting in unburned fields depends mainly on the cane variety and soil fertility. The V 71-51 variety (second most widely grown variety) is a high biomass producer with 80% of residue to cane ratio, on the opposite side we have the new Colombian varieties bred by Cenicaña and Mayaguez sugar mill with as low as 30%. Most of the commercial varieties planted nowadays in the valley have a residue to cane ratio above 0.5, which makes green cane harvesting a difficult task and residue management difficult. The target ratio of residue to cane has been fixed at 0.3, which allows easy manual and mechanical harvesting. A question is posed on the appropriateness of this decision if power generation using residues becomes economically attractive in the near future (Torres, J *et al.* 1998a).

The average moisture content of the green cane residues immediately after harvesting is between 65 to 75%. Residue samples of the MZC 74-275, which is the most planted variety, were sent to Universidad del Valle for analysis (Table 1).

Table 1 – Analysis of residue samples of the MZC 74275 Variety

Residue component	Moisture % Initial	Moisture % residual	Volatile %	Ash %	Fixed carbon %	Sulfur %	Caloric value kcal/kg
Tops	78.6	6.0	71.2	7.1	15.6	0.20	4 253
Green leaves	65.7	6.2	66.7	9.8	17.2	0.26	4 021
Dry leaves	11.9	5.9	68.6	11.6	13.9	0.22	3 993

In general, the analysis is similar to that of cane residue analysis reported from Brazil and Florida. It appears that there is little difference between the composition of residues from widely different environments. Therefore, no additional effort has been made to characterise each of the local planted varieties. The main difference between environments is in the total amount of trash left behind in the field due to varieties, soil fertility and local weather conditions.

We estimate that in gross terms, Colombian's 23 million tons of cane could be expected to produce about 11 million tons (at 35% moisture) of boiler fuel. Depending on the efficiency of the combustion equipment in which it is utilised, this represents fuel enough to sustain from 300 to 1 200 megaWatts of electricity production.

However, not all of this material can or should be collected, a portion of the residues should remain on the field to provide organic matter for the soil. Furthermore, light mulch of residues is often desirable to retain moisture and inhibit weed growth while the new shoots of cane are establishing themselves.

2.2 Natural drying process of residues in the field

The natural dehydration process of manual and mechanical harvested cane residues of MSZ 74-275 and V 71-51 were observed directly under local weather conditions at the Mayaguez sugar estate. Right after the harvest, the residues were either spread all over the field as a full trash blanket (0x0) or were windrowed (2x1), placing the residues from three adjacent inter-rows into one inter-row space, leaving two inter-rows of trash (Torres, J *et al.* 1998a).

The dehydration rates of manual and mechanical harvested cane residues varied between 3 to 4% per day. A week after harvest, if it does not rain, the average moisture content of the residues can be reduced from 60-65% to 35-40%. If any rainfall event occurs, the residues will trap most of the moisture increasing the moisture content to a level similar to the starting value. In this case, rain water is mainly surface water and the following dehydration rate is greater at 5 to 6% per day. Manual and mechanically harvested residues dried at similar rates. There is no difference in drying rates of windrowed and spread residues, therefore it is not attractive to trash line the residues to increase the dehydration rate, although this practice may facilitate collection of residues.

The effect of chopping length on dehydration rates of fresh residues was observed on manually collected residues chopped at 2.5, 5 and 10 cm length. Dehydration rates were similar for all treatments suggesting that chopping residues to speed up the drying process offers no advantage.

2.3 Mechanical Properties – Bulk Density

The viability of using cane residues as a valuable by-product is limited by the low bulk density of baled and chopped residues which has a direct influence on transport costs. Round and rectangular bales of sugarcane residues and forage crops usually vary between 110 and 200 kg/m^3 with moisture content around 50 to 60%.

Fresh green cane residues with moisture contents above 56% were chopped to 2.5, 5 and 10 cm length and compressed using a hydraulic cylinder. Wet bulk density values between 500 and 700 kg/m^3 were obtained with pressure values close to 250 kPa. Cane residues are of elastic nature and are able to expand after releasing the compression force, which results in a lower bulk density value. A question can be raised if there is a means to maintain the compression force while the residues are transported to the gathering site. A simulation exercise indicated that uncompressed chopped residues in an open wagon would have an extremely low density of around 80 kg/m^3. On the other hand, density values close to 200 kg/m^3 are easily obtained with round and large rectangular bales (stacks). Copersucar in Brazil has found that large rectangular bales is the best option for transporting sugarcane residues because manipulation time and transport capacity of the trucks are used more effectively.

Residues left on the field by mechanical harvesters appears partially split or chopped into large pieces. Samples of MZC 74-275 variety were collected and compressed at moisture contents ranging from 10 to 52%. The wet density of the compressed residues increased as the moisture content was higher. The dry density of the compressed residues was insensitive to moisture content, at any given compressing pressure the amount of dry biomass per unit volume remains the same, however, as the residues become drier their rebound capacity is reduced.

2.4 Selecting Machinery Systems to Harvest and Deliver Cane Residues

Experience with the collection of cane trash is very limited in the sugar industry. In the Dominican Republic it is harvested by hand and transported by oxen to provide the feedstock for the manufacture of furfural. In India it is often removed from the field by hand and stacked for use as thatching material and cattle feed. In Jamaica a program of field tests was scheduled in 1986, in conjunction with a project designed to convert the Monymust estate in that country to electricity production (Keppeler, J P 1987). Also, the Government of Puerto Rico has undertaken a plan to test techniques for the production and management of high-tonnage cane and its residues for combustion in the Aguirre region of that island. Nowhere, however, are green cane residues currently collected on a large scale for boiler fuel.

We conclude that there is no existing proven system for collecting and transporting cane residues to a central site. Cenicaña assumes that attempts at cane-residue co-generation in the Cauca Valley, will be preceded by a program of field experimentation, similar to that underway in Jamaica and Thailand (Jakeway, L A, 1988), to test a variety of techniques for harvesting, transporting and processing trash for use as a fuel. In fact Cenicaña and the Cauca mill have already embarked on this approach.

2.4.1 The Colombian Approach

The two most promising systems for cane residue handling appear to be chopping and baling. The baling approach has been tried in various sites throughout the world, however, to our knowledge Cenicaña, through a business alliance with the company Claas of Germany is leading the field in chopped trash alternatives. We are working on the adaptation and development of a trash chopping machine, with a capacity of more than 70 t/h. The machine was brought to Colombia in July of 1997 and has been continuously developed and modified with the participation of Claas, Lundahl, Cenicaña engineers and the mills. It is still not capable of chopping residues at the rates of 60-70 t/h due to problems of lifting trash out of the bottom of the inter-row furrows and feeding problems.

Chopped residues

The conditions of the fields after harvest, are variable due to the lack of uniformity of spacing among the rows, the height and form of the ridges and the changes induced by continuous traffic of transport equipment, especially in rainy season. The development of a floating shoe, which can pick up the residues of the bottom of rows efficiently, is an exciting innovation which may resolve problems of feeding either trash balers or choppers. Up to now, significant advances have been achieved in the development of the trash chopping machine, but some problems, expected to be solved promptly, still persist.

The Claas-Cenicaña chopper machine has an estimated cost of US$ 180 000. The target performance is 70 t/h. The estimated cost for chopping and discharging the residues in dump cars is US$ 3.1-3.6/t (Table 2).

Preliminary results from compression of residues using a cane loader to compress residues in wagons indicates that densities of about 250 kg/m^3 can readily be achieved. Another possibility would be the use of a Stakhand 60B (a wagon with a compression system like a garbage collector car) from Cencorp Inc. (Hesston, Kansas, USA) to recover and compact the residues in the field. It has a cost of US$ 42 000 FOB Hesston (USA).

Baled residues

Ingenio Cauca is evaluating baling as a system for collection of residues from green manual harvesting in nearby areas (10 to 15 km) away from the mill, with the purpose to use them mixed with bagasse and burn it in the boilers. The program will last 6 months and it is expected to have results by the end of October 1999.

Recollection and transport process

The following possible scenarios for recollection and transport of residues were analysed.

> The material is allowed to continue drying for 2-3 days. As noted, the residues can be expected to reach a moisture content of 45% or less during this period if fine weather occurs. In the best case scenario residues would dry to 35% moisture and in the worst case would stay at close to 65%. In the best case scenario the machinery would be able to pick up residues as they lie in the field, and in the worst case they would need to be windrowed before collection.

(a) Baled residues. The residues would be baled in the field and transported to storage sites near the cane fields using bale movers. Decentralised storage is important, as the material required for power production is bulky and would occupy too much space if stored at the site of the power plant. The bales will continue to dry, covered if necessary, bringing moisture levels down to as low as 40% or less. Bales are transported to the mill for shredding and combustion, as they are needed. Transportation will take place via the same types of vehicles, and along the same routes, that are currently used for cane.

(b) Chop the residues, compact chopped residues and transport them to the mill in special large cages similar to the present bagasse haulage systems. The residues would normally not be stored for long periods and would be handled with the traditional bagasse handling equipment.

For this pre-feasibility approach, Cenicaña chose the **Incauca Mill** as a base for the analysis on the grounds of: 1) technical suitability, including size and location; 2) availability of data, and 3) the expressed interest of management in electricity production from residues and also the fact they are already selling to the grid.

The Incauca Factory, Incauca S.A., is a company of the Ardila Lulle organisation, which was established since July 29, 1963. It now has an installed capacity of more than 14 000 t cane per day and is selling electricity to the grid.

2.5 Trash Transportation

Cenicaña, has considered that for transportation of chopped residues, it would use, as its first choice, a pressing system (like the stakhand 60B) which reduces its volume before filling wagons trains drawn by a tractor 910 trains with 4 trips/day would be required) for distances not longer than 15 km. Another option could be a grab loader to tamp the residues located inside the wagons. We have shown that residues can easily be compacted to 250 kg/m^3 with this system. For the case of baled residues, we used the outline submitted by Copersucar (Appendix C).

2.6 Estimated Cost for Collection, Handling and Residues Transportation

For all cases, the residual collection was taken on the basis of a distance of 10 km from the power transformer centre (current and projected). The critical condition of cost, was fixed by a ton of coal value (with 10.500 BTU/lb) at a cost of Col.$36 000/t placed in Ingenio Cauca (Appendix B). The project can be considered as potentially viable if costs (based on BTU/lb equivalence to coal) are US$ 8/t in the case of residues with 35% moisture and US$ 4.3 at 65% moisture.

To get a support for estimate costs of the different operations involved in the collection, handling, transportation and preparation of the residues, a detailed approach was prepared (Appendix C) using 1984 and Turhollow, A *et al.* 1996. The procedure was applied looking for the target cost of US$ 8/t at 35% moisture and US$ 4.3 at 65% moisture for residues delivered at the factory.

Due to the uncertainty surrounding the technology, we have prepared two scenarios (1 and 2) with different assumptions and figures for the baling process and two additional scenarios (3 and 4) for the chopping system (Table 2). For the best case scenarios 1 and 3, we took a negative value of US$0.5 for the farmer as he has to manipulate the residues in order to grow his crops and this has a cost. For the scenarios 2 and 4, we assumed that in the long run, the residues will acquire a minimum value of US$ 0.5/t.

The calculations considered for scenarios 1 and 3 were the lowest* expenses resulting from greater efficiency or the elimination of some activities such as windrowing before collecting the residues. For scenarios 2 and 4, we chose the highest estimated costs*. The lower costs of the best case scenario are attractive, however it should be noted that the worst case scenario costs are also considerably greater than the target costs.

The difference between actual costs and the proposed targets (US$ 8/t or USD$ 4.3/t) can be taken as an incremental cost and would be compensated by recognition in monetary terms of the reduction in CO_2, greenhouse gases and particulate emissions.

2.7 Analysis and Comments

The stated costs show the technical and economic potential of the harvest and management of the residues to produce energy (US$0.81-1.28/GJ). However, to date, trials have not been extensive enough to obtain complete performance and cost data, nor to establish the technical and economic feasibility of collecting and transporting the residues (bales or chopped residues) commercially.

Whether the crop residues are used as boiler fuel, feedstocks for gasification, or other conversion processes, the gathering, drying, transport and storage needs are similar.

We have used several critical figures and assumptions (moisture %, baler, chopper and densifier efficiencies) to get the target costs of USD$ 8/t (for residues with a density of 300 kg/m^3) or US$ 4.3/t (for residues with a density of 200 kg/m^3).

The conditions in the Cauca Valley appear generally favourable to the exploitation of cane residues in the production of energy. The round the year production of cane reduces the capital cost per unit of material collected and transported and minimises the need to store residues for long periods. In general, field conditions are favourable to the operation of field equipment. Cane fields close to the power plant reduces the transport distance and makes it easier and less expensive to use field trash for biomass fuel. The dense concentration of cane round the factories minimises transport distances.

The residues chopping system is a novel practice, that does not have any precedents as a formal and continuous operation in other countries where sugar cane is cultivated.

Operations	For Scenarios 1 and 3⁽¹⁾	For Scenarios 2 and 4⁽²⁾
Price of trash	US$ 0.5/ton	US$ 0.5/ton
Windrowing	No	Yes (US$ 0.4/t)
Baler and Tractor Production	50 tons/hour	30 tons/hour
Twine	US$ 1.0/ton⁽³⁾	US$ 1.5/ton⁽³⁾
Chopper production	50 tons/hour	30 tons/hour
Densifier production	60 tons/hour	30 tons/hour
Density of residues	0.300 ton/m^3	0.200 ton/m^3
Moisture of residues	35% (4337 BTU/lb)	65.8% (2803 BTU/lb)
Transportation cost	US$ 3.32/ton	US$ 5.0/ton
Target total cost	US$ 8/ton residues	US$ 4.3/ton residues

(1) Detailed calculations in Appendix C
(2) Using the relations presented in Appendix C and working with a worksheet
(3) Only for Scenarios 1 and 2

TABLE 2
Preliminary estimated costs of operations in field, per ton trash*

Area	Cost Components	Cost per ton of residues (US$ /t) scenarios			
		Baled		Chopped	
		1	2	3	4
Farmer	Price of trash	-0.5	0.5	-0.5	0.5
	Windrowing	0	0.4	0	0.4
Cane trash	Baling	2.9	3.4	-	-
Harvesting	Twine	1.0	1.5	-	-
	Chopping	-	-	3.1	3.6
	Densification	-	-	0.7	0.9
Partial Cost 1		**3.4**	**5.8**	**3.3**	**5.4**
Hauling	Loading	1.0	1.2	0.5	0.8
	Transportation	2.5	3.8	3.3	5.0
	Unloading	0.5	0.5	0.5	0.5
Partial Cost 2		**4.0**	**5.5**	**4.3**	**6.3**
Total Cost		**7.4**	**11.3**	**7.6**	**11.7**
	US$/MBTU	0.85**	1.30	0.88	1.35
	US$/GJ	0.81***	1.23	0.83	1.28
Target Cost	**US$/t**	**[8.0]**	**[4.3]**	**[8.0]**	**[4.3]**

* For computational procedures see Appendix C.

**

$$\frac{\text{US\$ } 7.4}{\text{t x } 1000 \text{ K/t x lb/}0.500 \text{ kg x } 4337 \text{ BTU/lb x } 10^{-6} \text{ MBTU/BTU}}$$

***

$$\frac{\text{US\$ } 0.85}{\text{MBTU x } 10^{6} \text{ BTU/MBTU x } 1055 \text{ J/BTU x } 1 \text{ GJ/}10^{9}\text{J}}$$

7. APPENDIX 1C

FINAL REPORT-SRDC PROJECT BS157S "REMOVAL OF EXTRANEOUS MATTER IN SUGAR MILLS FOR CO-GENERATION OF POWER AND REDUCTION OF CANE LOSS"

By D R Ridge and P A Hobson

Executive Summary:

Baling of trash and tops in the field did not appear to be an economic proposition compared to using current harvesting equipment for collection of trash in the field by reducing cleaning efficiency.

3.11 Investigation of baling as an option for transporting trash to the mill

The practice of baling trash and tops following green cane harvesting is common in the Rocky Point area and data was obtained from two large scale operators on capital, maintenance and operating costs for raking, baling, loading and transport. These are summarised as $ per tonne of dry trash and tops (10% moisture) in table 3.

TABLE 3.3
Costs of raking, baling, loading and transport of trash and tops in the Rocky Point mill area

Operation	Cost component	$/tonne
Baling	Maintenance	4.82
	Wages	1.18
	Fuel	0.59
	Twine	2.35
	Capital	5.76
Raking and loading	Maintenance	0.24
	Wages	2.82
	Fuel	0.35
	Capital	3.24
Cartage		4.7
Total		**26.05**

Feasibility of baling as an option for transporting trash to the mill

The data in table 3.3 indicates a cost of approximately $26 per tonne for baling and transport of tops and trash from the field. For the reference case it was assumed that approximately 11% of the tops and trash is present in the cane supply after starting with 25% in standing cane in the field. This is equivalent to approximately 19 t ha^{-1} of fresh trash blanket in the field (at 60% moisture) or 8.4 t ha^{-1} at 10% moisture.

Costs of baling and transport assuming 90% recovery would be $197 per hectare. When compared to the costs of infield and mill transport of approximately $87 per hectare (assuming field transport costs of $2.50 per tonne, mill transport costs of $2 per tonne including the bin tare weight and a 90% recovery of the additional trash). It is obvious from these figures that baling is not a cost competitive means of collecting trash from the field. The only proviso is that loss in capacity in field and mill transport is uncertain at very high trash levels and this requires further field validation.

8. APPENDIX 2

OMNITRAC Australia

Track systems for the future

A division of Hunter Hitech Pty Ltd - ABN 53 001 920 038
PO Box 3078, Valentine NSW 2280 - Ph: (02) 4946 6188 - Fax: (02) 4946 6288
Email: hunterhitech@hunterlink.net.au

FAX

		DATE:	6 Jun 00
TO:	Southern Sugar Experimental Station	*FROM:*	Brad Scott
ATTENTION:	Brian Robotham	*OUR REF:*	BS-2894
YOUR REF:	Telecon 5.6.00	*PAGES:*	2

QUOTATION No: 00492-B

We hereby submit our quotation for the supply of the following Cane Bin Tractor and Trailer Transport System.

ITEM 1: One (1) off Caterpillar Challenger 65A second hand track machine, modified as per Omnitrac drawing CV39128 dated 2.6.00.

- Unit will have a standard 285 HP Caterpillar engine and transmission (checked and overhauled if necessary), and a new forward mounted driver's cabin complete with all controls and instrumentation.
- Omnitrac positive drive rubber track system CV39128 will be fitted to drive train assembly, giving very good tractive effort or draw bar pull.
- Excellent turning will be achieved from fields to headland roads due to dead axle positioning and hydraulic cylinder pivot arrangement on track assembly.
- Unit will be fitted with an EHS partial lift and side tipping 32m^3 cane bin. Dimensions are - 2500 wide x 2900 high x 4500 long.
- Unit will be fully tested, painted, complete and ready for use.

PRICE - ITEM 1: $263,200.00 (Two hundred and sixty three thousand, two hundred dollars only) + GST

ITEM 2: One (1) off Trailed EHS partial lift and side tipping 32m^3 cane bin 2500 wide x 2900 high x 4500 long, connected through a chassis system to the above tractor.

- Unit will be fitted with an Omnitrac positive drive rubber track system TS3286, utilising drive arrangement for two (2) multi-plate, oil immersed, spring applied, hydraulic release, fully enclosed brake system.
- Brakes are dynamic to meet regulations for a trailer.
- Tracks will be non-powered on trailer.
- Hydraulics for bin on tractor and trailer will be provided from the tractor’s hydraulics.
- Positioning and connection of the track system under the trailer will ensure limited damage or disturbance to headlands or roadways when turning.
- Unit will be fully tested, painted and ready for use.

PRICE - ITEM 2: $136,660.00 (One hundred and thirty six thousand, six hundred and sixty dollars only) + GST

TOTAL PRICE - Items 1 & 2: $399,860.00 + GST

PAYMENT TERMS: At completion of final agreed design and order placement, a direct deposit into our nominated bank account for the full amount will be required, before the project will proceed.

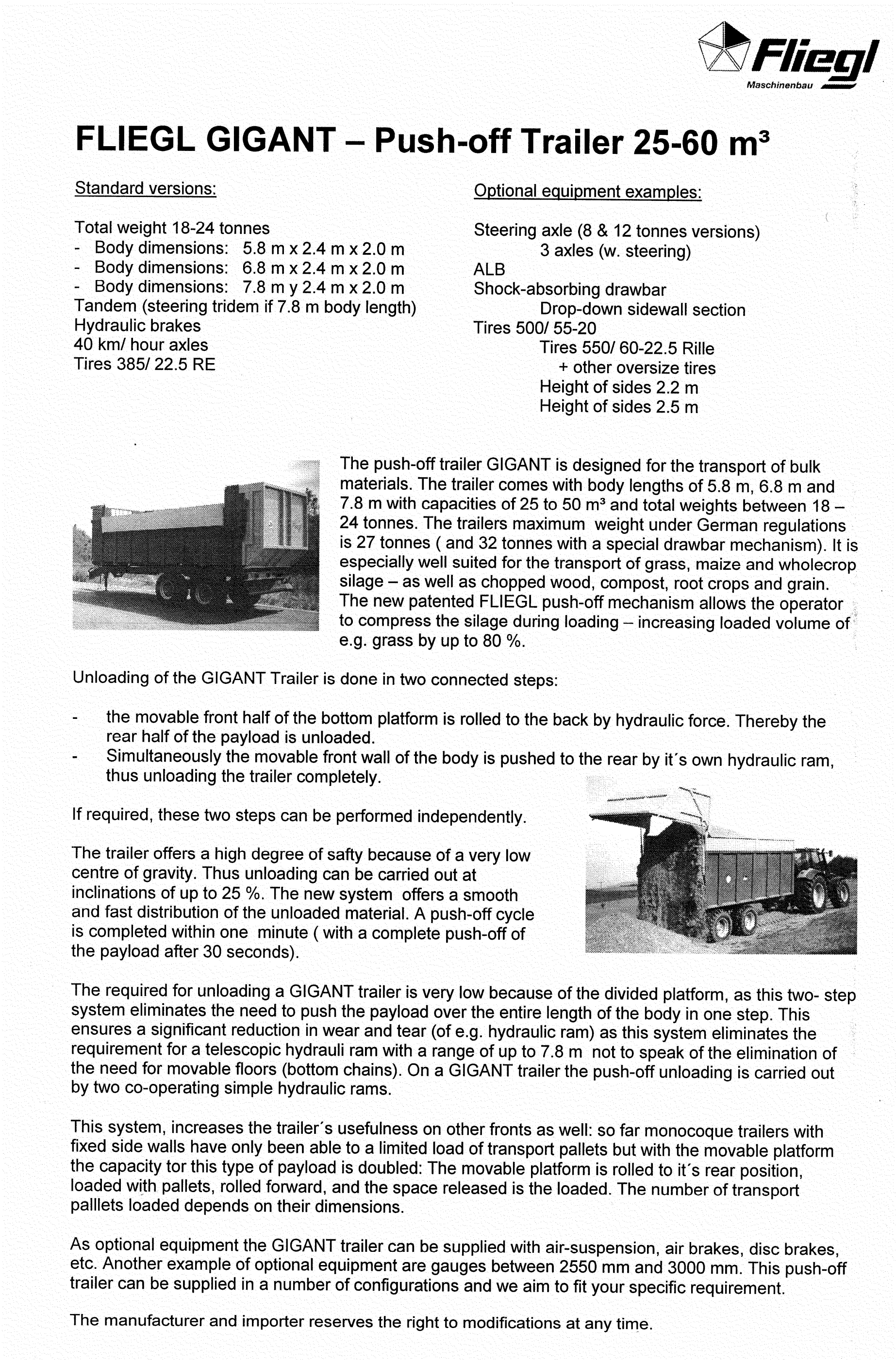
DELIVERY: As previously explained, Omnitrac USA have been working with Caterpillar Inc for some time on a new Challenger Series machine with positive drive tracks. Omnitrac own a Challenger 65A machine which they are currently fitting out with the same system as nominated in Item 1 above, and detailed in drawings in your possession.
Subject to negotiations, tractor delivery could be 16-18 weeks.
Subject to negotiations, trailer delivery could be 12-16 weeks.

We trust the above meets your requirements and look forward to supplying any further information which may be needed.

Yours sincerely

Brad Scott
Managing Director

9. APPENDIX 3



FLIEGL GIGANT – Push-off Trailer 25-60 m^3

Standard versions:

Total weight 18-24 tonnes
- Body dimensions: 5.8 m x 2.4 m x 2.0 m
- Body dimensions: 6.8 m x 2.4 m x 2.0 m
- Body dimensions: 7.8 m y 2.4 m x 2.0 m

Tandem (steering tridem if 7.8 m body length)
Hydraulic brakes
40 km/ hour axles
Tires 385/ 22.5 RE

Optional equipment examples:

Steering axle (8 & 12 tonnes versions)
3 axles (w. steering)
ALB
Shock-absorbing drawbar
Drop-down sidewall section
Tires 500/ 55-20
Tires 550/ 60-22.5 Rille
+ other oversize tires
Height of sides 2.2 m
Height of sides 2.5 m

The push-off trailer GIGANT is designed for the transport of bulk materials. The trailer comes with body lengths of 5.8 m, 6.8 m and 7.8 m with capacities of 25 to 50 m^3 and total weights between 18 – 24 tonnes. The trailers maximum weight under German regulations is 27 tonnes (and 32 tonnes with a special drawbar mechanism). It is especially well suited for the transport of grass, maize and wholecrop silage – as well as chopped wood, compost, root crops and grain. The new patented FLIEGL push-off mechanism allows the operator to compress the silage during loading – increasing loaded volume of e.g. grass by up to 80 %.

Unloading of the GIGANT Trailer is done in two connected steps:

- the movable front half of the bottom platform is rolled to the back by hydraulic force. Thereby the rear half of the payload is unloaded.
- Simultaneously the movable front wall of the body is pushed to the rear by it´s own hydraulic ram, thus unloading the trailer completely.

If required, these two steps can be performed independently.

The trailer offers a high degree of safty because of a very low centre of gravity. Thus unloading can be carried out at inclinations of up to 25 %. The new system offers a smooth and fast distribution of the unloaded material. A push-off cycle is completed within one minute (with a complete push-off of the payload after 30 seconds).

The required for unloading a GIGANT trailer is very low because of the divided platform, as this two- step system eliminates the need to push the payload over the entire length of the body in one step. This ensures a significant reduction in wear and tear (of e.g. hydraulic ram) as this system eliminates the requirement for a telescopic hydrauli ram with a range of up to 7.8 m not to speak of the elimination of the need for movable floors (bottom chains). On a GIGANT trailer the push-off unloading is carried out by two co-operating simple hydraulic rams.

This system, increases the trailer´s usefulness on other fronts as well: so far monocoque trailers with fixed side walls have only been able to a limited load of transport pallets but with the movable platform the capacity tor this type of payload is doubled: The movable platform is rolled to it´s rear position, loaded with pallets, rolled forward, and the space released is the loaded. The number of transport palllets loaded depends on their dimensions.

As optional equipment the GIGANT trailer can be supplied with air-suspension, air brakes, disc brakes, etc. Another example of optional equipment are gauges between 2550 mm and 3000 mm. This push-off trailer can be supplied in a number of configurations and we aim to fit your specific requirement.

The manufacturer and importer reserves the right to modifications at any time.

10. APPENDIX 4

Harvesting Considerations in Large Unburnt Crops: Where to from here?

by

Chris Norris, Senior Research Officer
BSES Bundaberg

While the increases in the power harvesters used by the Australian sugar industry have increased over the years, allowing significant increases in harvesting speed, the issue of product quality and the causes of poor product quality have not received the attention it could have received. The move towards green cane harvesting has bought a number of issues relating to machine performance into the limelight.

The rise in levels of extraneous matter associated with higher pour rates and difficult feed conditions are a significant issue when sugar quality is considered. Likewise, billet quality and the losses associated with the billeting process are also significant issues.

Research by the BSES agricultural engineering team on the feeding of green cane by harvesters, and on the losses associated with billeting are discussed in more detail in this article.

Problems with gathering and feeding cane

The current harvester design does not offer an appropriate solution to the problems of with harvesting large green crops. The increase in engine power and hence the power available to various systems (basecutter, feedrollers, chopper, etc) has allowed harvesters to achieve some improvement in the ability to process these large crops. It has not however, addressed the fundamental problems with the current designs, and the quality of the product being sent to the mill has continued to decline.

The problem is not confined to Australia. US Sugar in Florida is currently running trials examining the agronomic and economic aspects of green and burnt cane production systems. To date, their results have shown that the output of harvesters cutting large unburnt crops is significantly lower than the output achieved with large burnt crops. Field trial results quoted were that output of harvesters operating in 180-190 t/ha unburnt crops was only one third the output of the same harvesters operating in the same crop when burned. Other results presented indicated that in a 130 t/ha unburnt crop, machine productivity is approximately 60 to 70% of burnt cane productivity/machine. This drop in productivity is primarily related to inability of the machines to feed large green crops effectively.

Machines seen attempting to cut large green crops in Colombia (200-300 t/ha) were suffering the same problems of low productivity caused by inability to feed and constant choking that are experienced in high yielding areas in Australia. One mill owner spoken to in Colombia introduced Australian harvesters in the early 1990’s for a short period before reverting to full hand-cutting. The Legislation driven necessity to move to green cane harvesting has forced the mill to re-introduce a small “front” of new model 7700’s for the 2000 harvest. The anticipated output of the machines for the year is 22 t/engine hour. Operating in the same field conditions but in burnt cane, the anticipated harvesting rate is well over twice this figure, and more in-line Australian expectations of machine performance in large burnt crops.

An efficient means of mechanically cutting large crops green is yet to be commercialised.

Research addresses harvesting efficiency

Early work by Schembri and Garson from the Sugar Research Institute identified that harvesters typically operate in a "glut-starve" feed pattern (the cane feeds in gluts followed by a "gap" in the feed as the glut passes through the machine). The effect becomes more extreme as harvesting conditions become more adverse. Realising the issues in New South Wales and the Burdekin, the Sugar Research Development Corporation funded research by BSES in 1997 on Enhancing the Feeding of Green Cane.

The initial phases of this project included the instrumentation of the BSES/SRDC 7000 harvester, with data collection and video monitoring equipment. A prototype machine developed by Massey Ferguson in the early 1980's, the ZX11 (known as the 405 prototype), was also made available to the project by its owners (Mahommad Brothers, Gordonvale) and instrumented in a similar fashion. A series of field trials using the harvesters were then conducted in north Queensland and the Burdekin under a range of crop conditions.

This research identified the processes that occur during the feeding of cane into the harvester, and the clearly demonstrated the magnitude of the problem in current machines. As forward speed increased, the severity of the overloads in the machine increased as it processes the gluts of cane passing through it. Billet damage typically increased and trash and dirt levels rose as harvesting conditions become more difficult. Analysis of the data gathered demonstrated that aspects of the gathering and feeding systems which impacted on the feeding capacity of the harvester included:

- geometry of spirals (ie diameter, length, taper, angle to crop);
- opportunities for bridging of cane stalks during initial gathering (including interactions between the cane and the dual gathering spirals), and transfer of cane along the throat of the machine;
- feeding of the cane across the basecutters and into the feedtrain of the machine;
- the "length" of unassisted feed between the first "disturbance" of the cane by the spirals and when positive feed is achieved in the feedtrain.

Clearly, significant potential existed to enhance the performance of the harvester if the issues identified could be addressed. It was believed that whilst some issues could be addressed with relatively minor modifications (eg the geometry of the gathering spirals), to address the major problems a more fundamental redesign of the forward sections of the harvester was required. Coincidentally, in 1998, BSES embarked on the development of a harvester to be capable of harvesting "high density" or close-row sugarcane. The understanding achieved from the research into enhancing the feeding of green cane during harvesting was pivotal in the development of the close-row harvester. The machine was based on a standard Austoft 7700, but incorporated significant changes to the gathering and feeding systems. After some initial “fine-tuning” comparative trials were conducted between the close-row machine and the standard BSES 7000 in a heavily lodged crop of dual-row Q124. Figures 1 and 2 show data relating to chopper pressure and feedtrain roller opening for these trials.

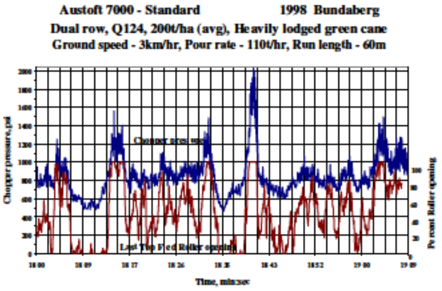


Fig 1: Chopper Pressure and top roller opening for standard harvester, 200 t/ha Q124, 110 t/h

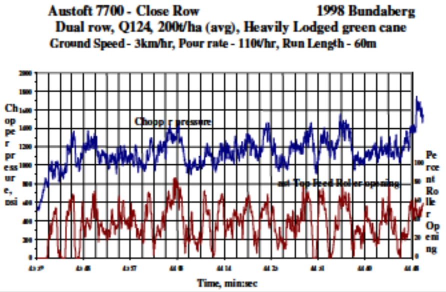


Fig 2: Chopper Pressure and top roller opening for close row harvester, 200 t/ha, Q124, 110 t/h.

The dramatic improvement in evenness of feed by the close-row harvester was also reflected in improvements to billet quality. The standard machine achieved an average billet quality of 26% sound billets in these trials, whereas the close-row machine averaged 49% sound billets. The machine also operated at higher pour rates under adverse conditions than standard machines, with higher engine power.

Modified gathering fronts

As the initial goal of the research was to develop modifications to standard machines to enhance performance, it was decided to develop retro-fit fronts to suit standard harvesters. These fronts incorporated a development of the geometry of the gathering spirals used on the close-row harvester, however no changes were made to any of the forward feed components. After promising trials in the Bundaberg district, the close-row harvester and the modified fronts for standard machines were trialed on a grower’s property in northern NSW. The outputs of the chopper pressure transducers from the machines is presented in Figures 3, 4 and 5. The length of run in each of the graphs is approximately 220 m.

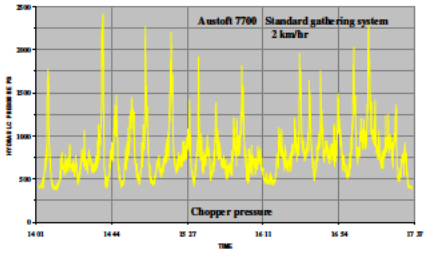


Figure 3: Chopper Pressure, standard Austoft 7700, Pimlico, 290 t/ha crop, 2kph. (220m sample length)

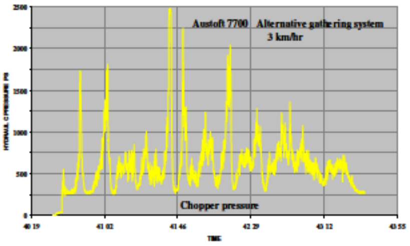


Figure 4: Chopper Pressure, standard Austoft 7700, modified gathering fronts, Pimlico, 290 t/ha crop, 3kph.

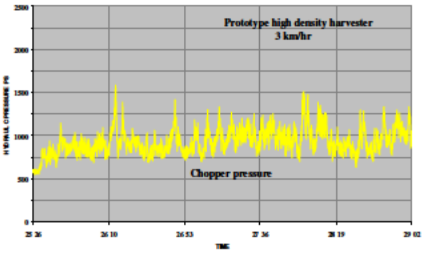


Figure 5: Chopper Pressure, Austoft 7700, "close row" harvester, Pimlico, 290 t/ha crop, 3kph.

Further data from these trials is presented in Table 1.

TABLE 1
Damage assessment and EM results from northern NSW trials

Harvester	Variety	Pour rate t/h	Billet damage % sound	Trash
Standard front[a]	Q124	90	55.3[f]	4.2
New front[b]	Q124[d]	90	52.2[f]	3.2
Close row[c]	Q124[d]	90	54.1[f]	2.8
Standard front[a]	Q170[e]	98	46.8[f]	3.6
New front[b]	Q170[e]	147	44.5[f]	2.1
Close row[c]	Q170[e]	147	42.7[f]	1.1

Notes:

a: 1991 Austoft 7700 – Standard front setup, three blade
b: 1991 Austoft 7700 – Retrofitted alternative gathering system to above machine.
c: 1990 Austoft 7700 – Modified close row, fitted with Austoft 2 blade standard choppers.
d: 2nd ratoon 2 year old green cane – 160t/ha
e: 2nd ratoon 2 year old green cane – 298 t/ha
f: Because different chopper systems are fitted, comparisons between machines should be avoided.

Speed: In these trials, improved gathering achieved through the fitting of the new fronts allowed the machine to operate at a higher speed than the standard machine in Q124. The close-row machine had the potential to operate at still higher speeds , but was limited by available engine power and elevator capacity. The harvesting rates achieved by the Close Row harvester in the Q170 would be similar to harvesting rates expected in this cane when burnt.

Plate 1 - BSES modified fronts on Austoft 7700 harvester
The harvester is operating in a 160 t/ha crop of Q124

Extraneous matter: Extraneous matter (EM) levels are usually strongly related to pour rate. A quite dramatic increase in EM levels would normally be associated with an increase in pour rate. The machines in the trial were running near identical cleaning system specifications, including matched fan speeds. Lower EM levels achieved by the standard machine with modified fronts, and the close-row machine, can be explained by the more even feed achieved by these machines. This is supported by analysis of the logged data from the harvesters.

Billet damage: Billet damage for all machines was similar, which was not expected. The slight increase in damage between the new fronts and the standard machine is not significant, but difficult to explain given the other indicators of enhanced evenness of feed. Due to mechanical damage, the after-market chopper drums, which had been fitted to the close-row harvester, were replaced by a set of original Austoft two blade units. Hence, comparative analysis of billet quality between machines should not be undertaken.

Summary of harvester feeding issues:

From the results presented, and associated research, the following conclusions can be drawn:

- The design of current harvesters has not been optimised for the harvesting of large green crops. Considerable damage occurs to the cane and the cane stool during gathering and feeding. The machines feed in a “glut – starve” mode which induces a cyclic loading pattern on the chopper system and the cleaning system, causing further deterioration in product quality. Increasing available power to the harvester systems increases harvesting rate but does not address the fundamental issues relating the processes which occur as cane is gathered and fed into the harvester.

- Improving the gathering of the current harvester by the retro-fitting of fronts of similar design to those developed in this research program can be expected to make incremental but significant improvements in the performance of a harvester operating in heavy unburnt crops. Further testing of these fronts will be undertaken this year and discussions have been held with potential manufacturers.

- Further significant gains can be achieved by more extensive changes to the design of the harvester. The work with the close-row harvester has demonstrated that improved design can enhance both harvesting rate and improve product quality whilst reducing the required power. Further work in this area will undoubtedly result in significant additional gains, including improvements in dirt rejection by the machine.

Conclusion:

Feeding of large unburnt crops is difficult relative to harvesting the same crop burnt. The research undertaken by the BSES Engineering group has led to a significantly better understanding of the aspects of harvester design which impact on the efficiency with which large unburnt crops can be harvested.

Clearly, the design of the current harvester is not optimal for the harvesting and processing of large unburnt crops, however optimisation of the current harvester setup is important to achieve acceptable results. Options such as the new fronts which have been developed by BSES offer significant advantages to operators faced with the necessity to harvest large unburnt crops. The design of these fronts is being finalised for field testing of a number of units early in the 2000 crushing season. It is anticipated they will then be available from a supplier of after-market equipment.

Continued research on machine design to enhance performance in large unburnt crops is essential. The trials undertaken with the high density harvester and the BSES fronts have given clear indications that further significant gains can be made, with appropriate Research and Development.

Acknowledgments:

We would like to thank Yusof Mahommad Gordonvale and Warren, Wayne and Graig Rogers from Pimlico (NSW) for the use of their machines during the test programs run as part of this project. We would also like to thank the various farmers on whose properties tests were carried out.

11. APPENDIX 5

Effects of Row Spacings and machinery track widths on area of field compacted

Figure - Current system

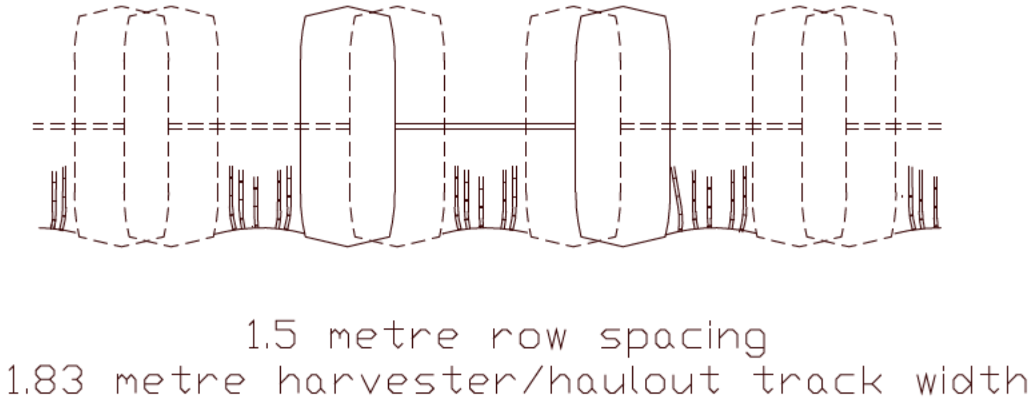
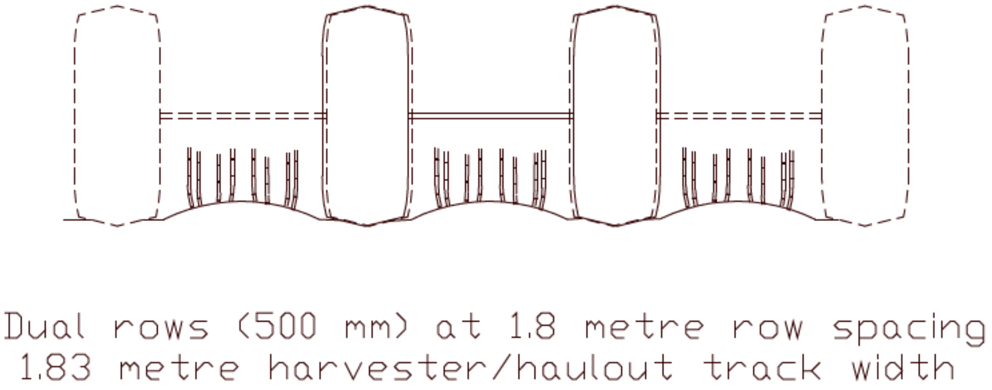


Figure - Dual row on 1.8 m centres



System	Assumptions	Driving Error	% of Area Compacted
1.5 m rows (Conventional)	Tyre width = 622 mm (24.5 x 32), wheel centres 1.9 m	No error ± 200 mm	68% 95%
1.8 m rows (Dual Rows)	As above	No error	28%
		± 200 mm	55%
	With vehicle guidance	± 25 mm	31%
HDP 2.1 m beds	Haulout Tractor tyres (14.9 x 32)	No error	18%
	wheel centres 2.1 m With vehicle guidance	± 25 mm	20%

12. APPENDIX 6

TABLE 1A. BURNT CANE, BASE CASE - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout					**Haul**	**0.75 km**
COST /TONNE BURNT CANE EQUIVALENT				**$5.50**	**TOTAL CAPEX**	**$1,197,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.6	0.46	1.06
	Fuel&Oil	0.19	0.22	0.41
	Repairs	0.2	0.13	0.33
	Subtotal	0.99	0.81	1.80
	Total	$2.65	$2.75	$5.40
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.63	0.52	1.15
	Fuel&Oil	0.22	0.25	0.47
	Repairs	0.2	0.13	0.33
	Subtotal	1.05	0.90	1.95
	Total	$2.71	$2.84	$5.55
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.62	0.50	1.12
	Fuel&Oil	0.21	0.24	0.45
	Repairs	0.20	0.13	0.33
	Subtotal	1.03	0.87	1.90
	Total	**$2.69**	**$2.81**	**$5.50**

Assumptions:			
Haul Distance -	0.75 km		
Unloading time - 1 min			
Turning Time - 1.5 min			
Speed unloaded	24 km/h		
Speed loaded	22.5 km/h		
Harvester fuel (l/hr)			
In-Use	46/48		
Idle	20		
Infield (l/hr)			
In-Use	26		
Idle	10		
Infield Sizes	32 m^3		
Cane Bulk Density	380 kg/m^3		
Load Carried	12 tonnes		

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	83.5	71.9	75.96
Total harvest time (hr/day)	5.3	6.2	5.9
Harvester waiting time (min/day)	17.8	9.1	12
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$500,000
2 Infields	$697,000
Gross Capex	$1,197,000

TABLE 1B. BURNT CANE, BASE CASE - TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT	**$6.01**	**TOTAL CAPEX**	**$1,197,000**

Crop Size 150tpha

		Harvester	*Infield*	*Total*
Fixed Costs				
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.68	0.59	1.27
	Fuel&Oil	0.22	0.29	0.51
	Repairs	0.2	0.30	0.50
	Subtotal	1.1	1.18	2.28
	Total	$2.76	$3.12	$5.88

Crop Size 100tpha

		Harvester	*Infield*	*Total*
Fixed Costs				
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.73	0.67	1.4
	Fuel&Oil	0.25	0.33	0.58
	Repairs	0.2	0.30	0.50
	Subtotal	1.18	1.30	2.48
	Total	$2.84	$3.24	$6.08

Assumptions:	
Cart Distance - 2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	46/48
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	32 m^3
Cane Density	Bulk 380 kg/m^3
Load Carried	12 tonnes

Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha

		Harvester	*Infield*	*Total*
Fixed Costs				
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.71	0.64	1.35
	Fuel&Oil	0.24	0.32	0.56
	Repairs	0.20	0.30	0.50
	Subtotal	1.15	1.26	2.41
	Total	**$2.81**	**$3.20**	**$6.01**

HARVESTER PERFORMANCE

Tpha	150	100	*Weighted av*
Tonnes per engine hour	63.6	56.7	59.12
Total harvest time (hr/day)	7.1	8.0	7.7
Harvester waiting time (min/day)	122	113	116
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX

Harvester	$500,000
2 Infields	$697,000
Gross Capex	$1,197,000

TABLE 1C. BURNT CANE, BASE CASE - TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $7.35 **TOTAL CAPEX $1,197,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.94	1	1.94
	Fuel&Oil	0.29	0.46	0.75
	Repairs	0.2	0.70	0.90
	Subtotal	1.43	2.16	3.59
	Total	$3.09	$4.10	$7.19

Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	1	1.1	2.1
	Fuel&Oil	0.33	0.5	0.83
	Repairs	0.2	0.70	0.90
	Subtotal	1.53	2.30	3.83
	Total	$3.19	$4.24	$7.43

Assumptions:

Cart Distance - 5 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	27.2 km/hr
Speed loaded	24.5 km/hr
Harvester fuel (l/hr)	
In-Use	46/48
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	32 m^3
Cane Bulk Density	380 kg/m^3
Load Carried	12 tonnes

Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha

Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.98	1.07	2.04
	Fuel&Oil	0.32	0.49	0.80
	Repairs	0.20	0.70	0.90
	Subtotal	1.50	2.25	3.75
	Total	**$3.16**	**$4.19**	**$7.35**

HARVESTER PERFORMANCE

Tpha	150	100	*Weighted av*
Tonnes per engine hour	40.6	37.6	38.65
Total harvest time (hr/day)	11.2	12.1	11.8
Harvester waiting time (min/day)	372	363	366
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX

Harvester	$500,000
2 Infields	$697,000
Gross Capex	$1,197,000

TABLE 2A. GREEN CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $6.01 — **TOTAL CAPEX $1,217,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.69	0.61	1.3
	Fuel&Oil	0.38	0.3	0.68
	Repairs	0.25	0.24	0.49
	Subtotal	1.32	1.15	2.47
	Total	$2.98	$3.09	$6.07
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.67	0.58	1.25
	Fuel&Oil	0.36	0.28	0.64
	Repairs	0.25	0.24	0.49
	Subtotal	1.28	1.10	2.38
	Total	$2.94	$3.04	$5.98
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.68	0.59	1.27
	Fuel&Oil	0.37	0.29	0.65
	Repairs	0.25	0.24	0.49
	Subtotal	1.29	1.12	2.41
	Total	**$2.95**	**$3.06**	**$6.01**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		61.9	65.1	63.98
Total harvest time (hr/day)		7.3	6.9	7.0
Harvester waiting time (min/day)		0	0	0
Turning lost time (min)		89	133	
Pour rates		81 tcph	100 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$697,000	
Steel track infield			$0	
Gross Capex	$1,217,000			

Assumptions:

Cart Distance -0.75 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	24 km/h
Speed loaded	22.5 km/h
Harvester fuel (l/hr)	
In-Use	66
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	35.5 m^3
Cane Bulk Density	340 kg/m^3
Load Carried	12 tonne
Cane Equivalent	11.25 t

TABLE 2B. GREEN CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $6.68 **TOTAL CAPEX $1,197,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.76	0.71	1.47
	Fuel&Oil	0.4	0.35	0.75
	Repairs	0.25	0.60	0.85
	Subtotal	1.41	1.66	3.07
	Total	$3.07	$3.60	$6.67
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.77	0.73	1.5
	Fuel&Oil	0.39	0.35	0.74
	Repairs	0.25	0.60	0.85
	Subtotal	1.41	1.68	3.09
	Total	$3.07	$3.62	$6.69
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	0.77	0.72	1.49
	Fuel&Oil	0.39	0.35	0.74
	Repairs	0.25	0.60	0.85
	Subtotal	1.41	1.67	3.08
	Total	**$3.07**	**$3.61**	**$6.68**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		53	52.3	52.55
Total harvest time (hr/day)		8.5	8.7	8.6
Harvester waiting time (min/day)		74	105	94
Turning lost time (min)		89	133	
Pour rates		140 tcph	135 tcph	
CAPEX				
Harvester			$500,000	
2 Infields			$697,000	
Steel track infield			$0	
Gross Capex	$1,197,000			

Assumptions:

Cart Distance -2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	66
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	35.5 m^3
Cane Bulk Density	340 kg/m^3
Load Carried	12 tonne
Cane Equivalent 11.25 t	

TABLE 2C. GREEN CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout

5km Haul

COST /TONNE BURNT CANE EQUIVALENT **$8.56**

TOTAL CAPEX **$1,217,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	1.06	1.18	2.24
	Fuel&Oil	0.47	0.53	1
	Repairs	0.25	1.45	1.70
	Subtotal	1.78	3.16	4.94
	Total	$3.44	$5.10	$8.54
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	1.07	1.2	2.27
	Fuel&Oil	0.46	0.54	1
	Repairs	0.25	1.45	1.70
	Subtotal	1.78	3.19	4.97
	Total	$3.44	$5.13	$8.57
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.89	3.5
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	1.94	3.6
Variable Costs				
	Wages	1.07	1.19	2.26
	Fuel&Oil	0.46	0.54	1.00
	Repairs	0.25	1.45	1.70
	Subtotal	1.78	3.18	4.96
	Total	**$3.44**	**$5.12**	**$8.56**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		35.3	34.9	35.04
Total harvest time (hr/day)		12.9	13.1	13.0
Harvester waiting time (min/day)		341	372	361
Turning lost time (min)		89	133	
Pour rates		81 tcph	100 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$697,000	
Steel track infield			$0	
Gross Capex	$1,217,000			

Assumptions:

Cart Distance -5 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	27.2 km/h
Speed loaded	24.5 km/h
Harvester fuel (l/hr)	
In-Use	66
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	35.5 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	12 tonne
Cane Equivalent	11.25 t

TABLE 3A. SHREDDED TRASH - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout						**0.75 km Haul**
COST /TONNE BURNT CANE EQUIVALENT				**$6.57**	**TOTAL CAPEX**	**$1,259,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	0.76	0.71	1.47
	Fuel&Oil	0.49	0.36	0.85
	Repairs	0.3	0.15	0.45
	Subtotal	1.55	1.22	2.77
	Total	$3.32	$3.24	$6.56
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	0.76	0.72	1.48
	Fuel&Oil	0.5	0.36	0.86
	Repairs	0.3	0.15	0.45
	Subtotal	1.56	1.23	2.79
	Total	$3.33	$3.25	$6.58
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	0.76	0.72	1.48
	Fuel&Oil	0.50	0.36	0.86
	Repairs	0.30	0.15	0.45
	Subtotal	1.56	1.23	2.78
	Total	**$3.33**	**$3.25**	**$6.57**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	53.2	52.8	52.94
Total harvest time (hr/day)	8.5	8.6	8.6
Harvester waiting time (min/day)	0	0	0
Turning lost time (min)	89	133	
Pour rates	66 tcph	74 tcph	

CAPEX		
Harvester		$535,000
2 Infields		$724,000
Steel track infield		$0
Gross Capex	$1,259,000	

Assumptions:

Cart Distance -0.75 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	24 km/h
Speed loaded	22.5 km/h
Harvester fuel (l/hr)	
In-Use	74
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	39.5 m^3
Cane Bulk Density	300 kg/m^3
Load Carried	11.8 tonne
Cane Equivalent	10 tonne

TABLE 3B. SHREDDED TRASH - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $7.08 **TOTAL CAPEX $1,259,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	0.83	0.83	1.66
	Fuel&Oil	0.51	0.39	0.9
	Repairs	0.3	0.36	0.66
	Subtotal	1.64	1.58	3.22
	Total	$3.41	$3.60	$7.01
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	0.86	0.87	1.73
	Fuel&Oil	0.52	0.41	0.93
	Repairs	0.3	0.36	0.66
	Subtotal	1.68	1.64	3.32
	Total	$3.45	$3.66	$7.11
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	0.85	0.86	1.71
	Fuel&Oil	0.52	0.40	0.92
	Repairs	0.30	0.36	0.66
	Subtotal	1.67	1.62	3.29
	Total	**$3.44**	**$3.64**	**$7.08**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		47	45.3	45.90
Total harvest time (hr/day)		9.6	10.0	9.9
Harvester waiting time (min/day)		69	88	81
Turning lost time (min)		89	133	
Pour rates		66 tcph	74 tcph	
CAPEX				
Harvester			$535,000	
2 Infields			$724,000	
Steel track infield			$0	
Gross Capex	$1,259,000			

Assumptions:

Cart Distance -2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	74
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	39.5 m^3
Cane Density	Bulk 300 kg/m^3
Load Carried	11.8 tonne
Cane Equivalent 10 tonne	

TABLE 3C. SHREDDED TRASH - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $8.32 **TOTAL CAPEX $1,259,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	1.18	1.37	2.55
	Fuel&Oil	0.59	0.6	1.19
	Repairs	0.3	0.87	1.17
	Subtotal	2.07	2.84	4.91
	Total	$3.84	$4.86	$8.70
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	1.21	1.42	2.63
	Fuel&Oil	0.6	0.62	1.22
	Repairs	0.3	0.18	0.48
	Subtotal	2.11	2.22	4.33
	Total	$3.88	$4.24	$8.12
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.72	1.97	3.69
	Incidentals	0.05	0.05	0.10
	Subtotal	1.77	2.02	3.79
Variable Costs				
	Wages	1.20	1.40	2.60
	Fuel&Oil	0.60	0.61	1.21
	Repairs	0.20	0.87	0.72
	Subtotal	2.00	2.89	4.53
	Total	**$3.77**	**$4.91**	**$8.32**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		31.2	30	30.42
Total harvest time (hr/day)		14.7	15.0	14.9
Harvester waiting time (min/day)		371	390	383
Turning lost time (min)		89	133	
Pour rates		66 tcph	74 tcph	
CAPEX				
Harvester			$535,000	
2 Infields			$724,000	
Steel track infield			$0	
Gross Capex	$1,259,000			

Assumptions:

Cart Distance -5 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	21.8 km/h
Speed loaded	20 km/h
Harvester fuel (l/hr)	
In-Use	74
Idle	20
Infield (l/hr)	
In-Use	32
Idle	10
Infield Sizes	39.547.5 m^3
Cane Density	Bulk 300 kg/m^3
Load Carried	11.8 tonne
Cane Equivalent	10 tonne

TABLE 4A. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$6.02** **TOTAL CAPEX** **$1,217,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	0.68	0.59	1.27
	Fuel&Oil	0.23	0.29	0.52
	Repairs	0.2	0.24	0.44
	Subtotal	1.11	1.12	2.23
	Total	$2.83	$3.06	$5.89
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	0.73	0.67	1.4
	Fuel&Oil	0.26	0.33	0.59
	Repairs	0.2	0.24	0.44
	Subtotal	1.19	1.24	2.43
	Total	$2.91	$3.18	$6.09
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	0.71	0.64	1.35
	Fuel&Oil	0.25	0.32	0.57
	Repairs	0.20	0.24	0.44
	Subtotal	1.16	1.20	2.36
	Total	**$2.88**	**$3.14**	**$6.02**

HARVESTER PERFORMANCE

Tpha	150	100	*Weighted av*
Tonnes per engine hour	63.8	56.8	59.25
Total harvest time (hr/day)	7.0	7.9	7.6
Harvester waiting time (min/day)	121	112	115
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX

Harvester	$520,000
2 Infields	$697,000
Steel track infield	$0
Gross Capex	$1,217,000

Assumptions:

Cart Distance -0.75 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	24 km/h
Speed loaded	22.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	31.7 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.5 t

TABLE 4A. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout

2 km Haul

TOTAL CAPEX $1,217,000

COST /TONNE BURNT CANE EQUIVALENT				**$7.02**
Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	0.88	0.9	1.78
	Fuel&Oil	0.29	0.22	0.51
	Repairs	0.2	0.60	0.80
	Subtotal	1.37	1.72	3.09
	Total	$3.09	$3.66	$6.75
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	0.94	1	1.94
	Fuel&Oil	0.31	0.46	0.77
	Repairs	0.2	0.60	0.80
	Subtotal	1.45	2.06	3.51
	Total	$3.17	$4.00	$7.17
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	0.92	0.97	1.88
	Fuel&Oil	0.30	0.38	0.68
	Repairs	0.20	0.60	0.80
	Subtotal	1.42	1.94	3.36
	Total	**$3.14**	**$3.88**	**$7.02**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		44	40.5	41.73
Total harvest time (hr/day)		10.3	11.2	10.9
Harvester waiting time (min/day)		319	310	313
Turning lost time (min)		89	133	
Pour rates		140 tcph	135 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$697,000	
Steel track infield			$0	
Gross Capex	$1,217,000			

Assumptions:

Cart Distance -2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	31.7 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	8 tonne
Cane Equivalent 6.5 t	

TABLE 4C. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **5km Haul**

COST /TONNE BURNT CANE EQUIVALENT $9.79 — **TOTAL CAPEX $1,217,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	1.43	1.76	3.19
	Fuel&Oil	0.41	0.75	1.16
	Repairs	0.2	1.45	1.65
	Subtotal	2.04	3.96	6.00
	Total	$3.76	$5.90	$9.66
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	1.49	1.85	3.34
	Fuel&Oil	0.43	0.78	1.21
	Repairs	0.2	1.45	1.65
	Subtotal	2.12	4.08	6.20
	Total	$3.84	$6.02	$9.86
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.89	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	1.94	3.66
Variable Costs				
	Wages	1.47	1.82	3.29
	Fuel&Oil	0.42	0.77	1.19
	Repairs	0.20	1.45	1.65
	Subtotal	2.09	4.04	6.13
	Total	**$3.81**	**$5.98**	**$9.79**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		25	24	24.35
Total harvest time (hr/day)		18.2	19.0	18.7
Harvester waiting time (min/day)		791	782	785
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$697,000	
Steel track infield			$0	
Gross Capex	$1,217,000			

Assumptions:

Cart Distance -5 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	27.2 km/h
Speed loaded	24.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	31.7 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.5 t

TABLE 5A. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $7.01 **TOTAL CAPEX $1,565,500**

		Harvester	Infield	Total
Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	0.59	0.68	1.27
	Fuel&Oil	0.2	0.32	0.52
	Repairs	0.2	0.29	0.49
	Subtotal	0.99	1.29	2.28
	Total	$2.71	$4.18	$6.89
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	0.62	0.76	1.38
	Fuel&Oil	0.22	0.37	0.59
	Repairs	0.2	0.29	0.49
	Subtotal	1.04	1.42	2.46
	Total	$2.76	$4.31	$7.07
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	0.61	0.73	1.34
	Fuel&Oil	0.21	0.35	0.57
	Repairs	0.20	0.29	0.49
	Subtotal	1.02	1.37	2.40
	Total	**$2.74**	**$4.26**	**$7.01**

Assumptions:

Cart Distance -0.75 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	24 km/h
Speed loaded	22.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.5 tonne

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	85	73.6	77.59
Total harvest time (hr/day)	5.2	6.1	5.8
Harvester waiting time (min/day)	12	0	4
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX		
Harvester		$520,000
3 Infields		$1,045,500
Steel track infield		$0
Gross Capex	$1,565,500	

TABLE 5B. WHOLE-CANE, - 3 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **2 km Haul**

TOTAL CAPEX **$1,565,500**

COST /TONNE BURNT CANE EQUIVALENT				**$7.93**
Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	0.7	0.93	1.63
	Fuel&Oil	0.24	0.45	0.69
	Repairs	0.2	0.65	0.85
	Subtotal	1.14	2.03	3.17
	Total	$2.86	$4.92	$7.78
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	0.74	1.04	1.78
	Fuel&Oil	0.26	0.51	0.77
	Repairs	0.2	0.65	0.85
	Subtotal	1.2	2.20	3.40
	Total	$2.92	$5.09	$8.01
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	0.73	1.00	1.73
	Fuel&Oil	0.25	0.49	0.74
	Repairs	0.20	0.65	0.85
	Subtotal	1.18	2.14	3.32
	Total	**$2.90**	**$5.03**	**$7.93**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	61	54.8	56.97
Total harvest time (hr/day)	7.4	8.2	7.9
Harvester waiting time (min/day)	141	130	134
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX		
Harvester		$520,000
3 Infields		$1,045,500
Steel track infield		$0
Gross Capex	$1,565,500	

Assumptions:

Cart Distance -2 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.5 t

TABLE 5C. WHOLE-CANE, - 3 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **5km Haul**

COST /TONNE BURNT CANE EQUIVALENT				**$10.32**	**TOTAL CAPEX**	**$1,565,500**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	1.03	1.71	2.74
	Fuel&Oil	0.32	0.77	1.09
	Repairs	0.2	1.50	1.70
	Subtotal	1.55	3.98	5.53
	Total	$3.27	$6.87	$10.14
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	1.09	1.85	2.94
	Fuel&Oil	0.34	0.82	1.16
	Repairs	0.2	1.50	1.70
	Subtotal	1.63	4.17	5.80
	Total	$3.35	$7.06	$10.41
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.84	4.51
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.89	4.61
Variable Costs				
	Wages	1.07	1.80	2.87
	Fuel&Oil	0.33	0.80	1.14
	Repairs	0.20	1.50	1.70
	Subtotal	1.60	4.10	5.71
	Total	**$3.32**	**$6.99**	**$10.32**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	36.3	34.1	34.87
Total harvest time (hr/day)	12.6	13.4	13.1
Harvester waiting time (min/day)	452	440	444
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$520,000
3 Infields	$1,045,500
Steel track infield	$0
Gross Capex $1,565,500	

Assumptions:	
Cart Distance -5 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	27.2 km/h
Speed loaded	24.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent 6.5 t	

TABLE 6A. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — 0.75 km Haul

COST /TONNE BURNT CANE EQUIVALENT				**$5.74**
TOTAL CAPEX	**$1,244,000**			
Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	0.61	0.48	1.09
	Fuel&Oil	0.21	0.23	0.44
	Repairs	0.2	0.15	0.35
	Subtotal	1.02	0.86	1.88
	Total	$2.74	$2.88	$5.62
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	0.66	0.55	1.21
	Fuel&Oil	0.24	0.27	0.51
	Repairs	0.20	0.15	0.35
	Subtotal	1.10	0.97	2.07
	Total	$2.82	$2.99	$5.81
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	0.64	0.53	1.17
	Fuel&Oil	0.23	0.26	0.49
	Repairs	0.20	0.15	0.35
	Subtotal	1.07	0.93	2.00
	Total	**$2.79**	**$2.95**	**$5.74**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		77.8	67.7	71.24
Total harvest time (hr/day)		5.7	6.6	6.3
Harvester waiting time (min/day)		42	33	36
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$724,000	
Steel track infield			$0	
Gross Capex	$1,244,000			

Assumptions:	
Cart Distance -0.75 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	24 km/h
Speed loaded	22.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	26
Idle	10
Infield Sizes	47.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	12.5 tonne
Cane Equivalent 10 tonne	

TABLE 6B. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$6.37** **TOTAL CAPEX** **$1,244,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	0.72	0.66	1.38
	Fuel&Oil	0.25	0.32	0.57
	Repairs	0.2	0.36	0.56
	Subtotal	1.17	1.34	2.51
	Total	$2.89	$3.36	$6.25
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	0.77	0.73	1.5
	Fuel&Oil	0.27	0.36	0.63
	Repairs	0.2	0.36	0.56
	Subtotal	1.24	1.45	2.69
	Total	$2.96	$3.47	$6.43
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	0.75	0.71	1.46
	Fuel&Oil	0.26	0.35	0.61
	Repairs	0.20	0.36	0.56
	Subtotal	1.22	1.41	2.63
	Total	**$2.94**	**$3.43**	**$6.37**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		57.6	51.8	53.83
Total harvest time (hr/day)		7.8	8.7	8.4
Harvester waiting time (min/day)		168	160	163
Turning lost time (min)		89	133	
Pour rates		140 tcph	135 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$724,000	
Steel track infield			$0	
Gross Capex	$1,244,000			

Assumptions:	
Cart Distance -2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	2632
Idle	10
Infield Sizes	47.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	12.5 tonne
Cane Equivalent 10 tonne	

TABLE 6C. WHOLE-CANE, - 2 TRACKED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $7.59 **TOTAL CAPEX $1,244,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	1.05	1.18	2.23
	Fuel&Oil	0.33	0.53	0.86
	Repairs	0.2	0.87	1.07
	Subtotal	1.58	2.58	4.16
	Total	$3.30	$4.60	$7.90
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	1.12	1.27	2.39
	Fuel&Oil	0.35	0.56	0.91
	Repairs	0.2	0.18	0.38
	Subtotal	1.67	2.01	3.68
	Total	$3.39	$4.03	$7.42
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	1.97	3.64
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.02	3.74
Variable Costs				
	Wages	1.10	1.24	2.33
	Fuel&Oil	0.34	0.55	0.89
	Repairs	0.20	0.87	0.62
	Subtotal	1.64	2.66	3.85
	Total	**$3.36**	**$4.68**	**$7.59**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	35.5	33.2	34.01
Total harvest time (hr/day)	12.9	13.8	13.5
Harvester waiting time (min/day)	471	462	465
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$520,000
2 Infields	$724,000
Steel track infield	$0
Gross Capex	$1,244,000

Assumptions:

Cart Distance -5 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	21.8 km/h
Speed loaded	20 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	32
Idle	10
Infield Sizes	47.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	12.5 tonne
Cane Equivalent	10 tonne

TABLE 7A. WHOLE-CANE, - 2 TRACKED SP INFIELDS, 70,000 t Group Size

Debt Amortised over 5 years for Harvester and 7.5 years for Haulout **0.75 km Haul**

TOTAL CAPEX **$1,543,000**

COST /TONNE BURNT CANE EQUIVALENT				**$6.80**
Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.64	0.52	1.16
	Fuel&Oil	0.23	0.35	0.58
	Repairs	0.2	0.14	0.34
	Subtotal	1.07	1.01	2.08
	Total	$2.79	$3.84	$6.63
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.7	0.62	1.32
	Fuel&Oil	0.26	0.42	0.68
	Repairs	0.2	0.14	0.34
	Subtotal	1.16	1.18	2.34
	Total	$2.88	$4.01	$6.89
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.68	0.59	1.26
	Fuel&Oil	0.25	0.40	0.65
	Repairs	0.20	0.14	0.34
	Subtotal	1.13	1.12	2.25
	Total	**$2.85**	**$3.95**	**$6.80**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		71.4	60.8	64.51
Total harvest time (hr/day)		6.3	7.4	7.0
Harvester waiting time (Min/day)		45	36	39
Turning lost time (Min)		118	177	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$1,023,000	
Steel track infield			$0	
Gross Capex	$1,543,000			

Assumptions:

Cart Distance - 0.75 km
Unloading time - 3 Min
Turning Time - 2.0 Min

Speed unloaded	24 km/h
Speed loaded	22.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	36
Idle	16
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

TABLE 7B. WHOLE-CANE, - 2 TRACKED SP INFIELDS, 70,000 t Group Size

Debt Amortised over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT	**$7.33**	**TOTAL CAPEX**	**$1,543,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.72	0.66	1.38
	Fuel&Oil	0.26	0.45	0.71
	Repairs	0.2	0.32	0.52
	Subtotal	1.18	1.43	2.61
	Total	$2.90	$4.26	$7.16
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.79	0.76	1.55
	Fuel&Oil	0.29	0.51	0.8
	Repairs	0.2	0.32	0.52
	Subtotal	1.28	1.59	2.87
	Total	$3.00	$4.42	$7.42
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.77	0.73	1.49
	Fuel&Oil	0.28	0.49	0.77
	Repairs	0.20	0.32	0.52
	Subtotal	1.25	1.53	2.78
	Total	**$2.97**	**$4.36**	**$7.33**

Assumptions:	
Cart Distance - 2 km	
Unloading time - 3 Min	
Turning Time - 2.0 Min	
Speed unloaded	26 km/h
Speed loaded	23.8 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	45
Idle	16
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	57.2	50	52.52
Total harvest time (hr/day)	7.9	9.0	8.6
Harvester waiting time (Min/day)	142	134	137
Turning lost time (Min)	118	177	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$520,000
2 Infields	$1,023,000
Steel track infield	$0
Gross Capex	$1,543,000

TABLE 7C. WHOLE-CANE, - 2 TRACKED SP INFIELDS, 70,000 t Group Size

Debt Amortised over 5 years for Harvester and 7.5 years for Haulout — **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$8.71** — **TOTAL CAPEX** **$1,543,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	0.98	1.06	2.04
	Fuel&Oil	0.32	0.67	0.99
	Repairs	0.2	0.74	0.94
	Subtotal	1.5	2.47	3.97
	Total	$3.22	$5.30	$8.52
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	1.06	1.18	2.24
	Fuel&Oil	0.35	0.73	1.08
	Repairs	0.2	0.74	0.94
	Subtotal	1.61	2.65	4.26
	Total	$3.33	$5.48	$8.81
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	2.78	4.45
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.83	4.55
Variable Costs				
	Wages	1.03	1.14	2.17
	Fuel&Oil	0.34	0.71	1.05
	Repairs	0.20	0.74	0.94
	Subtotal	1.57	2.59	4.16
	Total	**$3.29**	**$5.42**	**$8.71**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	38.7	35.3	36.49
Total harvest time (hr/day)	11.8	12.9	12.5
Harvester waiting time (Min/day)	375	367	370
Turning lost time (Min)	118	177	
Pour rates	131 tcph	121 tcph	

CAPEX		
Harvester		$520,000
2 Infields		$1,023,000
Steel track infield		$0
Gross Capex	$1,543,000	

Assumptions:	
Cart Distance - 5 km	
Unloading time - 3 Min	
Turning Time - 2.0 Min	
Speed unloaded	27.2 km/h
Speed loaded	24.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	36
Idle	16
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent 12.8 tonne	

TABLE 8A. BURNT CANE, BASE CASE - 2 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT	**$5.61**	**TOTAL CAPEX**	**$1,220,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	0.68	0.58	1.26
	Fuel&Oil	0.23	0.22	0.45
	Repairs	0.2	0.09	0.29
	Subtotal	1.11	0.89	2.00
	Total	$2.77	$2.89	$5.66
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	0.67	0.57	1.24
	Fuel&Oil	0.23	0.17	0.4
	Repairs	0.2	0.09	0.29
	Subtotal	1.1	0.83	1.93
	Total	$2.76	$2.83	$5.59
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	0.67	0.57	1.25
	Fuel&Oil	0.23	0.19	0.42
	Repairs	0.20	0.09	0.29
	Subtotal	1.10	0.85	1.95
	Total	**$2.76**	**$2.85**	**$5.61**

Assumptions:

Cart Distance - 0.75 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	31.5 km/h
Speed loaded	25 km/h
Harvester fuel (l/hr)	
In-Use	46
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	21 m^3
Cane Bulk Density	380 kg/m^3
Load Carried	8 tonnes

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	75.5	66	69.33
Total harvest time (hr/day)	5.9	6.8	6.5
Harvester waiting time (min/day)	53	44	47
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$500,000
2 Infields	$495,000
Steel Track	$225,000
Gross Capex	$1,220,000

TABLE 8B. BURNT CANE, BASE CASE - 2 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT	**$5.95**	**TOTAL CAPEX**	**$995,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	0.73	0.67	1.4
	Fuel&Oil	0.24	0.2	0.44
	Repairs	0.2	0.14	0.34
	Subtotal	1.17	1.01	2.18
	Total	$2.83	$3.01	$5.84
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	0.78	0.75	1.53
	Fuel&Oil	0.26	0.22	0.48
	Repairs	0.2	0.14	0.34
	Subtotal	1.24	1.11	2.35
	Total	$2.90	$3.11	$6.01
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	0.76	0.72	1.48
	Fuel&Oil	0.25	0.21	0.47
	Repairs	0.20	0.14	0.34
	Subtotal	1.22	1.08	2.29
	Total	**$2.88**	**$3.08**	**$5.95**

Assumptions:	
Cart Distance - 2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	34.75 km/h
Speed loaded	27.5 km/h
Harvester fuel (l/hr)	
In-Use	46
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	21 m^3
Cane Bulk Density	380 kg/m^3
Load Carried	8 tonnes

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	56.4	51	52.89
Total harvest time (hr/day)	8.0	8.9	8.6
Harvester waiting time (min/day)	178	170	173
Turning lost time (min)	88	133	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$500,000
2 Infields	$495,000
Steel Track	$225,000
Gross Capex	$995,000

TABLE 8C. BURNT CANE, BASE CASE - 2 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout				5 km Haul	
COST /TONNE BURNT CANE EQUIVALENT			$7.17	TOTAL CAPEX	$1,490,000

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	1.06	1.19	2.25
	Fuel&Oil	0.32	0.33	0.65
	Repairs	0.2	0.28	0.48
	Subtotal	1.58	1.80	3.38
	Total	$3.24	$3.80	$7.04
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	1.12	1.29	2.41
	Fuel&Oil	0.34	0.35	0.69
	Repairs	0.2	0.28	0.48
	Subtotal	1.66	1.92	3.58
	Total	$3.32	$3.92	$7.24
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.61	1.95	3.56
	Incidentals	0.05	0.05	0.10
	Subtotal	1.66	2	3.66
Variable Costs				
	Wages	1.10	1.26	2.35
	Fuel&Oil	0.33	0.34	0.68
	Repairs	0.20	0.28	0.48
	Subtotal	1.63	1.88	3.51
	Total	**$3.29**	**$3.88**	**$7.17**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		35.2	32.9	33.71
Total harvest time (hr/day)		13.0	13.9	13.6
Harvester waiting time (min/day)		477	469	472
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester		$500,000		
2 Infields		$495,000		
Steel Track Infield		225,000		
Gross Capex	$1,490,000			

Assumptions:

Cart Distance - 5 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	36.7 km/h
Speed loaded	29 km/h
Harvester fuel (l/hr)	
In-Use	46
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	21 m^3
Cane Bulk Density	380 kg/m^3
Load Carried	8 tonnes

TABLE 9A. WHOLE-CANE - 2x WHEELED INFIELDS, 70,000 t Group Size

Debt Amortised over 5 years for Harvester and 7.5 years for Haulout — **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $5.99 — **TOTAL CAPEX $1,240,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	0.72	0.65	1.37
	Fuel&Oil	0.24	0.2	0.44
	Repairs	0.2	0.14	0.34
	Subtotal	1.16	0.99	2.15
	Total	$2.88	$2.99	$5.87
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	0.77	0.73	1.5
	Fuel&Oil	0.27	0.22	0.49
	Repairs	0.2	0.14	0.34
	Subtotal	1.24	1.09	2.33
	Total	$2.96	$3.09	$6.05
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	0.75	0.70	1.45
	Fuel&Oil	0.26	0.21	0.47
	Repairs	0.20	0.14	0.34
	Subtotal	1.21	1.06	2.27
	Total	**$2.93**	**$3.06**	**$5.99**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		58	52.2	54.23
Total harvest time (hr/day)		7.8	8.7	8.4
Harvester waiting time (Min/day)		165	156	159
Turning lost time (Min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$495,000	
Steel track infield			$225,000	
Gross Capex	$1,240,000			

Assumptions:

Haul Distance - 0.75 km	
Unloading time - 1 Min	
Turning Time - 1.5 Min	
Speed unloaded	31.5 km/h
Speed loaded	25 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	23.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	5.8 tonne
Cane Equivalent	4.7tonne

TABLE 9B. WHOLE-CANE - WHEELED INFIELDS, 70,000 t Group Size

Debt Amortised over 5 years for Harvester and 7.5 years for Haulout		**2 km Haul**	
COST /TONNE BURNT CANE EQUIVALENT	**$6.79**	**TOTAL CAPEX**	**$1,240,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	0.95	1.02	1.97
	Fuel&Oil	0.3	0.29	0.59
	Repairs	0.2	0.19	0.39
	Subtotal	1.45	1.50	2.95
	Total	$3.17	$3.50	$6.67

Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	1.01	1.11	2.12
	Fuel&Oil	0.32	0.31	0.63
	Repairs	0.2	0.19	0.39
	Subtotal	1.53	1.61	3.14
	Total	$3.25	$3.61	$6.86

Assumptions:	
Cart Distance - 2 km	
Unloading time - 1 Min	
Turning Time - 1.5 Min	
Speed unloaded	34.75 km/h
Speed loaded	27.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	23.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	5.8 tonne
Cane Equivalent 4.7t	

Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha

Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	0.99	1.08	2.07
	Fuel&Oil	0.31	0.30	0.62
	Repairs	0.20	0.19	0.39
	Subtotal	1.50	1.57	3.07
	Total	**$3.22**	**$3.57**	**$6.79**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	40	37.1	38.12
Total harvest time (hr/day)	11.4	12.3	12.0
Harvester waiting time (Min/day)	382	373	376
Turning lost time (Min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX	
Harvester	$520,000
2 Infields	$495,000
Steel track infield	$225,000
Gross Capex $1,240,000	

TABLE 9C. WHOLE-CANE - 2x WHEELED INFIELDS, 70,000 t Group Size

Debt Amortised over 5 years for Harvester and 7.5 years for Haulout — **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$8.87** — **TOTAL CAPEX** **$1,240,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	1.55	1.95	3.5
	Fuel&Oil	0.41	0.5	0.91
	Repairs	0.2	0.38	0.58
	Subtotal	2.16	2.83	4.99
	Total	$3.88	$4.83	$8.71
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	1.61	2.05	3.66
	Fuel&Oil	0.46	0.53	0.99
	Repairs	0.2	0.38	0.58
	Subtotal	2.27	2.96	5.23
	Total	$3.99	$4.96	$8.95
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortisation	1.67	1.95	3.62
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2	3.72
Variable Costs				
	Wages	1.59	2.02	3.60
	Fuel&Oil	0.44	0.52	0.96
	Repairs	0.20	0.38	0.58
	Subtotal	2.23	2.91	5.15
	Total	**$3.95**	**$4.91**	**$8.87**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		23	22	22.35
Total harvest time (hr/day)		20.0	21.0	20.7
Harvester waiting time (Min/day)		900	890	894
Turning lost time (Min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$495,000	
Steel track infield			$225,000	
Gross Capex	$1,240,000			

Assumptions:

Cart Distance - 5 km
Unloading time - 1 Min
Turning Time - 1.5 Min

Speed unloaded	36.7 km/h
Speed loaded	29 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	1620
Idle	8
Infield Sizes	23.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	5.8 tonne
Cane Equivalent	4.7t

TABLE 10A. WHOLE-CANE - 3 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$6.66** — **TOTAL CAPEX** **$1,487,500**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	0.61	0.72	1.33
	Fuel&Oil	0.21	0.21	0.42
	Repairs	0.15	0.23	0.38
	Subtotal	0.97	1.16	2.13
	Total	$2.69	$3.84	$6.53
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	0.65	0.82	1.47
	Fuel&Oil	0.23	0.25	0.48
	Repairs	0.15	0.23	0.38
	Subtotal	1.03	1.30	2.33
	Total	$2.75	$3.98	$6.73
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	0.64	0.79	1.42
	Fuel&Oil	0.22	0.24	0.46
	Repairs	0.15	0.23	0.38
	Subtotal	1.01	1.25	2.26
	Total	**$2.73**	**$3.93**	**$6.66**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		78	68.6	71.89
Total harvest time (hr/day)		5.7	6.5	6.2
Harvester waiting time (min/day)		40	28	32
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$742,500	
Steel track infield			$225,000	
Gross Capex	$1,487,500			

Assumptions:	
Cart Distance - 0.75 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	31.5 km/h
Speed loaded	25 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	23.5 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	5.8 tonne
Cane Equivalent 4.7t	

TABLE 10B. WHOLE-CANE - 3 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **2km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$7.27** — **TOTAL CAPEX** **$1,487,500**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	0.74	1.02	1.76
	Fuel&Oil	0.25	0.3	0.55
	Repairs	0.2	0.23	0.43
	Subtotal	1.19	1.55	2.74
	Total	$2.91	$4.23	$7.14
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	0.78	1.12	1.9
	Fuel&Oil	0.27	0.34	0.61
	Repairs	0.2	0.23	0.43
	Subtotal	1.25	1.69	2.94
	Total	$2.97	$4.37	$7.34
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	0.77	1.09	1.85
	Fuel&Oil	0.26	0.33	0.59
	Repairs	0.20	0.23	0.43
	Subtotal	1.23	1.64	2.87
	Total	**$2.95**	**$4.32**	**$7.27**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		55.9	50.7	52.52
Total harvest time (hr/day)		8.1	8.9	8.6
Harvester waiting time (min/day)		183	171	175
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$742,500	
Steel track infield			$225,000	
Gross Capex	$1,487,500			

Assumptions:

Cart Distance - 2 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	34.75 km/h
Speed loaded	27.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	23.5 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	5.8 tonne

Cane Equivalent 4.7t

TABLE 10C. WHOLE-CANE - 3 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — 5 km Haul

COST /TONNE BURNT CANE EQUIVALENT **$9.07** — **TOTAL CAPEX** **$1,487,500**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	1.12	1.91	3.03
	Fuel&Oil	0.34	0.52	0.86
	Repairs	0.2	0.42	0.62
	Subtotal	1.66	2.85	4.51
	Total	$3.38	$5.53	$8.91
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	1.17	2.05	3.22
	Fuel&Oil	0.36	0.55	0.91
	Repairs	0.2	0.42	0.62
	Subtotal	1.73	3.02	4.75
	Total	$3.45	$5.70	$9.15
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.63	4.3
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.68	4.4
Variable Costs				
	Wages	1.15	2.00	3.15
	Fuel&Oil	0.35	0.54	0.89
	Repairs	0.20	0.42	0.62
	Subtotal	1.71	2.96	4.67
	Total	**$3.43**	**$5.64**	**$9.07**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		33.2	31.3	31.97
Total harvest time (hr/day)		13.7	14.6	14.3
Harvester waiting time (min/day)		524	512	516
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$742,500	
Steel track infield			$225,000	
Gross Capex	$1,487,500			

Assumptions:

Cart Distance - 5 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	36.7 km/h
Speed loaded	29 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	8
Infield Sizes	23.5 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	5.8 tonne
Cane Equivalent	4.7t

TABLE 11A. WHOLE-CANE, - 2 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$5.85** **TOTAL CAPEX** **$1,286,600**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	0.62	0.5	1.12
	Fuel&Oil	0.22	0.15	0.37
	Repairs	0.2	0.20	0.40
	Subtotal	1.04	0.85	1.89
	Total	$2.76	$2.98	$5.74
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	0.67	0.58	1.25
	Fuel&Oil	0.24	0.17	0.41
	Repairs	0.2	0.20	0.40
	Subtotal	1.11	0.95	2.06
	Total	$2.83	$3.08	$5.91
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	0.65	0.55	1.20
	Fuel&Oil	0.23	0.16	0.40
	Repairs	0.20	0.20	0.40
	Subtotal	1.09	0.92	2.00
	Total	**$2.81**	**$3.05**	**$5.85**

Assumptions:			
Cart Distance - 0.75 km			
Unloading time - 1 min			
Turning Time - 1.5 min			
Speed unloaded	39 km/h		
Speed loaded	32.5 km/h		
Harvester fuel (l/hr)			
In-Use	51/47.5		
Idle	20		
Infield (l/hr)			
In-Use	1620		
Idle	9		
Infield Sizes	31.7 m^3		
Cane Density	Bulk 250 kg/m^3		
Load Carried	8 tonne		
Cane Equivalent	6.4 tonne		

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	74.5	65.2	68.46
Total harvest time (hr/day)	6.0	6.9	6.6
Harvester waiting time (min/day)	58	49	52
Turning lost time (min)	89	133	
Pour rates	131 tcph	121 tcph	

CAPEX		
Harvester		$520,000
2 Infields		$541,600
Steel track infield		$225,000
Gross Capex	$1,286,600	

TABLE 11B. WHOLE-CANE, - 2 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$6.27** **TOTAL CAPEX** **$1,286,600**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	0.73	0.67	1.4
	Fuel&Oil	0.25	0.2	0.45
	Repairs	0.2	0.26	0.46
	Subtotal	1.18	1.13	2.31
	Total	$2.90	$3.26	$6.16
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	0.78	0.75	1.53
	Fuel&Oil	0.27	0.22	0.49
	Repairs	0.2	0.26	0.46
	Subtotal	1.25	1.23	2.48
	Total	$2.97	$3.36	$6.33
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	0.76	0.72	1.48
	Fuel&Oil	0.26	0.21	0.48
	Repairs	0.20	0.26	0.46
	Subtotal	1.23	1.20	2.42
	Total	**$2.95**	**$3.33**	**$6.27**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		56.3	51	52.86
Total harvest time (hr/day)		8.0	8.9	8.6
Harvester waiting time (min/day)		179	170	173
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$541,600	
Steel track infield			$225,000	
Gross Capex	$1,286,600			

Assumptions:

Cart Distance -2 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	43.5 km/h
Speed loaded	36.25 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	9
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.4 tonne

TABLE 11C. WHOLE-CANE, - 2 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$7.50** — **TOTAL CAPEX** **$1,286,600**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	1.05	1.17	2.22
	Fuel&Oil	0.32	0.32	0.64
	Repairs	0.2	0.51	0.71
	Subtotal	1.57	2.00	3.57
	Total	$3.29	$4.13	$7.42
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	1.11	1.27	2.38
	Fuel&Oil	0.35	0.25	0.6
	Repairs	0.2	0.51	0.71
	Subtotal	1.66	2.03	3.69
	Total	$3.38	$4.16	$7.54
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.08	3.75
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.13	3.85
Variable Costs				
	Wages	1.09	1.24	2.32
	Fuel&Oil	0.34	0.27	0.61
	Repairs	0.20	0.51	0.71
	Subtotal	1.63	2.02	3.65
	Total	**$3.35**	**$4.15**	**$7.50**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		35.6	33	33.91
Total harvest time (hr/day)		12.8	13.7	13.4
Harvester waiting time (min/day)		468	460	463
Turning lost time (min)		89	133	
Pour rates		131 tcph	121 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$541,600	
Steel track infield			$225,000	
Gross Capex	$1,286,600			

Assumptions:

Cart Distance -5 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	46.2 km/h
Speed loaded	38.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	16
Idle	9
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.4 tonne

TABLE 12A. WHOLE-CANE, - 3 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **0.75 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $7.08 **TOTAL CAPEX $1,557,400**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.62	0.74	1.36
	Fuel&Oil	0.24	0.28	0.52
	Repairs	0.15	0.23	0.38
	Subtotal	1.01	1.25	2.26
	Total	$2.73	$4.12	$6.85
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.69	0.93	1.62
	Fuel&Oil	0.27	0.35	0.62
	Repairs	0.15	0.23	0.38
	Subtotal	1.11	1.51	2.62
	Total	$2.83	$4.38	$7.21
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.67	0.86	1.53
	Fuel&Oil	0.26	0.33	0.59
	Repairs	0.15	0.23	0.38
	Subtotal	1.08	1.42	2.49
	Total	**$2.80**	**$4.29**	**$7.08**

Assumptions:	
Cart Distance - 1 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	37.5 km/h
Speed loaded	32.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	20
Idle	9
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.4 tonne

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	75.5	61.4	66.34
Total harvest time (hr/day)	5.9	7.3	6.8
Harvester waiting time (min/day)	0	0	0
Turning lost time (min)	155	232	
Pour rates	140 tcph	135 tcph	

CAPEX	
Harvester	$520,000
3 Infields	$812,400
Steel track infield	$225,000
Gross Capex	$1,557,400

TABLE 12B. WHOLE-CANE, - 3 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$7.27** — **TOTAL CAPEX** **$1,557,400**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.66	0.85	1.51
	Fuel&Oil	0.23	0.32	0.55
	Repairs	0.15	0.23	0.38
	Subtotal	1.04	1.40	2.44
	Total	$2.76	$4.27	$7.03
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.74	1.02	1.76
	Fuel&Oil	0.29	0.38	0.67
	Repairs	0.15	0.23	0.38
	Subtotal	1.18	1.63	2.81
	Total	$2.90	$4.50	$7.40
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.71	0.96	1.67
	Fuel&Oil	0.27	0.36	0.63
	Repairs	0.15	0.23	0.38
	Subtotal	1.13	1.55	2.68
	Total	**$2.85**	**$4.42**	**$7.27**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	66.1	55.5	59.21
Total harvest time (hr/day)	6.8	8.1	7.6
Harvester waiting time (min/day)	53	48	50
Turning lost time (min)	155	232	
Pour rates	140 tcph	135 tcph	

CAPEX	
Harvester	$520,000
3 Infields	$812,400
Steel track infield	$225,000
Gross Capex	$1,557,400

Assumptions:

Cart Distance - 2 km
Unloading time - 1 min
Turning Time - 1.5 min

Speed unloaded	41.25 km/h
Speed loaded	36.25 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	20
Idle	9
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.4 tonne

TABLE 12C. WHOLE-CANE, - 3 WHEELED INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout						**5 km Haul**
COST /TONNE BURNT CANE EQUIVALENT				**$7.58**	**TOTAL CAPEX**	**$1,557,400**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.86	1.31	2.17
	Fuel&Oil	0.3	0.48	0.78
	Repairs	0.15	0.23	0.38
	Subtotal	1.31	2.02	3.33
	Total	$3.03	$4.89	$7.92
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.74	1.02	1.76
	Fuel&Oil	0.29	0.38	0.67
	Repairs	0.15	0.23	0.38
	Subtotal	1.18	1.63	2.81
	Total	$2.90	$4.50	$7.40
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.82	4.49
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.87	4.59
Variable Costs				
	Wages	0.78	1.12	1.90
	Fuel&Oil	0.29	0.42	0.71
	Repairs	0.15	0.23	0.38
	Subtotal	1.23	1.77	2.99
	Total	**$2.95**	**$4.64**	**$7.58**

Assumptions:	
Cart Distance - 5 km	
Unloading time - 1 min	
Turning Time - 1.5 min	
Speed unloaded	43.5 km/h
Speed loaded	38.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	20
Idle	9
Infield Sizes	31.7 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	8 tonne
Cane Equivalent	6.4 tonne

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	45.1	55.5	51.86
Total harvest time (hr/day)	10.1	8.1	8.8
Harvester waiting time (min/day)	249	48	118
Turning lost time (min)	155	232	
Pour rates	140 tcph	135 tcph	

CAPEX		
Harvester		$520,000
3 Infields		$812,400
Steel track infield		$225,000
Gross Capex	$1,557,400	

TABLE 13A. WHOLE-CANE, - 2 WHEELED BD INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **0.75 km Haul**

TOTAL CAPEX **$1,469,200**

COST /TONNE BURNT CANE EQUIVALENT				**$7.25**
Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	0.77	0.73	1.5
	Fuel&Oil	0.32	0.34	0.66
	Repairs	0.15	0.23	0.38
	Subtotal	1.24	1.30	2.54
	Total	$2.96	$3.93	$6.89
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	0.92	0.96	1.88
	Fuel&Oil	0.41	0.43	0.84
	Repairs	0.15	0.23	0.38
	Subtotal	1.48	1.62	3.10
	Total	$3.20	$4.25	$7.45
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	0.87	0.88	1.75
	Fuel&Oil	0.38	0.40	0.78
	Repairs	0.15	0.23	0.38
	Subtotal	1.40	1.51	2.90
	Total	**$3.12**	**$4.14**	**$7.25**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		52	41.7	45.31
Total harvest time (hr/day)		8.7	10.9	10.1
Harvester waiting time (min/day)		63	60	61
Turning lost time (min)		259	388	
Pour rates		140 tcph	135 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$724,200	
Steel track infield			$225,000	
Gross Capex	$1,469,200			

Assumptions:	
Cart Distance - 1 km	
Unloading time - 4 min	
Turning Time - 2.5 min	
Speed unloaded	30 km/h
Speed loaded	25 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	25
Idle	9
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

TABLE 13B. WHOLE-CANE, - 2 WHEELED BD INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT $7.47 **TOTAL CAPEX $1,469,200**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	0.84	0.84	1.68
	Fuel&Oil	0.34	0.38	0.72
	Repairs	0.15	0.23	0.38
	Subtotal	1.33	1.45	2.78
	Total	$3.05	$4.08	$7.13
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	0.99	1.07	2.06
	Fuel&Oil	0.4	0.47	0.87
	Repairs	0.15	0.23	0.38
	Subtotal	1.54	1.77	3.31
	Total	$3.26	$4.40	$7.66
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	0.94	0.99	1.93
	Fuel&Oil	0.38	0.44	0.82
	Repairs	0.15	0.23	0.38
	Subtotal	1.47	1.66	3.12
	Total	**$3.19**	**$4.29**	**$7.47**

Assumptions:

Cart Distance - 2 km
Unloading time - 4 min
Turning Time - 2.0 min

Speed unloaded	32.5 km/h
Speed loaded	27.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	25
Idle	9
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	46.7	38.4	41.31
Total harvest time (hr/day)	9.7	11.9	11.1
Harvester waiting time (min/day)	125	125	125
Turning lost time (min)	259	388	
Pour rates	140 tcph	135 tcph	

CAPEX	
Harvester	$520,000
2 Infields	$724,200
Steel track infield	$225,000
Gross Capex	$1,469,200

TABLE 13C. WHOLE-CANE, - 2 WHEELED BD INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT **$8.13** **TOTAL CAPEX** **$1,469,200**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.33	4
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.38	4.1
Variable Costs				
	Wages	1.06	1.18	2.24
	Fuel&Oil	0.39	0.51	0.9
	Repairs	0.15	0.23	0.38
	Subtotal	1.6	1.92	3.52
	Total	$3.32	$4.30	$7.62
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.58	4.25
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.63	4.35
Variable Costs				
	Wages	1.21	1.42	2.63
	Fuel&Oil	0.45	0.59	1.04
	Repairs	0.15	0.23	0.38
	Subtotal	1.81	2.24	4.05
	Total	$3.53	$4.87	$8.40
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.4925	4.1625
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.5425	4.2625
Variable Costs				
	Wages	1.16	1.34	2.49
	Fuel&Oil	0.43	0.56	0.99
	Repairs	0.15	0.23	0.38
	Subtotal	1.74	2.13	3.86
	Total	**$3.46**	**$4.67**	**$8.13**
HARVESTER PERFORMANCE				
Tpha		150	100	*Weighted av*
Tonnes per engine hour		35.4	30.3	32.09
Total harvest time (hr/day)		12.9	15.1	14.3
Harvester waiting time (min/day)		315	312	313
Turning lost time (min)		259	388	
Pour rates		140 tcph	135 tcph	
CAPEX				
Harvester			$520,000	
2 Infields			$724,200	
Steel track infield			$225,000	
Gross Capex	$1,469,200			

Assumptions:	
Cart Distance - 5 km	
Unloading time - 4 min	
Turning Time - 2.5 min	
Speed unloaded	34 km/h
Speed loaded	29km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	25
Idle	9
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

TABLE 14A. WHOLE-CANE, - 2 WHEELED SP INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout — **1 km Haul**

COST /TONNE BURNT CANE EQUIVALENT				**$6.78**
TOTAL CAPEX				**$1,416,000**

Crop Size	**150tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.43	4.1
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.48	4.2
Variable Costs				
	Wages	0.69	0.6	1.29
	Fuel&Oil	0.28	0.38	0.66
	Repairs	0.15	0.21	0.36
	Subtotal	1.12	1.19	2.31
	Total	$2.84	$3.67	$6.51
Crop Size	**100tpha**			
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.43	4.1
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.48	4.2
Variable Costs				
	Wages	0.79	0.76	1.55
	Fuel&Oil	0.35	0.47	0.82
	Repairs	0.15	0.21	0.36
	Subtotal	1.29	1.44	2.73
	Total	$3.01	$3.92	$6.93
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha				
Fixed Costs		*Harvester*	*Infield*	*Total*
	Amortization	1.67	2.43	4.1
	Incidentals	0.05	0.05	0.10
	Subtotal	1.72	2.48	4.2
Variable Costs				
	Wages	0.76	0.70	1.46
	Fuel&Oil	0.33	0.44	0.76
	Repairs	0.15	0.21	0.36
	Subtotal	1.23	1.35	2.58
	Total	**$2.95**	**$3.83**	**$6.78**

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	62.3	50.3	54.50
Total harvest time (hr/day)	7.2	9.0	8.4
Harvester waiting time (min/day)	26.7	23.3	24
Turning lost time (min)	207	310	
Pour rates	140 tcph	135 tcph	

CAPEX	
Harvester	$520,000
2 Infields	$671,000
Steel track infield	$225,000
Gross Capex	$1,416,000

Assumptions:	
Cart Distance - 1 km	
Unloading time - 3 min	
Turning Time - 2.0 min	
Speed unloaded	37.5 km/h
Speed loaded	32.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	33
Idle	11
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

TABLE 14B. WHOLE-CANE, - 2 WHEELED SP INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **2 km Haul**

COST /TONNE BURNT CANE EQUIVALENT				**$6.94**	**TOTAL CAPEX**	**$1,416,000**
Crop Size	**150tpha**					
Fixed Costs		*Harvester*	*Infield*	*Total*		
	Amortization	1.67	2.43	4.1		
	Incidentals	0.05	0.05	0.10		
	Subtotal	1.72	2.48	4.2		
Variable Costs						
	Wages	0.73	0.67	1.4		
	Fuel&Oil	0.29	0.42	0.71		
	Repairs	0.15	0.21	0.36		
	Subtotal	1.17	1.30	2.47		
	Total	$2.89	$3.78	$6.67		
Crop Size	**100tpha**					
Fixed Costs		*Harvester*	*Infield*	*Total*		
	Amortization	1.67	2.43	4.1		
	Incidentals	0.05	0.05	0.10		
	Subtotal	1.72	2.48	4.2		
Variable Costs						
	Wages	0.84	0.84	1.68		
	Fuel&Oil	0.34	0.51	0.85		
	Repairs	0.15	0.21	0.36		
	Subtotal	1.33	1.56	2.89		
	Total	$3.05	$4.04	$7.09		
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha						
Fixed Costs		*Harvester*	*Infield*	*Total*		
	Amortization	1.67	2.43	4.1		
	Incidentals	0.05	0.05	0.10		
	Subtotal	1.72	2.48	4.2		
Variable Costs						
	Wages	0.80	0.78	1.58		
	Fuel&Oil	0.32	0.48	0.80		
	Repairs	0.15	0.21	0.36		
	Subtotal	1.27	1.47	2.74		
	Total	**$2.99**	**$3.95**	**$6.94**		

HARVESTER PERFORMANCE			
Tpha	150	100	*Weighted av*
Tonnes per engine hour	56.4	46.4	49.90
Total harvest time (hr/day)	8.0	9.8	9.2
Harvester waiting time (min/day)	73.2	70	71
Turning lost time (min)	207	310	
Pour rates	140 tcph	135 tcph	

CAPEX	
Harvester	$520,000
2 Infields	$671,000
Steel track infield	$225,000
Gross Capex	$1,416,000

Assumptions:	
Cart Distance - 2 km	
Unloading time - 3 min	
Turning Time - 2.0 min	
Speed unloaded	41.25 km/h
Speed loaded	36.25 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	33
Idle	11
Infield Sizes	63.3 m^3
Cane Bulk Density	250 kg/m^3
Load Carried	16 tonne
Cane Equivalent	12.8 tonne

TABLE 14C. WHOLE-CANE, - 2 WHEELED SP INFIELDS, 70,000 t Group Size

Debt Amortized over 5 years for Harvester and 7.5 years for Haulout **5 km Haul**

COST /TONNE BURNT CANE EQUIVALENT				**$7.58**	**TOTAL CAPEX**	**$1,416,000**
Crop Size	**150tpha**					
Fixed Costs		*Harvester*	*Infield*	*Total*		
	Amortization	1.67	2.43	4.1		
	Incidentals	0.05	0.05	0.10		
	Subtotal	1.72	2.48	4.2		
Variable Costs						
	Wages	0.88	0.91	1.79		
	Fuel&Oil	0.33	0.54	0.87		
	Repairs	0.15	0.21	0.36		
	Subtotal	1.36	1.66	3.02		
	Total	$3.08	$4.14	$7.22		
Crop Size	**100tpha**					
Fixed Costs		*Harvester*	*Infield*	*Total*		
	Amortization	1.67	2.43	4.1		
	Incidentals	0.05	0.05	0.10		
	Subtotal	1.72	2.48	4.2		
Variable Costs						
	Wages	1.1	1.1	2.2		
	Fuel&Oil	0.38	0.63	1.01		
	Repairs	0.15	0.21	0.36		
	Subtotal	1.63	1.94	3.57		
	Total	$3.35	$4.42	$7.77		
Weighted Average assumes 65% @ 100tpha & 35% @ 150 tpha						
Fixed Costs		*Harvester*	*Infield*	*Total*		
	Amortization	1.67	2.43	4.1		
	Incidentals	0.05	0.05	0.10		
	Subtotal	1.72	2.48	4.2		
Variable Costs						
	Wages	1.02	1.03	2.06		
	Fuel&Oil	0.36	0.60	0.96		
	Repairs	0.15	0.21	0.36		
	Subtotal	1.54	1.84	3.38		
	Total	**$3.26**	**$4.32**	**$7.58**		
HARVESTER PERFORMANCE						
Tpha		150	100	*Weighted av*		
Tonnes per engine hour		43.6	37.4	39.57		
Total harvest time (hr/day)		10.4	12.2	11.6		
Harvester waiting time (min/day)		218	215	216		
Turning lost time (min)		207	310			
Pour rates		140 tcph	135 tcph			
CAPEX						
Harvester			$520,000			
2 Infields			$671,000			
Steel track infield			$225,000			
Gross Capex	$1,416,000					

Assumptions:	
Cart Distance - 5 km	
Unloading time - 3 min	
Turning Time - 2.0 min	
Speed unloaded	43.5 km/h
Speed loaded	38.5 km/h
Harvester fuel (l/hr)	
In-Use	51/47.5
Idle	20
Infield (l/hr)	
In-Use	33
Idle	11
Infield Sizes	63.3 m^3
Cane Density	Bulk 250 kg/m^3
Load Carried	16 tonne
Cane Equivalent 12.8 tonne	

APPENDIX 7

	Current system	Option 1 same no. trips	Option 2 20% more trips	Option 3 use current	Option 1 same no trips	Option 2 increased no trips	Option 3 use current	Option 1 same no. trips	Option 2 increased no. trips	Option 3 use current
Infield Bin Volume	burnt	vol (182%)	vol (52%)	increase infield bins	vol (228%)	vol (90%)	increase infield bins	vol (152%)	vol (27%)	increase infield bins
Infield Bin Mass		mass (20%)	same mass		mass (20%)	same mass		mass (20%)	same mass	
Bulk density kg /cu m	380	250	250	250	200	200	200	300	300	300
Multi-lift bin volume cu m	65	95	95	95	95	95	95	95	95	95
Infield bin volume (a)	32.5	59.3	49.4	32.5	74.1	61.8	32.5	49.4	41.2	32.5
Infield bin volume (b)	26	47.4	39.5	26.0	59.3	49.4	26.0	39.5	32.9	26.0
Infield bin volume (c.)	21.7	39.5	32.9	21.7	49.4	41.2	21.7	32.9	27.4	21.7
Trips fill m-l bin using (a)	2	1.6	1.9	2.9	1.3	1.5	2.9	1.9	2.3	2.9
Trips fill m-l bin using (b)	2.5	2.0	2.4	3.7	1.6	1.9	3.7	2.4	2.9	3.7
Trips fill m-l bin using (c.)	3	2.4	2.9	4.4	1.9	2.3	4.4	2.9	3.5	4.4
Trips to harvest	1.00	1.00	1.20	1.82	1.00	1.20	2.28	1.00	1.20	1.52
given area	1.25	1.25	1.50	2.28	1.25	1.50	2.85	1.25	1.50	1.90
	1.50	1.50	1.80	2.74	1.50	1.80	3.42	1.50	1.80	2.28

13. APPENDIX 7

Group Name	Infield description	Capacity (tonnes)	Volume (cu.m)
Riverend	2 x Fiat F130 with McLean wheel driven tipper – RH	12	28
	1 x Ford 8360 with home made McLean wheel driven tipper – LH	12	28
	No load cells		
	1 x Home made self-propelled fulltrack – ex harvester	12	28
Partridge	3 x McLean 1 x Fulltrack	8	21
Brunswick	1 x Valmet (120 hp) with home made trailed tipper on wheels	9	21
	1 x Massey Ferguson (100 hp) with home made trailed tipper on wheels	8	21
	1 x Toft Powerhaul side tipper	8	21
	1 x Self-propelled fulltrack – ex harvester	8	21
West Tweed	3 x Fiat F130 with home made pto driven tipper on wheels – LH	9	23
	2 x Fiat F130 with home made trailed tipper on wheels with air bags – RH	9	23
	On board oil pressure weighing device (3 units)		
	2 x Home made self-propelled fulltrack – ex harvester	9	23
Morrin	1 x John Deere 7810 (175 hp) with home made trailed tipper on wheels with air bags and weight indicator – LH	12	33
	1 x Fiat F130 with home made pto driven tipper on wheels	8	21
	1 x Home made pto driven fulltrack	8	21
Pacific	2 x Cat Challenger CH45 rubber track with McLean rubber track side tipper – 1 LH, 1 RH Load cells	14	31
Central Tweed	4 x Cat Challenger CH35 rubber track with McLean rubber track side tipper – 1 LH, 1 RH Load cells	14	33
Catteral	2 x Deutz DX630 (120 hp) with McLean trailed tipper – LH	8	21
	1 x Deutz DX638 (130 hp) with McLean trailed tipper, air bags – LH	9	21
	No weighing device No full track		