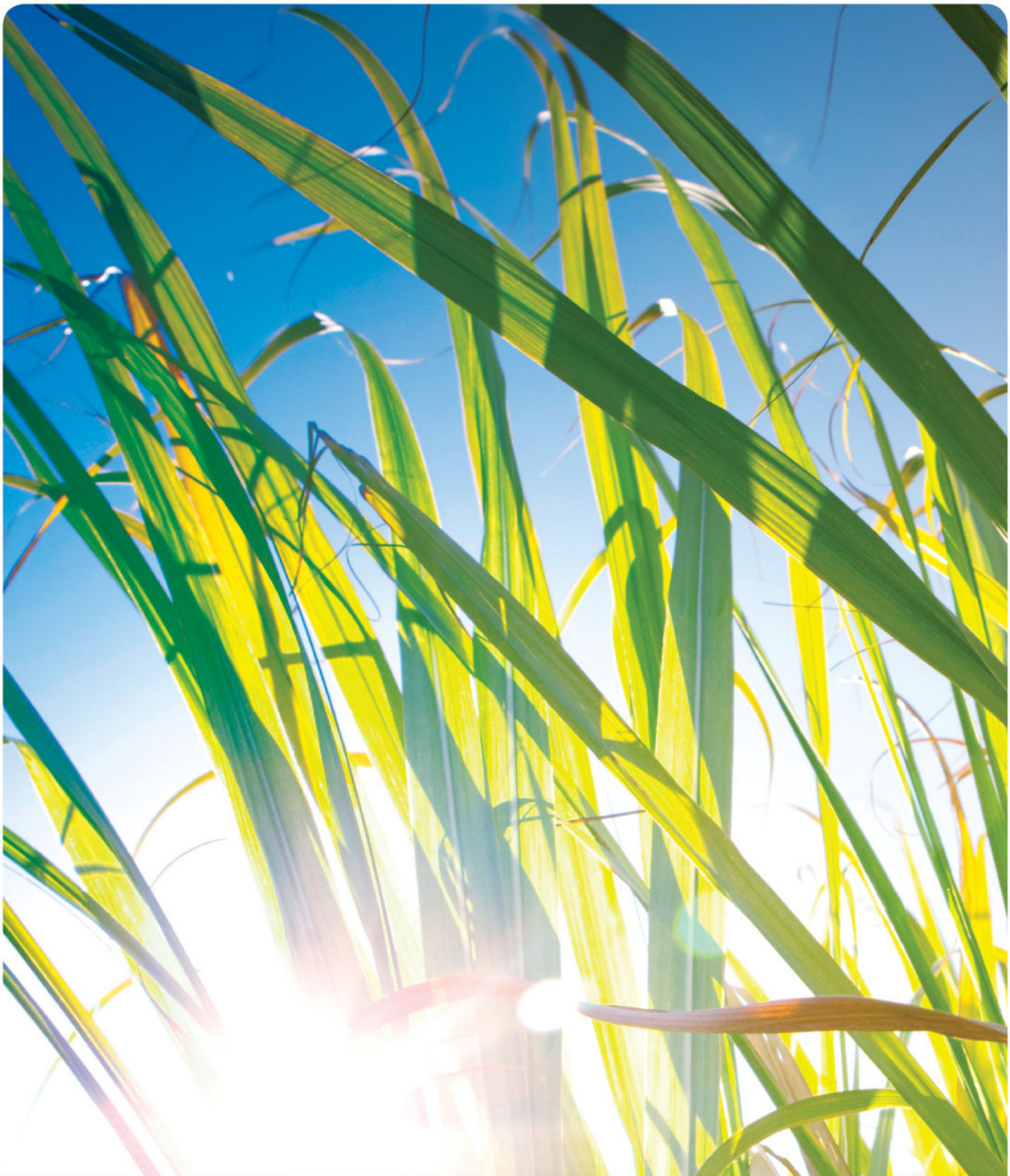
NORRIS
Energy Crop Technology



Prepared for

Australian Government
Sugar Research and Development Corporation

NET001 Interim Report

Quantification of the potential to reduce harvesting losses with field edge trash separation technology

Executive Summary

NorrisECT conducted a series of SRDC supported trials into the potential to improve industry profitability through the use of post-harvest cleaning at sites in the New South Wales Sugar Milling Cooperative and Isis Mill cane catchments during the 2012 crushing season. The aim of the trials was to determine the potential to improve profitability by circumventing the existing compromise between high fibre levels in milled cane, and high cane loss during harvesting under commercial harvesting conditions. This was achieved through utilising 'low loss' harvesting to reduce the cane lost through the harvester cleaning system then a mobile cane cleaning plant to clean the cane before transport to the mill. The impact on tonnes of cane and CCS recovered per hectare, and the transport bulk density were measured.

The trials investigated the impact on recovered cane yields and CCS across three treatments, including 'commercial' harvesting practices (moderate to high extractor fan speed), 'low loss' harvesting practices (low extractor fan speeds, reduced ground speed), and 'low loss' harvesting with post-harvest cleaning (using a NorrisECT mobile cane cleaning plant). Total biomass yield (tonnes per hectare), cane yield (tonnes per hectare), load density (kg per m3) were measured in the field, and the respective mills provided corresponding information on Pol, Brix, Ash, Fibre and CCS measurement (NIR).

Trial results showed significant increase in biomass and delivered CCS yields per hectare resulting from 'low loss' harvesting practices, and a further increase in delivered CCS per hectare (through significant reduction in EM and fibre levels) attributable to post-harvest cleaning. Post-harvest cleaning treatments also demonstrated significantly higher transport load densities.

The actual impact on harvesting costs were estimated based on the change in harvester productivity (hectares per hour) and haul out requirement (m^3 of biomass per hectare) and benchmarked against a large harvesting dataset. Actual sugar recovery was estimated based upon both CCS determinations and earlier Australian and American work on the effect of extraneous matter and fibre on sugar recovery.

The trials have demonstrated that there is potential to significantly increase the industry profitability with post-harvest cane cleaning based on the significant increase in potential sugar production per hectare of land, significant improvement in transport load density and significant reduction in fibre levels in cane milled. It is recommended that further work be undertaken to better quantify the actual impact

on harvesting and transport costs under commercial conditions, and to better quantify the impact on mill performance and costs, and sugar recovery through reduced fibre and extraneous matter levels.

Australian Government
Sugar Research and Development Corporation

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A	Interim Report for SRDC Review	15/03/2013	GL

1 Background

1.1 Importance of harvesting to the value chain

The harvest and transport process is the interface between production (growing) and processing (milling) of the sugarcane crop. It is significant in that in all sugar Industries around the world:

- It is a major source of losses of crop mass and a major determiner of crop quality, and
- Apart from the end of crop cycle land preparation and planting operations, it is typically the most significant cost in the annual crop production cycle for sugarcane.

Mechanical harvesting is known to adversely impact both crop quality and harvesting losses, however the move to mechanical harvesting is typically driven by a need to reduce costs. Australia was the first Industry in the world to embrace chopper harvesting, although Industries such as Hawaii and Louisiana had adopted highly mechanised harvesting strategies prior to the move to full mechanisation in Australia. Inherently, the move to mechanical harvesting, and in particular chopper harvesting results in:

- An increase in the mass loss of product associated with the harvesting process, although this mass loss is nominally at least partially offset by an increase in the extraneous matter which is co-delivered; and
- A reduction in nominal cane quality due to both increased damage and deterioration to the cane stalk and the increased extraneous matter.

The increased extraneous matter both dilutes the cane product and adds deleterious and contaminating components to the product being milled. These both work to reduce the actual sugar which can be recovered relative to the total sucrose delivered.

The primary performance relationships for a harvester, as identified by researchers such as Whiteing (BSES) are:

- Extractor fan speed is the primary determiner of cane loss on the harvester, with other factors such as pour rate and crop condition having relatively minor relative impact on cane loss; and

- Pour rate, crop conditions and field conditions are the primary determinants of trash levels in the delivered product, with pour rate being the primary variable able to be managed.

These issues have been exacerbated in recent years by:

- The increase in harvesting rate and installed power of harvesters, without a corresponding increase in the capacity of the machine to clean the cane being processed, and;

- The need for harvesters to be operated at or near maximum capacity as a strategy to minimise per tonne harvesting costs.

These factors have resulted in increasing leaf levels in the product being delivered, as witnessed by the well reported increase in fibre levels across the Industry. This increase in leaf levels has had a very significant impact on load densities and consequently transport vehicle payload. This then impacts on both haulout capacities required to match harvester capacity and rail bin fleet requirement. An additional issue of increasing interest has been the limitation this causes to the capacity of the tippler system at the mills.

To mitigate this load density problem, there has been a move by the Industry towards shorter billets. The increase in losses (which are predominantly juice rather than fibre) associated with reducing billet length can be hypothesised to further increase the measured fibre level in delivered cane, which has been identified as a significant issue for the Industry.

Research in the late 1990s focused on Harvesting Best Practice (“HBP”) which aimed to reduce cane loss by reducing fan speed, but manage the expected increase in trash levels in the load by reducing harvester pour rate. Whilst small gains in cane cleanliness and greater gains in reduced cane loss could be achieved by this strategy, there was no mechanism to quantify the gains or adequately compensate the harvesting contractor for the increased costs (through reduced harvester hourly productivity).

The Industry, driven by the existing payment structures and without any method to quantify direct and indirect losses, has progressed down a path of:

- Increased harvester pour rates and subsequently increasing leaf and extraneous matter levels in the harvested crop;

- Increased extractor fan capacity and use resulting in increased cane loss;
- Reduced transport system payloads;
- Increased fibre levels in cane; and
- Reduced recovery of the delivered sucrose at the mill.

These factors have contributed to an overall decline in the quantity of the sugar recovered as a percentage of the sucrose available prior to the commencement of the harvesting operation.

Harvesting is a key component of the sugarcane production value chain, both because of the magnitude of the direct costs, but also due to the magnitude of indirect costs associated with direct and indirect losses.

1.2 Drivers of common harvesting practice

The Australian sugar industry value chain is comprised of three groups:

- The grower sector
- The harvesting sector
- The milling sector.

Whilst legislative frameworks exist relating to the interactions between these groups, each have different economic drivers for their own profitability.

- For the growing sector the drivers are to minimise harvesting costs and known or acknowledged losses. Grower payment to the harvester is normally on a per tonne basis.
- For the harvesting sector, the drivers are to maximise utilisation and productivity of equipment to maximise the tonnage of product delivered (thereby reducing per tonne costs), whilst achieving a visually acceptable outcome for the grower. The harvester's costs are predominantly time based (capital, labour), and he is therefore economically motivated to maximise tonnes per hour/day; and
- For the milling sector, payment is made on the analysis of the product

delivered, with the miller getting a higher proportion of the sugar produced from lower quality cane as a compensation for increased mill infrastructure requirements. The degree of loss of crop value prior to the product reaching the mill is of relatively little importance providing the capacity of the mill can be utilised; however crop loss does reduce total tonnes available to the mill from a fixed catchment area.

The industry works with each individual having the primary aim of maximising his individual profitability.

This strategy has, however, been shown not to maximise the total industry income, and has resulted in reducing incomes for all sectors of the industry. It could be argued that existing economic interactions actually serve to reduce the value of the entire value chain.

1.3 Quantifying losses associated with mechanical harvesting

Cane and sucrose loss during the harvesting operation occurs at every interaction between the cane stalk and the machine (Davis & Norris, 2001). Under normal harvesting conditions, the most significant sources of loss are:

- Basecutter losses;
- Billeting losses; and
- Trash extractor losses.

Each of these sources of loss is affected by the setup of the machine and operational decisions by the operator, with the maximisation of the economic viability of the harvesting business being a primary driver of all decisions. An equally important consideration is that the cane loss associated with each of these functions is difficult to quantify and is primarily “invisible”. All forms of loss contribute to the significant Industry “loss of value” which occurs during the harvesting operation.

The losses and the primary drivers impacting on machine setup and operational strategies which impact on this loss can be discussed separately.

1.3.1 Basecutter losses.

Basecutter losses are most significantly impacted on by basecutter configuration (number of blades, disc RPM etc.), setup (blade sharpness and effective length) and machine forward speed. Both losses and damage to the crop stool associated with the basecutting operation increase dramatically when forward speed reaches a critical relationship associated with basecutter blade length and sharpness (Kroes & Harris, 1994). Mass loss associated with the actual basecutting process at low forward speed and with sharp blades is in the order of 1.5-2.5% by weight (Neeves Pers. Comm.), with the loss at higher speeds or with blunt blades being a multiple of this loss.

The move to increasing forward speed increases the proportion of time the basecutters are operating in a high loss and high damage mode. Strategies to reduce forward speed can be anticipated to result in both reduced basecutting losses and reduced damage to the crop stool, potentially positively impacting on ratoon cycle length and yields.

Strategies which result in reduced harvester forward speed are beneficial with respect to both direct losses and indirect (subsequent crop) losses.

1.3.2 Billeting

Sucrose losses attributed to the billeting function on the harvester are well understood. Work by Hocking et.al (Hockings, Davis, & Norris, 2000) investigated billeting losses across a number of different harvester billeting systems, and determined:

- The mass loss associated with billeting indicated a proportionally higher loss of liquid than indicated by stalk composition, i.e. the mass proportion of juice of the total mass lost was higher than the proportion of juice in fresh stalk;
- With sharp new blades, moderate pour rates (120t/hr) and all other parameters optimised, the total mass loss is 0.6%-0.7% per cut in each meter of stalk. A 250mm billet has 4 cuts/m and the total losses can be estimated at 2.4-2.8%. This is consistent with the results from the work of Ridge and Dick (Ridge D R & Dick , 1987) and Fuelling et.al (Fuelling & Henkle, 1979) etc.
- As the blades lose their “edge”, losses increase rapidly, with Hocking et.al noting losses trebling with blunt blades relative to new blades. Work by Neeves (Pers. Com.) indicated similar effects in trials at CTC in Brazil.

- As billet length is shortened by slowing the feedtrain, the choppers rapidly become a primary component with respect to feed of machine through the roller train, and the tension induced in the cane bundle rises very significantly. This causes an increase in both juice loss during the billeting process, and observed damage to the billets.

- Increasing pour rate through the chopper system was also demonstrated by Hockings to increase billeting losses, with billeting losses at a pour rate of 240t/hr being 50% higher than the losses at 120t/hr.

Billet length very significantly impacts on the packing density and thus the bulk density and payload achieved in the transport units. Whilst initially chopper harvesters were set to give a billet length of approximately 300mm, there has been a sustained move to reduce billet length over ensuing years, primarily to mitigate the impact of increasing levels of extraneous matter, particularly leaf material, on load density.

These effects are well demonstrated in Figure 1, which presents data on the impact of harvester average billet length and season average load density for a number of harvesters operating on a plantation in New Guinea. Figure 1 also gives the estimated mass loss for different billet length settings for different chopper configurations, based on the results of the BSES chopper test rig trial program (Hockings et.al).

Figure 1: The impact of billet length on billeting losses and load density.

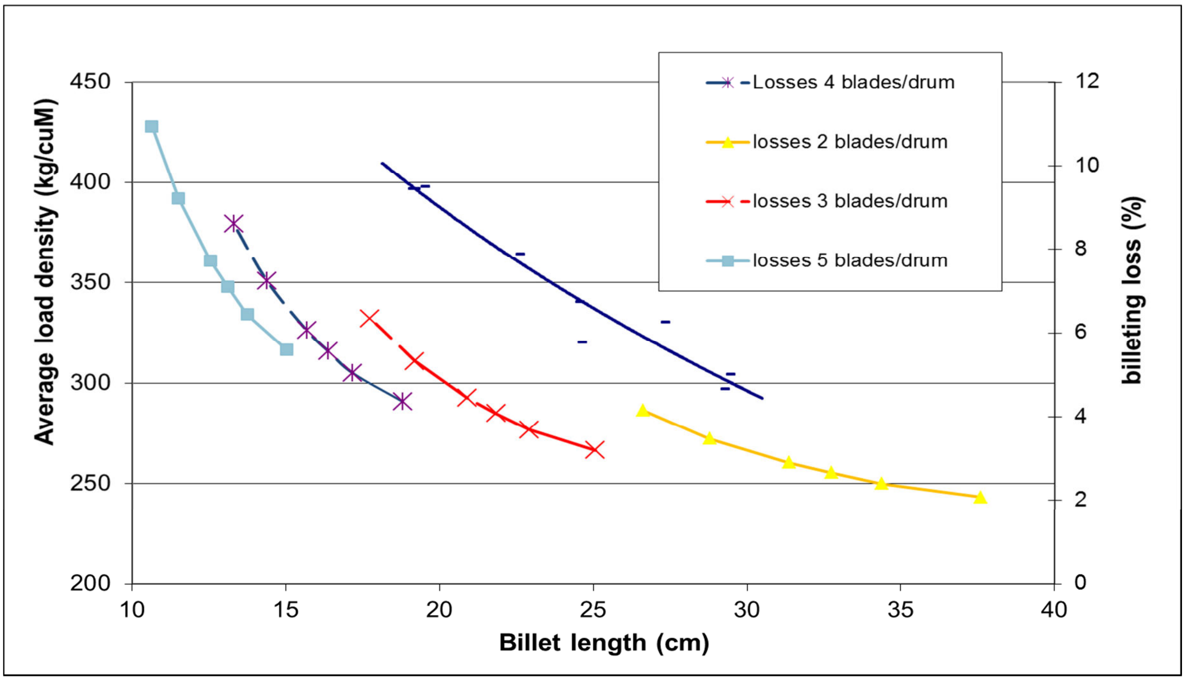


Figure 1 also indicates the impact of billet length on payload density, for a combination of green and burned harvested cane. The data indicates a strong relationship between reducing billet length and increasing load density. Reducing billet length is an effective method of mitigating the impact of increasing trash levels in cane being delivered.

The general move by the industry from 300 mm billets (data set not shown for the original 12 inch x 2 blades/drum) to configurations of five or six blades/drum (10-12 blade systems) arose from the need to increase load density and thus has resulted in a nominal increase in chopper losses (mass loss) from approximately 2% to approaching 10%. These estimates based on the results of the chopper test rig operating under controlled conditions are known to be lower than actual losses suffered by machines in the field. Under field conditions material flow to the choppers is much more variable, with the choppers periodically operating at much higher product flow rates, with higher inherent losses.

1.3.3 Trash extraction efficiency and associated cane losses

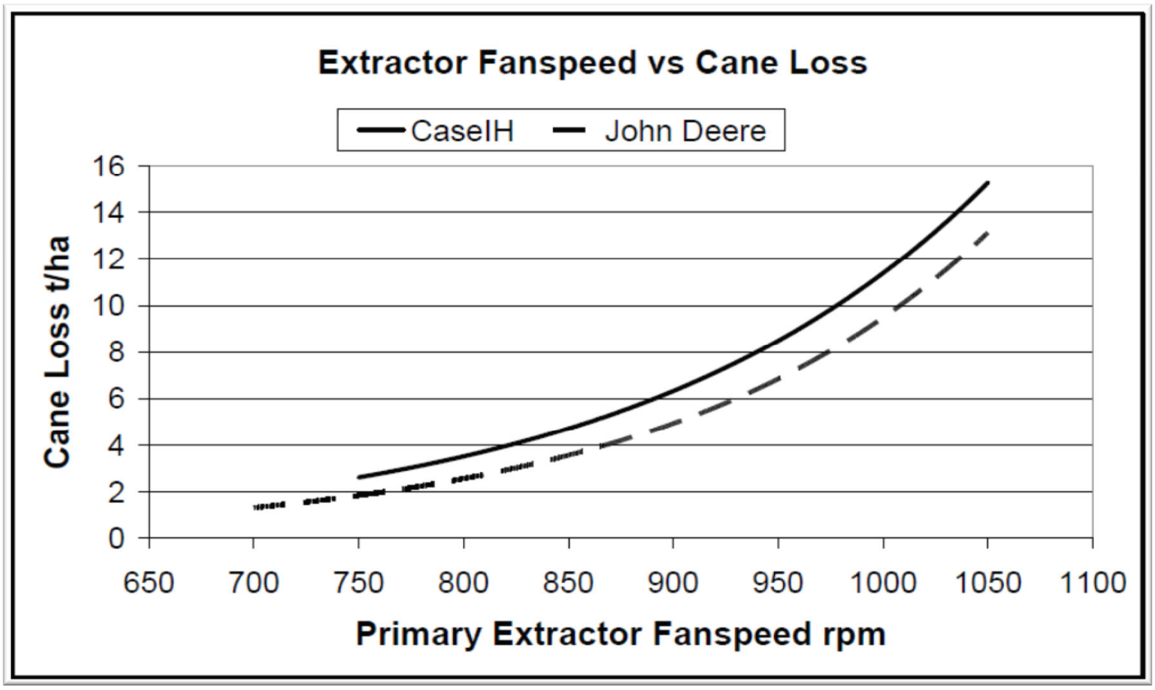
The most significant source of losses on a chopper harvester operating in unburned crops and common operating practice are those associated with the trash extraction system. The primary issues are:

- The material processing rate which is required in a current harvesting operation to be commercially viable,
- The variability in instantaneous material processing rate, and the mode of presentation of material into the extraction chamber by the chopper mechanism, and,
- The spatial constraints, and in particular the height constraints, which dictate that the trajectory of cane billets must be close to the face of the extractor fan.

These constraints mean that trash extraction on chopper harvesters will always be an unhappy compromise between increasing fan speed in an attempt to enhance trash removal, and the increased loss of cane billets which will also occur.

More recently, Whiteing (Pers. Comm.) has undertaken a large number of trials determining the relationship between extractor fan speed and extractor losses on current model harvesters. Results are indicated in Figure 2 below.

Figure 2 Whiteing, Tully & Herbert 2009-2010 cane loss as a function of current model harvester extractor fan speeds.



The overall situation relating to trash extraction on the harvester can be argued to have changed very little since the findings by Whiteing et.al, which are summarised as:

- Under given field conditions, EM is predominantly controlled by harvester pour rate.
- As pour rate increases, fan speed becomes relatively ineffective in reducing EM.
- Field conditions significantly impact on the final EM levels a harvester can achieve. Reducing pour rate in difficult conditions will give better results, bur harvesters are very limited in their ability to produce a clean sample in adverse conditions.
- Cane loss is primarily determined by fanspeed, with the crop having some influence. Typically, increases in fanspeed will cause exponential increases in cane loss, with minimal reductions in trash levels.
- Significant cane loss (>20t/ha) can occur at more extreme fan speeds. At low fan speeds the extractor removes a fair proportion of the total EM with minimal losses. As fanspeed is increased further, the inefficiency of the primary extractor leads to excessive losses, with no significant impact on cleaning.
- The challenge for operators is to select a fan speed which minimises losses then operate at a pour rate that gives acceptable cleaning and still remain viable as a business.

Typical aggressive fan speeds can result in between two and five tonnes of cane can be lost with each additional tonne of trash extracted, with the loss being primarily invisible, due to disintegration of billets by the extractor fan. Attempts to achieve high bin weight targets, reduced contract harvesting costs and reduced mill cane transport costs has significantly reduced clean cane tonnages delivered to the mill. The field cane loss attributed to trash extraction systems is comprised of both visible and invisible losses with the latter being the most significant portion. Extractor losses can be up to 25%. A conservative industry estimate by Whiteing of 10% “avoidable” cane loss equates to an industry loss of $175 Million dollars annually.

1.4 Quantifying the impact of harvesting on transport load density

Cane transport systems for billeted cane are primarily volumetric transport systems, with bin volume determined to give close to maximum allowable axle loadings with “typical” product.

In the initial move to chopper harvested cane, the crop was all burned prior to harvest and the early harvesters typically produced a billet length of approximately 300mm. This resulted in load densities in the order of 360 kg/m^3 in “average” crops. The mill transport system, along with field transport systems were designed to achieve design payload with this load density.

The move to green cane harvesting resulted in a downward trend in load density (Pope, 1989), however this effect was countered by the general move to reduced billet length by the Industry. Subsequent models of harvesters have facilitated further reductions in billet length, with current models offering “10 blade” and “12 blade” systems, giving billet lengths approaching 100mm.

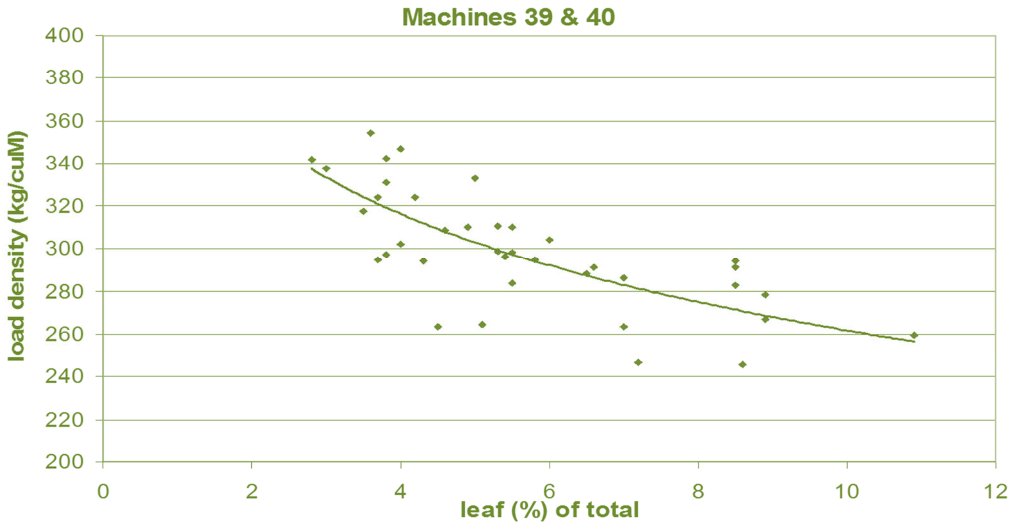
More recently, the increase in harvester pour rate has resulted in further increases in leaf and other extraneous matter levels, and despite the shortening of billet lengths, load density remains an issue for the Industry.

Apart from the transport cost associated with sub-optimal load densities, an equally significant issue is the impact of load density on milling rate. This is because the cane unloading systems at the mills are designed to achieve a volumetric capacity (bins/hr) rather than tonnage/hr. Low load densities reduce the capacity of the unloading system to supply the mill.

Large datasets have been collated on the impact of both leaf levels and billet length on load density, with Figure 3 based on a dataset from a large trial in New Guinea. The data illustrates a reduction in load density from 340-360 kg/m^3 at 2-3% leaf to approximately 260 kg/m^3 at 10% leaf.

Somewhat less work has been done on evaluating the combined effect of varying both billet length and leaf levels simultaneously.

Figure 3: The relationship between leaf levels and load density at fixed billet length. Norris 2010.



The increasing EM levels, and in particular leaf EM levels have become a significant issue for the Industry because of the impact on load density in a volume limited transport system.

The Industry strategy of managing this load density issue by reducing billet length has very significant hidden costs. Strategies which were effective in reducing leaf EM levels in the delivered cane would be of very significant benefit.

1.5 Quantifying the impact of Extraneous Matter on milling performance

The impact of EM on milling performance is multi-faceted, and has been widely studied in many Industries around the world. The accepted ideal is that the cane milled should have the lowest possible levels of EM.

Despite this ideal, EM levels in cane being delivered for milling across the Australian Industry has showed a significant increasing trend, as evidenced by the increasing fibre levels recorded across the Industry.

Wilson and Leslie (Wilson & Leslie, 1996) identified that the reducing CCS problem in the Industry on the Wet Tropic Coast was primarily a result of the impact of increasing trash and other level, with the effect being believed to be primarily driven by the dilution effect of additional trash.

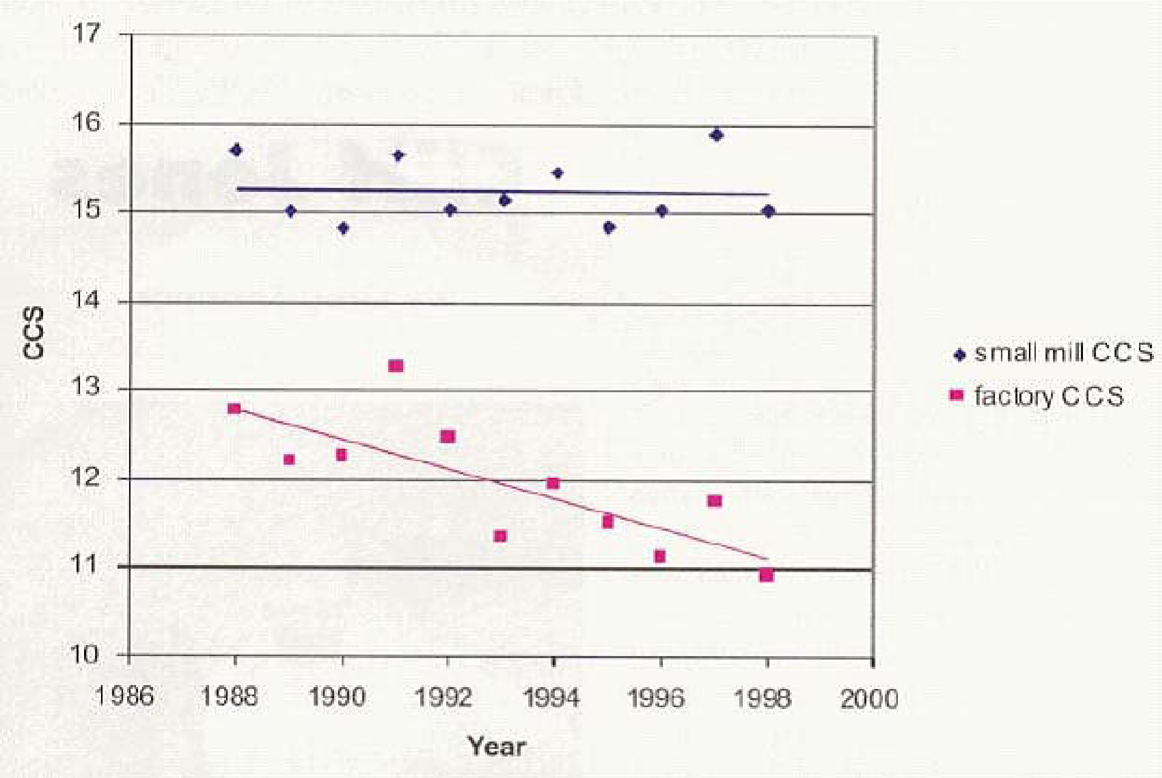
Subsequent work undertaken by Crook et.al (Crook, Pope, Staunton, & Norris, 1999) demonstrated an apparent sequential reduction in the CCS of the cane stalk from the standing crop to after billeting on the harvester, with a further reduction after transport to the mill. In the series of 42 replicated trials, two very significant effects were:

- The increase in apparent fibre in the cane product both associated with the harvesting process (fibre of clean billets higher than that of clean cane stalk), as well as the impact of the included extraneous matter on prepared cane fibre, and;

- The associated effect of the increased fibre levels on CCS of the prepared cane, with the prepared cane CCS being significantly lower than the cane billet fibre component at time of shredding.

Further analysis of trends was undertaken by Lawes (Lawes, 2000), with the data being presented in Figure 4. Lawes attributed the decline in mill CCS relative to the small mill CCS of cane samples to increasing levels of extraneous matter in the milled product, with associated increases in fibre.

Figure 4: Data indicating the reduction in CCS in milled cane relative to clean cane stalk at Tully



All the datasets infer that sugar recovery, as measured by CCS of the prepared cane product at the mill is adversely impacted on by increasing trash levels, however one line of argument is that the final CCS of the prepared cane nominally reflects the recoverable sugar, from all sources, e.g. leaf, tops etc, and as such is an appropriate method to evaluate cane quality for payment.

Significant research from many countries indicates that increasing levels of EM, (particularly leaf material) has significantly greater impact on sugar recovery in the mill than is indicated by the "CCS" type formulae. More typically, increasing leaf and extraneous matter levels will reduce both milling rate (because of increased fibre loadings) and sucrose recovery because the losses increase more significantly.

Trials conducted by Reid and Lionet (Reid & Lionet, 1989), looked at the impact of the different trash levels associated with different treatments on a number of milling parameters. The numbers relating to milling performance are presented in Table 1.

Table 1: Results from milling trials conducted on cane with different levels of trash.

	Milling Rate	Bagasse % cane (Fibre % cane)	Milling rate: bagasse	Milling Train Extraction	Boiling House Recovery	Overall Sucrose Recovery	Relative Sugar Recovery	Sugar Production Rate	"A" Sugar Colour
	(t/hr cane)	(%)	(t/hr)	(%)	(%)	(%)	(%)	(t_s/hr)	
Burnt + Topped	180.6	32.1 (14.4)	58	96.7	91.3	88.3	100%	21.6	870
Unburned, Untopped	127	48.34 (21.7)	61.4	96.3	83.7	80.6	92.3%	10.9	1784

Reid and Lionet's data indicated that:

- The unburned and untopped treatment resulted in an approximately constant bagasse production rate by the milling train, with increasing trash levels having limited impact on milling train extraction and a highly significant impact on milling rate;
- The increasing fibre levels associated with the tops and trash significantly reduced boiling house recovery and overall sucrose recovery;
- The sugar production rate was affected by both the reduced cane crushing rate and the lower boiling house recovery at the high trash levels; and
- Sugar colour appears to be highly correlated with the presence of leaf trash.

Further analysis of the published results indicates that, assuming nominally similar fibre levels in the bagasse (assumed Fibre % Bagasse = 46%) from different treatments:

- The increase in trash provides an increase in the percentage of fibre in the incoming product from 14.8 to 22.3%, an increase of 51%; and
- The overall sucrose recovery from the incoming product is reduced from 88.3% to 80.6%. The higher trash level results in an 8.7 % reduction in

total sucrose recovery relative to topped burned cane.

The trend defined by the results can be defined as:

- A 51% increase in fibre coincides with an 8.7% reduction in total sugar recovery (t sugar/acre). This equates to a 1.7% reduction in actual sucrose recovery from the cane stalk delivered for each 10% increase in fibre levels associated with extraneous matter.

Other researchers have also studied the impact of this increase in non-cane product on various aspects of milling and sucrose recovery. The findings include:

- While not observed in the results from Reid & Lionnet, losses to bagasse are nominally related to bagasse production. Kent (Kent, Allen, Hoare, & Dixon, 1999) quotes findings from a number of researchers indicating POL % bagasse typically remaining constant, or even increasing as trash fibre levels increase in the bagasse. Kent observed similar results in trials at Mossman Mill in Australia;

- Research typically indicates higher losses to bagasse and higher bagasse moisture content as trash levels increase, even when fibre crushing rate is maintained as a constant. Assuming constant sucrose % fibre in the bagasse, the increase in fibre loadings of 50% will increase sucrose losses to bagasse at least proportionally. As with the Reid findings, Kent observed that the fibre milling rate remained near-constant as trash levels varied, however bagasse moisture content typically increased;

- In a series of trials in 2010 in Australia, Kent et al. (Kent & Moller, The Effect of Whole Crop Processing on Sugar Recovery and Sugar Quality, 2010) notes that on average “for each percentage unit of fibre introduced by leaf material, the total sucrose recovery (sucrose % total milled product) is reduced by between 0.9 and 1.5 percentage units”. He further notes that the largest losses were associated with increased molasses production, followed by losses to filter mud and then bagasse; and

- Further findings from these trials indicated that a significant impact of high trash levels was the high non-POL product entering the boiling house. Apart from reduced recoveries and increased molasses production, a reduced rate of crystallization significantly reduced commercial sugar production rates (R. Farrell, Chief Engineer, Broadwater Mill, NSW Sugar, Pers Comm.).

For a given amount of clean billeted cane entering the milling train, reducing EM, and in particular trash leaf levels actually increases the total sugar production. This finding is consistent across the results of researchers both in Australia and overseas. Additional benefits of reducing EM are the increase in mill capacity, both of the milling train and the boiling house.

Strategies to reduce EM levels in delivered cane product potentially increase the net returns to both the growing and milling sectors of the Industry.

1.6 Alternative strategies: Post-harvest cane cleaning.

Post-harvest cane cleaning is a strategy which can be utilised to enhance the quality of the cane to be milled by reducing the levels of extraneous matter.

1.6.1 History of post-harvest cane cleaning

Cane cleaning has been common in many Industries around the world, with the first strategy typically being cane laundries, designed to remove soil from mechanically loaded wholestalk cane. These systems were initially used on chopper harvested cane, however the losses of sucrose were considered excessive, and the disposal of the high sucrose wash water was problematic.

The Cuban Industry was an early adopter of green cane chopper harvesting, however the issue of the impact of high extraneous matter levels on both transport system performance and mill performance was also recognised by that Industry. The issue of the compromise between cane loss and high levels of trash extraction on the harvester were more evident because of the predominance of Soviet built harvesters based on Claas designs, which utilised blower systems for trash extraction, rather than extractor fans. Cane loss was therefore clearly visible as whole billets, and this was an incentive against aggressive cleaning on the harvester.

The Cuban Industry then adopted a strategy of post-harvest cane cleaning at the trans-loading point between field transport units and the mill rail transport units. Whilst relatively simple in design Photograph 1, hundreds of these units are still in operation, and they continue to demonstrate the advantages of post-harvest cleaning. Separated trash is used for a variety of purposes.

Photograph 1: Post-harvest trash separation has been in use in Cuba since the introduction of chopper harvesting. Over 900 facilities such as this are apparently still in use (Nixon, pers com. 2010).

The large scale move by Brazil into chopper harvesting, commencing in the late 1990's meant that the mills had to find alternative strategies to the cane laundries, which had been installed as standard equipment in all new mills during the expansion of the Industry as part of the Pro-alcohol program.

Whilst labour cost and availability was one driver for the adoption of chopper harvesters by the Brazilian industry, a second major impact has been the requirement by government to move to green cane harvesting.

In order to address the issues of increased levels of EM in machine harvested product, the Brazilian Industry invested in cane cleaning R&D, with significant development occurring in the late 1990's. Many of the initial designs attempted to be suitable for both hand cut (wholestalk) and chopper harvested cane. Whilst useful in "cleaning up" the cane supply, actual trash separation efficiency was low and power consumption was high.

1.6.2 Current technology cane cleaning systems

Most recent developments have focused on systems which are designed for trash separation from billeted cane, and the primary drivers of cane cleaning are now both the utilisation of the separated trash for value-added uses such as cogeneration, whilst also capitalising on the benefits of clean cane for the milling process.

"Fourth Generation" cane cleaning systems achieve very high levels of trash removal from the cane supply (>85% under most conditions) with very low levels of cane loss (typically < 0.3%), whilst having very conservative power consumption. Many designs incorporating pneumatic separation but different operating concepts are now available. Raizen, Brazil are aggressively adopting trash separation at their sugar mills, both to capitalise on the value of the trash as an energy resource, but also to enhance the performance (throughput and recovery) of the mills. Examples of cane cleaning facilities at Raizen mills are shown in Photograph 2.

NorrisECT has developed class leading trash separation technology and has designed and/or installed mill based systems in South America, Pakistan and Southern Africa.

Photograph 2: Trash removal systems at four Raizen sugar mills in Brazil.

The re-locatable cane cleaning unit developed by NorrisECT utilises this technology in a compact unit with on-board storage capacity to allow minimal impact on the harvesting process.

1.6.3 Benefits of post-harvest cane cleaning

The benefits of post-harvest cleaning of cane can be anticipated to be:

- The reduction in the requirement for “clean” cane from the harvester will allow the harvester to operate at less aggressive extractor fan settings. This will then result in a significant reduction in cane loss through the harvester extractor fan.

- The product being transported from the harvester to the cleaning facility will have low bulk density. If the cleaning facility is at the mill, this will impact on the logistics of all sections of the transport system. Siding based systems result in clean high density payloads to be carried in the mill transport system.
- At the mill, cleaned cane will have lower EM and fibre levels, and consequently lower fibre levels. This will facilitate higher crushing rates and higher total sucrose recovery.

2 Trial Methodology

2.1 General Methodology

The project consisted of a series of mass balance trials to determine the effect on both total biomass recovery and sucrose recovery through different harvesting treatments, and subsequently the net economic impact.

The trial consisted of three treatments as outlined below.

2.1.1 Low Loss Harvesting (Treatment A)

Treatment A was conducted at reduced primary extractor fan speed without secondary extractor, and where possible at reduced ground speed. This treatment was to reflect operation of the harvester at very low primary extractor speeds in order to minimise cane loss. Ground speed was reduced where possible in order to reduce elevator pour rate, and thus maximise the trash extraction efficiency achieved at the reduced extractor fan speeds.

It was anticipated that this treatment would demonstrate significantly increased cane recovery per hectare, with reduced %CCS due to high extraneous matter levels. Table 2 contains target and achieved operating parameters for Treatment A

Table 2 Target and Achieved Operating Parameters for Treatment A

Parameter	Target	Measured NSW	Measured ISIS
Primary Extractor RPM	550	550	602
Secondary Extractor	OFF	OFF	OFF
Ground Speed km/h	4	4	4.1

2.1.2 Low Loss Harvesting with Post-Harvest Cleaning (Treatment B)

Treatment B was conducted as per Treatment A, with the difference that each haulout payload was cleaned prior to trans-loading to the mill haulage system (NSW Sugar Multilift bins and Isis rail wagons).

Table 3 Treatment B Target and Achieved Operating Parameters

Parameter	Target	Measured NSW	Measured ISIS
Primary Extractor RPM	550	550	601
Secondary Extractor	OFF	OFF	OFF
Ground Speed	4	4	4.2

2.1.3 Commercial High Load Density Harvesting (Treatment C)

Treatment C was intended to represent common commercial harvesting practice, and was carried out at higher primary extractor fan speed, with secondary extraction and at an increased ground speed.

Table 4 Treatment C operating parameters

Parameter	Target	Average Measured NSW	Average Measured ISIS
Primary Extractor RPM	1100	1093	971
Secondary Extractor	ON	ON	ON
Ground Speed	6	6.1	5.5

2.1.4 Cane Harvesters used in Trials

The cane harvesters used in the trials are listed in Table 5 below.

The NSW harvester was fitted with a standard 8 blade chopper configuration, giving a billet length of up to 190mm at “optimised” relationship between feed train roller speed and chopper tip speed. The observed billet length indicates that this machine was running at close to maximum billet length setting and high billet quality could then be anticipated.

The harvester used in the Childers trials was fitted with the 2013, 10 blade chopper system. This system aims to give a shorter billet length than the 8 blade system, whilst retaining a reasonable relationship between feed roller speed and chopper tip speed.

Table 5 Harvester models used for the NSW and Isis trials.

Harvester	New South Wales Trial	Isis Trial
Manufacturer	John Deere	John Deere
Model	3510	3520
Model Year	2007	2013
No of Chopper Blades	8	10
Nominal Billet Length	180 mm	150 mm
Extractor Fan Blade Type	Standard	"Anti-Vortex"

The billet quality observed at Isis was lower than anticipated and variability of billet length was greater. The cause observed increase in billet length variability is difficult to explain, however the results do flag significant issues for the Industry in the move to shorter billets. Physical constraints relating to the available distance between the chopper drum axes means that increasing the number of blades unavoidably reduces the space available for the cane stalk as it passes between the blades. Damage will then be expected to increase as pour rate increases. The harvester used in the Childers trials was generally operating at higher pour rates than the NSW machine.

2.2 Trial Procedure

2.2.1 New South Wales

Alternating treatments were cut from a single block of cane over a single day. Where possible, treatments were cut in a pre-determined randomised sequence to minimise effects of variation throughout the field.

The row length distance travelled by the harvester to fill each haul out was recorded, and subsequent haul outs of the same treatment were transferred to designated road transport bins. The total distance (and therefore field area) required to fill each road transport bin was then known. NSW Sugar road transport bins have a volume of 90m^3 and a maximum allowable load capacity of 22 tonnes.

Total weight and mill NIR results were then requested from the mill for each bin in the trial. Two random samples were also taken from each bin, and sorted to determine the relative proportions of crop components by weight. The sample components were categorised into:

- Cane Billets,
- Tops, and

- Leaf.

2.2.2 Isis

A similar procedure was followed for the Isis trial with minor adjustments to accommodate the Isis rail transport system and NIR cane sampling procedures.

Isis Central Mill's cane delivery system utilises 17.5 m^3 rail bins, of 6.5 tonnes nominal capacity. The infield haulouts used during the trial had a 12 tonne nominal capacity, each haul out generally filling two rail bins. Isis mill's NIR sampling system requires a minimum sample size of a four bin rake to enable validated results. Each harvesting treatment's replicate consisted of a minimum of two haulout loads filling four rail bins. The post-harvest cleaning treatments (Treatment B) generally required an additional haulout load to be bought from the field to the cleaner in an effort to fill the four bins, due to the improved load density and reduced leaf content.

As with the NSW trial the row length travelled by the harvester to fill each haulout was recorded to calculate crop yields for each treatment's replicates.

The total weight and mill NIR results were then requested from the mill for each four bin rake in the trial. A random sample was taken from each bin constituting a replicated NIR sampling rake to determine the relative proportions of crop components by weight. Again the sample components were categorised into:

- Cane Billets,
- Tops, and
- Leaf

2.2.3 Randomisation of samples

In both locations the trials were incorporated into the commercial harvesting schedule of both harvesting contractors, and as such some compromise was necessary in the ordering of replicates because of the time taken for the cleaning operation. Every effort was used to ensure that maximum randomisation was maintained.

3 Impact of low loss harvesting strategies on potentially recoverable sugar being delivered from the field

3.1 Expected impact of low loss strategies on delivery of potentially recoverable sugar

The trials sought to establish the effect of a low loss harvesting strategy on the delivery of potentially recoverable sugar from the field. Significant work by Whiteing (Whiteing, Norris, & Paton, 2001), Viator (Viator, 2007), and Norris (Norris, 2010) have established that significant loss of cane occurs as a consequence of on harvester cleaning with primary and secondary extractors. Further work by Norris and Davies (Hockings, Davis, & Norris, 2000) has also established that significant sucrose losses occur as part of the billeting process.

For the purpose of this study, potentially recoverable sugar has been defined as the total tonnes of material delivered, multiplied by the payment CCS for that material.

It was expected that the trials would demonstrate increased potentially recoverable sugar (tonnes of CCS) per hectare through low loss harvesting practices against the “current practise” control treatment.

3.2 Trial Results

3.2.1 Combined Results

The total potentially recoverable sugar being delivered from the field is a function of the total sucrose in cane being delivered to the mill. Effects of extraneous matter on actual mill sugar recovery are ignored at this stage, as they do not impact upon *potentially* recoverable sugar. For the purpose of this analysis, total recoverable sugar per hectare is defined as the total biomass recovered per hectare multiplied by the sucrose (CCS) content of that biomass. For the purpose of comparison, the effect of harvesting practice on a clean cane per hectare basis was also measured.

Table 6 Average total biomass yield by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes Biomass/ha	Commercial Harvesting (Treatment C) Tonnes Biomass/ha	Field Edge Separation (Treatment B) Tonnes Biomass/ha
New South Wales	109.9	76.9	99.4
Isis	163.5	135.6	149.6

Table 6 demonstrates the average total biomass yield, on a fresh weight basis, of each treatment and trial. The low loss harvesting strategies of treatments A and B produced the highest yields, minimising harvesting losses. Analysis of the treatment replicates revealed the difference between all treatments was statistically significant at the 5% level.

Table 7 Average change in total biomass yield by treatment and trial series against treatment C

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
New South Wales	42.9	29.3
Isis	20.6	10.3

Table 7 shows the changes in total biomass yield attributed to low loss harvesting strategies. An increase of 20.6% was observed for Isis low loss treatments while an increase of 42.9% was observed in the NSW trial. The field edge separation treatments displayed a similar trend of increased yields, the Isis treatments increased by 10.3% while the NSW treatments increased by 29.3%.

Table 8 Average cane component in total biomass (all components except leaf)

Trial Series	Low Loss Harvesting (Treatment A) % Cane	Commercial Harvesting (Treatment C) % Cane	Field Edge Separation (Treatment B) % Cane
New South Wales	88.4	97.9	98.3
Isis	93.3	96.7	99.3

Table 8 shows the proportion of non-leaf material in each trial. Treatment C averaged significantly higher cane proportion than Treatment A across all trial series. This is expected despite the indications of significant cane loss associated with on-harvester cleaning as leaf represents a much smaller proportion of the total prior to cleaning. Treatment B (post-harvest cleaning) consistently produced the highest proportion of cane in all trials.

Table 9 Average 'clean' cane yield by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes 'Clean' Cane /ha	Commercial Harvesting (Treatment C) Tonnes 'Clean' Cane /ha	Field Edge Separation (Treatment B) Tonnes 'Clean' Cane /ha
New South Wales	97.2	75.3	97.7
Isis	152.5	131.1	148.6

Table 9 demonstrates the average clean cane yield, on a fresh weight basis, of each treatment and trial. The low loss harvesting strategies of treatments A and B produced the highest yields and clearly demonstrate the effective cane loss associated with commercial harvesting practices of treatment C. Analysis of the treatment yield replicates revealed a statistically significant difference between treatment C in comparison with treatments A and B at the 5% level. This result is further evidence of the cane loss associated with current commercial harvesting practices.

Table 10 Average change in 'clean' cane yield by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
New South Wales	29.1	29.7
Isis	16.3	13.3

Table 10 shows the changes in clean cane yield attributed to low loss harvesting strategies. An increase of 16.3% was observed for Isis low loss treatments while an increase of 29.1% was observed in the NSW trial. The field edge separation treatments displayed a similar trend of increased yields; the Isis treatments increased by 13.3% while the NSW treatments increased by 29.7%. The results demonstrate that current commercial harvesting practices account for a cane loss in the order of 20%.

Table 11 Average Pol in Cane by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Pol in Cane	Commercial Harvesting (Treatment C) % Pol in Cane	Field Edge Separation (Treatment B) % Pol in Cane
Isis	14.72	15.63	17.09

Table 11 contains average mill calculated Pol in cane for all treatments at the Isis trials. Pol in cane data was not available from NSW Sugar, and as such NSW data has not been included in this analysis. Treatment A yielded the lowest Pol in Cane and this is attributed to the high extraneous matter levels in delivered cane, effectively reducing the proportion of Pol in cane. Treatment B produced the highest Pol in Cane and is attributed to the lowest extraneous matter levels in delivered cane.

Table 12 Average tonnes Pol per hectare by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes Pol /ha	Commercial Harvesting (Treatment C) Tonnes Pol /ha	Field Edge Separation (Treatment B) Tonnes Pol /ha
Isis	24.06	21.19	25.58

Table 12 contains the calculated average tonnes Pol per hectare for all Isis trial treatments. The tonnes of Pol per hectare are defined as the total biomass yield multiplied by the percentage Pol in Cane. Treatment C produced the lowest Pol yield as a result of the associated cane loss while treatment B produced the highest yield. Analysis of the treatment yield replicates revealed a statistically significant difference between treatment C in comparison with treatments A and B at the 5% level. This result is further evidence of the cane loss associated with current commercial harvesting practices.

Table 13 Average change in Pol per hectare by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
Isis	13.5	20.7

The Isis trial results show an increase in total Pol delivered per hectare of between 13.5% by adopting low loss harvesting practices (Treatment A) and an increase of 20.7% by adopting post-harvest cleaning (Treatment B).

Table 14 Average CCS by Treatment and Trial Series

Trial Series	Low Loss Harvesting (Treatment A) Average CCS	Commercial Harvesting (Treatment C) Average CCS	Field Edge Separation (Treatment B) Average CCS
New South Wales	12.10	13.71	14.03
Isis	12.80	13.75	15.42

Averaged NIR CCS analyses of treatment samples from cane delivered to the mill as part of the trial are shown in Table 14. Mill calculated CCS of Treatment A was between 6.9% and 11.7% lower than Treatment C. This is expected due to the elevated leaf (fibre) level in Treatment A, and its associated effect on the CCS formula. CCS for Treatment B ranged between 2.3% and 12.1% higher than Treatment C.

Fibre and impurity levels in delivered cane also influence the actual amount of sugar able to be recovered by the mill. Commercial Cane Sugar ("CCS") estimates the commercially recoverable sugar content of cane delivered to the mill, taking into account fibre and impurity levels.

CCS formula (Canegrowers):

$$CCS = \frac{3}{2}P\left(1 - \frac{F+5}{100}\right) - \frac{1}{2}Bx\left(1 - \frac{F+3}{100}\right)$$

Where:

P : % pol in first expressed juice,
Bx : % brix in first expressed juice, and
F : % fibre in cane.

A method for estimating commercial cane sugar, CCS, was developed as a measure of the commercially recoverable sugar. CCS is widely used as a measure of commercially recoverable sugar as it takes into account impurity and fibre levels. Despite the shortcomings of the CCS formula, it remains widely used as the basis for distribution of sugar income between growers and millers, and as such is seen as an appropriate method for comparing potentially recoverable sugar delivered to the mill.

Table 15 Average tonnes CCS by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes CCS /ha	Commercial Harvesting (Treatment C) Tonnes CCS /ha	Field Edge Separation (Treatment B) Tonnes CCS /ha
New South Wales	13.29	10.54	13.95
Isis	20.93	18.64	23.07

Table 15 lists the average CCS yield (tonnes CCS per hectare) of each treatment and trial. Treatment C consistently produced the lowest CCS yield while treatment B produced the highest yields. Analysis of the treatment yield replicates revealed a statistically significant difference between treatment C in comparison with treatments A and B at the 5% level. No statistically significant difference is found between treatments A and B as the NIR CCS measurement is not a record of actual recovered sucrose. As stated by Kent et al. "for each percentage unit of fibre introduced by leaf material, the total sucrose recovery is reduced by between

0.9 and 1.5 percentage units". Treatment A had significantly higher levels of fibre attributed to its higher leaf content and applying the findings of Kent et al. suggest the actual recovered sucrose of treatment A is significantly less than treatment B.

Table 16 Average change in CCS yield by Treatment and Trial Series

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) Average CCS % Change
New South Wales	26.1	32.4
Isis	12.3	23.8

Initial NIR results of Table 16 show an overall trend of increasing CCS yield for the low loss treatments A and B when compared to the control treatment C. Treatment A produced increases of 12.3% at Isis and 26.1% in NSW, while treatment B produced increases of 23.8% at Isis and 32.4% at NSW. Low loss harvesting with post-harvest cleaning, treatment B, consistently increases CCS yield by an order of 20%. It must be noted that these increases are based on NIR sample analysis of delivered cane, and do not make any allowance for the effects of impurity or fibre levels on mill performance or recovery.

3.3 Conclusions

Low loss harvesting strategies, treatments A and B, increase the harvested crop yield and total tonnes cane delivered to the mill without increasing the area under cane. The net cane yield per unit area of low loss harvesting strategies confirms the existence and magnitude of cane loss, in the order of 20%, associated with commercial harvesting. The significant difference between treatments A and B is the proportion of cane in each bin delivered to the mill. The higher proportion of leaf and extraneous matter delivered to the mill in treatment A reduces the recoverable CCS through increased losses to molasses, bagasse and mud.

The results of this project demonstrated that harvesting practices have a significant impact on the delivered cane quality and potentially recoverable sugar yield per hectare. Low loss harvesting with field edge separation consistently increases recoverable sugar in delivered cane by more than 20% through superior cane quality and reduced losses, associated with both harvesting and milling.

4 Impact of low loss harvesting strategy on harvest costs and in-field transport costs

4.1 Commercial harvesting cost structure

Harvesting and transport costs are the greatest single cost associated with the production and delivery of the crop. Cost pressures have resulted in a continuing reduction in harvesting costs, relative to standardised benchmarks. Whilst a number of payment systems are used, a typical cost for a cane harvesting and haulage operation in green cane (2012 harvest season) is benchmarked at \$8.50/t of product delivered to the mill. This analysis assumes that the harvesting unit consists of:

- A recent model harvester, and
- Two haulout units, with capacity matched to the current mill transport system.

Field data collection by Powell et.al. Ridge et.al and others indicate that, in a "typical" harvesting operation approximately 2/3 of the total ownership and operating costs will be associated with the harvester and 1/3 associated with the haulout units. Whilst the combined capital cost of the haulout units will be higher than for the harvester, the operating and maintenance costs are significantly lower.

To conduct a standardised cost analysis it is assumed that:

- The harvester currently harvests approximately 850t/day, and the contract price is \$8.50/t of delivered product.
- For the purposes of the exercise, it is assumed that average harvested crop yield will be 100t/ha, with the product composition being similar to the product composition for the "commercial" product at Isis.
- The average harvesting pour rate is approximately 155t/hr, which equates to a delivery rate to the rail siding of approximately 85t/hr when bins are available, given typical in-field efficiencies.
- The typical daily operation then requires approximately 10 hours of engine operation to harvest the crop, with additional engine and staff time associated with machine moving, servicing etc.

On this basis the cost of the components of the harvesting operation are total income/engine hour of the harvester and harvesting cost.

Table 17 Overview of commercial harvester and haulout costs

Description	Commercial Harvesting
Product ex-harvester	100 T/Ha
Product to mill	100 T/Ha
Harvest contract price $/t at mill	$ 8.50
Harvest cost/ha	$ 850.00
Harvester forward speed (1.8m rows)	9 km/h
Harvester pour rate	155 T/h
Harvester time efficiency elevator/engine	55%
"On the line" productivity	85 T/Eng h
Harvesting rate	0.85 Ha/h
Harvest gross income rate ($/hr)	$ 722.50
Daily allocation (tonnes nominal)	850 T
Harvester engine hours/day	10.00
Harvester hourly cost	$ 476.85
Haulouts hourly cost (two units)	$ 245.65
Hourly cost/haulout (two units)	$ 122.825
Harvester daily cost	$ 4,769
Haulout daily cost (each)	$ 2,457
Harvester cost $/ha	$ 561.00
Haulout cost $/ha	$ 289.00

The analysis in Table 17 assumes that the daily cost associated with:

- The harvester is approximately $4,769/day or $561/Ha
- Each haulout is approximately $2,457/day or $289/Ha.

These costs are assumed to encapsulate all ownership and operating costs for each of the machines, for the basis of this analysis.

4.2 Impact on harvester and haulout productivity

4.2.1 Operational parameters for low loss harvesting

The separation process in the primary cleaning chamber of the harvester is primarily a “diffusion” process, where leaf components are drawn through the groups of billets as they traverse the extractor chamber. The trash components and any entrapped billets are then drawn through the extractor fan. By nature, the efficiency of the extraction process of trash from the cane billets is heavily impacted on by the mass flow rate of product, both billets and leaf, through the cleaning chamber.

Low harvester pour rates result in higher selectivity of leaf removal and conversely, higher pour rates result in reduced selectivity. Field conditions also impact strongly on the selectivity of trash extraction on the harvester, with lower selectivity being associated with more humid field conditions,

Research by Whiteing et.al (Whiteing, Norris, & Paton, 2001) indicated that extractor fan speed is strongly related to extraction mass flow rate, however increasing mass flow rate of material into the cleaning chamber does reduce the total extracted mass flow rate at lower fan speeds but has limited impact at higher extractor fan speeds. To minimise cane loss during the harvesting operation, it is therefore essential to minimise the harvester pour rate in association with reduced extractor fan speeds.

Harvester elevator capacity can also be a constraining factor on harvester pour rate, with the elevator primarily being a volumetric device. As product density reduces, the maximum transfer volume reduces. The volumetric transfer capacity of the elevator is well matched to current harvesting practices, so additional leaf material will potentially impact on the maximum harvesting rate because of elevator volumetric capacity limitations.

The two primary drivers impacting on the optimum harvesting pour rate for “low loss” harvesting strategies in commercial operations are;

- The capacity of the elevator, and;
- The conflicting requirements of maximising harvester output whilst also maximising the selectivity of the extractor to minimise cane loss.

To mitigate these issues, the forward speed of the harvester is reduced by approximately 20% and the extractor fan speed is reduced by approximately 50% for the purpose of this analysis. The resultant impact of these changes on harvester operation includes:

- The reduction in harvester extractor fan speed will nominally reduce engine power consumption by 20-30kW, giving an anticipated reduction in fuel burn of 4-6 l/hr, based on typical harvester fuel usage patterns

- The reduction in travel speed will increase the time taken for each row to be harvested, however turning time as a percentage of total harvesting time will reduce

- The time lost to bin change stops will increase, because of the increased volume of material to be handled by the haulout fleet.

In a “worst case” scenario, the most significant factor for the harvester will be the reduction in forward speed and the increased time to harvest each hectare of crop. The impact of the change in operating strategies on haulout costs are related to the volume of material to be transferred from the field to the mill bins or to the cleaning unit, as the haulout process is a materials handling operation. It is assumed that haulout capacity will not be limiting, with additional haulout capacity being available to the harvester. Initially it is assumed that this will be achieved by an increase in haulout numbers, however in an optimised system, this would primarily be achieved by a re-design of the haulouts to increase volume.

For the purpose of comparative analysis, the following assumptions are made:

- Crop size is assumed to be similar to an average 100 tonnes per hectare commercially harvested yield

- Forward speed is reduced by around 20%

- Fan speed reduced by around 50%

- Actual total pour rate will remain similar because of increased biomass (cane & trash).

- Initially, the number of standard haulouts will be increased rather than buy units optimised for higher volume application

- Total hours/day of harvesting operation will remain the same as commercial practice. ie. 10 harvester engine hrs/day.

- Total daily payment to harvesting operation increases by additional cost of ownership and operation of an additional haulout.

- *Area harvested per harvester over the season will actually reduce, but profitability remains or improves because of reduced fuel consumption and repairs and maintenance but similar total income.*

These assumptions allow the harvesting costs to be derived for the "low loss" operation. Table 18 presents the impact of the changed operating parameters associated with low loss harvesting (and low loss harvesting with field edge separation) on both harvesting and haulout operations.

Table 18: The impact of low loss harvesting strategies on harvesting and haulout costs.

Description	Unit	Current Practise	Low Loss	Low Loss + Cleaning
Product ex-harvester	T/Ha	100	120.5	120.5
Product to mill	T/Ha	100	120.5	110.4
Harvester forward speed (1.8m rows)	km/h	9	7	7
Harvester/cleaner product delivery rate	T/h	155	152	139
Harvester time efficiency elevator/engine	%	55	55	55
"On the line" productivity (after cleaning)	T/h	85	84	77
Harvesting rate (ha/hr)	ha/h	0.9	0.7	0.7
Hours of engine operation/day	h/day	10	10	10
Tons delivered to mill/day	T	850	835	765
Area harvested/day	ha	8.50	6.93	6.93
Harvester daily cost	$/Day	$4,769	$4,769	$4,769
$/t delivered	$/T	$5.61	$5.71	$6.93
Harvesting cost $/ha	$/ha	$561	$688	$688
Load density in haulouts	kg/m^3	370	265	265
Haulout capacity	m^3	36	36	36
Haulout payload	T	13.3	9.5	9.5
Haulout loads/ha		7.5	12.6	12.6
Haulout loads/hr		6.4	8.8	8.8
Loads/haulout/hr		3.2	2.9	2.9
Haulouts in use		2	3	3
% utilisation		90%	82%	82%
Daily cost of haulouts	$/Day	$2,457	$3,685	$3,685
Haulout cost /ha harvested	$/ha	$289	$532	$532
Total harvest + haulout cost	$/ha	$850	$1,220	$1,220

The move to "low loss" harvesting strategies:

- increased the product being delivered off the harvester elevator from 100t/ha to 120.5 t/ha,
- The reduced harvesting speed (9km/hr to 7km/hr) resulted in total product delivery/hr falling only marginally from 155t/hr to 152 t/hr, with the cleaned cane delivery being 110.4 t/hr.
- The lower observed density of the product from the low loss treatments 265 kg/m^3 v's 370 kg/m^3 for the commercial treatment meant that the

number of haulout trips per unit area harvested increases from 7.5 to 12.6 loads/ha.

- Assuming two haulouts are in use with the current commercial practice, and overall time utilisation is 90% (10% time waiting at harvester), the requirement for the “low loss harvesting” strategy will be for three haulouts. The time efficiency will be 82% (18% waiting time).

4.2.2 Impact of changed operational parameters on harvesting costs

Low loss harvesting strategies impact harvester operating costs. Under low loss parameters harvester productivity is limited by pour rate and elevator capacities. Reduced pour rates and elevator capacity reduce the ground speed of the harvester, increasing the time taken to harvester the crop and resulting in increased operator and engine hours.

The impact of the low loss harvesting strategy on harvester operating costs is demonstrated in Table 19. The per hectare cost increase for treatment A is 22.7% which translates to an 11.2% increase on a per tonne CCS basis.

Table 19 Operational harvesting cost changes

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	% Change
Cost / Hectare	$688.10	$561.00	22.7
Cost / Tonne CCS	$44.58	$40.10	11.2

4.3 Impact on in-field transport costs

Infield transport can be either a mass limited or volume limited operation, depending on the density of the product delivered by the harvester. Typically transport unit volume is selected to achieve maximum allowable mass with “average” product density, and variations in this may change the payload.

Reducing harvester extractor fan speed and increasing leaf content in the extracted product reduces the bulk density of the product being transferred by the haulout. This then reduces the payload of the haulout. The payload reduction, in conjunction with the increased mass of material to be transferred because of the reduced fan speed, requires a significant increase in haulout trips per hectare harvested.

The optimisation of the haulout fleet to match a harvester relates to the cycle time for the haulout (i.e. fill, travel to trans load point, empty, return to field, re-enter field). Optimisation may involve one of two options, namely increasing the number of haulouts supporting a harvester or increasing the payload capacity of the existing haulouts.

The direct impact of the low loss harvesting strategy is an increase of in-field transport costs. Table 20 demonstrates the impact in comparison with the control treatment, commercial harvesting treatment C. The in-field transport costs associated with low loss strategies result in an expected increase in costs. The increase is attributed to the relative increase in harvested product yield requiring additional haulout trips per hectare harvested. The per hectare cost increase for treatment A, of 84%, translates to a 66.7% increase on a per tonne CCS basis.

Table 20 Operational in-field transport cost changes

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	% Change
Cost / Hectare	$532.00	$289.00	84.0
Cost / Tonne CCS	$34.45	$20.66	66.7

4.4 Net impact on harvest and in-field transport costs

The combined effect of low loss harvesting strategies on harvester and in-field transport is an increase in operating costs. This is a direct result of the increase in product, both cane and extraneous matter, delivered to the trans-loading area. The significance of evaluating the costs on a per tonne CCS basis is that it allows for consideration of the harvesting and transport operational cost changes relative to the changes in revenue associated with increased sucrose delivered to the mill. Table 21 demonstrates a summary of the expected impact of low loss harvesting strategies on harvester and in-field transport costs on a per hectare basis. Treatment A has an associated cost of $1,220.10/ha, an increase of 43%, which translates to a cost of $79.03 per tonne CCS, an increase of 30%. The net impact of low loss strategies must not be considered in isolation but analysed with the improvement in crop yield, quality of delivered cane and revenue changes.

Table 21 Net impact on harvesting and in-field transport cost

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	% Change
Cost / Hectare	$1,220.10	$850.00	43%
Cost / Tonne CCS	$79.03	$60.76	30%

5 Impact of field edge separation on extraneous matter levels in the cane supply, and in-field costs

5.1 Impact of extraneous matter levels

The trial program sought to establish the effect of post-harvest cane cleaning on the levels of extraneous matter in cane delivered to the mill. Significant work in Australia and elsewhere (Whiteing, Norris, & Paton, 2001) (Hurney, Ridge, & Dick, 1984) (Viator, 2007) has demonstrated that extraneous matter levels in delivered cane are significant, even with aggressive on-harvester cleaning.

Whilst the research indicates that increasing extractor fan speed is relatively inefficient at reducing extraneous matter levels, there is still an effect. Reducing extractor fan speed in an effort to reduce cane loss will result in some increase in EM levels in cane delivered to the mill.

Extraneous matter levels for each treatment were measured both by manual sorting and weighing of samples from each treatment, and analysis of NIR data from the mill. The effect on extraneous matter components is discussed below.

5.1.1 Impact on leaf in delivered cane

The impact on leaf levels in delivered cane is shown in Table 22. Analysis of the treatment replicates revealed a statistically significant difference between all treatments at the 5% level. The results clearly demonstrate the effect of pneumatic cane cleaning on leaf content in delivered cane. The low extractor fan speed setting of treatment A consistently produced the highest proportion and mass of leaf delivered to the mill. While the high extractor fan speed setting of treatment C (commercial practice) significantly reduced leaf content in delivered cane, the superior cleaning efficiency of the NorrisECT field edge separator produced the lowest leaf content with minimal cane loss.

Table 22 Average leaf levels delivered to the mill by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Leaf	Commercial Harvesting (Treatment C) % Leaf	Field Edge Separation (Treatment B) % Leaf
New South Wales	11.6	2.1	1.7
Isis	6.7	3.4	0.8

Table 23 shows the changes in leaf content of delivered cane in comparison to the control treatment. Treatment A consistently delivered a significantly higher proportion of leaf to the mill with a 452% increase observed in NSW while a 97% increase was observed in Isis. Treatment B consistently delivered reduced leaf content to the mill with a 19% reduction observed in NSW and a 76% reduction observed in Isis.

Table 23 Average changes in leaf levels delivered to the mill by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Leaf	Field Edge Separation (Treatment B) % Leaf
New South Wales	452%	-19%
Isis	97%	-76%

From the analysis of the treatment's leaf content it is clear that low loss harvesting must be coupled with post-harvest cleaning to ensure high quality cane is delivered to the mill. Leaf content in delivered cane has a direct correlation with extraneous matter levels, and therefore the ability of field edge separation to reduce leaf levels while reducing harvester losses is a significant industry benefit.

5.1.2 Impact on tops in delivered cane

The impact of cleaning on the level of tops in delivered cane was determined from manual sorting and weighing of samples from each treatment. The results are shown in Table 24. The mass of tops per hectare in delivered cane is relatively consistent across all three treatments, with neither on-harvester or post-harvest cleaning significantly reducing the level of tops in delivered cane. This is to be expected, as both on-harvester and post-harvest cleaning are pneumatic separation systems, and the similarity of the characteristics (mass, density and shape) of tops and billets makes them difficult to separate pneumatically.

Table 24 Average tops levels delivered to the mill by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Tops	Commercial Harvesting (Treatment C) % Tops	Field Edge Separation (Treatment B) % Tops
New South Wales	7.5	8.7	9.0
Isis	7.3	6.9	6.0

It is important to note that the increase in tops as a proportion of the delivered cane is due to the reduction of the leaf fraction.

5.1.3 Impact on dirt levels in delivered cane

It was not possible to directly measure dirt levels in delivered cane via manual sampling or NIR, and for the purpose of this study NIR ash levels were thought to be the most suitable measure.

Average NIR ash levels by trial and treatment are shown in Table 25. Analysis of the treatment replicates revealed a statistically significant difference between all treatments at the 5% level. Low loss harvesting (treatment A) consistently returned the highest NIR has levels, with on-harvest cleaning consistently producing reduced NIR ash levels, and post-harvest cleaning consistently producing the lowest NIR ash levels.

Table 25 Average dirt levels delivered to the mill by treatment and trial series

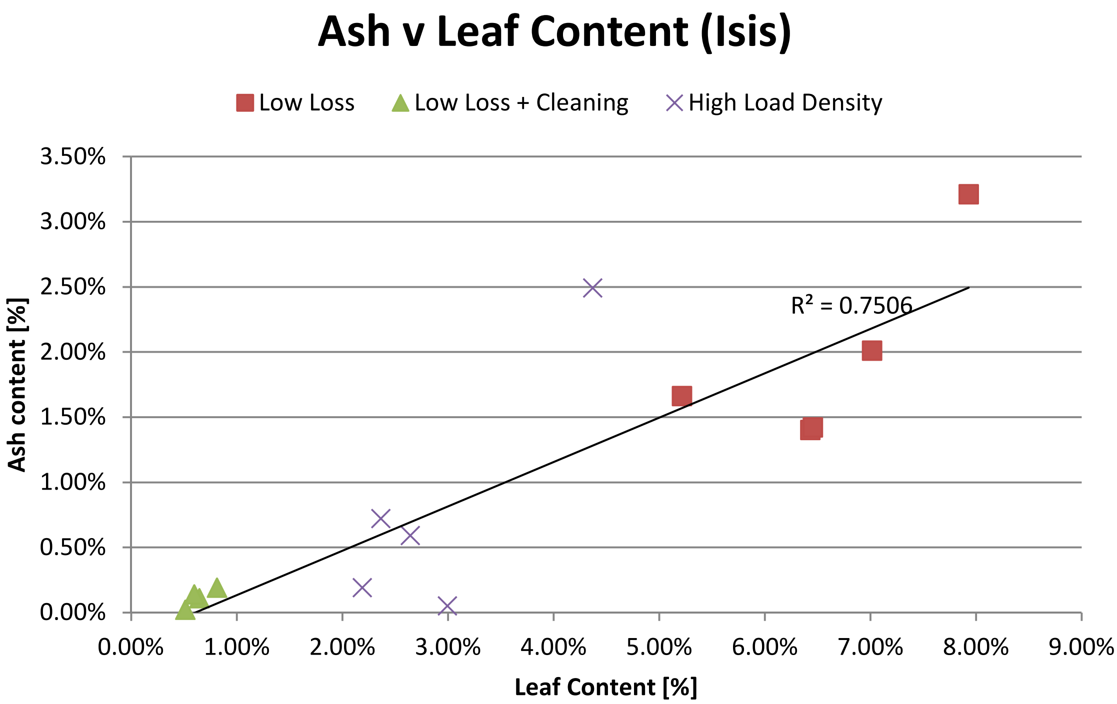
Trial Series	Low Loss Harvesting (Treatment A) Ash % Cane	Commercial Harvesting (Treatment C) Ash % Cane	Field Edge Separation (Treatment B) Ash % Cane
New South Wales	1.63	0.87	0.57
Isis	2.29	1.61	0.04

The relationship between leaf content and ash levels is consistent with previous work, which established that ash and dirt levels were strongly related to leaf content. This was found to be due to dirt content being strongly related to surface area (Ridge D R & Dick , 1987)

It is understood that there is potential for systemic 'zero error' associated with the calibration of the NIR system (Staunton, SG Pers Comm.). It is through that the extremely low NIR ash readings for post-harvest cleaned treatments at the Isis trials may be the result of this error. Figure 5 shows the relationship and reasonably strong correlation between measured ash and leaf content for Isis treatments. It would make sense that the value of Ash Content at zero Leaf

Content should approximate clean stalk Ash Content, and as such Isis NIR ash readings may be reading approximately 1.5% low.

Figure 5 Leaf and Ash content relationship. Isis data shown



This data showed a strongly (R^2=0.75) correlated linear relationship between ash and leaf levels in delivered cane. It is presumed that the y-intercept of this relationship (when leaf content = 0%) would equate to the clean stalk ash content, and as such all Isis NIR ash levels should be increased by approximately the ash content of clean stalk.

In all trials, both on-harvester and post-harvest cleaning showed reductions in NIR ash analysis. Post-harvest cleaning consistently produced the lowest NIR ash levels of all treatments.

Table 26 Average tonnes dirt per hectare delivered to the mill by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes Ash /Ha	Commercial Harvesting (Treatment C) Tonnes Ash /Ha	Field Edge Separation (Treatment B) Tonnes Ash /Ha
New South Wales	1.74	0.65	0.54
Isis	3.74	2.18	0.06

5.1.4 Impact on fibre levels in delivered cane

The impact on fibre levels in delivered cane is shown in Table 27. The level of fibre in delivered cane was determined from mill NIR sample analyses, supported by laboratory analysis, of each treatment.

The low loss harvesting strategy with low extractor fan and ground speeds is consistently associated with the highest fibre levels, which is to be expected due to the significantly higher level of leaf present in the delivered cane. The impact of high fibre levels on milling capacity and sucrose recovery is well established. High fibre levels are directly related to increased milling tandem power consumption and reduced crushing capacity. As demonstrated by Kent et.al. sucrose recovery is known to decrease by 0.9 units for every 1 unit increase in fibre. The reduction in sucrose recovery associated with increased fibre levels effectively lowers the industry revenue per hectare. Both the commercial harvesting and field edge separation treatments consistently produced lower fibre levels, with the latter associated with the lowest fibre levels. The commercial harvesting involved aggressive fan speeds and higher ground speeds while the field edge separation strategy used low loss harvester settings coupled with supplementary cleaning at the field edge. The resultant trend of decreasing fibre levels for both strategies is attributed to cane cleaning, be it on-harvester or post-harvest cleaning. The justification for clean cane is clearly driven by the resultant reduction in fibre levels.

Analysis of the treatment replicates for fibre levels revealed a statistically significant difference between all treatments at the 5% level. Treatment A consistently produced the highest fibre levels between 17.9% and 21.5% while Treatment B consistently produced the lowest fibre levels ranging between 14.1% and 14.5%.

Table 27 Average fibre levels by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Fibre	Commercial Harvesting (Treatment C) % Fibre	Field Edge Separation (Treatment B) % Fibre
New South Wales	17.90	14.77	14.53
Isis	21.51	18.11	14.17

A proportional relationship between leaf and fibre levels is evident from Table 22 and Table 27.

Table 28 demonstrates the significant reductions in delivered fibre, on a per hectare basis, associated with commercial harvesting and field edge separation. Both treatments support improved milling capacity and sucrose recovery with the latter delivering the least amount of fibre to the mill. Cane quality is strongly related to fibre levels and by association leaf levels too.

Table 28 Average tonnes fibre per hectare delivered to the mill by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes Fibre /Ha	Commercial Harvesting (Treatment C) Tonnes Fibre /Ha	Field Edge Separation (Treatment B) Tonnes Fibre /Ha
New South Wales	19.17	13.90	10.88
Isis	35.17	27.09	19.21

5.1.5 Impact on CCS levels in delivered cane

The impact on CCS levels in delivered cane is shown in Table 29 while the average tonnes of CCS per hectare are shown in Table 31. The level of CCS of delivered cane was determined from mill NIR sample analyses, calibrated with laboratory analysis, of each treatment. The CCS levels make no allowance for losses associated with the milling and recovery processes but refer to the potentially recoverable sugar in the delivered cane. CCS levels were considered a critical analysis criterion due to its use in the calculation of cane payments to the grower. The tonnes of CCS are reflected as a function of gross crop yield by NIR recorded CCS levels.

The low loss harvesting strategy, treatment A, is consistently associated with the lowest CCS levels, between 6.9% and 11.7% lower in comparison with the commercial harvesting strategy, treatment C. This result is to be expected due to the significantly higher levels of extraneous matter present in the delivered cane. The net or clean cane proportion of the “low loss” delivered product is the lowest of the three treatments (refer to Table 7) and is another significant factor in the resultant low CCS levels associated with low loss harvesting. The tonnes of potentially recoverable CCS for low loss harvesting are significantly higher than commercial harvesting with an average increase in the range of 12% to 26%.

The field edge separation strategy, treatment B, produced the highest CCS levels of between 2.3% and 12.1% higher than the commercial harvesting treatment. This is attributed to the treatments ability to produce high quality harvested cane with the:

- lowest levels of extraneous matter
- highest proportion of net of clean cane in the delivered product and
- lowest levels of cane loss associated with harvester leaf extractors.

The tonnes of potentially recoverable CCS for field edge separation are significantly higher than commercial harvesting. The increase in tonnes of CCS ranged from 23.8% to 32.4%.

Table 29 Average NIR CCS levels by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) CCS %Cane	Commercial Harvesting (Treatment C) CCS %Cane	Field Edge Separation (Treatment B) CCS %Cane
New South Wales	12.10	13.71	14.03
Isis	12.80	13.75	15.42

Table 30 Average change in NIR CCS levels by treatment and trial series against treatment C

Trial Series	Low Loss Harvesting (Treatment A) CCS %Cane	Field Edge Separation (Treatment B) CCS %Cane
New South Wales	-11.7%	2.3%
Isis	-6.9%	12.1%

Table 31 Average tonnes CCS by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes CCS /ha	Commercial Harvesting (Treatment C) Tonnes CCS /ha	Field Edge Separation (Treatment B) Tonnes CCS /Ha
New South Wales	13.29	10.54	13.95
Isis	20.93	18.64	23.07

Table 32 Average change in tonnes CCS by treatment and trial series against treatment C

Trial Series	Low Loss Harvesting (Treatment A) Tonnes CCS /ha	Field Edge Separation (Treatment B) Tonnes CCS /Ha
New South Wales	26.1%	32.4%
Isis	12.3%	23.8%

5.1.6 Impact on mill performance

The limited scale of the trial prevented any performance monitoring of the full milling and recovery processes. It is however possible to establish a limited assessment of the impact of extraneous matter levels on mill performance by observing the recoverable CCS on milled fibre. Increased fibre levels associated with high leaf content in delivered cane is known to decrease the milling rate, juice purity and sugar production (Kent et al. 1999). The tonnes of fibre milled for every tonne of recoverable CCS is therefore indicative of cane quality and milling efficiency, the lower the ratio the higher the cane quality and milling efficiency. Reducing the amount of fibre milled to recovered sucrose has multiple benefits for mill performance including:

- Reduced milling power demand per tonne of recovered sucrose
- Increased milling capacity as a result of a reduced fibre delivery rate
- Reduced losses to molasses, bagasse and mud

Table 33 demonstrates the relationship between CCS and Fibre of delivered biomass for each treatment. Treatment A consistently produced the highest ratio of fibre to CCS, while treatment B consistently produced the lowest ratio of fibre to CCS. Analysis of the treatment replicate yields revealed a statistically significant difference between all treatments at the 5% level.

Table 33 Average tonnes fibre milled per tonne recoverable CCS by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes Fibre / CCS	Commercial Harvesting (Treatment C) Tonnes Fibre / CCS	Field Edge Separation (Treatment B) Tonnes Fibre / CCS
New South Wales	1.44	1.32	0.78
Isis	1.68	1.45	0.83

Table 34 demonstrates the change in fibre on cane ratio for treatments A and B in comparison with the control treatment C. Treatment A consistently increased the ratio of milled fibre to recoverable CCS by 9% in NSW and 15% in Isis. Treatment B consistently decreased the ratio of fibre to recoverable CCS by 40.1% in NSW and 42.8% in Isis.

Table 34 Average change in fibre milled per recoverable CCS by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
New South Wales	9.1	-40.1
Isis	15.9	-42.8

Treatment B clearly increases the milling efficiency and sucrose recovery through the reduction in fibre levels and leaf associated extraneous matter delivered to the mill.

5.2 Impact on in-field costs

5.2.1 Effect on cost of harvesting operation

Field edge separation utilises low loss harvesting parameters (namely pour rates, extractor fan speeds, harvester ground speed) to harvest the crop and the effect of this strategy has been established in section 4. A significant difference is however noted in the associated costings on a per tonne CCS basis. The difference is attributed to the superior CCS yield of field edge separation, treatment B. (refer to Table 15)

The impact of field edge separation on harvester operating costs is demonstrated in Table 35. The per hectare harvesting cost increase for field edge separation (treatment B) is unchanged in comparison with low loss harvesting (treatment A) and results in a 22.7% or $127.10/Ha increase on commercial harvesting costs (treatment C). The superior CCS yield of field edge separation produces a reduced cost increase in comparison with low loss costings on a per tonne CCS basis. The resultant harvesting cost changes of field edge separation against commercial harvesting on a per tonne CCS basis is 5.7% or $2.30/Ha.

Table 35 Operational harvesting cost changes for field edge separation

Trial Series	Field Edge Separation (Treatment B)	Commercial Harvesting (Treatment C)	% Change
Cost / Hectare	$688.10	$561.00	22.7
Cost / Tonne CCS	$42.40	$40.10	5.7

5.2.2 Effect on cost of additional haulout operation

Field edge separation utilises low loss in-field practices (namely an additional haulout) to transport the harvested crop to the separator and the effect of this strategy has been established in section 4. A significant difference is however noted in the associated costings on a per tonne CCS basis. The difference is attributed to the superior CCS yield of field edge separation, treatment B. (refer to Table 15)

The impact of field edge separation on in-field operating costs is demonstrated in Table 36. The per hectare in-field cost increase for field edge separation (treatment B) is unchanged in comparison with low loss harvesting (treatment A) and results in an 84% or $243.00/Ha increase on commercial harvesting costs (treatment C). The superior CCS yield of field edge separation produces a reduced cost increase in comparison with low loss costings on a per tonne CCS basis. The resultant harvesting costs changes of field edge separation against commercial harvesting on a per tonne CCS basis is 58.6% or $12.10/Ha.

Table 36 Operational in-field transport cost changes for field edge separation

Trial Series	Low Loss Harvesting (Treatment B)	Commercial Harvesting (Treatment C)	% Change
Cost / Hectare	$532.00	$289.00	84.0
Cost / Tonne CCS	$32.76	$20.66	58.6

5.2.3 Effect on cost of mobile separator

The costs of the mobile separator are derived on the basis of anticipated ownership and operating costs, with a nominal annual throughput of 100,000 tonnes of cleaned cane and a design capacity at high trash extraction efficiency of

150t/hr and a peak capacity of 180t/hr. The average operating costs of a mobile separator are shown in Table 37.

Table 37 Average operating costs of a mobile separator

Description	Cost / Tonne Cane
Financing costs including depreciation	$0.36/T
Fuel	$0.30/T
Repairs & Maintenance	$0.25/T
Operator	$0.40/T
Total Net Cost	$1.31/T
Cost including profit	$1.64/T

The ownership and associated per hectare operating cost of the separator is $180.78 calculated using a delivered cane yield of 110.4T/Ha. The operating costs of the separator when considered on a per tonne CCS basis is $11.14/$T_{CCS}$. This cost is additional to the harvesting and infield costs.

5.2.4 Effect on cost of trash disposal

In most Industries, post-harvest trash separation occurs at the mill, and the driver for trash separation is the utilisation of the trash as a fuel source. The benefits of trash removal from the delivered cane, with respect to efficiency in milling recoveries, are generally considered "secondary" benefits. One of the exceptions to this strategy, where widespread cane cleaning is routinely undertaken is Cuba, where the primary reason for cane cleaning is the cane transport density and mill recovery advantages.

In the Australian context, the "best-case" scenario for field edge cleaning is when a positive value exists for the trash, at the separation point.

- Examples of "high value" potential uses for the trash can include utilisation of the trash for products such as for energy source, where trash would otherwise have to be baled after harvest. A relatively high value for trash can positively impact on the overall crop value.
- Examples of "moderate" value for trash include the processing and utilisation for mulch and other products. This can potentially marginally increase the overall value of the cane crop.
- Examples of low trash value are envisaged as charring the trash for re-

distribution on the field, with potential for some payment for carbon sequestration. These strategies will typically result in a minimisation of the cost of trash removal rather than having a potential positive cost.

- Trash removal and re-spreading. This is the most expensive strategy for trash management, as a cost is incurred to remove the trash.

Benefit-costs for post-harvest trash separation is then impacted on by the cost or additional income associated with the trash management after the separation process.

Analysis of the "worst case" scenario "trash removal and re-spreading" is demonstrated in Table 38.

Table 38: Costs associated with trash removal from the separator and spreading on fields

Description	Cost / Tonne Cane	
Tractors (55kW) x2	$50,000.00	per unit
Self-unloading trailers x2	$60,000.00	per unit
Season length	150	days
Daily utilisation	11	hours
Fuel usage	$17,696.00	per annum
R&M Tractors & trailers	$26,544.00	per annum
Ownership cost (tractors)	$17,000.00	per annum
Ownership cost (trailers)	$17,000.00	per annum
Labour	$35,000.00	per annum
Annual net cost	$113,241.00	
Annual cost including profit	$141,551.00	
Daily cost	$976.00	
Cost/ha	$141.00	
Cost/T_{CCS}	$8.68	

Table 38 presents the cost associated with utilising two lightweight high volume self-unloading tractor/trailer units to take the trash from the separator to the field.

The tractor/trailer units would be articulated, with a trash payload of approximately 5t. One unit would be being filled while the second unit is being unloaded.

On the basis of this analysis, the trash transport and spreading cost will be approximately $14/t, which on a per-ton basis is significantly higher than the cost of the cane transport. For comparative purposes a per hectare and per tonne CCS costing has been calculated of \$141.00/Ha and \$8.68/T_{CCS} respectively.

5.3 Net impact of field edge separation

The net impact of field edge separation in comparison to commercial harvesting strategies is considered on both per hectare (Table 39) and per tonne CCS basis (Table 40). The operational costs of trash separation and disposal are included for a 'worst case' strategy of returning the separated trash to the field post harvesting when there is no identified market for the trash. (eg. Garden cane mulch, cogeneration purposes, charring, and biofuels) An increase in operating costs for field edge separation is expected.

Table 39 demonstrates that on a per hectare basis the field edge separation strategy (treatment B) has an 81.4% or \$692.00 increase in costs in comparison with commercial harvesting strategies (treatment C). The per hectare cost increase is expected to be substantially more than the low loss harvesting strategy and this is attributed to the additional costs associated with trash separation and disposal.

Table 39: Total cost per hectare of different harvesting options, including trash management.

Description	Field Edge Separation (Treatment B) \$/Ha	Commercial Harvesting (Treatment C) \$/Ha	% Change
Harvester & haulout	\$1,220.00	\$850.00	
Trash separation	\$181.00		
Trash cartage & spreading	\$141.00		
Total	\$1,542.00	\$850.00	81.4

Table 40 demonstrates that on a per tonne CCS basis the field edge separation strategy (treatment B) has an 56.3% or \$34.22 increase in costs in comparison with commercial harvesting strategies (treatment C). The per tonne CCS cost increase is substantially more than the low loss harvesting strategy and once again this is attributed to the additional costs associated with trash separation and disposal.

Table 40: Total cost per tonne CCS of different harvesting options, including trash management.

Description	Field Edge Separation (Treatment B) $/tonne CCS	Commercial Harvesting (Treatment C) $/tonne CCS	% Change
Harvester & haulout	$75.16	$60.76	
Trash separation	$11.14		
Trash cartage & spreading	$8.68		
Total	$94.98	$60.76	56.3

The combined effect of low loss harvesting and field edge separation strategies on harvester and in-field transport is an increase in operating costs. This is a direct result of the increase in product, both cane and extraneous matter, delivered to the trans loading area. On a per hectare basis the cost increase of harvesting and in-field transport for treatments A and B is of the same proportion. It is only when compared on the basis of tonnes of potentially recoverable CCS that a difference is noticed between treatments A and B. The significance of evaluating the costs on a per tonne CCS basis is that it allows for consideration of the harvesting and transport operational cost changes relative to the changes in revenue associated with increased cane product and quality delivered to the mill. The cost increase associated with treatment B is less than treatment A and this is attributed to its superior CCS yield. (refer to Table 15)

The additional cost considerations for field edge trash separation are the additional processes of trash separation and disposal. While these processes contribute to an overall strategy cost that exceeds that of low loss harvesting the benefits of these processes far exceed their costs.

Table 41 Summary of net impact on harvesting and in-field transport cost

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	Field Edge Separation (Treatment B)
Cost / Hectare	$1220.10	$850.00	$1542.00
Cost / Tonne CCS	$79.03	$60.76	$94.98

6 Impact on siding to mill transport costs

6.1 Impact on siding to mill transport costs

For the purpose of the transport cost analysis it is assumed that the bin costs are fixed on a volumetric basis. This assumes there are no other transport constraints and that transport costs are inversely proportional to the bulk load density. The transport costs from the siding to mill are however directly proportional to the number of delivered bins per unit area harvested.

Low loss harvesting strategies increase the harvested biomass yield and associated bin deliveries per unit area. This translates to a direct increase in transport costs per unit area. The proportion of clean cane in the low loss loads is lower than commercial and post-harvest cleaned cane and increases the cost per delivered tonne of cane. The higher proportion of extraneous matter present in low loss loads produces a lower bulk density of delivered biomass and higher transport costs.

Post-harvest cane cleaning will impact siding to mill transport costs both by increasing the net cane harvested per hectare, the proportion of net cane in the load, and by altering the bulk density of the delivered material. Cleaner cane produces both higher bulk density, and reduced extraneous matter fractions, thereby both increasing the mass of net cane per load, and reducing the cost of each tonne delivered to the mill. The benefit may be less apparent in road transport systems, as maximum load mass may become a constraint on payload.

6.2 Impact on load density

Both trial programs demonstrated a significant impact on load density associated with both on-harvester cleaning and post-harvest cleaning. It should be noted that the benefit of increased load densities may be less apparent in road transport systems, as maximum load mass may become a constraint on payload. Table 42 shows post-cleaning bulk density by treatment and trial series.

Table 42 Average load densities of product delivered to the mill by treatment and trial series

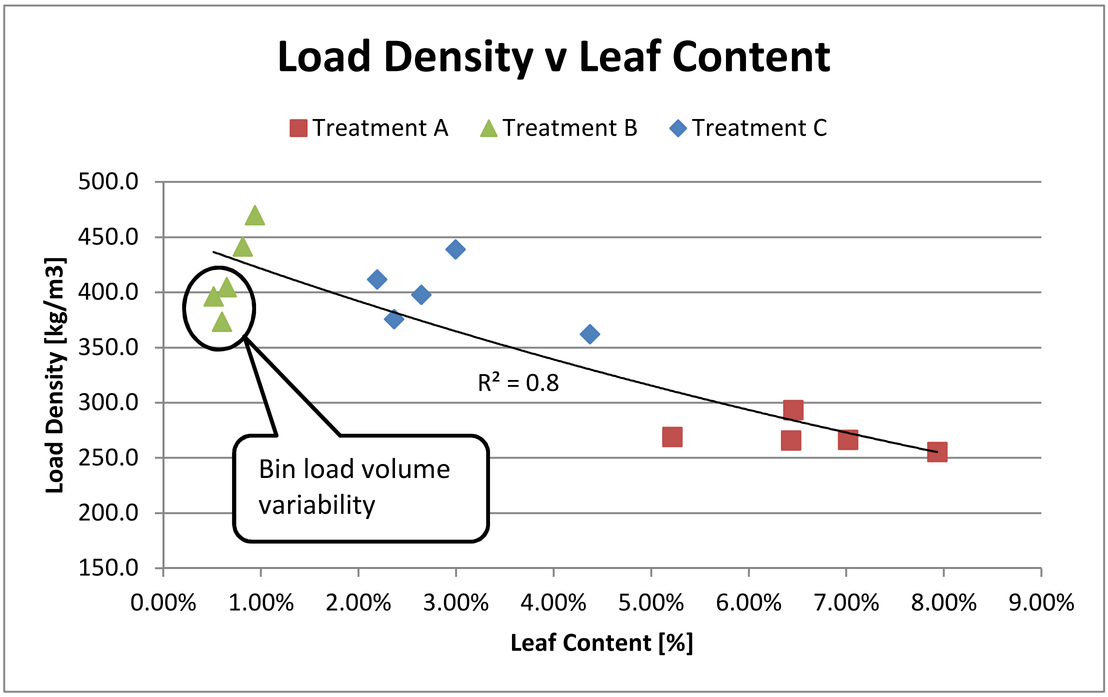
Trial Series	Low Loss Harvesting (Treatment A) kg/m3	Commercial Harvesting (Treatment C) kg/m3	Field Edge Separation (Treatment B) kg/m3
New South Wales	217	349	377
Isis	263	369	439

Isis bulk density was calculated using bin weight data from the mill, divided by nominal bin volume. Bulk density figures for Treatment B across all trials are artificially low due to operational constraints during the trial series. The New South Wales road transport system is highly sensitive to bin weight, with stiff penalties for overloading. As NSW bins generally approach maximum weight under current practices, it was not possible to increase bin weights however the calculated bulk density between treatments B and C is still significantly different. The respective treatment bins were only 50% to 75% full and it was not practical to use nominal bin volume in bulk density calculations, for analysis purposes, and as such the actual bulk density was calculated. On average the NSW C treatment filled 75% of the bin volume and their bulk densities were calculated using this volume. The NSW B treatments produced a similar result with an average filled bin volume of 50% and the bulk densities were calculated accordingly.

No weight limitation was placed on rail bins during the Isis trial series, however there was greater variability in bin weight due to an excess of bin capacity allocated for the trials (despite the greater cane yield per hectare with post-harvest cleaning, the significantly increased bulk density significantly reduced the volume of cane to be transported).

Referring to Table 42, Treatment A consistently produced the lowest load densities and was significantly different to the other treatments at the 5% level. The lower load densities are associated with high leaf content as demonstrated in Figure 6. Treatment B produced the highest load densities however statistically it was not significantly different to Treatment C. This is attributed to the nominal volume used to calculate bulk densities for the Isis trial. A portion of the B Treatment bins were not fully loaded, accounting for the densities ranging from 350kg/m3 to 400kg/m3 shown in Figure 6.

Figure 6 Leaf content and load density relationship



The data shown in Figure 6 demonstrates a strong (R^2 = 0.8) exponential correlation between load densities and leaf content. Load densities increase with reductions in leaf content in the delivered product. The lower densities found in the low leaf content are attributed to Isis data where bin load volume variability was experienced.

6.2.1 Actual Impact on Road Transport

The 90m^3 multilift bins used by New South Wales were designed with the capacity to deliver whole crop product to the mill however the road transport system is mass limited, and therefore unable to take advantage of increased bulk density by increasing transport payloads.

Key issues for consideration are:

- Due to trial protocols, it was not possible to load the “cleaned cane” treatments to achieve maximum allowable payload.
- The actual payloads are therefore not relevant with respect to commercial

payloads of on-harvester cleaned cane

- The correct strategy is therefore to derive an anticipated payload for cleaned cane, which will be maximum payload for NSW and something above design payload of the bins for Isis.
- This payload is then used for the siding to mill transport density calculations. (refer to Table 43)

Reducing costs of existing road transport systems is based on the premise of increasing load densities, primarily through reduced billet length and aggressive on-harvester cleaning. The respective sucrose and cane losses associated with these practices do not justify the apparent transport cost savings. As with the NSW transport system, most road transport systems are load limited which reduces the ability to capitalise on increased load densities.

Table 43 provides an analysis of the transport system performance for each treatment. A maximum payload correction has been applied to treatment B as described in the key consideration points listed previously.

On a per hectare basis, the NSW low loss harvesting and field edge separation treatments did not reduce the number of bins of product delivered to the mill, they actually increased the bin count, by 2.29 and 2.52 respectively, when compared to commercial harvesting (3.34 bins per hectare). This is an increase of 68.3% for low loss harvesting and 29.3% for field edge separation. The result is driven by the increase in the yield of harvested biomass associated with the two treatments.

Table 43 NSW analysis of product delivered by road to the mill by treatment and trial series, including payload corrections

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	Field Edge Separation (Treatment B)
Tonnes Biomass / Bin	19.51	23.00	16.95
Corrected Tonnes Biomass / Bin	-	-	**23.00**
Bins / Hectare	5.63	3.34	4.32

Table 44 NSW changes in road transport system indicators by treatment and trial series.

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
Tonnes Biomass / Bin	-15.2	0
Bins / Hectare	68.3	29.3

Even with the load limits associated with road transport systems there is still potential to utilise field edge separation to improve transport efficiencies. The significant increase in bulk density associated with post-harvest cleaning would allow the New South Wales industry to consider increasing average billet length to maximise sucrose recovery by reducing billeting losses associated with billet length and the number of "cuts" per stalk.

6.2.2 Actual impact on rail transport

The Isis rail transport system shares the characteristics of the majority of the Queensland mill rail transport systems however is must be noted that the Isis rail bins were designed with a 17.5m^3, 6.5tonne capacity.

Referring to Table 45 the low loss treatment produced the highest bin count per hectare, 35.46 Bins/Ha, a 68.7% increase when compared with control treatment C. This is attributed to the increase in harvested biomass yield. The resultant impact of this treatment is a requirement for an increased rolling stock of bins to deliver the harvested crop with an associated higher transport cost per harvested unit area.

The field edge separation treatment produced lowest per hectare bin count, 19.5 Bins/Ha, a 7.2% reduction when compared with control treatment C. The resultant impact of this treatment, in comparison with the control treatment C, is a marginal reduction in rolling stock of bins and an increase in total cane delivered to the mill. This all culminates in a decrease in transport costs on a per hectare basis while increasing the amount of harvested cane without affecting the mill's rolling stock of bins.

Table 45 Isis analysis of product delivered by rail to the mill by treatment and trial series.

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	Field Edge Separation (Treatment B)
Tonnes Biomass / Bin	4.30	6.23	7.61
Bins / Hectare	35.46	21.02	19.50

Table 46 Isis changes in rail transport system indicators by treatment and trial series.

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
Tonnes Biomass / Bin	-31	22.2
Bins / Hectare	68.7	-7.2

As with the road transport system the rail system can also capitalise on the potential to increase billet length without increasing transport costs associated with reductions in load densities (due to the reduction in bins per hectare). This would further reduce sucrose losses associated with billeting. The possibility even exists to maintain the current commercial rail bin load densities by increasing billet lengths however this may lead to an increase in the mills required rolling stock of bins (increased net cane yield of treatment B) and would require further assessment.

6.3 Impact on net clean cane per hectare

Table 10 demonstrated that both low loss harvesting and field edge separation increased the net clean cane yield in comparison with the control treatment, commercial harvesting, by 24.4% and 20.9% respectively. This is a result of reducing cane losses associated with commercial harvesting. The immediate increase in net clean cane yield per hectare produces an increase in the bin count per hectare (more cane to be delivered to the mill). It is the proportion of clean cane in delivered bins that is of greater significance.

Table 47 demonstrates the resultant tonnes clean cane per bin and Table 48 lists the changes in the tonnes of clean cane per bin. The comparison of treatment A with the control treatment revealed an overall decrease in the tonnes of cane per delivered bin. A reduction of 24 % was noted in New South Wales while a reduction of 31% was observed in Isis. This is attributed to the lower proportion of clean cane and higher proportion of extraneous matter present in each bin of the delivered product. The field edge separation, treatment B, generally matched or exceeded the tonnes of clean cane per delivered bin of control treatment C. The NSW result appeared to match the control treatment with a margin increase of 0.4% while the Isis result of a 22% increase exceeded the control treatment. These results are attributed to the similarly high proportions of net clean cane present in both treatment B and the control treatment C (refer to Table 8). The higher the proportion of cane in the delivered bins the higher the bin revenue.

Table 47 Average net impact on tonnes cane per bin by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes Cane / Bin	Commercial Harvesting (Treatment C) Tonnes Cane / Bin	Field Edge Separation (Treatment B) Tonnes Cane / Bin
New South Wales	17.24	22.52	22.61
Isis	4.30	6.23	7.61

Table 48 Average change in tonnes cane per bin by treatment and trial series against treatment C

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
New South Wales	-24%	0.4%
Isis	-31%	22%

Evaluating the costs changes on a per tonne CCS basis allows for a direct analysis of cost against revenue on a rateable scale by using CCS as a common denominator. An analysis of tonnes CCS per bin has revealed a similar trend of results to the tonnes cane per bin. Table 49 demonstrates the average tonnes CCS per bin and Table 50 reveals the change in tonnes CCS per bin. The comparison of treatments A against the control treatment revealed a consistent reduction in the tonnes of CCS per delivered bin. A reduction of 25 % was noted in New South Wales while a reduction of 34% was observed in Isis. This is attributed to the lower proportion of clean cane and higher proportion of extraneous matter present in the delivered product. The field edge separation, treatment B, generally matched or exceeded the tonnes of CCS per delivered bin of control treatment. NSW marginally exceeded the control treatment with an increase of 2.5% while the Isis results of a 33% increase exceeded the control treatment. These results reflect the same trends displayed in the tonnes cane per bin.

Table 49 Average net impact on tonnes CCS per bin by treatment and trial series

Trial Series	Low Loss Harvesting (Treatment A) Tonnes CCS	Commercial Harvesting (Treatment C) Tonnes CCS	Field Edge Separation (Treatment B) Tonnes CCS
New South Wales	2.36	3.15	**3.23**
Isis	0.59	0.89	1.18

Table 50 Average change in tonnes CCS per bin by treatment and trial series against treatment C.

Trial Series	Low Loss Harvesting (Treatment A) Tonnes CCS	Field Edge Separation (Treatment B) Tonnes CCS
New South Wales	-25%	2.5%
Isis	-34%	33%

The analysis of tonnes CCS per delivered bin demonstrates a correlation for transport cost changes associated with each treatment based on the volumetric fixed cost assumption. The higher the bin CCS content the greater the bin revenue which effectively reduces the transport costs on a per tonne CCS basis.

The low loss harvesting treatment's reduced tonnes of CCS per bin produces lower bin revenue and higher bin transport cost per tonne of delivered CCS.

The field edge separation treatment's improved tonnes of CCS per bin produce higher bin revenues and lower bin transport cost per tonne of delivered CCS.

6.4 Net impact on siding to mill transport and costs

The net impact of low loss harvesting, treatment A, and field edge separation, treatment B, on mill transport systems is significantly different. The low loss harvesting treatment delivers more biomass to the mill along with the lowest proportion of clean cane. The result is a:

- Reduced tonnes of clean cane per delivered bin
- Reduced load densities
- Increased bin count per hectare harvested (ie. fleet capacity)
- Increased transport costs per hectare harvested

- Increased transport costs per tonne of delivered cane

Ultimately low loss harvesting reduces the transport system efficiency while increasing the costs on both a per hectare and tonnes delivered cane basis.

The field edge separation treatment delivers more biomass to the mill along with the highest proportion of clean cane. The result is an:

- Increased tonnes of clean cane per delivered bin
- Increased load densities†
- Increased bin count per hectare harvested (ie. fleet capacity)
- Increased transport costs per hectare harvested, but a
- Reduced transport costs per tonne of delivered cane (and CCS)

While field edge separation increases the transport costs per hectare it effectively reduces the costs on a per tonnes delivered cane and CCS basis. This is an overall increase in the efficiency of the transport system.

†The limitations of road transport systems, demonstrated in the New South Wales trial, restricts the exploitation of increasing transport load densities however it does provide an opportunity for reducing billeting losses by increasing average billet lengths.

7 Net change in returns associated with the reduced harvesting and milling losses, after accounting for changed harvest costs and in-field and field to mill transport costs

7.1 Net change in recoverable CCS per hectare

Recoverable CCS per hectare was calculated from the tonnes per hectare of material delivered to the mill and the mill derived CCS of that material. Condong Mill CCS was determined using the traditional CCS formula from NIR inputs. Isis CCS is determined using NIR inputs, but the figures provided by the mill differed slightly from calculated CCS using the traditional CCS formula. No consideration was given to effect on NIR Pol measurement or mill recovery rates due to elevated extraneous matter levels.

For the purpose of this analysis, Treatment C (Current Practise) was used as the base case or control treatment with the recoverable CCS for the other two treatments compared against control. Table 51 compares the calculated CCS per hectare of Treatments A and C. CCS per hectare for Treatments B and C is shown in Table 52.

Table 51 shows an increase in CCS due to low loss harvesting practices of between 2.29 and 2.75 tonnes CCS per hectare, or between 12.3 and 26.1%.

Table 51 Average net change in recoverable CCS by treatment and trial series (without cane cleaning)

Trial Series	Commercial Harvesting (Treatment C) Tonnes CCS /Ha	Low Loss Harvesting (Treatment A) Tonnes CCS /Ha	Net Change Tonnes CCS /Ha
New South Wales	10.54	13.29	2.75
Isis	18.64	20.93	2.29

Table 52 shows an increase in CCS due to field edge separation practices of between 3.41 and 4.43 tonnes CCS per hectare, or between 32.4% and 23.8%.

Table 52 Average net change in recoverable CCS by treatment and trial series (with cane cleaning)

Trial Series	Commercial Harvesting (Treatment C) Tonnes CCS /Ha	Field Edge Separation (Treatment B) Tonnes CCS /Ha	Net Change Tonnes CCS /Ha
New South Wales	10.54	13.95	3.41
Isis	18.64	23.07	4.43

Tables 51 and 52 clearly demonstrate the increases in CCS yield of delivered cane associated with low loss and field edge separation strategies. Low loss harvesting with field edge separation consistently produced a CCS yield increase of more than 23%.

7.2 Change in gross revenues

The change in cane payment revenue for each treatment is analysed using:

- Cane payment formula
- Isis trial data

The cane payment formula (Canegrowers) used to calculate the grower cane revenue is the formula previously arbitrated by the Queensland government and published on the Canegrowers website.

$$P_{Cane} = \left(P_{Sugar} \times \left(\frac{90}{100}\right) \times \left(\frac{CCS - 4}{100}\right)\right) + 0.578$$

Where

P_{Cane} : Price of cane per tonne of delivered cane

P_{Sugar} : Sugar price per tonne of sugar

The formula does not consider any shares the grower may have in molasses, furfural, cogeneration and other by-products. The formula was applied to the treatment models using the Isis trial data. Table 53 demonstrates the average gross revenue of each treatment while Table 54 lists the change in revenue of low loss harvesting and field edge separation compared to commercial harvesting.

The low loss harvesting treatment resulted in the lowest cane payment value, a reduction of 10.1%, on a delivered tonnes basis. This is attributed to the treatments poor CCS levels and elevated extraneous matter. The gross revenue on a per hectare basis was however greater than the commercial harvesting treatment, recording an 8.3% increase. This is a direct result of the increase in the crop yield of harvested cane and associated with the reduction in harvesting cane losses.

The field edge separation treatment produced the highest cane payment value, an increase of 16.2% on a delivered tonnes basis. This is attributed to the treatments superior CCS levels and low extraneous matter. Field edge separation produced the highest gross revenue on a per hectare basis with an increase of 28.3%. This is a direct result of the increase in the crop yield and quality of harvested cane.

Table 53 Average cane payment gross revenue by treatment.

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	Field Edge Separation (Treatment B)
Crop Yield T/Ha	120.5	100	110.4
$/Tonne Cane	$34.15	$38.00	$44.17
$/Ha	$4115.60	$3800.00	$4876.12

Table 54 Average change in gross revenue by treatment.

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
$/Tonne Cane	-10.1	16.2
$/Ha	8.3	28.3

Field edge separation increases gross revenue by 28.3% without increasing the area under cane or production practices.

7.3 Net change in revenue

An analysis of the net change in revenue associated with each treatment is necessary to demonstrate the absolute impact on returns. The analysis does not consider the change in Miller revenue but focuses on the grower and harvesting operations. Analysis of mill costs is complex and beyond the scope of this project however the impact of cane quality on mill performance and recoveries is well established allowing millers to easily drawn conclusions from the projects outcomes.

Table 55 lists the revenue and costs associated with each treatment concluding with the grower's net revenue.

Table 56 demonstrates the change in net revenue of low loss harvesting and field edge separation in comparison with commercial harvesting. In order to evaluate the net change in revenue for the treatments a crop production cost of $1,500.00 was assumed across all treatments. The justification being that production cost is the same for each treatment as there is no change in their inputs.

Low loss harvesting produces higher per hectare revenue, $4,115.60/Ha, as a result of a reduction in harvesting losses however it is not possibly to capitalise on this improvement due to the greater increase in associated harvesting and transport costs. Low loss harvesting results in a 3.8% reduction in grower net revenue.

Field edge separation produces the highest per hectare revenue, $4,876.12/Ha, as a result of a reduction in harvesting losses and improved cane quality. The improved revenue greatly exceeds the increase in harvesting, transport and separation costs and results in a 26.2% increase in grower net revenue.

Table 55 Average cane payment revenue and operating costs per hectare by treatment.

Trial Series	Low Loss Harvesting (Treatment A)	Commercial Harvesting (Treatment C)	Field Edge Separation (Treatment B)
Revenue / Hectare	$4115.60	$3,800.00	$4876.12
Production Cost / Hectare	$1,500.00	$1,500.00	$1,500.00
Harvesting Cost / Hectare	$688.10	$561.00	$688.10
In-field Transport Cost / Hectare	$532.00	$289.00	$532.00
Separation Cost / Hectare	-	-	$181.00
Trash Disposal Cost / Hectare	-	-	$141.00
Grower Net Return / Hectare	$1395.50	$1450.00	1834.02

Table 56 Average change in net revenue by treatment. (compared to control treatment)

Trial Series	Low Loss Harvesting (Treatment A) % Change	Field Edge Separation (Treatment B) % Change
Net Revenue	-3.8%	26.2%

8 Conclusion

The trial results quantified cane loss associated with commercial harvesting practices is in the order of 20%. These losses can be reduced however the strategy for achieving this involves more than just low loss harvester parameters.

While the low loss harvesting strategy is responsible for increasing the harvested crop yield it must not be considered in isolation as the net result is a 3.8% decrease in grower net revenue in comparison with commercial harvesting practices. Low loss harvesting reduces harvester cane loss and in so doing increases the harvested cane yield. The isolated retarding of on-harvester cleaning to reduce cane loss has a significant negative effect on delivered cane quality. As the leaf and other extraneous matter levels increase in the delivered cane the measured CCS decreases. The associated increase in fibre and dirt levels impede sucrose recovery at the mill and result in greater non-pol losses, primarily to molasses, bagasse and mud (Kent et al., 2010). The high fibre levels associated with increased leaf content in delivered cane reduces mill crushing capacity (Kent et al., 1999). The result is an increase in milling power consumption and operating costs per tonne CCS. Low loss harvesting increases harvesting costs by 22.7% which is a direct result of a reduction in harvester ground speed. The reduction in ground speed increases the engine hours per harvested hectare. In-field transport costs increase by 84% as a result of the increase in the bin count per harvested hectare. The primary factors driving the increased costs are the 34% reduction in load densities associated with increased proportions of leaf and extraneous matter per bin and the increase in crop yield. Mill transport costs are influenced in the same manner as in-field costs. The increases in harvested product coupled with fixed bin volumes increases mill transport costs by 68.3% per harvested hectare in a relationship directly proportional to the change in bin count per harvested hectare.

The field edge separation strategy combines the benefits of low loss harvesting with high efficiency cane cleaning to produce a grower net revenue increase of 26.2% in comparison with commercial harvesting practices. By comparison field edge separation improves delivered cane quality through increased CCS and reduced levels of extraneous matter. Field edge separation produces a CCS yield increase in the order of 23.5%. Sucrose recovery is improved by the reductions in fibre (9.5%) and dirt (19.3%) levels and as a result losses to molasses, bagasse and mud are reduced while available milling capacity increases. Field edge separation increases harvesting costs by the same proportion as low loss harvesting, 22.7% however additional costs are incurred for trash separation and disposal, resulting in a total cost increase for field operations of 81.4%. Field edge separation improves harvested product load densities of field to mill transport, reducing volume limited transport system costs by up to 19% per harvested hectare. The net result is an increase in revenue greater than the increase in operating costs. The primary drives are reduced cane losses, improved cane quality, load densities and sucrose recovery.

The overall industry benefit is best summarized by the change in sugar revenue per hectare harvested, an increase in the order of 23%. This exceeds the conservative estimate at the start of the project of 12.5%. 10% cane loss (Whiteing et al.) and 2.5% recovery loss attributed to extraneous matter levels in delivered cane with current harvesting practices. With industry billeting losses of 2.5% attributed to shorter billet lengths to increase load densities, there remains the potential to further increase overall industry revenue beyond 23%. Low loss harvesting with field edge separation increases industry production and revenue without increasing the existing hectares of cultivated cane land.

9 Recommendations

An extension of the project to a commercial scale is now needed to confirm the trial results beyond row lengths per bin load to on a block and paddock basis. A large scale commercial trial involving the processing of 100,000 tonnes of cane, or more, with a commercially sized separator is required to further quantify the benefits of post-harvest cane cleaning. Further large scale commercial trials are critical in assisting each sector and production region to understand and potentially capitalise on the opportunity to increase revenue and efficiency. The results of the larger scale trials must then be communicated to all sectors of the industry to ensure the benefits and considerations are understood not only on a strategic level but on a sector basis too. (factors that specifically affect growers, harvesters and millers)

The initial results of the project were presented separately to Canegrowers and ASMC followed by a demonstration day. On a strategic level the benefit of the low loss harvesting strategy coupled with post-harvest cane cleaning was widely accepted however both growers and millers consider trash disposal to be a practical problem or “road block”. The value of trash or its inherent opportunity cost varies across each production region be it an agronomic value as a trash blanket, income stream for cogeneration, garden mulch or biofuel. Growing regions like Isis and Maryborough have an established trash value as cane mulch feedstock, while in NSW investigations revealed a cogeneration fuel value. A sea change in thinking and perception is needed to understand that sugarcane trash is no longer a waste product with disposal costs but; a potential income and at the worst an opportunity cost for reaping the benefits of increased cane revenue through reduced losses, as demonstrated in the trash disposal costs for post-harvest cane cleaning (refer to section 5). It is in the industries interest to investigate established and near future markets for sugarcane trash. The Brazilian industry’s characterisation of sugarcane as an energy crop broke the barriers preventing their millers and growers from maximising the crop and industry value. This type of progressive and strategic thinking needed to realise the value of trash.

NorrisECT is aware of a growing interest in and demand for sugarcane trash from multiple sectors. Great strides are being made by research groups such as the Australian Institute for Bioengineering and Nanotechnology (AIBN) at the University of Queensland with respect to additional sugarcane product streams. Biochemicals from sugarcane “waste” and biorefining are just a few of the areas in which institutions like AIBN are making great progress. These institutions are interested in working with the industry however the lack of engagement by the industry is hampering the realisation of the sugarcane crop's total value.

To take advantage of the benefits associated with low loss harvesting and post-harvest cane cleaning a review of the cane payment system is required after the completion of large scale commercial trials. Two significant considerations are the change in operating practices and costs for the contract harvester and the value of trash in each region. The grower and miller receive the direct revenue benefit of this harvesting strategy however it is only made possible by the contract harvester's change in operational practice and equipment inventory. Growers must be aware of the proportional increase in harvesting costs associated with the strategy and willingly reward the contract harvester. The cane payment agreement between growers and millers will need reviewing subject to trash value or opportunity cost in each production region. Mill revenue derived from cogeneration using trash fibre would need apportioning between the grower and miller. Similar payment reviews have been completed in the industry where growers are paid a portion of the molasses revenue.

The improvement in transport load densities of post-harvest cane cleaning merit an investigation into increasing billet lengths to reduce sucrose loss associated with short billets. The benefit of increased billet lengths is maximised in load limited transport systems where bins have additional volumetric capacity. The road transport system of NSW Sugar is a prime example. Increased sugar recovery associated with reduced billeting losses can be optimised while maximising the efficiency of the transport system.

NorrisECT recommends further industry investigation and engagement in:

- Extension of the post-harvest cane cleaning strategy on a larger commercial scale. (+100,000 tonnes processed)
- Billet length and load density optimisation
- Available sugarcane trash markets and trash values
- Research institutions and commercial ventures focused on bio refining
- Cane payment system and contract harvesting rates associated with low loss field edge cleaning

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Appendix

Summary of Statistical Analysis

In the planning of the project a trial methodology and design was developed for each location. The decision to develop designs for each location was primarily driven by the parameters of the available crop, contract harvester and the individual mill's transport systems and NIR cane sampling protocols.

New South Wales Trial

The New South Wales trial had to be designed to accommodate the road based multilift bin system in use at Condong mill. The large capacity of the bins, 90m3, was originally designed to allow whole crop product (for cogeneration purposes) to be transported via road to the mill. An NIR cane sample analysis report was provided for each trial bin delivered to the mill.

The trial protocol issued to NSW Sugar stipulated a minimum requirement of 4 replicates to ensure the validity of the statistical analysis. Each replicate consisted of 3 treatments (1 control treatment and 2 comparison treatments). The New South Wales results are not considered statistically valid as a result of the limited number of replicates (3). This is attributed to the limited availability of cane for green cane harvesting at the time of the trial. The New South Wales trial did however demonstrate a trend of results with a strong correlation to the Isis trials.

Isis Trial

The Isis trial had to be designed to accommodate the rail based wagon bin system in use at Isis mill. The Isis rail wagons have a maximum bin capacity of 17.5m3. A rake of 4 bins per treatment was required to ensure a valid mill NIR cane sample analysis.

The Isis trial consisted of 5 replicates to ensure the results were statistically valid.

Summary of Treatments

The trials consisted of 3 treatments:

A. Low Loss Harvesting

B. Field Edge Separation

C. Commercial Harvesting (control treatment)

Summary of Data

A summary of the trial data is shown in Table 57. The NIR report for NSWSMC Condong Mill did not provide a Pol in Cane analysis and as a result the NSW data excludes Pol in Cane.

Table 57 Summary of project trial data

Description			Product Yield																		
	Treatment	Region	Crop [T/Ha]	Cane [%]	Cane [T/Ha]	Leaf [%]	Leaf [T/Ha]	Tops [T/Ha]	CCS [%]	CCS [T/Ha]	Pol in Cane [%]	Pol [T/Ha]	Fibre [%]	Fibre [T/Ha]	Ash [%]	Ash [T/Ha]	Load Density [kg/m3]	Clean cane / CCS	Cane [T/Bin]	CCS [T/Bin]	Bins/Ha
1	A	NSW	109.9	88.4	97.1	11.64	12.79	8.24	12.10%	13.29	-	-	17.90%	19.66	1.63%	1.79	212.2	7.30	17.24	2.36	5.63
2	B	NSW	99.4	98.3	97.7	1.69	1.68	8.93	14.03%	13.95	-	-	14.53%	14.45	0.57%	0.56	368.9	7.01	16.67	2.38	5.86
3	C	NSW	76.9	97.9	75.2	2.10	1.62	6.70	13.71%	10.54	-	-	14.77%	11.35	0.87%	0.67	350.5	7.14	22.80	3.19	3.30
4	A	Isis	163.5	93.3	152.5	6.72	10.99	11.99	12.80%	20.92	14.72%	24.07	21.51%	35.17	2.29%	3.75	263.4	7.29	4.30	0.59	35.5
6	B	Isis	135.6	96.6	131.0	3.37	4.57	9.31	13.75%	18.64	15.63%	21.20	18.11%	24.56	1.61%	2.18	368.7	7.03	6.23	0.89	21.0
8	C	Isis	134.2	99.5	133.5	0.53	0.71	7.80	13.64%	18.30	15.59%	20.92	16.07%	21.57	0.08%	0.11	384.7	7.30	6.70	0.92	19.9