Rural R&D for Profit Program

Enhancing the sugar industry value chain by addressing mechanical harvest losses through research, technology and adoption

Final Report 2016/901

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Contents

Plain English summary

The project addressed the challenges of mechanical sugarcane harvesting, that include damage to the crop, cane loss from the harvester and high levels of extraneous matter sent to the mill. It did this by developing harvester modifications, new sensing technology and decision-support tools, better cane-cleaning systems, and delivering an adoption program to drive Harvesting Best Practice.

Experimental modifications were made to the front of commercial harvesters – the basecutters and forward-feed components – to improve the quality of the harvested cane and minimise damage to the remaining cane stool to minimise the impairment of crop ratooning. Concurrently, dynamic modelling of the interaction of the cane stalks and the harvester front end was done to develop alternative harvester designs. The performance of modified machines was tested in field trials in New South Wales and Queensland.

Matching basecutter rotational speed and ground speed improved cane feeding but improvement in stool damage and subsequent ratooning and yield was inconsistent. Field results and modelling indicated that much stool damage is caused by the gathering and feeding (knockdown) processes rather than the basecutters. While adjusting the rotational speed of forward-feed machine components had limited impact on the level of damage to both billets and the stool, there was a significant improvement the evenness of feed and ability to harvest larger crops.

Before and at the time of these projects, harvest operators had no way of determining the amount of cane lost during harvesting operations. To counter this challenge, a system was developed to provide a real-time estimate of cane loss that could be retrofitted to existing machines. The system measures the energy dissipated in the processes of extracting cane and leaf by the harvester extractor fans. Data was collected for the development of the cane loss algorithms in field trials with conventional cane loss measurement protocols.

The resulting tool, named Schlot Live (Sugar Cane Harvesting and Logistics Optimisation Tool), estimates cane loss in real-time and provides instantaneous feedback via an in-cab display. It allows the harvester operator to optimise harvester performance as crop conditions change throughout the day, and it drove significant changes in operating strategies by the harvester operator in field trials. On harvesters fitted with appropriate telemetry and software, cane loss can be categorised according to its conformation or not with Harvesting Best Practice (HBP) and displayed on a remote device.

Novel sensing technologies may offer additional opportunities to provide meaningful information about actionable harvesting issues, such as stool damage, cane loss and cane quality. A feasibility study was undertaken to identify sensors with the greatest likelihood of delivering benefit and identify strategies for further research. Information was collected through literature review, industry-wide surveys, and consultation with industry experts and researchers, industry service providers (growers, contractors and millers), harvesting machinery manufacturers, sensor manufacturers and method specialists.

The industry consultations improved feedback for quality and loss control revealed four main priorities namely (1) extractor losses, (2) basecutter quality (height control) and (3) cane supply quality. Best suggested solutions included spectral imaging, proximal near-infrared (NIR) spectroscopy and radar technologies.

HBP is a balance between cane loss and cane quality. Providing a cleaner cane supply by increasing the speed of the extractor fans increases in-field cane loss while reducing cane loss to a minimum (low-loss harvesting) increases extraneous matter (EM) in the cane supply. Low-loss harvesting with post-harvest cane cleaning can potentially manage these issues. To assess the productivity and economic benefits of this approach, a mobile cane cleaning plant was constructed in the south and north Queensland. Three treatments were evaluated in these field trials and these were (a) commercial harvesting, (b) low-loss harvesting and (c) low-loss harvesting plus cleaning.

The results supported the expectation of higher sugar yield with lower extractor fan speed, but much of the higher yield was lost after post-harvest cane cleaning. The economic analysis quantified harvesting costs and the resulting product income for trials in northern Queensland using varieties Q208 and KQ228. The analysis considered costs associated with harvest and haulouts, transport, trash and cane cleaner operation, along with gross income based on tonnes of cane and commercial cane sugar (CCS) at the factory. In all three experiments, the treatment with post-harvest cane cleaning was less attractive than the harvest-only treatments.

Using existing harvesting equipment and technologies, the vision of the sugar industry harvesting program, to maximise harvesting returns from both the harvested crop and subsequent ratoons for improved industry profitability, must be achieved by the adoption of HBP. To increase adoption of HBP, more than 100 replicated harvesting demonstrations plus attached workshops were undertaken across 12 sugarcane regions between Harwood (NSW) and Mossman (QLD). The performance of settings recommended by HBP was compared with each harvesting operation's standard practice, treatments with higher and lower pour rates and fan speeds were also trialled. Results were presented to each harvesting group to inform their decision-making and promote HBP adoption.

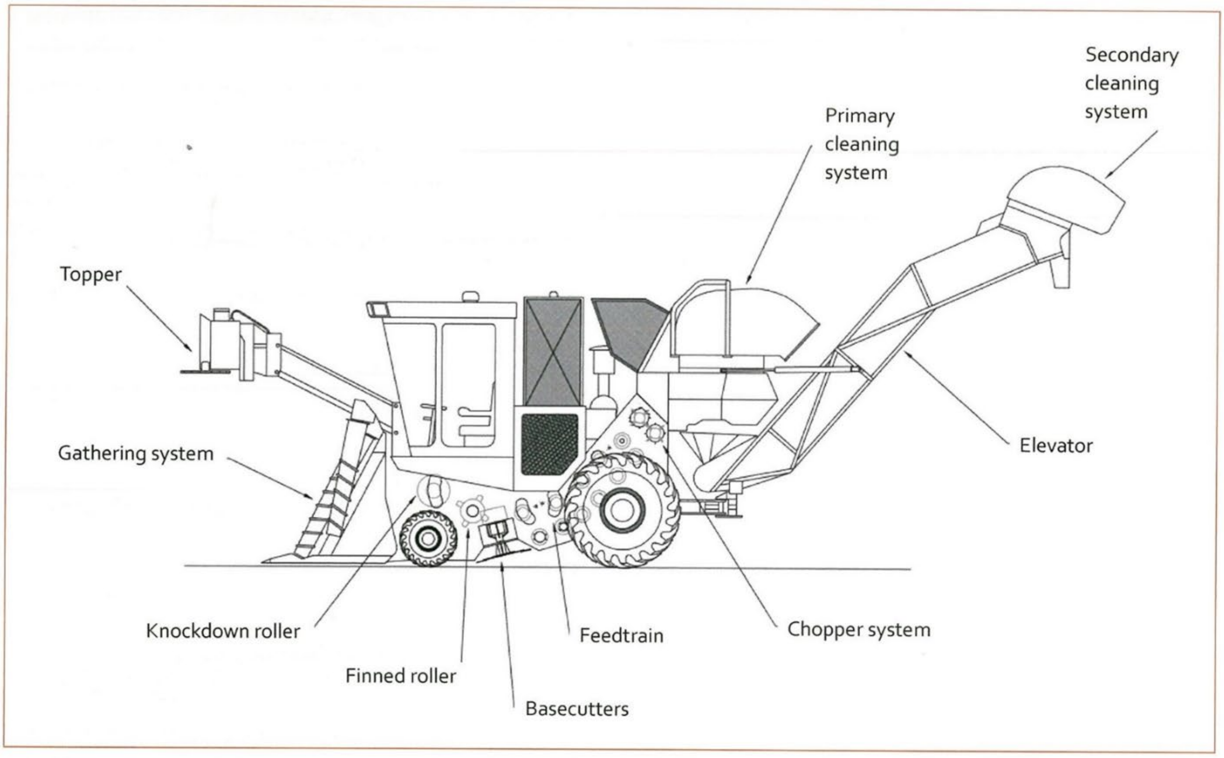
On average across the 95 trials in 2017 and 2018, increased cane and sugar yields generated by HBP increased grower gross revenue by $181/ha, while reduced ground speeds increased the cost of harvesting by an average of $61/ha. This net benefit of $115/ha, extrapolated across the Australian green-cane-harvested area, could deliver an additional value of over $69 M to the industry. The productivity and economic results for individual trials were presented at a workshop for each harvesting group to work through options to maximise crop value. After completion of the 2017-18 adoption program, there had been a positive change in many workshop participants: a reduction in average harvester ground speed and extractor fan speed by harvester operators, reduction in the average number of blades per chopper drum (leading to longer billets and lower levels of sugar loss) and increased support for HBP, including interest in revising harvesting payments to incentivise HBP.

In summary, the project has delivered:

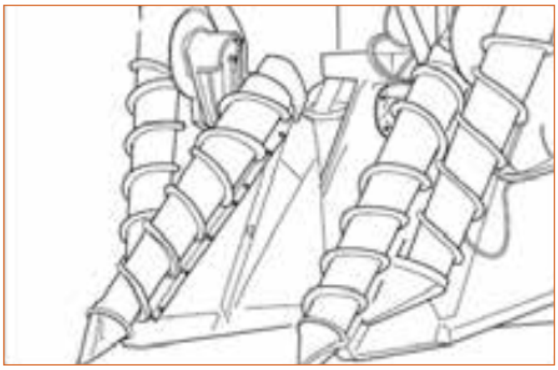
- A 'next generation' intelligent tool for the harvesting sector which will allow more informed decision making.
- Recommendations for improved front-end harvester design to reduce stool damage and cane loss
- Economic data to determine the whole-of-industry effect of different harvesting and cane-cleaning practices
- A feasibility study evaluating sensors for improved harvesting feedback and a course of action for future research to develop effective measurement products
- A concerted adoption program to change industry beliefs, which has led to substantive practice change

This project brought together a diversity of research organisations to focus on a high-priority industry issue. Intellectual input and operational assistance came from all sectors of the sugarcane industry. Strong support from representatives of the project Research Management Group and others at a harvesting workshop in December 2019 for development of an on-going sugarcane industry RD&A harvesting program indicates that the collaborations established in the project will be on-going.

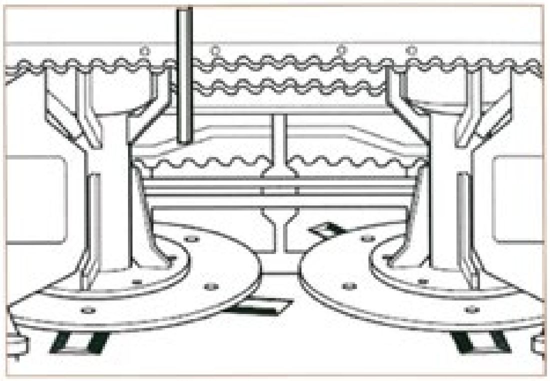
Glossary – harvester components



Gathering spirals



Front view of basecutters



Forward feed components - knockdown roller and finned roller

Primary extractor fan – looking upwards inside hood

1. Project rationale and objectives

Australian agriculture operates within an environment of rising production costs, climate variability, pests and diseases and, for the sugar industry, changing global patterns of production and consumption. Rising costs for fuel, nutrients, chemicals, water, electricity and labour continue to squeeze profitability, with declines in the strength of the Australian dollar and volatility in world sugar prices affecting farm returns and adding to the difficulties in controlling on-farm costs. Most significantly, the fall in the value of the Australian dollar has driven an increase in the cost of the equipment utilised for the harvest of the crop. This operating environment requires a continual improvement in productivity or farming efficiency coupled with controlled costs just to maintain profitability and industry viability.

- Harvest and value losses are a major threat to sugar industry viability with complex issues impacting across all industry sectors and all sugarcane growing regions:
- Under 'average' harvesting conditions, avoidable cleaning losses range from 5-15%, while direct and indirect losses associated with billeting range from 5-10%. This lost cane is produced in the field but never reaches the mill (lost to growers and millers).
- Mills are experiencing increasing levels of fibre and extraneous matter in harvested cane in the order of 25%. This directly increases mill operating costs and reduces sugar recovery by 3-5%.
- Harvester operators have increasing equipment/running costs and the number of harvesters has halved in the last decade, with each machine now cutting more cane at a higher ground speed.
- Field productivity often declines annually, in part due to harvesting damage that results in poor regrowth (ratooning) for next year. Increasing harvester speed exacerbates this problem.

Conservative estimates cost this problem at over $150M annually in cane loss, billet damage and high extraneous matter levels during milling.

The causes of these problems are many and not easily solved. Limitations on transport fleets (particularly cane rail bins) mean that cane billet lengths have been reduced to try to increase bulk density and bin weights. However, this increases sugar losses due to increased cuts to the cane stalk. The juice loss and subsequent accelerated deterioration are essentially invisible and cannot be easily measured.

The harvesting payment system predominantly operates on a fixed price per tonne of cane, a payment system that rewards operators for maximising throughput. This leads to higher levels of extraneous matter at the mill, as trash cannot be efficiently removed when high rates of material pass through the harvester. Attempts to remove extraneous matter by increasing extractor fan speeds lead to higher levels of cane billets lost through the cleaning system. The damage to cane billets during this process is another invisible or unmeasured loss.

Harvesters maximise throughput by increasing groundspeed, but this leads to cane stool damage, as forward-feeding components of the harvester are not generally matched to machine groundspeed. Cane loss and crop damage reduce with slower ground speed but this increases harvesting costs, and most growers focus on minimising costs per tonne of cane.

Manufacturers supply machines that suit harvester operator requirements and overseas markets (John Deere and Case largely supply the Australian market but manufacture overseas) and are not designed to maximise whole-of-industry returns. Over time, harvesters have become more powerful, heavier and more expensive, with fields now cut faster with more crop damage, higher cane losses, and a poorer quality product. This situation is unlikely to improve in the short to medium term.

This project addressed harvesting issues across the whole value chain by:

- Developing sensors and telemetry for real-time monitoring of harvester performance to benefit harvester operators, growers and millers.
- Improving harvester operation by fundamental engineering studies and machinery modifications.
- Assessing post-harvest cane cleaning as an option to reduce harvest losses and improve the quality of supply to the mill.
- Evaluating alternative payment systems using value chain benefit/cost analyses.
- Facilitating the adoption of improved practices through engagement and regional demonstrations.

2. Method and project locations

Opportunities to reduce sugar cane harvest losses were investigated within the project by six different sub-projects:

- Development of an intelligent tool to allow real-time evaluation of harvesting practices as part of a framework for improved harvester payment systems (SRA Project 2016/951)
    - Development of the tool was undertaken by work in commercial canefields in New South Wales (Condong) and in Queensland at Rocky Point, Childers, Bundaberg, Ingham and Tully.
- Understanding interactions between basecutters and other forward-feed components with the cane stalk, and determining practical strategies to minimise damage as harvester speed increases (SRA Project 2016/952, Norris ECT and Queensland University of Technology, QUT)
    - Modelling of the interaction between the harvester and cane stalks was undertaken at QUT, Brisbane, while field trials of modified harvesters were done in New South Wales (Condong) and in Queensland at Rocky Point, Childers, Ayr and Ingham.
- Commercial-scale economic evaluation of post-harvest cane cleaning to maximise the returns to the supply chain (SRA Project 2016/953, Queensland Department of Agriculture and Fisheries, DAF)
    - Field trials with a mobile post-harvest cane cleaning plant were conducted in southern Queensland at Childers and Bundaberg and in far north Queensland on the Atherton Tableland.
- Sensors for improved harvesting feedback: a feasibility study (SRA Project 2016/954, Sugar Research Australia, SRA)
    - A desktop study was done at SRA Brisbane with focus group meetings of the harvester and haulout contractors and operators, mill transport coordinators, harvester manufacturers, growers and researchers held in New South Wales, southern Queensland (Maryborough, Childers and Bundaberg), South Johnstone, Tully and Mulgrave.
- Adoption of practices to mitigate harvest losses (SRA Projects 2016/955 and 2019/951, SRA and DAF)
    - Adoption activities designed around replicated demonstration trials of Harvesting Best Practice were undertaken with key stakeholders in all sugarcane growing areas spanning northern New South Wales, Bundaberg, Isis, Mackay, Burdekin, Ingham, Tully, Far North Queensland and the Atherton Tableland cane growing regions.

Background and methods for each subproject are summarised below. More detail is available in the individual project reports that are available in the SRA e-library.

2.1 Development of an intelligent tool to allow real-time evaluation of harvesting practices (2016/951)

There is a growing awareness within the sugarcane industry of harvest losses, driven largely by this Rural R&D for Profit project, and an increasing desire by all three industry sectors, growing, harvesting and milling, to increase the value of the industry. Existing methods to measure harvest losses are labour intensive and provide data about a limited range of operating conditions and settings (e.g. see projects 2016/955 and 2019/951 below). There is still no way for a harvest operator to gauge actual cleaning losses while operating the machine. A high-quality, real-time estimate of cane loss would allow the operator to have instant feedback on likely losses under the exact conditions of the harvest that is underway and make operational adjustments (with ongoing feedback) to minimise losses and increase overall industry value.

Project 2016/951 led by Norris ECT and Agtrix undertook to develop a cane loss estimator now named SCHLOT Live (SCHLOT, Sugarcane Harvest and Logistics Optimisation Tool) that would be fitted in the harvester cabin to provide real-time feedback to the harvester operator and, with further development, provide remote access to harvest performance data by growers and contractors outside the cabin. Specific objectives were to:

- Fit and calibrate sensors for measuring cane loss, and conduct field trials to develop calibration curves for harvester sensors
- Develop the software algorithms to utilise this data within SCHLOT Live.

- Incorporate measured parameters into the Agtrix data acquisition/telemetry system for close to real-time telemetry
- Identify suitable commercially available hardware and software implementation
- Achieve near real-time transfer of all logged data on topper, feedtrain and extractor
- Implement Agtrix/SCHLOT interface, including development and implementation of a two-way, close to real-time data interface between Agtrix and SCHLOT
- Develop an interface between Agtrix telemetry system and SCHLOT algorithms

Instrumentation to measure relevant parameters on the machine were developed during this phase. Sensor installations were designed to measure various harvester operational parameters. These sensors were then logged during harvesting trials to generate calibration data for sensor values.

Replicated trials were designed to cover a representation of operating conditions, including a range of cane feed/pour rates, primary extractor speeds, and crop sizes and conditions. As the project progressed, SRA's infield sucrose loss measurement system (ISLMS) was used to a greater extent, due to the fact it could give an 'instantaneous' spot ground-truthing of cane loss rather than the 'average' number for a larger harvested area that was achievable with mass balance trials.

The mass balance trials followed a well-established protocol and generally involved three replicates of four different treatments in a randomised order. The treatments were variously designed to isolate the impact of pour rate (harvester speed), primary extractor speed and secondary extractor state (on or off).

Each serial (single replicate of a single treatment) involved harvesting a standardised volume of cane, generally corresponding to either an infield or mill transport unit in volume, with the total row distance taken to harvest that volume being recorded using a GPS in the cabin. From row distance, harvested area per serial was calculated (row distance x row spacing). The cane harvested from each serial was sampled for composition at the trial site, and mill data, including weight, was also gathered for each consignment.

Total delivered product mass per serial, sample composition (proportions of clean cane, leaf material, tops, and other extraneous matter) and consignment weights allowed yield and component yields to be calculated.

During each trial, data from the sensors was logged at ~1-second frequency to allow later correlation with the harvester performance as inferred from trial data (mass balance, ISLMS).

The next part of the work involved the development of an interface between the existing Agtrix harvest recording and reporting system and the SCHLOT cane loss estimation system. The interface is necessary to record and make available harvest information to stakeholders away from the cab. The activities in this subphase included field testing and data gathering and took place predominantly during the 2017 harvest.

The final phase was the implementation and fine-tuning of the real-time feedback system. This involved the in-cab operator interface and the external web-based recording interface.

The initial interfaces were developed in the preceding phase and refined further during this phase in line with feedback from potential users.

2.2 Harvester-cane interactions and strategies to minimise cane damage (Project 2016/952)

Increasing harvesting speed has been necessary to facilitate the large increases in productivity required by the harvesting fleet to manage sugarcane industry cost pressures. While the power and processing throughput of the harvesters has been easily able to meet this requirement, the design of the front end of the harvesters has undergone relatively little functional change since its initial development over 50 years ago. There has been little attempt to improve the interactions between harvester front-end components and the cane plant concerning damage caused by the gathering, knockdown and basecutting operations. This is a contributor to poor ratoon performance often seen through the industry, impacting on ratoon cycle economics. Linking rotational speeds of basecutters and gathering/forward-feed components to groundspeed was hypothesised to improve machine performance and minimise damage over a much wider operating speed range than with current machines. Additional gains could then also be achieved by the active optimisation of the design of the front end of the harvester through the modelling of the interactions between the cane stalk and machine components.

The project was organised to incorporate two research streams, with a common goal.

Stream 1 was the field-based components of the project. It aimed to develop and install equipment on commercial harvesters to facilitate and evaluate the benefits of adoption of currently adoptable knowledge relating to reduced crop damage during the gathering, feeding and basecutting by:

- Modifying hydraulic and electric systems to allow linking of both basecutter speed and the rotational speed of forward-feed components (knockdown and finned rollers) to groundspeed, based on currently understood guidelines for minimum damage.
- Undertaking field trials where the impact of this variable speed system on harvesting losses, cane quality and crop ratooning performance could be quantified under different harvesting and field conditions.
- Determining the robustness of the current machine components (e.g. basecutter box) for handling increased speeds and determine modifications needed to retain an economic life from the unit.

This component of the project was undertaken by NorrisECT, with assistance from co-operating harvesting groups and growers.

Stream 2 of the project aimed to use computational modelling to develop an improved design of the harvester basecutter to minimise damage to the cane stool, including but not limited to:

- Changes in the number of blades, blade shape/design and blade mounting configuration to optimise the actual cutting action and minimise stool and stalk damage when operating within optimised speed parameters.
- Further, develop optimisation guidelines relating to the relationships between harvesting groundspeed and components (gathering system and basecutter component rotational speeds).

This component of the project was undertaken by QUT.

Stream 1 – Machinery modifications and field trials

In the standard harvester, the rotational speed of the basecutters and forward-feed components is constant, irrespective of harvester ground speed (Fig. 1).

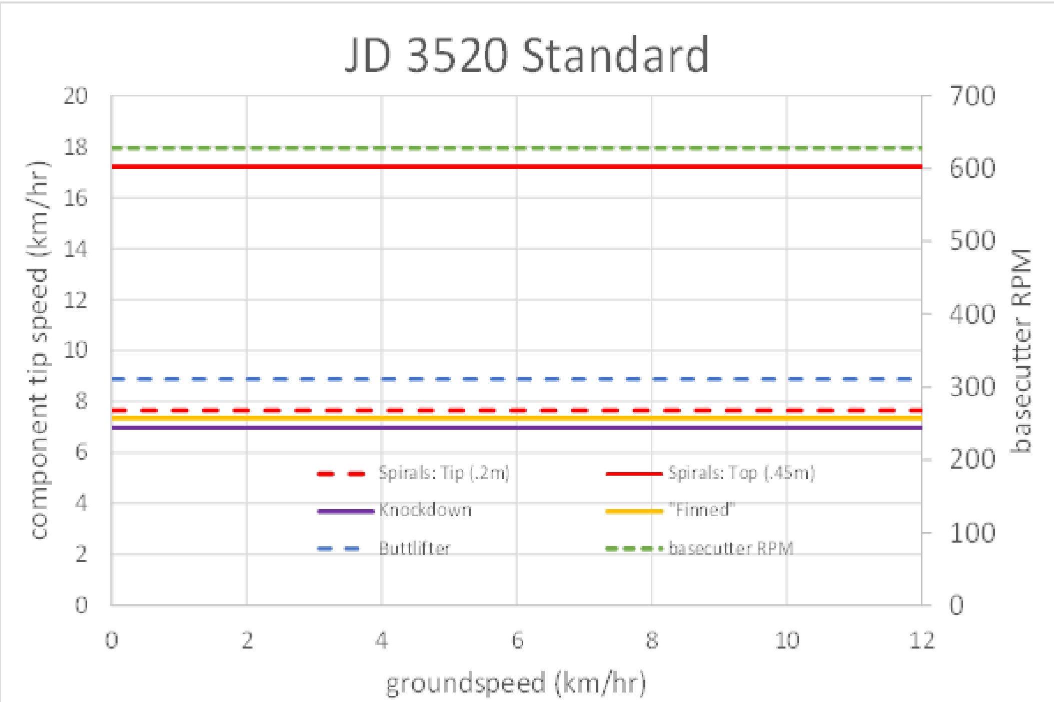


Figure 1. Component tip speeds for JD 3520 harvester in standard configuration

Simple spreadsheet analysis allowed the relationship to be described between component tip speed and the velocity at which the cane stalk moved past the roller surface as the harvester moves forward. This analysis indicated that the optimum tip speeds of forward-feed rollers should generally be below groundspeed, and the spirals' tip speed be at approximately groundspeed. In the absence of further information, these relationships between component tip speed and groundspeed were targeted in the modification to the harvester hydraulic systems (Fig. 2).

Figure 2. Target component tip speeds and basecutter RPM for the modified machines

Modifications were developed to hydraulic systems, motors, electronic controls and software to allow speeds of the basecutters and forward-feed components to be varied during operation, with the intent of assessing whether matching (or mismatching) of speed with harvester ground speed affected the quality of the harvesting job. Details of the modifications are not included here but are in the Project 2016/952 final report. Modifications were made to JD 3520 harvesters in New South Wales (Condong) and Queensland at Rocky Point, Childers and Ingham, and to a Case 8000 machine in the Burdekin region.

The initial aim of field trials was to assess the impact on stool damage, ratoon emergence and subsequent crop yield of different harvesting speeds with the standard harvester component speed configuration and compare the impact of matching optimised component speeds with groundspeed.

In the first year of trials, treatments of matched component speeds were compared with standard machine configuration (620 basecutter rpm) at high and low harvesting speed, giving four treatment combinations. Subsequent trials would incorporate both machine modifications and changes to the field protocols to capitalise on knowledge gained. In several trials in 2017 and 2018, the trial protocol was modified to accentuate differences between component speeds and groundspeed: the unmatched treatments were changed so that the low basecutter/front end speed was utilised with the high harvesting speed and vice versa.

The trial protocol at each site consisted of 12 plots, with three replicates and four treatments randomised within each replicate. Each plot was either four or six rows wide depending on row length, giving the area per plot of typically 0.3 to 0.5 ha, with the total harvested area per trial in the range of 3.6 to 6 ha. In all districts except the Burdekin, the sites chosen had row spacing matched to equipment width to minimise the impact of wheel traffic on the damage/ratooning result. Where possible, the harvesters utilised GPS Autosteer.

Billet quality is an indicator of a number of factors in the machine-crop interaction, with analysis of the type of damage on the billets being an indicator of the source of damage. In each of the trials, a damage assessment was undertaken on billets from each treatment. Billet damage was categorised according to the most probable source of the damage, i.e. gathering, basecutters and other/choppers.

Damage to cane stools remaining in the ground was assessed after the harvesting operation. Stool damage was categorised according to the guidelines developed by Kroes and Harris (1994)[1] and later used by other researchers. The criteria are based on assessments of the possible impact of the different modes of damage on the ability of the remaining stool to ratoon successfully. The actual level of ratoon emergence which occurs will depend not only on the level of damage associated with the harvesting operation but also on many factors affecting the crop after harvest, and similar levels of stool damage can be anticipated to give different outcomes under different field conditions.

After harvest, sub-plot sections were marked out, typically 50 m from the field edge to ensure that the plot locations represented 'steady-state' harvesting free from any end-of-row influences, and the stool damage assessment was undertaken on the second row of the treatment plot. Consistency in this measurement is essential to avoid complications relating to the direction of harvest. In crops with single-row planting configuration, the stool damage assessment was undertaken on a 10 m length of the plot which was then split into 20 x 0.5 m sub-plots. For dual-row configuration plots, the two rows were assessed separately over a 7.5 m length, effectively giving 15 m of row length assessment.

Semi-permanent markers were installed to allow the same reference point to be utilised for all subsequent activities in the plot. The trash was raked off the row in these sections and loose soil removed with a low-pressure air blower, typically down to the basecutter operating depth (Fig. 3, Fig. 4).

Figure 3. Cleaning-off trash and loose soil to allow assessment of stool damage

[1] Kroes S., Harris H. (1994) Effects of harvester basecutter parameters on the quality of cut. *Proc. Aust. Soc. Sugar Cane Technol.* 16, 169-177.

Figure 4. Different types of damage in the exposed stool

Based on the observations of the 2016 and 2017 harvest data (see later), damage to the cane stool associated with all harvest treatments was very high, despite the modifications that had been implemented to basecutter operation. Based on previous work, significant damage can be anticipated to result from the knockdown and feeding processes, particularly on modern harvesters where these settings are much more aggressive than older machines. Hence, a decision was made to introduce new treatments to separate the damage associated with gathering and knockdown from basecutting damage alone.

To quantify the impact of the gathering and feeding processes, an additional sub-plot was incorporated into each trial plot. The treatment protocol was to hand-cut additional sub-plots at a height of approximately 200-250 mm above ground level, before harvest. The 200-250 mm cutting height was to maximise the length of the uncut stalk but ensure there was no contact between the forward-feed components and the cane stalk before basecutter contact. The sub-plots were parallel in location to the initial sub-plots, but in the second row across: when the initial sub-plot was in row 3 of the main plot, the additional sub-plot was in row 1 so that direction of the harvest was the same. The pre-cut cane stalks were laid on top of the cut stumps, allowing them to be picked up by the harvester (Fig. 5). This protocol then allows the relative impact of the gathering and feeding and the basecutting to be better isolated.

Figure 5. Sub-plot manually harvested at approximately 250 mm above ground level at Childers

Stream 2 – Modelling of machinery modifications

Although it was initially intended that Discrete Element Modelling (DEM) be used for this component of the project, the recent advances made in Finite Element Modelling (FEM) prompted a more extensive assessment of the latter. A review identified sufficient (but not extensive) sugarcane plant property data for both DEM and FEM analyses to be undertaken. Some material properties relevant to the FEM model which have not been measured for cane were collated from the literature on other crops such as bamboo, energy cane and reed.

An FEM model of the cane stem, forward-moving harvester knockdown roller and the two counter-rotating basecutter disc-mounted blades has been completed. The model has been run to duplicate the harvester operating conditions associated with the most recent Childers field trials and qualitative comparisons made between the predicted and observed cane damage.

The first part of the modelling involved completion of an initial FEM model of the cane stalk, forward-moving harvester knockdown roller and the two counter-rotating basecutter disc-mounted blades.

Key simplifying assumptions in the model were:

- a solid stalk with isotropic, homogeneous material properties
- the bottom 100 mm of the stalk is simply ‘clamped’ to represent a non-deforming soil
- all harvester components are non-deforming
- the knockdown and feed rollers are smooth non-rotating cylinders
- friction between all components is neglected.

The configuration and dimensions of the modelled components are shown below (Fig. 6).

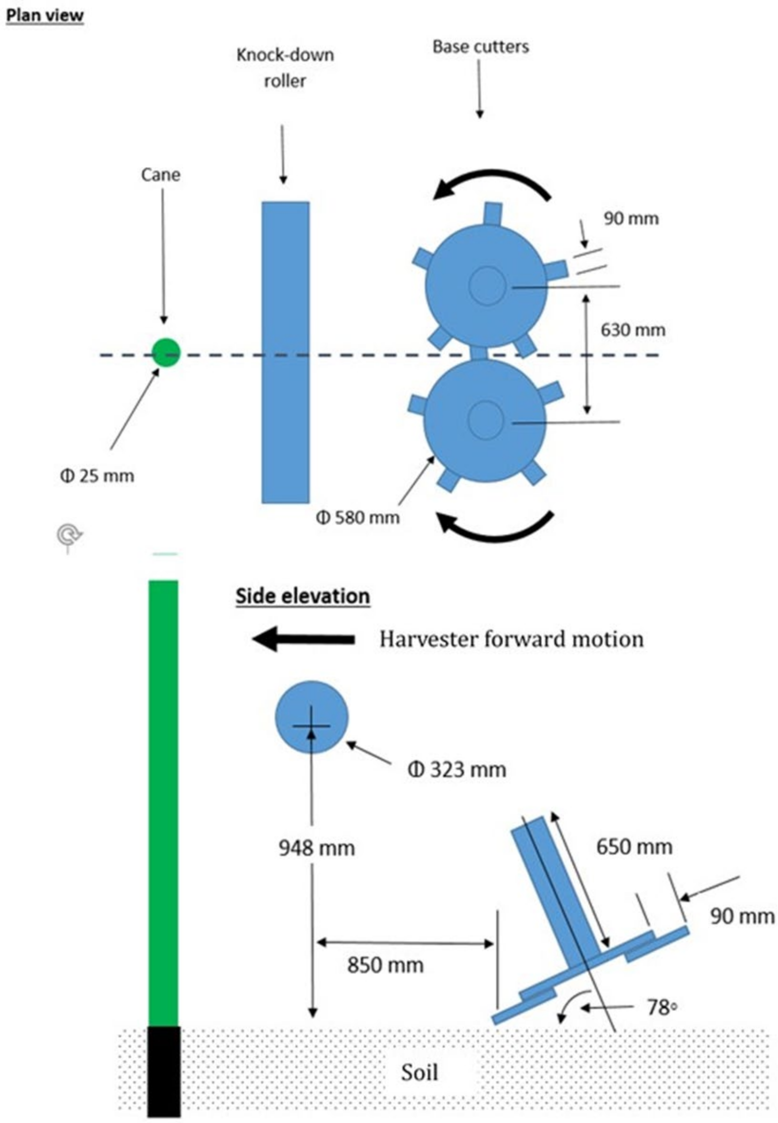


Figure 6. Configuration and dimensions of the modelled components

The model was created in ANSYS DesignModeller and ANSYS workbench LS-DYNA. A non-uniform FEM mesh was developed and applied such that cells were clustered more closely in regions of expected high-stress gradients. Details are provided in the final report of SRA Project 2016/952.

The model has been run to duplicate the harvester operating conditions associated with the Childers field trials and qualitative comparisons were made between the predicted and observed cane damage.

Modelling for quantitative model predictions and identification of possible design improvements

The second part of the modelling work involved quantitative model predictions of the single-stalk model in which experimental data from Kroes thesis[2] (as well as several other key publications) in bending by the knockdown roller and cutting by a basecutter blade of individual sugarcane stalks was used to calculate material properties and verify, calibrate and understand the quantitative behaviour of the single-stalk model. This was followed by the inclusion into the model (and adoption of specific material models) for the soil, root system and leaves, beginning with a single-stalk model but ultimately developing to have separate models with three or five stalks. In

[2] Kroes, S., 1996. *The cutting of sugarcane. PhD Thesis.,* Toowoomba: University of Southern Qld.

parallel, a typical harvester geometry and detailed geometries for the knockdown roller, finned roller, basecutters, butt-lifter roller and one-feed roller were developed as shown below. Friction was included between the cane stalks, leaves, and the components of the harvester. The separate models with differing numbers of stalks provided flexibility to investigate different parts of the feeding and cutting processes while dealing with the significant computational resource requirements. The harvester geometry shown below was labelled Model A (Figs. 7-9). Details are provided in the final report of SRA Project 2016/952.

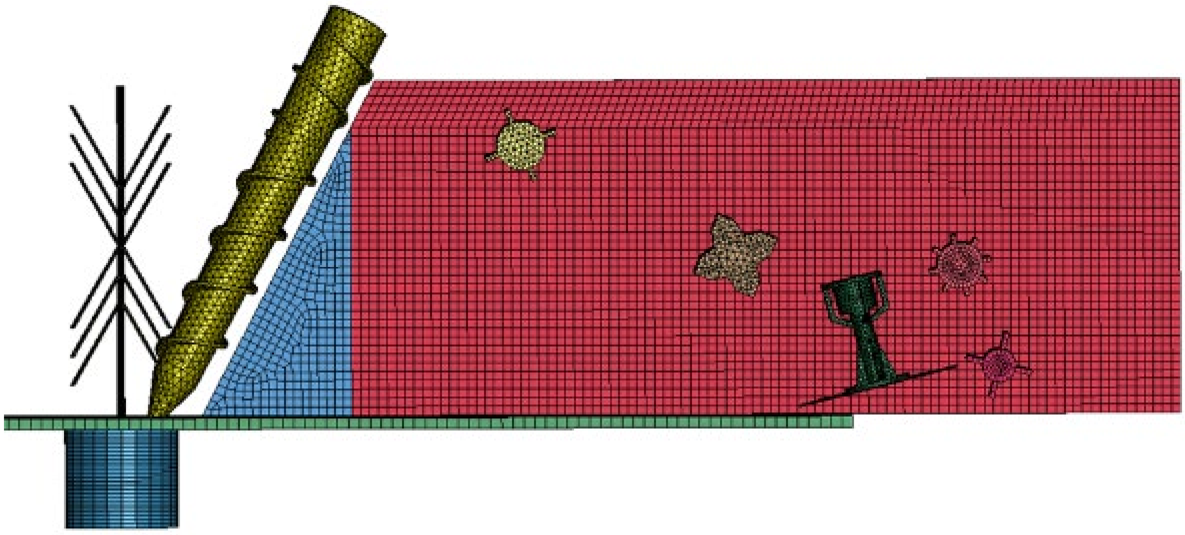


Figure 7. Model A, side view of single stalk and harvester components

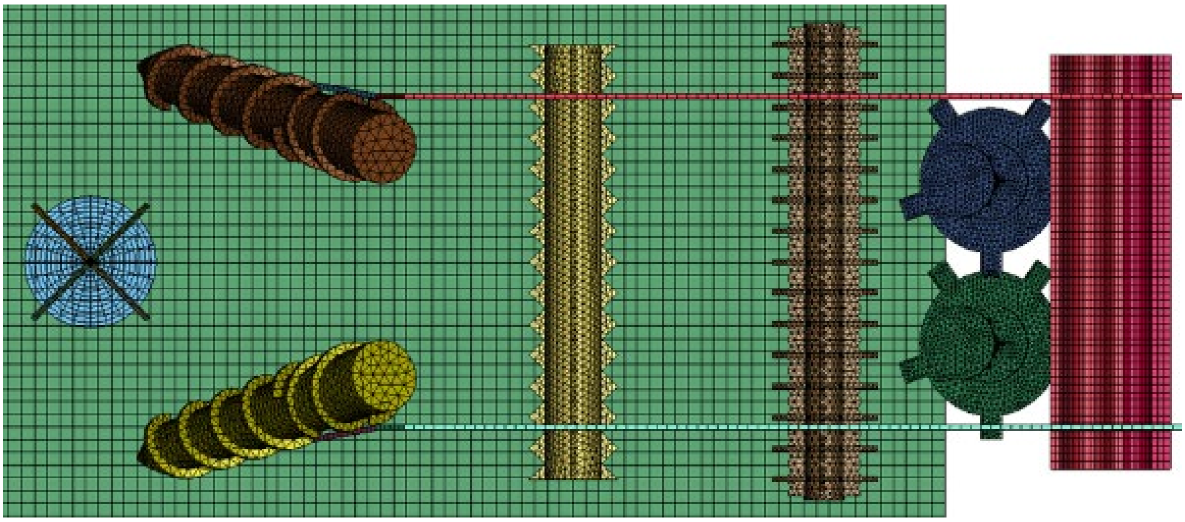


Figure 8. Model A, plan view of single stalk and harvester components

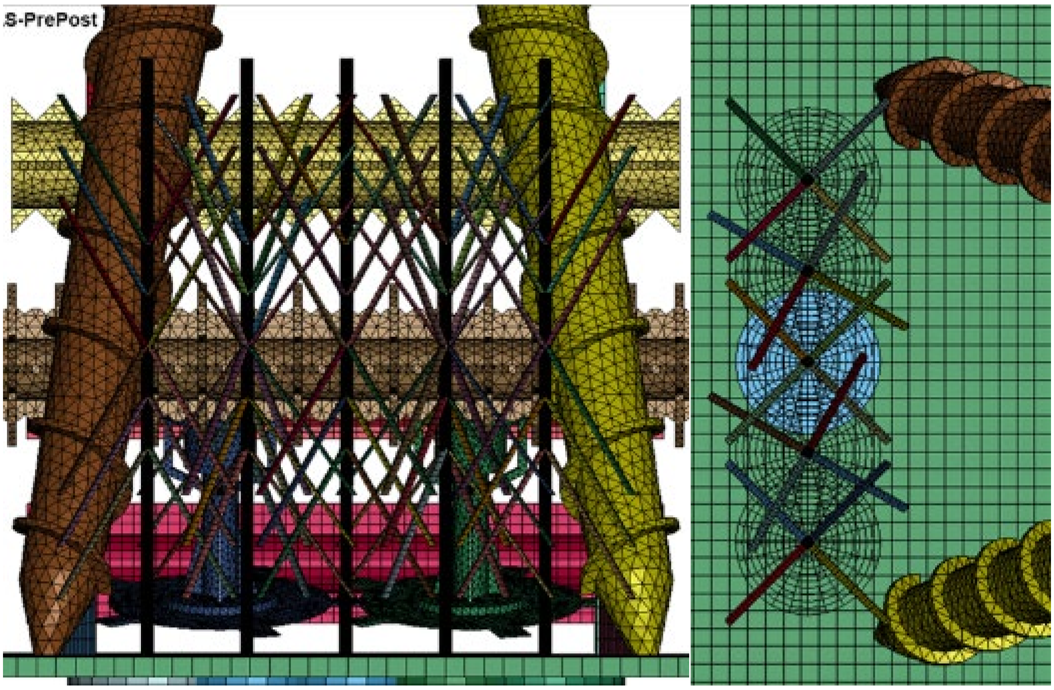


Figure 9. Model A, front and plan view of five stalk harvester model

The following models were also built, modified from the geometry in Model A:

1) Model B: spirals pitch increased to 280 mm
2) Model C: sideways spiral angle with the ground changed from 63.5° to 45°
3) Model D: move the knockdown roller horizontally towards the finned roller
4) Model E: sideways spiral angle with the ground changed from 63.5° degrees to 45° and move the knockdown roller horizontally towards the finned roller
5) Model F: sideways spiral angle with the ground changed from 63.5° degrees to 45°, move the knockdown roller horizontally towards the finned roller, and shorten the harvester in the horizontal direction

2.3 Commercial-scale economic evaluation of post-harvest cane cleaning (Project 2016/953)

Cane loss during harvesting is largely driven by the inefficiency of the cleaning process on the harvester, which removes not just extraneous matter (cane tops and leaf material) but also cane billets. Loss of cane billets increases as harvester speed increases, which can overload the cleaning chamber at high cane flow rates, and at high extractor fan speeds which may have been raised in an attempt to supply relatively clean cane to the mill. ‘Low-loss harvesting’ with reduced extractor fan speeds, in conjunction with post-harvest cane cleaning using a purpose-built cane cleaning unit, could potentially be used to manage this issue.

The objectives of this project, led by the Queensland Department of Agriculture and Fisheries (DAF), were to:

- Increase the proportion of sucrose in the crop before harvest that can be practically and economically recovered, by determining the impact of changes in harvester operating parameters to reduce cane loss on the harvester (‘low-loss harvesting’), combined with post-harvest cleaning to enhance sucrose recovery at the mill by presenting product which has low levels of leafy extraneous matter.
- Determine the impact of the different harvesting strategies and post-harvest cleaning on the productivity and cost of the harvesting operation, the potential impact on the transport system of different post-harvest cleaning strategies (field edge or mill-based), and the impact on sugar production costs.
- Enable the impact of post-harvest cleaning on all stakeholders to be determined.
- Inform the growing, harvesting and milling sectors of the industry of the benefits of changes to harvesting practices.
- Identify and address barriers to the adoption of changes to harvesting practices and the introduction of cane cleaning.
- Provide industry with a ‘closed loop’ economic analysis of improved harvester practice combined with post-harvest cane cleaning, a detailed evaluation on the impact on total industry returns, and the potential benefits and costs to all sectors of the industry.

A mobile cane cleaning plant was designed and built by Norris ECT for use in the project. Figure 10 shows the cane cleaning plant in operation on the Tablelands in far north Queensland, with cane from the field being tipped into the cane cleaner from the red haulout bin on the left and cleaned cane being delivered from an elevator into a second haulout bin on the right; extraneous matter (trash) is being expelled from the rear of the plant.

Figure 10. Mobile cane cleaning plant in operation

Three harvesting treatments were assessed:

- Commercial practice. Commercial harvesting practice for the area/contractor (relatively high primary extractor fan speeds coupled with secondary extraction) at commercial ground speed. The outcome is a high harvester pour rate and typical load density.
- Low-loss harvesting. The primary extractor fan was operated at a lower speed to reduce cane loss and the secondary extractor was turned off. The harvester was operated at a similar pour rate to commercial practice.
- Low-loss harvesting plus post-harvest cleaning. Low-loss harvesting followed by post-harvest siding/field edge cane cleaning using the cane cleaning plant before forwarding cane to the mill.

The cane supply for each treatment was randomly selected across the field using the mass balance or linear method. This proven method involved harvesting a haulout load of cane using one treatment and then applying another treatment, in random order, so that each treatment was composed of cane supply from across the field, minimising the effects of field variability on the experimental results. Harvesters were equipped with GPS to log the start and endpoint of each treatment, enabling yield assessments to be made.

All treatments were harvested using established protocols, with key field measurements being:

- Total harvested yield/ha, clean cane yield/ha and CCS yield/ha delivered to the mill for the different treatments.
- Extraneous matter percentage (EM%) where 15 kg to 20 kg samples were randomly taken from each bin. The collected material was processed to determine EM%. The sample components were categorised into cane billets, tops and trash and weighed.

In Year 1 (2017), trials were conducted in southern Queensland on farms owned by Bundaberg Sugar and Isis Central Sugar Mill. In Year 2, trials were conducted on MSF Sugar's Tablelands farm, supplying MSF's Tablelands mill, and on a commercial Tableland, farm supplying Mossman mill.

The economic analysis assumed that the grower or harvest group was the investor in the harvest and cane cleaning machinery, and partial budget analyses were developed whereby the cane cleaning plant could be introduced into the harvesting and transport process as compared to standard practice. For this analysis, the gross income from the experimental harvest was calculated based on CCS (NIR) results, less harvesting and haul-out contract rates (including fuel and labour). Where the cane cleaner was injected in the process, additional costs were accounted for and included FORM (fuel, oil, repairs and maintenance), depreciation and operating labour.

The results for each treatment, under each overarching experiment, were assessed similarly to derive a gross income per hectare and per tonne, to provide a standardised basis for comparison. The cost structures for each treatment were accounted for on this basis to provide a net income calculation for the same units of measure.

2.4 Sensors for improved harvesting feedback: a feasibility study (Project 2016/954)

This feasibility study led by SRA was broken down into: the Current Analysis, which defined the current harvesting systems and environment; the Requirements, which identified and specified the needs of the end-users − contractors, growers, millers, harvester manufacturers and sensor manufacturers; and the Evaluation, which identified a subset of systems with the greatest likelihood of being efficacious in a proof-of-concept.

The required information was collected through literature review, industry-wide paper and online surveys and consultation with industry experts and researchers, industry service providers (growers, contractors and millers), harvesting manufacturers, sensor manufacturers and method specialists. This consultation occurred by multiple means including workshops, face-to-face meetings and teleconferences.

The Current analysis developed a detailed understanding of the current harvesting systems and the environment by:

a) Identifying and defining the harvest quality and loss pathways
b) Examining why the quality/loss pathways exist (e.g. due to fundamental design flaw, cost pressure, cropping configuration etc.)
c) Identifying and documenting whether the causal factors of the pathway are controllable and if not, why not
d) Evaluating the current mechanisms/methods to measure losses and harvest quality
e) Reviewing the existing research surrounding harvesting sensors and identifying the reasons behind their success or failure

The Requirements identified what the contractors, growers and millers need from sensors in the harvesting environment by:

a) Prioritising which pathways are the most critical or valuable to control
b) Identifying what products and constituents will provide the most useful data when analysed
c) Identifying the level of involvement that end users are prepared to contribute for calibration, analysis, ongoing maintenance etc
d) Understanding the limits around the value proposition for end-users
e) Receiving feedback on expected barriers and factors to consider for adoption
f) Evaluating whether the mechanisms/methods used to measure harvest loss and quality are suitable as reference methods for sensing technologies

The Evaluation delivered a subset of systems with the greatest likelihood of being efficacious in a proof-of-concept. The Evaluation involved:

a) Comparing and contrasting systems, evaluating them on their ability to satisfy the Requirements
b) Assessing the economics of each system
c) Developing a proposal outlining the recommendations for future efficacy testing

Data collection methodologies included a literature review, interviews, industry surveys and focus groups.

The survey was composed of three individual surveys, one for each of the Harvesting Contractor, Grower and Milling Company Staff. Questions specific to each sector were asked as well as generic questions around harvesting best practice. The surveys and instructions were made available in paper and online (SurveyMonkey) formats to encourage all people within the industry to participate.

The majority of respondents completed the surveys in paper format. These were input into Survey Monkey by SRA staff to allow electronic data analysis of the results. The data were exported from SurveyMonkey into IBM SPSS Statistics version 24 for data clean up and statistical analysis.

The focus groups were conducted as guided discussions, where the facilitator recorded information relating to specific topics. To cover all areas to be investigated in the feasibility study, different focus groups had different key topics, although all focus groups discussed general quality and loss issues and sensors that would be useful. The information was used to explain the survey results and direct research activities for the project, to ensure that they are industry-relevant.

2.5 Adoption of practices to mitigate harvest losses (Project 2016/955)

Research dating back to the 1990s substantiates the significant gains to the sugar industry value chain when the cane is harvested within Harvesting Best Practice (HBP) parameters. Unfortunately, due to constraints, real or perceived, the industry continues with sub-standard harvesting practices (e.g. operating parameters above the identified optimal capacity), high fan speeds and too many blades per chopper drum.

The barriers to adopting HBP have become more apparent over time and include two important factors:

1) The industry has a limited understanding of the impact of harvesting cost changes and the importance of incentives
2) Poor implementation of HBP results in no significant production or economic benefit

These barriers are exacerbated by the complexities of differing regional requirements. Each region has unique drivers (e.g. payment arrangements between growers and contractors and between contractors and their machine operators) and pinch points (operating hours, bin fleets, number of contractors). To address these constraining forces, growers, contractors and millers must work together.

Overcoming the barriers to adoption of HBP requires a different approach from before. With some exceptions, past efforts to reduce losses have involved advisors urging harvester operators to slow down and reduce fan speed, without considering the economic and social constraints. To effect change, it was necessary to involve those with the ability to make decisions – the harvesting group (defined as the harvester owner and the growers serviced) and not just the operator. The involvement of milling companies was also part of the approach, to ensure that mill requirements in areas such as billet length and EM levels were not in conflict with settings to reduce losses. It was also necessary to demonstrate the outcomes of changes to harvesting practice within an economic framework, using a workshop approach.

The key objectives of this project led by SRA and DAF included the following:

- To work closely with at least 10% of harvesting groups in the industry each year to demonstrate losses in cane harvesting for each group and assist with decision support regarding an appropriate practice change to capture additional value
- To establish a change in harvesting practice in at least 50% of the harvesting groups engaged, measured by groups adopting a selection of the following:
    - Changed payment arrangements
    - Monitoring of major harvester operating parameters
    - Changes to harvester setup such as optimisation of harvester feed train changed choppers or changed schedules for blade maintenance
- To inform growers, harvester operators and millers of the outcome of changes made by the groups
- To inform growers and harvesting operations of the harvesting cost change when shifting from standard practice to HBP, as well as the overall net benefit to growers and harvesting operations

Workshop strategy

Field teams conducted demonstration trials (see below) on losses for each group. The groups were then invited to facilitated workshops led by SRA Adoption Officers, to review the results of the trials and discuss possible responses.

Interactions with harvesting groups included:

- Harvesting groups were invited to sign up for a demonstration trial, using entities such as regional productivity services, regional Canegrowers organisations and the milling sector to recruit volunteers. All members of the group were encouraged to participate in the trial with an expectation that growers representing at least half of the group's tonnage would commit to involvement.
- In a field on one grower's farm, the adoption team conducted a mass balance trial together with the Infield Sucrose Loss Measurement System (ISLMS) to demonstrate the sugar loss, production and revenue outcomes from harvesting at different pour rates (ground speeds) and fan speeds. All members of the group were encouraged to attend for at least part of the day (trials generally ran for around 12 hours).
- Trial data were analysed and economic analyses were undertaken to showcase the relative performance of each treatment.
- Results were presented at workshops facilitated by the adoption team, held towards the end of the season and during the first half of the following season. At the first of these workshops, groups were given the option for a follow-up meeting.

The workshops were pivotal to the adoption process. Most growers had seen the trial and had an improved understanding of the outcomes from various ground and fan speed combinations. In each workshop, the adoption team discussed various approaches through which change could occur, while reinforcing those harvester operators were not to blame for losses.

As the workshops were vital for practice change, it was recognised that facilitators should encourage the group to make decisions around implementing change at the meetings. The workshop facilitators asked decisional questions to encourage action – "What do you want to do?", "What would allow you to make a decision today?" This was successful in moving groups towards change.

Demonstration trial methodology

Demonstration of the economic consequences of different harvesting settings was central to the project approach. Replicated trials were designed to demonstrate the production and revenue implications from using commercial (standard) harvester settings instead of HBP settings. The trial protocols were block-specific, and all treatments were adapted for prevailing block and machine conditions. Harvesting groups were tasked with identifying blocks for their voluntary trial that were relatively even to mitigate the impact of yield variability and that would supply a minimum of 400 t of cane of a single variety.

The four harvesting treatments for green cane trials were labelled 'control', 'recommended' (HBP), 'contractor's standard' and 'aggressive'. The three treatments for the burnt cane trials were labelled 'control', 'moderate' and 'aggressive'. The 'control' treatment was designed to provide the best possible estimate of total biomass available in the paddock, by using harvester settings that minimised cane loss while noting that these settings would be impractical or uneconomic in commercial practice. In green cane harvest, the 'recommended' treatment targeted the HBP cane flow rate of 80-90 t/h to match the capacity of the harvester cleaning chamber while the 'contractor's standard' practice was the operator's nominated harvester settings for the particular block and conditions. In burnt cane harvest, the 'moderate' setting targeted a moderate extractor fan speed; extractor fans were fully turned off for the control treatment in burnt cane. The 'aggressive' practice in both green and burnt cane was designed to demonstrate the impact of more aggressive harvesting practices, with a higher cane pour rate and/or extractor fan speed than the contractor's preferred or moderate settings.

Cane yields were assessed using the conventional mass-balance protocol including bin weights collected at the mill and mill-based cane analysis. The GPS time-stamped waypoints enabled the calculation of average ground speeds and product flow rates into and exiting the harvester. Due to the industry's varied transport bin fleet capacities, all bin mass data was aggregated by bin volume to a nominal 10 t capacity bin of 27.2 m^3. For the green-cane trials, paddock losses were assessed using the SRA ISLMS protocol. For the burnt cane trials, mass balance was the only loss measurement protocol utilised due to no other method being available to date for burnt cane.

Total grower revenue was calculated using the cane payment formula for each mill region together with the cane yields and commercial cane sugar (CCS) or percent relative sugar (PRS) levels measured in the trials. To determine the most profitable harvester setting for the grower, the costs that varied among the treatments were also taken into account. Consequently, a second measure was determined by subtracting harvesting costs (including fuel) and levies from grower revenue, which we termed 'net revenue'. For the 2017 season, parameters for the analysis comprised of the five-year average sugar price ($423/t), and an average harvesting cost of $8.50 (including fuel at $1.25) and levies of 85c which were deducted per tonne of cane for the 2017 season. For the 2018 season, harvesting costs specific to each contractor and farm block were used along with levies for each mill region that the trial was undertaken. The trial harvesting cost changes were included based on yield changes and did not account for additional costs associated with ground speed differences. This was dealt with under further costing analyses conducted by DAF as below.

Trial data were statistically analysed to assess the effects of four harvesting settings on harvested outputs. Data were pooled from all regions into a single analysis. A linear mixed model was fitted to the data using Proc Mixed of SAS Analytical software package. The model applied to the data for each harvest output was:

$$\text{Trait} \sim \text{Treatment} + \text{Location (Replicate)} + \text{Grower/contractor} + \varepsilon,$$

where Trait was the harvested output of interest. Treatment was considered a fixed effect and replicate nested within location was treated as a random effect in the model. The error term ε represents the deviations from our predictions due to random factors that we cannot control experimentally. The random component effect was grouped by block/contractor. Where the treatment effect was significant, a Tukey's multiple comparison test was used to identify differences among means at a significance level of 5%.

Harvesting cost evaluation methodology

To assess cost changes associated with HBP adoption, nine trials were considered for further analysis. Operation-specific information was collected including cost data on in-season and pre-season labour, harvester and haulout depreciation, interest, repairs and maintenance, fuel and oil, and overheads. These were aggregated and relevant harvesting and haulout allowances subtracted to determine total harvesting costs. Interviews with participating harvesting operations who undertook the nine trials typically lasted up to four hours and generally required some follow up.

Given the number of harvesting cost evaluations planned, the requirement for consistency and transparency, and need to complete cost sensitivity analyses, a cost comparison model (Model) was developed by DAF. Its initial development drew heavily on the Bureau of Experiment Stations (BSES) Harvest-Haul Model (HHM) for underpinning harvester and haulage cycle calculations as well as several other formulae. Key contributions of the HHM included the time cycle-based interactions between the harvester and haulouts, determination of elevator pour rates and overall changes in harvesting time such as cutting and waiting times. Some of the original assumptions of the HHM were accounted for with trial data, making the calculation of costs specific to both the harvesting group and the characteristics of each trial paddock.

Various agronomic inputs (e.g. yield, row width, etc.) and machinery time cycle interactions (between harvester and haulouts) formed the basis of algorithms used to derive harvesting costs. Figure 11 includes a summary of the steps undertaken in modelling the cost of harvesting.

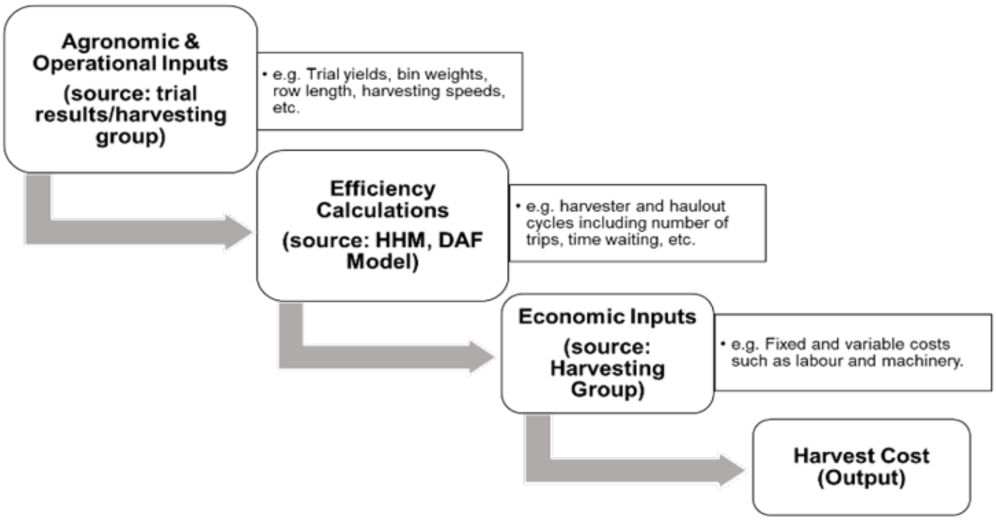


Figure 11. Harvesting cost modelling process

2.6 Adoption of practices to mitigate harvest losses – Phase 2 (Project 2019/951)

Cultural change is a protracted and evolutionary process. While significant progress was made in Project 2016/955, it was apparent that harvesting, a crucial component of the sugar value chain, required further work to realise the industry gains identified by the 95 trials from the 2017 and 2018 seasons.

To continue the work undertaken by project 2016/955, the 2019 project focused on the following key objectives:

- Work closely with harvesting groups and assist with decision-support regarding an appropriate practice change response to capture additional value
- Establish a change in harvesting practice in at least 50% of the harvesting groups engaged
- Evaluate the benefits and costs of improved harvesting practice across the value chain
- Validate outputs of the real-time cane loss monitoring system SCHLOT Live in commercial harvesting operations

Demonstration trials were continued using the same methodology as in 2016/955. An additional 14 trials were undertaken, 12 with green cane harvest and 2 with burnt cane harvest.

Also, 12 commercial trials (economic outcomes of standard vs recommended practice) were undertaken with two Herbert region contractors and their grower groups using the mass balance analysis. Data collected included cane and sugar yields, CCS, gross and net grower revenue per hectare, extraneous matter (EM), billet quality and length. Harvesting costs were evaluated for all 12 trials to determine the impact on harvesting costs from using HBP, which commonly involved slowing down the harvester. The cost evaluations were comprehensive and considered the full spectrum of costs (machinery depreciation, labour, fuel, maintenance, etc.), which drew upon trial data and required a substantial amount of operational information to be collected from the respective harvesting operations.

The 12 commercial trials were designed to demonstrate the production and revenue differences of commercial (standard) harvester settings and recommended settings based on HBP guidelines. All treatments were adapted for prevailing block and machine conditions. The two harvesting groups alternated between commercial and recommended settings across their entire contract for one round during the 2019 harvesting. This involved nine growers between both groups. Operational time, block size, row length/width and yield determined the number of replications completed for each treatment, which varied between trials. Relatively even blocks were selected to minimise the impact of yield variability. Other block selection criteria included a minimum 400 t of cane for replication purposes and a single variety. The two harvesting treatments for the demonstration trials were labelled ‘recommended’ (HBP), and ‘contractor’s standard’. A full rake was analysed to compare yield data between commercial and recommended settings.

Six trials incorporated into the 12 green cane trials were used to substantiate the accuracy of the SCHLOT Live cane loss monitor (from Project 2016/951) against the Infield Sucrose Loss Measurement System (ISLMS). Data was collected and recorded as stated in demonstration trial methodology and compared against logged data from SCHLOT Live. Data from SCHLOT Live was recorded throughout the field, but specific points logged as the harvester past over the tarpaulin used in the ISLMS.

3. Project Outcomes

3.1 Project level achievements

3.1.1 Activity B2 – Project planning and management

3.1.1.1 Final evaluation (KPI 7.1)

Project Outcomes as listed in the Project Plan are:

- A shared industry acceptance that harvest losses should be addressed and that harvest practices should be improved
- Reduced cane loss and improved cane and sugar quality as a result of improved harvesting practices
- Equitable sharing of the costs and benefits of changed harvesting practices across the value chain

with the following deliverables:

1) A 'next generation' intelligent tool for the harvesting sector which will allow more informed decision making
2) Recommendations for improved front-end harvester design to reduce stool damage and cane loss
3) Economic data to determine the whole-of-industry effect of different harvesting and cane-cleaning practices
4) A non-pneumatic cane cleaning unit, if initial proof-of-concept is positive
5) A feasibility study evaluating sensors for improved harvesting feedback and a course of action for future research to develop effective measurement products
6) A concerted adoption program to change industry beliefs and begin a process of substantive practice change

Most of the listed deliverables have been delivered. The exception is the non-pneumatic cane cleaning unit 4), which was investigated by QUT in a proof-of-concept project funded by SRA outside of 15-02-020. Although a small scale (20 t/h) unit was built and tested, a pilot-scale unit was not constructed due to the withdrawal of the commercial sugar industry partner, although the design and expected performance of such a unit was reported. This did not affect deliverable 3) which used a conventional pneumatic (air blast) cleaning unit to evaluate the economics of post-harvest cleaning. However, due to the late start of the cane-cleaning project (2016/953) and teething problems with the cleaning plant, economic data is not sufficient for industry to assess whether this is an economic strategy in all situations or regions, particularly for cane varieties that are not considered 'low loss' or where harvesting procedures deviate substantially from HBP. R&D on machinery improvements indicates that there are potential modifications, particularly around the design of knockdown rollers and the cleaning chamber, that are not currently being addressed.

A detailed evaluation is provided in Section 7.3.

3.1.2 Activity B3 – Communication and extension activities

3.1.1.2 Communication and extension activities (KPI 7.2)

Details of communications developed in the project are listed in the table below.

Nature of materials/activities	Details
Articles	https://sugarresearch.com.au/wp-content/uploads/2017/09/CaneConnection-Spring-17-F-LowRes.pdf https://sugarresearch.com.au/wp-content/uploads/2017/11/MillingMatters-Summer-17-F-LowRes.pdf https://sugarresearch.com.au/wp-content/uploads/2018/06/CaneConnection-Winter-2018-F-Web.pdf ; pages 14-17 (harvest optimisation program)

	https://sugarresearch.com.au/wp-content/uploads/2018/05/MillingMatters-Edition-8-2018-F-web.pdf ; pages 4-8 (harvest optimisation program) https://sugarresearch.com.au/wp-content/uploads/2018/03/CaneConnection-Autumn-2018_web.pdf ; pages 6-9 (harvest demonstrations), page 10 (sensors) https://sugarresearch.com.au/wp-content/uploads/2017/02/Sensors-for-Improved-Harvesting-Feedback-D.04.pdf Trials and practice change help find the sweet spot Real-time feedback to guide harvest efficiency in the cab Side-by-side trial examines after-market chopper systems Optimising the front end for better harvesting 2019 Herbert Harvesting demonstration project Two further articles are in development: one for SRA CaneConnection (Winter 2020) and one for the Australian Canegrower magazine (May 2020)
Videos	https://www.youtube.com/watch?v=kDwfNscE74w https://sugarresearch.com.au/caneclip/harvesting-demonstration-trials-chris-condon-tully/ https://sugarresearch.com.au/caneclip/harvesting-demonstration-trials-lorens-riera-innisfail/ Harvest optimisation: Phil Deguara SCHLOT Live Front-end harvester components
Web page	See the 'Harvesting' tab at https://sugarresearch.com.au/growers-and-millers/farming-systems/
Social media presence	https://www.facebook.com/sugarresearch.com.au/ https://twitter.com/sugarresearch
Publications	Ginns SP, Kent GA, Johnston W, Panitz JH, Robotham BG (2020) Economic evaluation of post-harvest cane cleaning. *Proceedings of the Australian Society of Sugar Cane Technologists* **42**, 87-93. Kent GA, Ginns SP, Panitz JH, Robotham BG (2020) Effect of post-harvest cane cleaning on cane yield. *Proceedings of the Australian Society of Sugar Cane Technologists* **42**, 79-86. Norris CP, Whiteing C, Norris SC (2020) Machine-crop interactions: what is the impact of 'front-end' design and harvester operation on product quality and crop ratooning? *Proceedings of the Australian Society of Sugar Cane Technologists* **42**, 504-518. Nothard B, Thompson M, Patane P, Landers G, Norris CA, Poggio M (2019) Cost assessment of the adoption of harvesting best practice (HBP). *Proceedings of the Australian Society of Sugar Cane Technologists* **41**, 497-506. Patane P, Landers G, Norris CP (2019) Assessing cane and sugar losses utilising world-class methods. *Proceedings of the Australian Society of Sugar Cane Technologists* **41**, 479-487. Patane P, Landers G, Thompson M, Nothard B, Norris CA, Olayemi M (2019) Adoption of practices to mitigate harvest losses: 2017 results. *Proceedings of the Australian Society of Sugar Cane Technologists* **41**, 488-496.

	Patane P, Landers G, Thompson M, Nothard B, Norris CA, Olayemi M (2020) Investigating losses from green and burned cane harvesting conditions. *Proceedings of the Australian Society of Sugar Cane Technologists* **42**, 343-351. Patane P, Milford B, Thompson M, Nothard B, Norris CA, Venables C (2019) Harvesting groups – the key to improving harvesting practice. *Proceedings of the Australian Society of Sugar Cane Technologists* **41**, 473-478. Plaza F, Bakir H, Hobson P (2018) Modelling interactions between the harvester basecutters and cane stalk – understanding cane loss. *Proceedings of the Australian Society of Sugar Cane Technologists* **40**, 321. (Poster paper) Thompson M, Nothard B, Patane P, Landers G, Norris CA (2019) Economic evaluation of sugarcane harvesting best practice (HBP). *Proceedings of the Australian Society of Sugar Cane Technologists* **41**, 507-511.

Extension activities were mostly included in the dedicated Adoption sub-projects 2016/955 and 2019/951, as below.

Communication and extension activities, sub-project 2016/955

The project team implemented a communication strategy specifically designed to address the diversified needs of the value chain (Growers, Contractors, Millers and industry stakeholders). The communication plan raised the awareness of project objectives and outcomes and outlined key messages, target audience, mechanisms and activities related to facilitating the dissemination of information.

TARGET AUDIENCE	KEY MESSAGES
Growers	• Losses are real and the grower should take an interest in how their harvesting contractor operates, planning the harvest with their contractor. • Economic cost modelling suggests additional revenue gained from harvesting at best practice adequately covers the harvesting cost to slow down and yield a net benefit to the grower. • Field conditions impact on harvesting efficiency. For example: o Suiting row profile to harvester setup will result in less chance of stool damage and better crop yield in future years. o Field arrangement to lengthen rows and facilitate turning.
Contractors - Harvesting	• Changed commercial arrangements can generally compensate for any potential cost increase from improved harvesting practices to reduce loss. • Grower / Contractor dialogue is crucial. • Harvesting contractors are operating within a constrained industry. • Grower returns can be greatly maximised by supplying high-quality cane (sound billets with reasonably low EM levels) to the mill thus increasing sugar yield. • Harvesting rates are governed by flow rate into the choppers: o 80 tph – Case (red machine). o 90 tph – John Deere (green machine). • Correct Flow Rate = function of yield, ground speed, row width. • Reduced loss = function of extractor fan and ground speed. • Relatively small changes to flow rate, forward speed and fan speed, to ensure optimum levels can make a big difference in reducing losses.
Millers	• Significant increase in cane delivered to the mill, with no increase in cane land. • No significant difference in EM levels across the Australian green cane industry. • No significant difference in bin weights and bin fill rates. • Improved cane quality through consistent billet length and improved billet quality.

	• Longer billet length will reduce sugar loss, not decrease bin density.
Industry Stakeholders	• Industry support is crucial to the adoption of harvesting the best practice. • Significant difference in industry cane yield, with no increase in cane land. • Changed contractor payment arrangements are required to adopt harvesting best practices. • Harvesting rates are governed by flow rate into the choppers: o 80 tph – Case (red machine). o 90 tph – John Deere (green machine). • Correct Flow Rate = function of yield, ground speed, row width. • Reduced loss = function of extractor fan and flow rate. • It is an essential industry adopts the use of decision-support tools, live monitoring and validation tools. • Cultural change is necessary for the sugar industry value change, requiring collaboration to diagnose solutions to barriers to adoption.

The following audiences were targeted as part of communication activities in this project:

- Growers and miller investors in SRA
- Harvester operators
- Regional groups
- State and Commonwealth Governments
- Industry representative bodies
- Private-sector research providers and Productivity Services organisations
- Environmental agencies and interest groups
- General community.

Key Objectives were to:

- Deliver a communication program that enhances and supports the adoption of harvesting best practice:
  - Communicate the vision for the Harvesting Best Practice Adoption project clearly
  - Deliver a communication program that outlines the benefits and impacts of the change
  - Deliver a communications program that provides opportunities for dialogue with the value chain
  - Promote the activities of SRA, and the various components of the Rural R&D for Profit program "Enhancing the Value Chain".
- Leave a long-term legacy of communication material that can be used beyond the project.
- Monitor and measure the effectiveness of communication through adoption of Harvesting Best Practice parameters amongst contractors and their grower groups participating in trials during the life of the project.

ACTIVITY	AUDIENCE	OUTCOME
Workshop presentations.	Growers; contractors; millers; industry.	Appropriately branded presentations outlining adoption trial results, highlighting the impact of moving from standard practice to harvesting best practice. Facilitated discussion, enquiry and adoption.
Appropriate and targeted social media activity throughout the project – publicising industry forums, field activities (trials, field days), research and adoption updates published in other media (caneClip videos, industry newsletter).	Growers; contractors; industry; government; journalists and community.	Regular updates which enabled the communication of the project's research and adoption activities. Generated ongoing interest and discussion among the value chain.
Graphic design of event invitations, hand-outs, survey	Growers; contractors; industry;	Ensured consistent branding across SRA while acknowledging SRA project partners (Australian Government – Department of Agriculture, Water and

questionnaires and communication materials.	government; journalists and community.	the Environment; Queensland Government – Department of Agriculture and Fisheries).
Media activity.	Growers; contractors; millers; industry; government; journalists and community.	Promotion of the project through the broadcast of encouraging good news stories, in particular, positive outcomes experienced by early adopters. This strategy validated the process and supported a move towards harvesting best practice parameters.
SRA e-newsletter updates.	Growers; contractors; millers; industry; government; journalists and community.	The provision of regular updates to SRA investors and stakeholders on project progress. These updates were in part vital to growing industry support for the adoption of harvesting best practices.
Regular updates in SRA Cane Connection magazine.	Growers; contractors and millers.	Dissemination of information to SRA's primary audience: growers and contractors.
Informal communication activities.	Growers; contractors; millers and industry.	Informal dialogue engaging in active listening while encouraging divergent thinking. Assisted in enabling constructive discussion and consequently raising SRA's and the project team's profile. Stakeholders recognised they were being consulted on drivers for and barriers to adoption.

The project embarked on a concerted program to brief the Australian sugarcane industry of trial results. These briefings have been useful collaboration sessions to inform the strategy and future direction of the project.

Harvesting forums 2018:

- Mossman/ Tablelands – 24 participants
- Mulgrave – 28 participants
- South Johnstone – 16 participants
- Tully – 72 participants
- Herbert –115 participants
- Proserpine – 20 participants
- Proserpine – ~35 participants
- Mackay/ Plane Creek – 27 participants
- Bundaberg – 12 participants
- Isis/ Maryborough – 32 participants
- Broadwater – 21 participants
- Condong – 33 participants
- Harwood – 12 participants

Presentations to Industry Stakeholder Groups:

- 4 x Presentations to Herbert River Canegrowers
- Canegrowers Executive
- Mackay Sugar Cane Supply and Transport
- Mackay Area Productivity Services Board
- Mackay Area Productivity Information Day
- Wilmar Plane Creek Mill
- Plane Creek Productivity Services Board presentation
- Sugar Services Limited Board
- Herbert Cane Productivity Services Ltd Board
- Numerous Isis industry stakeholders meeting
- Southern region focus group meeting
- MSF harvesting workshop

- Tully Canegrowers Board meeting
- Wilmar CPLT meeting
- Next-Gen Conference
- Wilmar CS&T meeting
- Bundaberg Sugar –farm manager's workshop

Milling Forums 2018

- Central Region
- Herbert Region
- Gordonvale Region
- NSW Region
- Southern Region

Milling Forums 2019

- Herbert Region
- Mackay
- Gordonvale

Grower updates 2019

- Southern Region
- Burdekin
- Central
- NSW
- Herbert
- Tully
- Wet Tropics

Harvesting Forum 2019

- Proserpine only

Communication and extension activities, sub-project 2019/951

During 2019-20 the Harvesting Adoption Team continued its concerted program to brief the Australian sugarcane industry of trial results.

- Herbert – Ongoing workshops to mentor growers and harvesting contractors towards the adoption of HBP
- Proserpine – one-on-one meetings with the Productivity Services, growers and harvesting contractors to develop a long-term strategy to support the adoption of HBP in the Proserpine region
- Mackay– One-on-one meetings with Mackay Sugar Executive Management, and presentation to Mackay Sugar 2020 pre-season harvesting contractor meeting (~100 attendees)
- Burdekin – Presentation to Regional Adoption Advisory Group and Burdekin harvesting focus group
- Bundaberg – Ongoing workshops to mentor growers and harvesting contractors towards the adoption of HBP
- Isis – Ongoing workshops to mentor growers and harvesting contractors towards the adoption of HBP
- NSW – Presentation on project findings to Sunshine Sugar and NSW harvesting focus group
- Cost analysis for changing bin fleet presented to Sunshine Sugar and NSW harvesting focus group

3.1.1.3 Results from the whole of the value chain and demonstration trials (KPI 7.3)

Projects 2016/955 and 2019/951, Adoption of practices to mitigate harvest losses

Green cane harvest: 2017-18

Table 1 shows the mean harvester settings, elevator pour rates and flow rates for each of four treatments implemented in demonstration trials. To achieve the recommended (HBP) settings, harvester ground speeds and primary extractor fan speeds were reduced on average by 0.9 km/h and 95 rpm, respectively, compared with contractor's standard. Consequently, the mean product flow rate into the harvester decreased by 20.6 t/h, which was partially offset by reduced cane loss out the primary extractor, resulting in an ultimate reduction in elevator pour rate of only 12.5 t/h. The actual throat pour rate (flow rate), which is the total quantity of material (cane and extraneous matter) entering the harvester feed train, was calculated by combining the mill production results (for the control treatment) with the ISLMS field biomass measurements.

The table also outlines the EM levels in the delivered cane, bin fill rates and average bin masses based on a nominal 10 t rail bin of 27.2m^3. While EM levels and average bin masses were very similar between the standard and recommended practice, the control treatment had significantly higher mean EM levels (approximately 3% higher) and lower average bin masses (by 1.5 t per 10 t bin) than both of these practices. The trend observed showed elevated EM levels to reduce overall bin mass. Given the lower elevator pour rate, recommended practice on average filled 0.6 fewer bins per hour (-8%) than standard practice (statistically significant difference).

Table 1. Average harvester performance under different practices

PARAMETER	PRACTICE			
	Control	Recommended	Standard	Aggressive
Ground speed, km/h	3.3	4.7	5.6	6.1
Primary fan speed, rpm	592	703	798	934
Elevator pour rate, t/h	57.4 a	76.1 b	88.6 c	92.5 d
Flow rate*, t/h	65.2 a	89.0 b	109.6 c	119.6 d
Extraneous matter, %	14.3 a	11.6 b	11.3 b	10.1 c
Average bin mass, t/10-t bin	7.31 a	8.78 b	8.84 b	9.27 c
Bin fill rates, bins/h	6.9 a	7.2 a	7.8 b	8.0 b

**Estimated flow rate using results from the ISLMS and delivered product*
Means in rows followed by the same letter are not significantly different (p = 0.05)

Table 2 presents the sugar loss and total biomass results for each treatment as measured by the in-field ISLMS trials. The ISLMS trials quantified the total biomass (t/ha) of trash blanket extracted from harvester extractor chambers and determined the total sugar content of measured field residue. The total tonnes of sugar/ha were then determined to give an indication of harvesting sugar loss. The recommended practice was found to have significantly lower mean in-field sugar loss (-0.15 t/ha) and total biomass (-1.7 t/ha, cane and EM) left in the paddock than standard practice. These results identified a strong positive relationship between ground/fan speed settings and sugar loss (speeds above harvester capacity equated to greater sugar loss).

Table 2. Sugar loss (measured in-field) and total biomass for each treatment

PARAMETER	PRACTICE			
	Control	Recommended	Standard	Aggressive
Sugar loss, t/ha	0.38 a	0.55 b	0.70 c	1.05 d
Total biomass, t/ha	13.7 a	17.0 b	18.7 c	21.9 d

Means in rows followed by the same letter are not significantly different (p = 0.05)

There were significant differences in production and revenue between the treatments, with the control and recommended settings obtaining significantly higher cane and sugar yield than standard practice, while the aggressive settings obtained the lowest yields (Table 3). In particular, the recommended practice obtained 4.9 t cane/ha (+5.2%) and 0.7 t sugar/ha (+5%) more than standard practice. Both CCS and fibre levels were very similar between recommended and standard practice (no significant differences), which showed that the increased sugar/ha was driven largely by increased cane yield.

Total grower revenue was calculated using the five-year average sugar price, yield and CCS results (at the plot level), together with the cane payment formula specific to the mill area where the trial was conducted. Net grower revenue subtracted harvesting costs, fuel costs and levies from total grower revenue. Results identified that the control and recommended settings obtained significantly higher total and net grower revenue than standard practice, while the aggressive settings obtained the lowest average revenues (Table 3). In particular, recommended practice delivered $181/ha (+4.8%) more total grower revenue, and $148/ha (+5.1%) more net grower revenue, than standard practice.

Table 3. Mean production and revenue results for each treatment

PARAMETER	PRACTICE			
	Control	Recommended	Standard	Aggressive
Gross cane yield, t/ha	100.7 a*	99.2 a	94.4 b	89.6 c
CCS, units	14.08 a	14.31 b	14.31 b	14.37 b
Fibre levels, %Cane	14.86 a	14.45 b	14.54 ab	14.32 b
Sugar yield, t/ha	14.57 a	14.40 a	13.71 b	13.15 c
Total grower revenue, $/ha	$4,037 a	$3,968 a	$3,787 b	$3,656 b
Net grower revenue**, $/ha	$3,047 a	$3,018 a	$2,870 b	$2,788 b

**Grower revenue minus average harvest costs, fuel costs and levies.*
Means in rows followed by the same letter are not significantly different (p = 0.05)

Green cane harvest: 2019

Table 4 shows the mean harvester settings, elevator pour rates and flow rates for each of the four treatments (from eight conforming trial sites). To achieve the recommended (HBP) settings, harvester ground speeds and primary extractor fan speeds were reduced on average by 0.9 km/h and 101 rpm, respectively, compared with contractor's standard. Consequently, the mean product flow rate into the harvester decreased by 19.5 t/h, which was partially offset by reduced cane loss out the primary extractor, resulting in an elevator pour rate reduction of 12.2 t/h. The table also outlines the EM levels which were very similar between the standard and recommended practice, but significantly higher at the control treatment (approximately 39% higher than standard). Given the lower elevator pour rate, recommended practice on average filled 0.7 fewer bins per hour (-6%) than standard practice (not significantly different).

Table 4. Average harvester performance under different practices

PARAMETER	PRACTICE			
	Control	Recommended	Standard	Aggressive
Ground speed	3.39	4.91	5.83	6.49
Primary fan speed, rpm	580	694	795	901
Elevator pour rate, t/h	67.7	92.7	104.9	110.9
Flow rate*, t/h	75.1	108.0	127.4	137.4
Extraneous matter, %	16.3 a	11.4 b	11.7 b	10.6 b
Bin fill rates, bins/h	11.5 a	10.9 a	11.6 a	12.4 a

**Estimated flow rate using results from the ISLMS and delivered product*
Means in rows followed by the same letter are not significantly different (p = 0.05)

The recommended practice was found to have a significantly lower mean in-field sugar loss (-0.21 t/ha) and total biomass (cane and EM, -1.8 t/ha) left in the paddock than standard practice (Table 5).

Table 5. Sugar loss (measured in the field) and total biomass for each treatment

PARAMETER	PRACTICE			
	Control	Recommended	Standard	Aggressive
Sugar loss, t/ha	0.52 c	0.61 c	0.82 b	1.05 a
Total biomass, t/ha	14.30 c	16.54 b	18.32 b	20.74 a

Means in rows followed by the same letter are not significantly different (p = 0.05)

Control and recommended settings obtained significantly higher cane and sugar yield than aggressive practice, which obtained the lowest yields (Table 6). The recommended practice gained 4.2 t cane/ha (+3.8%) and 0.5 t sugar/ha (+3.4%) more than standard practice; however, this difference was not significantly different due to the limited number of trials and variation within the data set. Both CCS and fibre levels were very similar between recommended and standard practice (no significant differences).

Grower gross and net revenue were significantly different for the control and recommended treatments against aggressive treatment. Although not statistically different, the trend identifies the recommended treatment delivering $136/ha (+3.2%) and $108/ha (+3.2%) respectively higher grower gross and net revenues than the standard treatment.

Table 6. Mean production and revenue results for each treatment

PARAMETER	PRACTICE			
	Control	Recommended	Standard	Aggressive
Gross cane yield, t/ha	120.8 a	114.1 b	109.9 bc	107.8 c
CCS, units	13.7 b	14.05 a	14.08 a	14.1 a
Fibre levels, %Cane	14.6 a	14.15 b	13.9 b	13.9 b
Sugar yield, t/ha	16.7 a	16.1 ab	15.6 bc	15.3 c
Total grower revenue, $/ha	$4,490 a	$4,422 ab	$4,286 bc	$4,204 c
Net grower revenue*, $/ha	$3,453 a	$3,431 a	$3,324 ab	$3,247 b

*Grower revenue minus average harvest costs, fuel costs and levies
Means in rows followed by the same letter are not significantly different (p = 0.05)

Burned cane harvest: 2018-19

Table 7 shows the mean harvester settings, fuel burn, elevator pour rates and flow rates for each of the three treatments from five conforming burnt cane trials undertaken during 2018 and 2019. Compared to the aggressive treatment, primary extractor fan speed for the moderate treatment was 150 rpm lower while the control treatment had the fan turned off. Ground speeds were the same for all three treatments across four of the five trials, but ground speed for the control treatment for one trial was 2 km/h slower than the remaining treatments and this lowered the average speed by 0.3 km/h. Due to the lower fan speed, the moderate treatment had a lower fuel burn than the aggressive (by 2.5 L/h); while the control treatment had the lowest fuel burn due to both lower fan and ground speeds (almost 10 L/h lower than aggressive).

While the control treatment's lower average ground speed decreased the quantity of material entering the harvester feed train marginally (flow rate), there was no significant difference in elevator pour rates. This was attributed to the yield gained through not running the extractor fans.

Because all the trial sites had good clean burns, there were only small increases (with no significant difference) in EM levels when the primary extractor fans were turned off. Given EM has a much lower bulk density than cane, going from the control to aggressive treatment resulted in a minor increase in bin weight (0.2 t per 10 t bin, a 2.5% increase). As with pour rates, bin fill rates were not statistically different between treatments.

Table 7. Average harvester performance under different practices (burned cane)

PARAMETER	PRACTICE		
	Control	Moderate	Aggressive
Ground speed, km/h	7.3	7.6	7.6
Primary fan speed, rpm	0	683	836
Fuel burn, L/h	44.2 c	51.1 b	53.6 a
Elevator pour rate, t/h	133.4 a	134.2 a	137.6 a
Flow rate, t/h	134.4 b	143.2 a	142.5 a
Extraneous matter, %	9.7 a	10.3 a	8.6 a
Average bin mass, t/10-t bin	9.6 b	9.7 ab	9.8 a
Bin fill rates, bins/h	13.8 a	14.1 a	13.4 a

Means followed by the same letter are not significantly different (p = 0.05)

There were significant differences in yield between treatments where the control and moderate treatments delivered 7.5 and 3.3 tc/ha respectively more than the aggressive treatment (Table 8). Mean CCS for the control treatment was slightly lower than the other two treatments but the difference was not statistically significant. Differences in mean fibre levels were found to be statistically significant, with the control treatment having fibre levels around 0.6 percentage points higher than the other treatments. While not significant, the sugar yield results had a similar trend to cane yield but were less distinct given the depressed CCS levels at the lower fan speeds.

While also not significantly different, the control treatment had the highest mean total grower revenue followed by the moderate (-$124/ha) and aggressive (-$249/ha) treatments. Net grower revenue followed a similar trend with the moderate and aggressive treatments obtaining $88/ha and $184/ha less than the control treatment, respectively.

Table 8. Mean production and revenue results for each treatment (burned cane)

Parameter	Practice		
	Control	Moderate	Aggressive
Gross cane yield, tc/ha	131.9 a	127.7 ab	124.4 b
CCS, units	14.6 b	14.8 ab	14.8 a
Fibre levels, %Cane	13.8 a	13.2 b	13.2 b
Sugar yield, ts/ha	19.6 a	19.2 a	18.9 a
Total grower revenue, $/ha	$5,582 a	$5,458 a	$5,333 a
Net grower revenue*, $/ha	$4,439 a	$4,351 a	$4,255 a

Discussion – green cane harvest

For green cane harvest, Figures 12-13 depict differences between standard and recommended practice in terms of ground speed, fan speed, flow rate, sugar loss, elevator pour rate and cane yield for the 2017-18 and 2019 harvest data. Compared to standard harvester settings, using recommended settings required operators to reduce ground speeds by an average of 0.9 km/h in both data sets and decrease primary extractor fan speeds by 95 rpm in 2017-18 and 111 rpm in 2019.

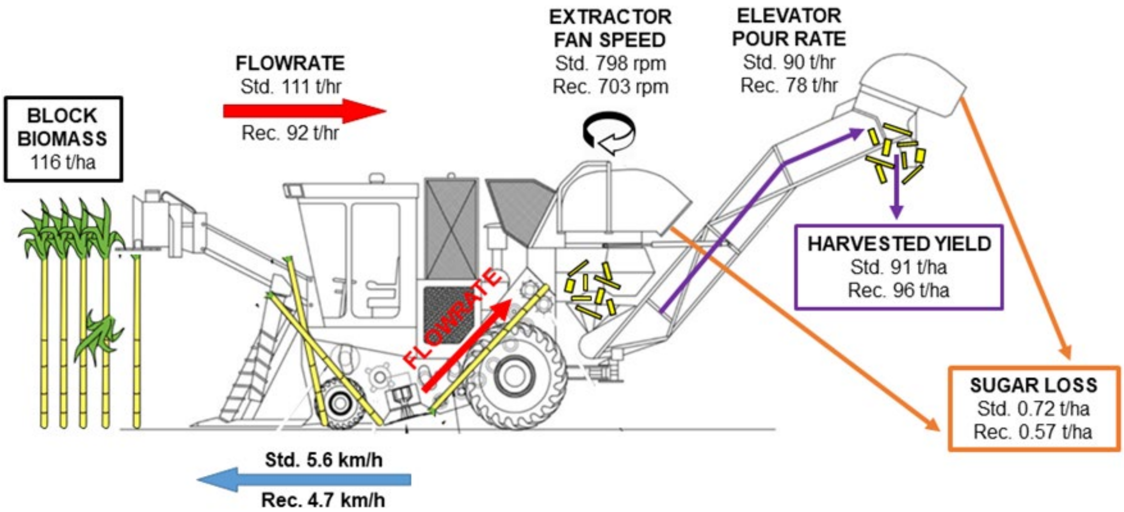


Figure 12. 2017-18 harvest data: Graphical depiction of different speeds, flow rate, sugar loss, pour rate and cane yield between standard (Std.) and recommended (Rec.) settings

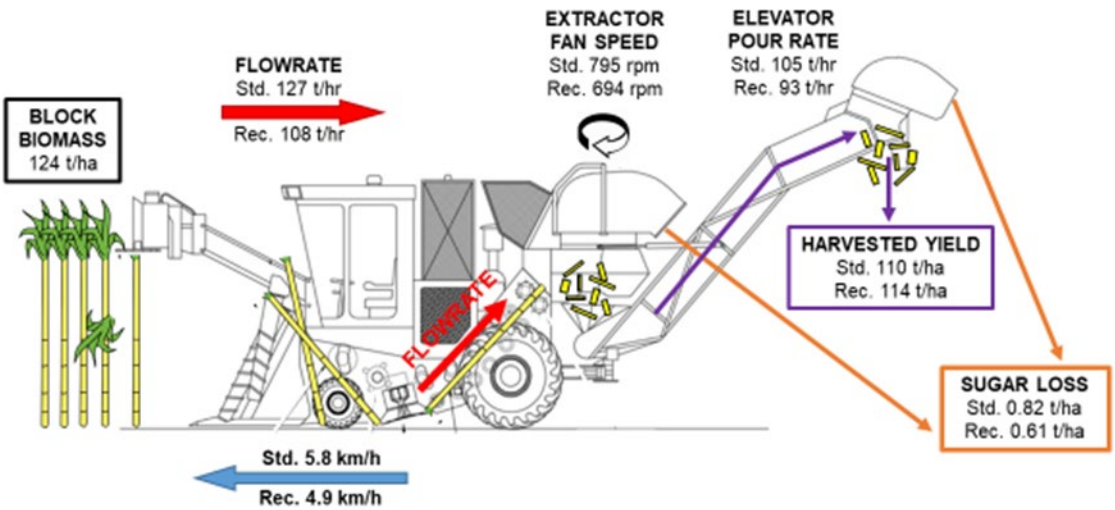


Figure 13. 2019 harvest data: Graphical depiction of different speeds, flow rate, sugar loss, pour rate and cane yield between standard (Std.) and recommended (Rec.) settings

The harvesting trials identified that reducing harvester ground speeds from current industry practice decreased the flowrate of material to within the threshold recommended for the cleaning chamber size. Consequently, the primary extractor fan could be operated at the recommended speed to effectively clean the cane by removing EM without unintended cane loss (e.g. minimal loss). Compared to standard practice, the trial results showed that operating the harvester at the recommended ground speeds (which were the maximum before exceeding flowrate threshold and cleaning capacity) and fan speeds increased the amount of recovered cane by 4.9 tc/ha (5.2%) on average in 2017-18, and 4.2 tc/ha (3.8%) in 2019. This was also shown to have no detrimental impact on EM levels, fibre levels or CCS, and no significant effect on nominal bin mass. Given no difference in CCS, the improvement in sugar yield and grower revenue followed a similar trend to cane yield: compared with standard practice, recommended practice obtained 0.7 t/ha more sugar and $181/ha more total grower revenue in 2017-18 and 0.5 t/ha more sugar and $136 more total grower revenue in 2019.

Similar to the mass balance results that were measured at the mill, in-field testing (ISLMS) also confirmed that standard practice had significantly greater sugar loss than recommended practice: 0.15 ts/ha or 21.6% increase in

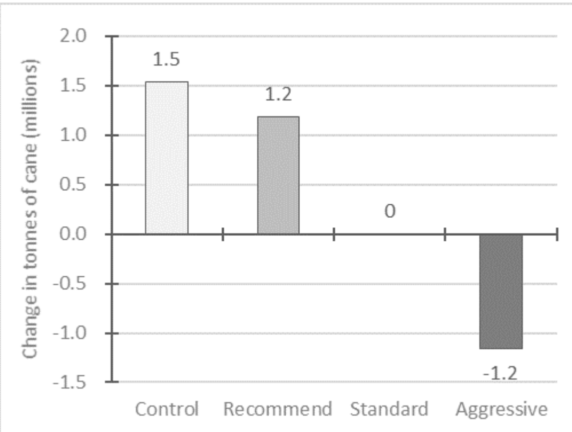
2017-18 and 0.21 ts/ha or 25.6% increase in 2019. In-field tests were carried out by laying tarps next to the moving harvester, which provided the opportunity on the day of the trial for growers to touch and smell each sample and feel that samples from the more aggressive harvesting practices (associated with increased fan and ground speeds) were moister, stickier and sweeter in aroma, thus enabling them to verify the increased sugar loss first hand.

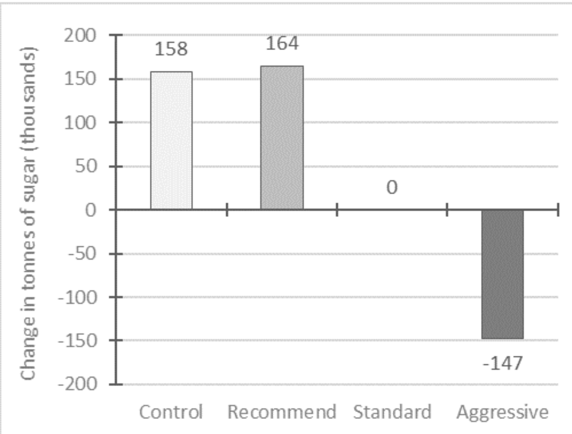
Using the recommended settings did have its drawbacks. The lower ground speeds decreased the quantity of cane material entering the elevator and distributed to haulouts (elevator pour rate) by 15 t/hr on average in 2017-18 and 12 t/h in 2019. Consequently, total harvesting time frequently increased so wider adoption of recommended practice would require longer workdays, increased season length, additional harvesting operations or some combination of these adjustments. Longer harvester times would also likely follow through to fewer rail bins being filled per hour (reduction of 0.6 bins/hr, for a nominal 10 t bin capacity) at the siding or pad, which could influence the efficiency of bin deliveries depending on the mill region's bin fleet capacity. In addition, reduced ground and fan speeds decreased fuel consumption per hour but increased fuel use per hectare, which generates additional costs per hectare.

Results from the aggressive and control treatments also provided some important learnings. Using ground and fan speeds greater than standard practice significantly reduced cane and sugar yield. Using ground and fan speeds lower than recommended practice did not significantly improve cane or sugar yield but did increase fibre and EM levels and decrease CCS and nominal bin mass. The higher fibre and EM levels would have implications for the mill in terms of transport logistics, crush rates and sugar recovery, further making the control treatment commercially impractical and unviable for industry adoption.

To provide guidance on the impact of industry-wide adoption of recommended harvesting settings, Figure 14 shows the estimated changes in cane tonnages, sugar tonnages, total grower revenue and industry revenue from full adoption using results from the 2017-18 harvests. The standard treatment was calculated as the benchmark using five-year average cane yields, CCS and total harvested area data from all the Australian green-cane harvested areas (SRA QCANESelect® 2018). The estimated changes from standard to each alternative treatment assume that the same cane yield and CCS percentage differences measured in the 2017-18 trials would be obtained across the entire Australian green-cane harvested area. A weighted-average mill constant (70.2 c/t) and the average coefficient of work were used to calculate grower and mill revenue, respectively (understanding that these differ between mill regions).

Extrapolating the 2017-18 trial results across the entire Australian green-cane harvested area identifies that an estimated additional 1,155,947 tonnes of cane could be generated each year from green-cane industry-wide adoption of the recommended harvesting settings. This increase translates to an additional 164,480 tonnes of sugar valued at over $69 million for the industry (an extra $2.86/t of cane). For growers, this amounts to an additional $44 million in gross revenue.





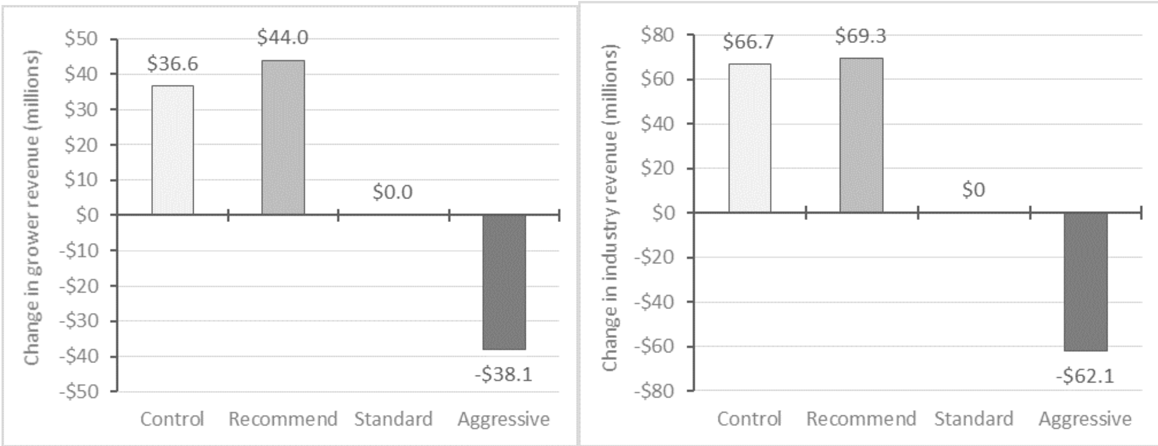


Figure 14. Impact across industry to cane and sugar production as well as total grower and industry revenue from adopting recommended harvesting practices

Discussion – burnt cane harvest

Results from five 'good burn' cane trials in 2018-19 gave a preliminary indication that running the primary extractor fan reduced delivered yields (increased losses) without significant gains in either cane quality or bin weights (or reduced fibre levels). In a move from an aggressive to a no-fan scenario, the 7.5 tonnes per hectare improvement in cane yield translated to an additional $249/ha in grower gross revenue. This would be a significant economic return from a marginal change in the overall harvesting operation. From the preliminary trial results, harvesting groups should consider excluding extractor fan operations from their harvesting regime under a good burn scenario. It is important to note that similar results would not be anticipated for a sub-optimal burn or for when basecutter discs are sunk during cutting (adding dirt to the process). Under these conditions, it is likely that the primary extractor fan would be necessary to remove both trash and soil (EM) via the harvester cleaning chamber, but further research would again be necessary to identify economically optimum settings.

Herbert demonstration trials

Table 9 shows the mean harvester settings and elevator pour rates for the commercial (Contractor standard practice) and recommended treatments for 12 trials undertaken in the 2019 harvesting season. To achieve the recommended (HBP) settings, harvester ground speeds and primary extractor fan speeds were reduced on average by 1 km/h and 53 rpm, respectively, compared with contractor's standard practice.

The table further outlines the EM levels in the delivered cane and average bin masses (using an average of 6, 8 and 10 tonnes bins for the Herbert region). EM levels and average bin masses were very similar between the standard and recommended practice, with no significant difference. However, given the lower ground speed, recommended practice gave a statistically significant reduction in the harvested area of 0.12 ha/h.

Table 9. Average harvester performance between recommended and contractor standard practice (commercial)

PARAMETER	PRACTICE	
	Recommended	Standard
Ground speed	6.1	7.1
Primary fan speed, rpm	657	710
Elevator pour rate, t/h	84.5 a	95.4 b
Extraneous matter, %	15.9 a	15.7 a
Average bin mass, t/bin	6.4	6.2
Average harvest rate, ha/hr	0.78 a	0.90 b

Means in rows followed by the same letter are not significantly different (p = 0.05)

Significantly higher cane and sugar yield occurred at recommended settings when compared to standard practice (Table 10). In particular, the recommended practice obtained 4.3 tc/ha (+4.9%) and 0.6 ts/ha (+5.2%) more than standard practice. Both CCS and fibre levels were very similar between recommended and standard practice (no significant differences), which demonstrated that the increased sugar/ha was driven largely by increased cane yield.

The table also presents the average economic results from the demonstration trials including total grower revenue and net grower revenue. Total grower revenue was calculated using the five-year average sugar price ($418/t), yield and CCS results (for each trial), together with the cane payment formula specific to the Herbert mill area. Actual harvesting costs and levies were $37/ha ($0.07/t) higher for the recommended setting due to higher yields, reduced harvester ground speeds and lower extractor fan speeds. Recommended settings obtained significantly higher total revenue ($151/ha, +4.7%). After deduction of the greater harvesting cost, there was an overall net benefit of $114/ha (+4.4% higher net revenue) in the adoption of recommended settings.

Table 10. Mean production and revenue results for each treatment

PARAMETER	PRACTICE	
	Recommended	Standard
Gross cane yield, t/ha	91.7 a	87.4 b
CCS, units *	14.2 a	14.2 a
Fibre levels, %Cane *	16.2 a	16.2 a
Sugar yield, t/ha	12.29 a	11.68 b
Total grower revenue, $/ha	$3,324 a	$3,173 b
Total harvesting/Levy cost*, $/ha	$650	$613
Net grower revenue, $/ha	$2,674 a	$2,560 b

*Total harvesting costs include the cost of harvesting, grower levies and cost for the harvester to slow down.
Means in rows followed by the same letter are not significantly different (p = 0.05)

The commercial demonstrations support the demonstrations reported earlier, by identifying HBP to be economically better than standard practice on a commercial scale.

3.1.1.4 Benefit/cost analyses for optimised systems (KPI 7.4)

The preceding sections analysed the benefit to growers of changed harvesting practices, using the standard payments to the harvesting contractor. This section completes the economic analysis by investigating the actual costs to the harvest contractor.

Nine harvesting operations with green cane harvest during 2017-18 were analysed in detail. The average harvesting cost per tonne, per hectare and per hour when using the contractor's standard settings had a range of $6.65 to $10.13 per tonne, highlighting the substantial cost variation between blocks and harvesting operations. Trial site characteristics such as yield, row length, soil type and variety were unique to each block, thus trial results would not necessarily reflect a harvesting operation's total contract. The same methodology was used for all nine harvesting cost evaluations, although there were some regional differences including harvester and haulage allowances, rostered cycles and wage payment structures.

Figure 15 shows a break-down of the average total harvesting cost for the contractor standard setting (excluding haulage and harvester allowances given for long hauls or overtime work). The three dominant costs were labour costs, machinery depreciation, and repairs and maintenance. Overheads and fuel also contributed significantly to the overall cost.

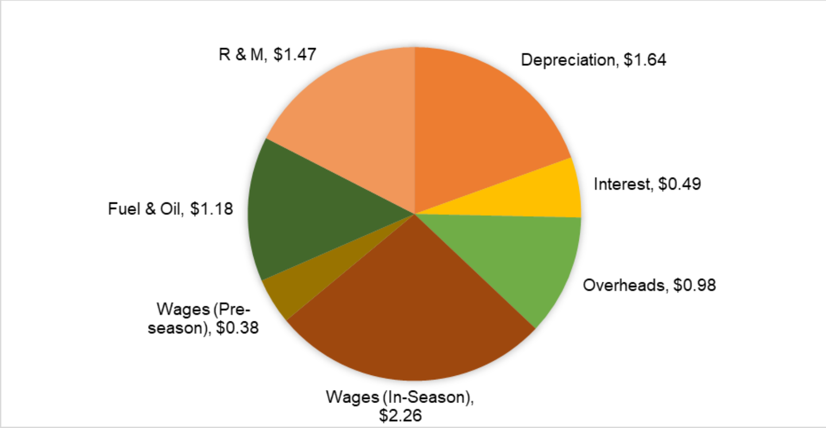


Figure 15. A break-down of harvesting costs per tonne for nine harvesting operations and harvested fields

Harvesting costs were found to be sensitive to changes in cane yield, row spacing, row lengths and contractor group size. The figures below show harvesting cost sensitivities relating to cane yield changes under two different assumptions. The first assumption was that the harvester maintained the same ground speed, while the second assumption was the harvester maintained the same elevator pour rate. This difference had a significant influence on harvesting costs. For example, if cane yields increased from 80 to 100 t/ha and the same ground speed was maintained, then harvesting costs would decrease from $8.71 to $7.19/t (Fig. 16). With the elevator pour rate having increased from 76 to 95 t/h, higher cane losses were also expected. On the other hand, if the harvester maintained the same pour rate by reducing ground speed from 5.1 to 4.1 km/h, then harvesting costs would only decrease from $8.71 to $7.90/t, although cane losses may not increase. The same trend occurred for a row width change from 1.5 to 1.8 m (Fig. 17) with harvesting costs decreasing substantially less if the same elevator pour rate were maintained.

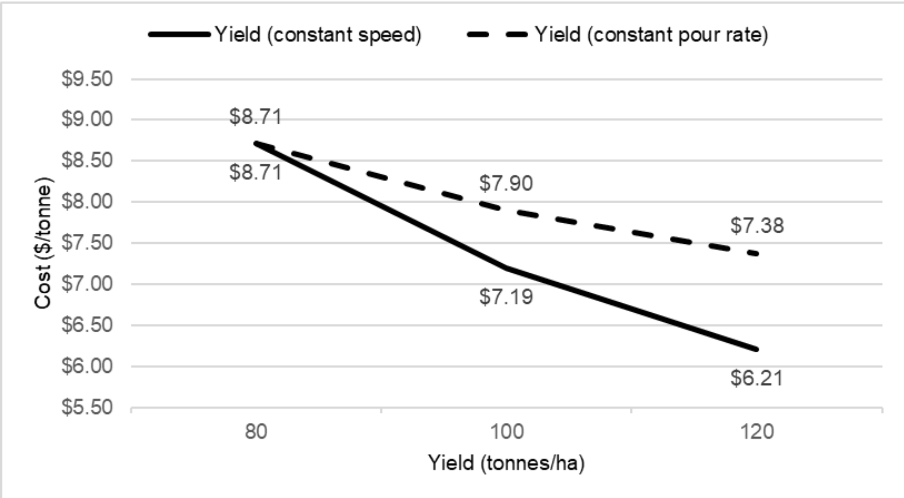


Figure 16. Yield change impact on harvesting costs

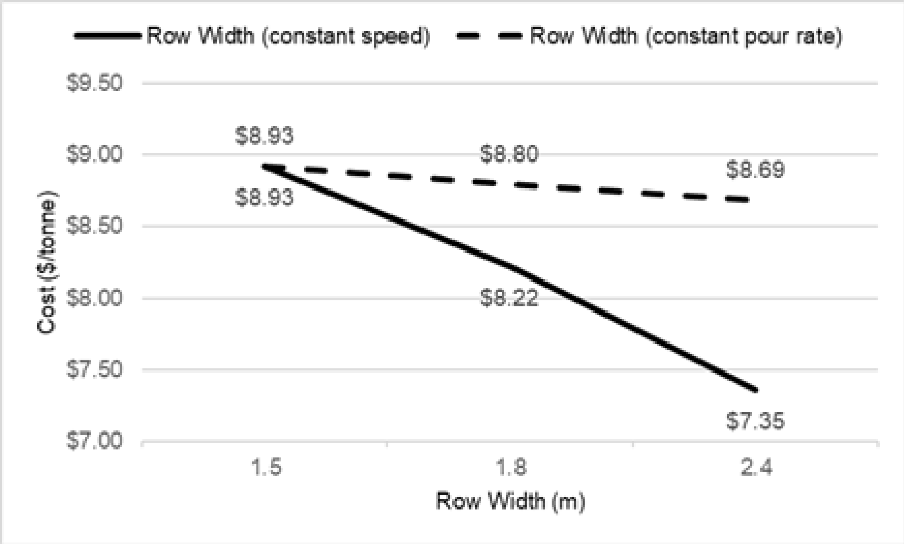


Figure 17. Row width change impact on harvesting costs

The impacts of row length, ground speed and group size changes on harvesting costs are presented in Table 11. The average cost reduction when doubling row length from 400 to 800 m was 31c per tonne. Adding a further 200 m for a row length of 1,000 m only reduced costs by a further 6c per tonne indicating that marginal cost savings declined with longer row lengths. Group size increases showed significant cost reductions and also showed, although to a lesser extent, diminished marginal cost savings when moving from 100,000 to 120,000 tonnes respectively. Decreasing ground speed from 7 to 6 km/h was found to increase harvesting costs by 26c/t, while the marginal cost increase was greater at lower speeds (due to the larger proportional change).

Table 11. Input Sensitivities

	ROW LENGTH (M)			GROUND SPEED (KM/H)			GROUP SIZE ('000S TONNES/YEAR)		
Input Change	400	800	1,000	7	6	5	80	100	120
Cost per tonne	$8.21	$7.90	$7.84	$7.48	$7.74	$8.12	$8.61	$7.89	$7.41
Cost Change		-$0.31	-$0.06		$0.26	$0.38		-$0.72	-$0.48

For nine different harvesting trial sites and respective harvesting operations, the average reduction in ground speed and fan speed between the contractor standard and recommended harvester settings was 1 km/h and 69 rpm respectively, resulting in an average change in elevator pour rate of 12 t/h. Using the recommended settings instead of the standard settings delivered an average of 6 tc/ha (or 6.7%) more cane yield across the trials.

Grower revenue and harvesting costs per hectare were higher for the recommended treatment at all but one site, where yields reduced at the recommended settings. Grower revenue increased by $224/ha on average across the nine trial sites when using the recommended settings instead of the harvesting contractor's standard settings (ranged between -$109/ha and $627/ha amongst the trials). Harvesting costs per hectare also consistently increased among the nine trials by between $11/ha and $101/ha with an average increase of $61/ha.

It is important to note that the range of harvesting cost differences showed more variability on a per tonne than per hectare basis, because of the influence of yield change. The differences in harvesting costs per tonne ranged between a decrease of 67c/t and an increase of 96c/t with an average increase of 10c/t across the nine comparisons. For one field, harvesting costs per tonne decreased substantially due to the recommended settings obtaining considerably higher yields than the contractor's standard settings (+18.6%). In another field and harvesting operation, harvesting costs per tonne also decreased by a substantial amount due to there being no reduction in ground speed while the lower fan speed reduced cane losses and delivered more cane yield. Outcomes like this may rarely occur but are the result of low changes in ground speed combined with significant changes in fan speed. This would improve yield but not increase harvesting times, a big driver of the cost when changing harvester settings. It is important to note that, with no yield response to changed practice, added harvesting costs are expected to result in a net loss to the grower and contractor.

Importantly, it must be kept in mind that these harvesting cost differences are specific to each trial block and each respective harvesting operation. For example, the average yield increase identified in the nine trials from using the recommended settings was 6.7%. This yield increase was above the 5.2% average identified across all the 2017/18 harvesting trials. Given that relatively larger yield improvements decreased harvesting costs per tonne, the harvesting cost changes identified by the nine evaluations shown here were likely underestimated if compared to what would be expected across the wider green cane industry.

Subtracting the additional harvesting costs from the additional grower revenue gave an average net economic benefit of $163/ha or $1.27/t of cane from using the recommended harvesting settings. Over the nine trials, the net benefit ranged between -$138/ha and $572/ha or -$1.10 and $8.19 per tonne.

Table 12 shows a breakdown of the harvesting operations average costs per tonne (excluding harvesting or haulage allowances) to highlight what specific costs are contributing to the overall cost change when using the recommended settings. Depreciation was the largest cost increase followed by fuel and in-season wages. Because ground speed decreases, the harvester and haulouts worked longer hours per hectare, which increased depreciation costs per hectare. However, some of this was offset per tonne due to reduced cane loss and more tonnes being delivered per hectare. A similar trend occurred with fuel and oil due to the machinery working more hours but some of this was also offset by reduced harvester fuel use per hour as ground speeds and fan speeds decreased. In terms of in-season wages, working more hours per hectare increased the wages paid to drivers in the Southern and Central regions on a per hectare basis, while some of this was offset on a per tonne basis. In Northern Queensland, drivers were paid on a per tonne basis, so in-season wages only increased on a per hectare basis. Interest, overheads and pre-season wages were generally fixed per year, so cane yield increases tended to reduce these costs per tonne. Some other differences between regions were also found to influence costs. Results on a per hectare basis gave a $67 overall increase in costs reflecting a higher 8% change (including harvester and haulage allowances).

Table 12. Breakdown of average harvesting costs and differences between standard and recommended settings ($/tonne) for nine harvesting operations

COST ITEM	STANDARD COSTS	RECOMMENDED COSTS	CHANGE*	CHANGE*
	($/tonne)	($/tonne)	($/tonne)	(percent)
Depreciation	$1.64	$1.78	$0.14	8.8%
Interest	$0.49	$0.46	-$0.03	-6.3%
Overheads	$0.98	$0.92	-$0.06	-6.1%
Wages (In-Season)	$2.26	$2.29	$0.03	1.1%
Wages (Pre-season)	$0.38	$0.35	-$0.03	-6.7%
Fuel & Oil	$1.18	$1.23	$0.05	4.2%
R & M	$1.47	$1.43	-$0.03	-2.2%
Total	$8.39	$8.46	$0.07	0.8%

* *The cost changes exclude the impact of harvest and haulage allowances available to the harvesting operations.*

Table 13 shows the same breakdown on a per hectare basis. What should be noted is fixed costs remained unchanged per hectare while others always showed an increase. This applied in all nine cases and reflected an average 7.8% increase excluding the impact of harvester and haulage allowances.

Table 13. Breakdown of average harvesting costs and differences between standard and recommended settings ($/hectare)

COST ITEM	STANDARD COSTS	RECOMMENDED COSTS	CHANGE*	CHANGE*
	($/hectare)	($/hectare)	($/hectare)	(percent)
Depreciation	$159.49	$184.82	$25.33	15.9%
Interest	$48.99	$48.99	$0.00	0.0%
Overheads	$100.45	$100.45	$0.00	0.0%
Wages (In-Season)	$216.26	$234.44	$18.18	8.4%
Wages (Pre-season)	$37.57	$37.57	$0.00	0.0%
Fuel & Oil	$112.50	$126.25	$13.75	12.2%
R & M	$142.91	$149.56	$6.65	4.7%
Total	$818.17	$882.08	$63.91	7.8%

* *The cost changes exclude the impact of harvest and haulage allowances available to the harvesting operations*

Given that the change in cane yield had a considerable impact on the cost difference per tonne, it was informative to explore the sensitivity of harvesting costs to various yield changes when shifting from the standard to recommended settings. Figure 18 shows the range of harvesting cost differences when assuming each trial site obtained a change of between -0.7% and 18.6% in cane yield. The yields used were based on the two most extreme cases of yield change as previously mentioned. The two dark lines reflect the most extreme cost change case results in the application of these yields. These reflect the outermost limits of cost change sensitivities based on yield response differences for the nine trials.

Limited by the two most extreme cases, the figure also shows the harvesting cost difference assuming a 5.2% yield increase. This was measured across all trials undertaken during 2017 and 2018 for the SRA Harvesting Project and is likely more representative of the full industry when compared to the nine-trial average of 6.7%. This yield result gave a cost difference range of a 32c saving to a 69c increase in cost per tonne for the nine trial sites (represented by the dotted line intersection with the outermost boundary lines).

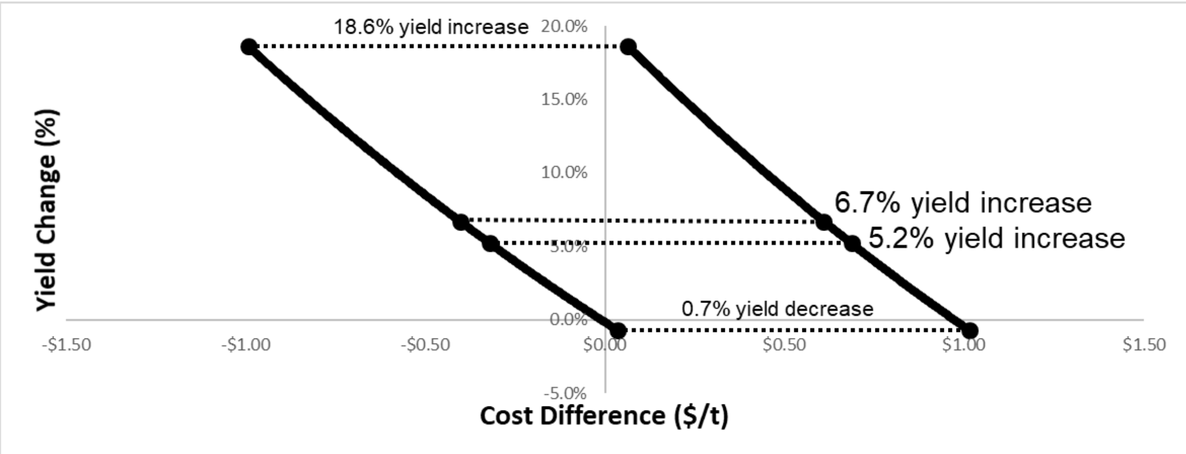


Figure 18. The range of yield changes to cost differences for the nine trial sites

Discussion

Results from the harvesting cost comparisons with green cane harvest showed that using the recommended settings instead of the contractor's standard settings increased harvesting costs by an average of $61/ha due to reduced ground speeds and longer harvesting times per hectare (ranged between $11/ha and $101/ha). Harvesting costs per tonne increased on average by 10 cents per tonne across the nine trials.

Harvesting cost differences varied more widely per tonne than per hectare because yield improvements from the difference in settings varied greatly between trial sites (-0.7% to 18.6%). In certain cases, yield increases proved more influential than cost increases, resulting in per tonne cost savings for the harvesting group. This highlights the need for doing full costing analyses where partial costings could severely over- or under-state the cost implication of HBP adoption.

Another key driver of harvesting cost included the decrease in ground speed required to achieve the recommended pour rates, which was dependent on the estimated yield in the block as well as the contractor's standard ground speed. Elevator pour rate changes were shown to have a significant influence on the overall cost: the lower the pour rate, the higher the additional cost incurred by harvesting groups. It is critical that yield estimates are accurate or targeted pour rates would be missed. This is important given that HBP targets are based on pour rates linked to the ability of harvester chambers to deal with total cane yield (including extraneous matter). Harvesting cost changes also varied because of other reasons such as the characteristics of the cane blocks (e.g. row spacing and lengths, and distance from siding) and differences between the harvesting operations (types of harvesters and haulouts, wages, number of haulouts used). It was also found that initial adjustments in paddock conditions (e.g. 400 m to 800 m row length) proved the most beneficial whereas marginal cost savings diminished for similar adjustments off an already improved base (e.g. 800 m to 1000 m row length).

Results from the cost comparisons identified that adopting the recommended settings at the nine trial sites would increase depreciation costs and in-season wages, given increased harvesting times due to lower ground speeds. Fuel costs also showed a significant contribution to the overall cost change as the result of longer operational hours. When calculating costs on a per tonne basis, all cases showed fixed costs decreasing per tonne, which in turn partially offset other cost increases and reduced the overall impact on the total cost difference.

Figure 19 presents the average cost sensitivity for all nine trial sites when applying both the lowest and highest yield differences. The costing results show that the average cost would increase by 63c per tonne ($54 per hectare) with a 0.7% decrease in yield. With an 18.6% increase in yield, the resulting cost reduced by 57c per tonne but still increased by $78 per hectare. Using an average yield increase of 5.2%, as measured for 51 of the 2017/18 trials when moving to recommended settings, the average increase in cost is 22c per tonne with a range of -32c to 69c per tonne at the outmost trial bounds. The cost increase per hectare range was $11 to $107. However, it cannot be assumed that these numbers are representative of the whole sugarcane industry.

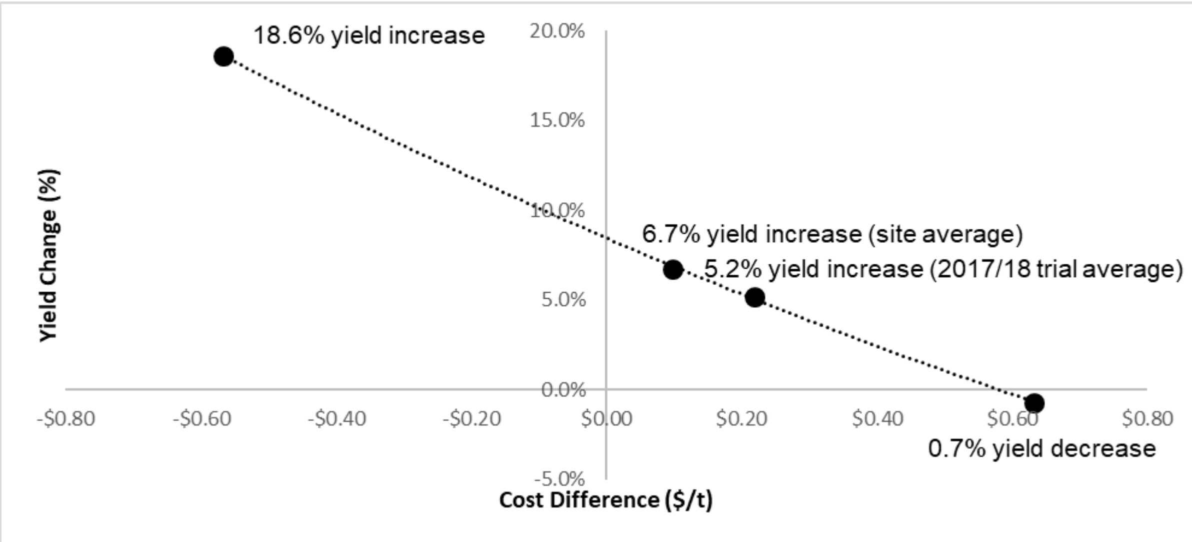


Figure 19. Yield change to cost difference sensitivity for the nine trial sites

Across the same nine trial sites, grower revenue was found to increase by $224/ha on average when using the recommended settings. These grower revenue findings correspond fairly well but are higher than results from all the harvesting trials undertaken in the 2017 and 2018 seasons ($181/ha). On average across the nine trials, the findings identified that using the recommended settings generated more grower revenue than the added harvesting costs from reducing ground speeds. The net economic benefit was $163/ha across the nine trials on average.

Extrapolating the findings from all trials undertaken in Project 2016/955 (2017-18) across the whole Australian green cane harvested area identifies that full industry-wide adoption of recommended settings could potentially increase grower revenue by $44 million annually (mentioned earlier). The additional harvesting costs examined in this paper were also extrapolated across the total green cane harvested area, which estimated that full adoption of recommended settings might increase harvesting costs by $17.2 million annually. Subtracting the additional harvesting costs and levies from the additional grower revenue would deliver an annual net benefit of $26 million ($92/ha or $1.06/t). This dollar per hectare figure was less than the $163/ha calculated for the nine trials, largely due to the latter's higher average cane yield improvement. Notably, industry benefit did not include revenue that the additional cane would generate for mills (around $25 million); however, the additional transport, milling and logistics costs, including potential investments into bin fleets, were unknown to the authors so the net miller benefit could not be established.

The sugar price strongly influenced the size of the net benefit obtained from using the recommended settings. While the net benefit mentioned above was calculated using the five-year average sugar price of $421, the net benefit will be less at lower sugar prices (e.g. $18.5 m at $350/t) and conversely greater with a higher sugar price.

The net benefit was also calculated for control and aggressive treatment across the nine trials with harvesting cost evaluations. The control had both lower ground and fan speed settings than those recommended, and the aggressive treatment had higher ground and fan speed settings than standard practice. While producing satisfactory revenue, the control treatment had substantially higher harvesting costs that outweighed the additional revenue and ended up delivering $261/ha less than the recommended settings overall. In contrast, the aggressive treatment had slightly lower harvesting costs and much lower mean revenue and ended up providing $257/ha less than the recommended treatment overall. These findings confirm that these settings were not commercially viable.

These results suggest that broader scale adoption of the recommended settings would increase industry profitability considerably and improve the sustainability of sugarcane farming. Focusing future research on determining where the largest gains from HBP adoption are (certain varieties, field conditions, crop presentation for harvest, etc.) would help inform extension activities so that these areas could be targeted in the short term to maximise industry gains. The economic analysis did not take into account the expected beneficial effect of reduced ground speeds on ratoon yields and crop cycle length, which is also likely to increase grower revenue.

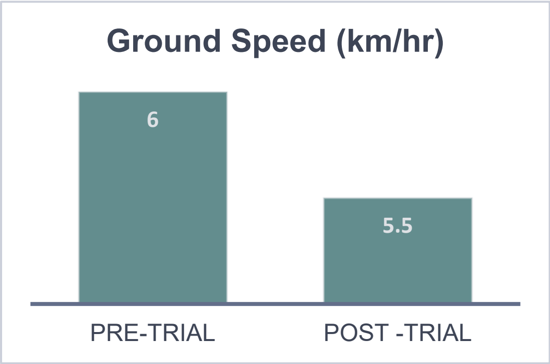
3.1.1.5 Outcomes from workshops for harvest operators (KPI 7.5)

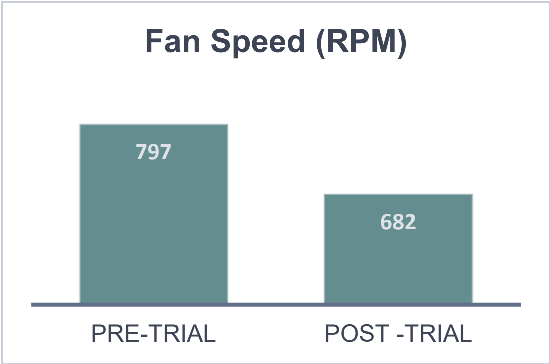
The adoption projects have delivered the following:

- Harvesting groups that have acknowledged the reality of harvest losses and that are working within the groups (growers and contractors) to minimise them
- Productivity evaluations from more than 100 demonstration trials evaluating sugar and cane loss from a suite of harvester settings, including HBP
- Nine economic evaluations which estimated the harvesting cost change and the net benefit from using HBP instead of standard practice
- Full commercial-scale evaluation of the economics of HBP in the Herbert region
- A proven methodology for bringing about practice change for HBP
- An economic model for detailed economic analysis of harvesting costs
- Key messages for HBP, including fact sheets and communication materials

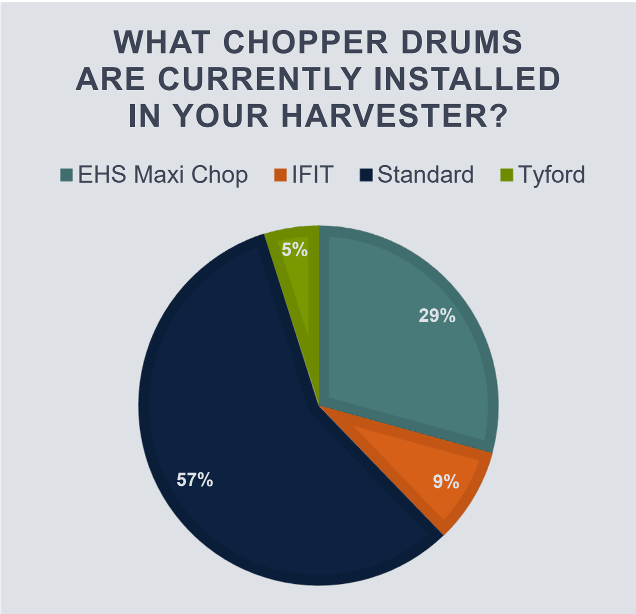
Outcomes after completion of the 2017-18 program (Project 2016/955)

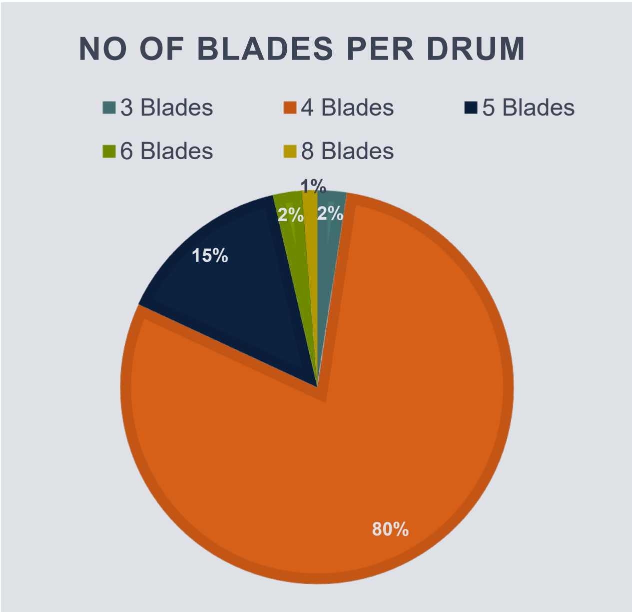
After completion of the 2017-18 adoption program, there had been a reduction in ground speed and fan speed by the contractor groups involved, with the expected benefit of reduced cane loss.



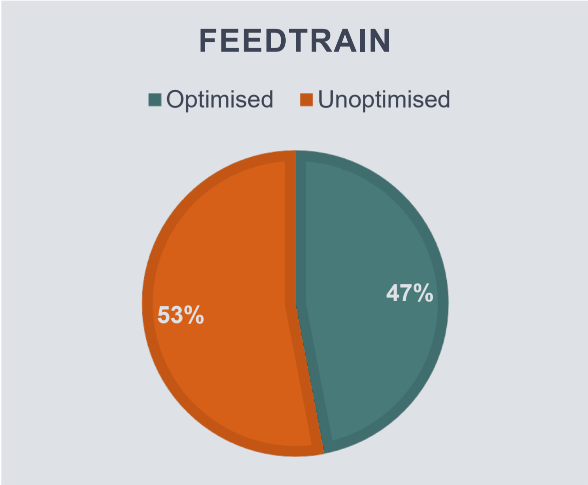


Since the completion of the program, there have been more low-loss chopper drums installed by harvesting contractor groups involved in the program. Simultaneously, there has been a reduction in the average number of blades per chopper drums with an expected reduction in chopper losses due to fewer cuts per cane stalk. There were a limited number of low-loss chopper drums installed when the program commenced.

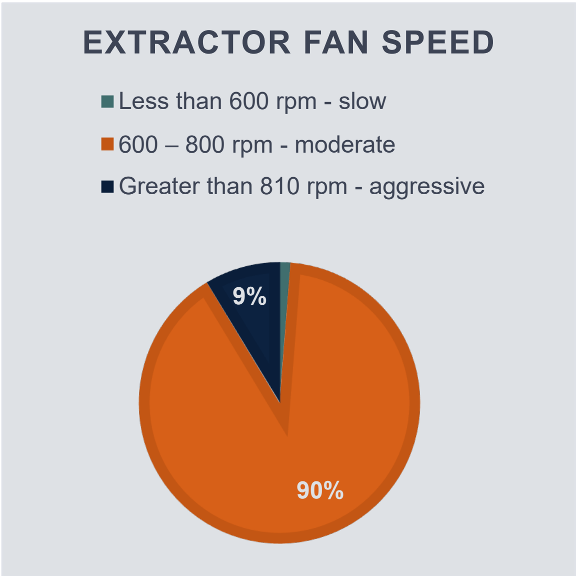




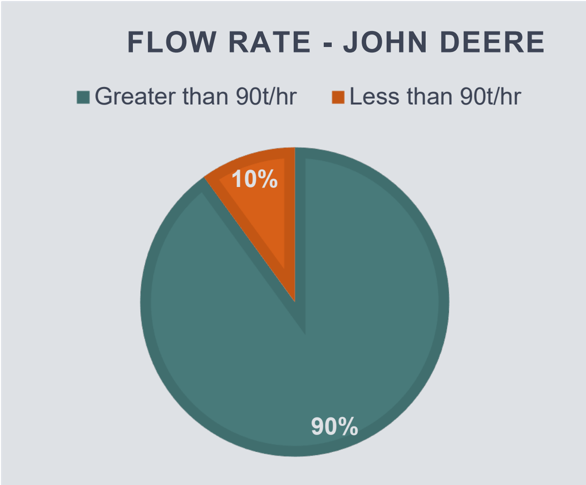
Before the program commenced, there were a limited number of optimised feedtrains on participant's harvesters. There is now an increased awareness of the value of machinery modifications.

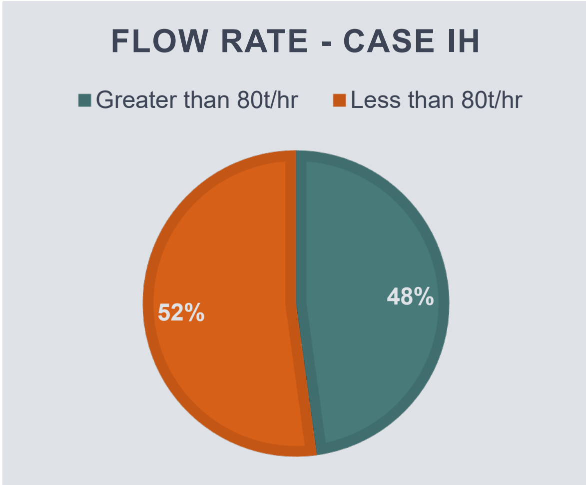


There has been an increase in moderate fan speeds used after the program and a reduction in aggressive fan speeds.

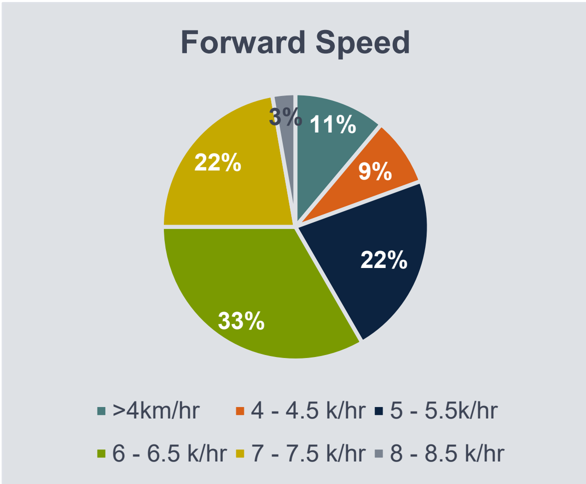


Recommended cane flow rates are up to 90 t/hr for a 5' cleaning chamber (John Deere) and 80 t/hr for a 4'3" cleaning chamber (Case IH). The amount of material entering the cleaning chamber is important for minimising cane loss and maintaining cane quality. Many harvesters are still operating at flow rates above those recommended, justifying the need for an in-cab indicator of cane loss (e.g. SCHLOT Live) and decision-support tools to allow growers and their contractor to negotiate an appropriate payment (plus incentive) for HBP.

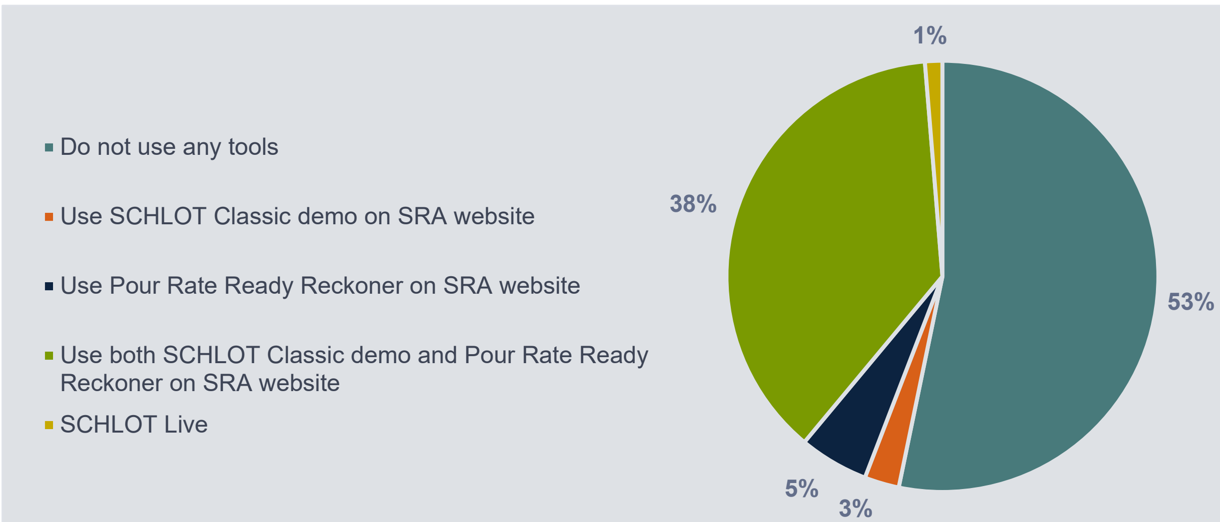




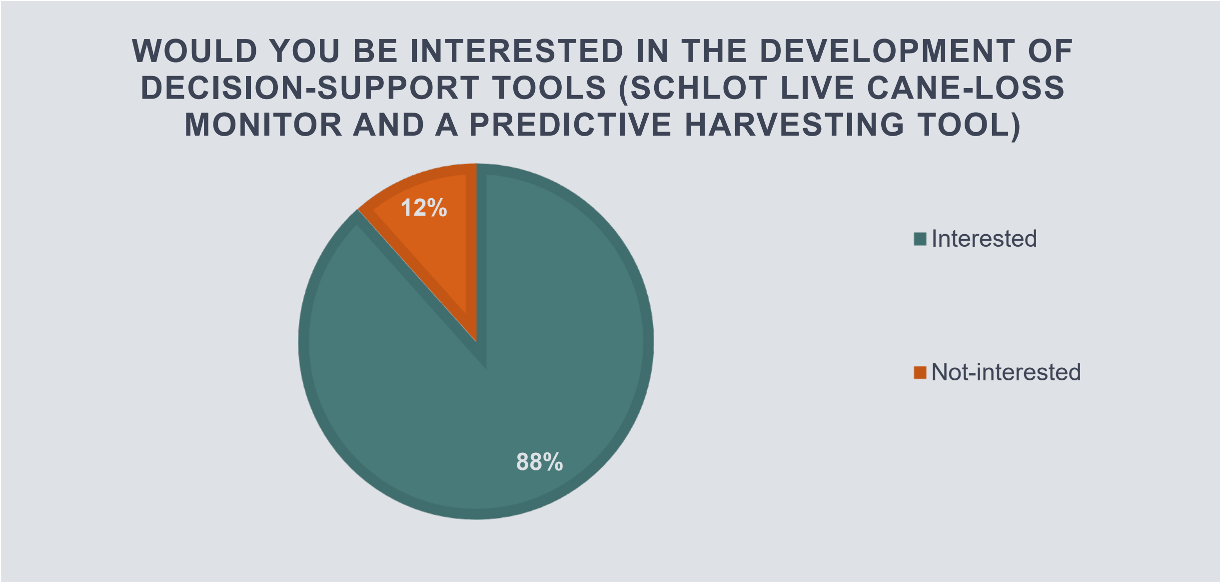
There was a reduction in average harvester forward speed throughout the program.



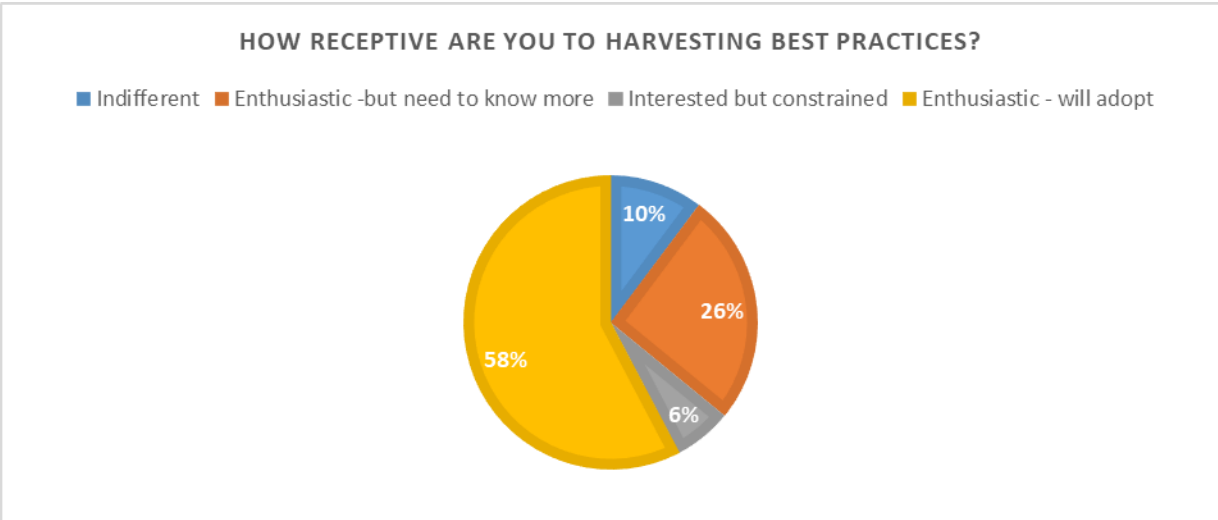
Most participants were not using a decision-support tool after completion of the program. 38% of participants utilise both a demonstration version of SCHLOT Classic and the SRA Pour Rate Ready Reckoner.



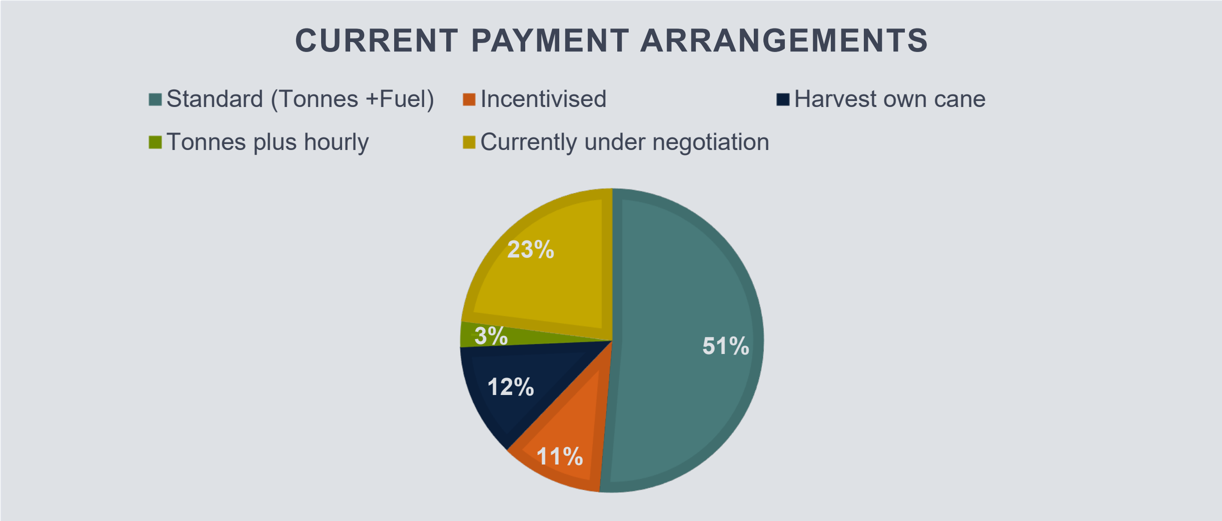
However, 88% of program participants would like a predictive tool and a live cane-loss monitor to improve HBP.



58% of participants were enthusiastic regarding HBP at completion of the program and intend adopting it in some form.



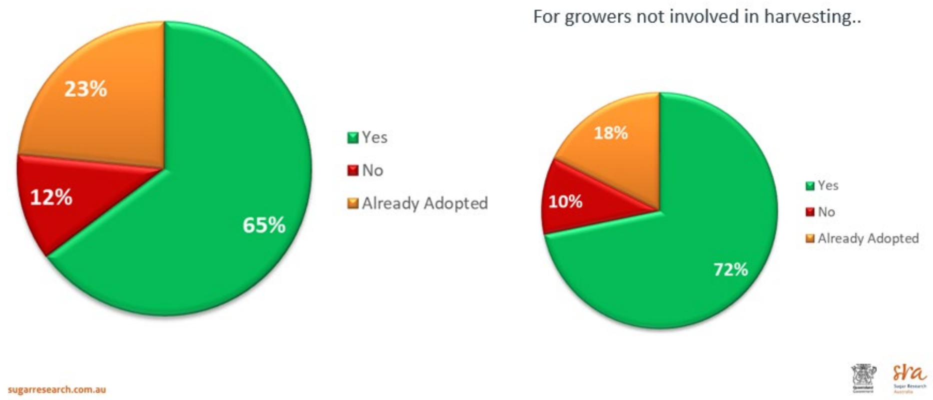
11% of engaged harvesting groups now pay an incentive-based payment for harvesting, with a further 23% now negotiating such an arrangement.



Industry survey at the completion of the 2019 program

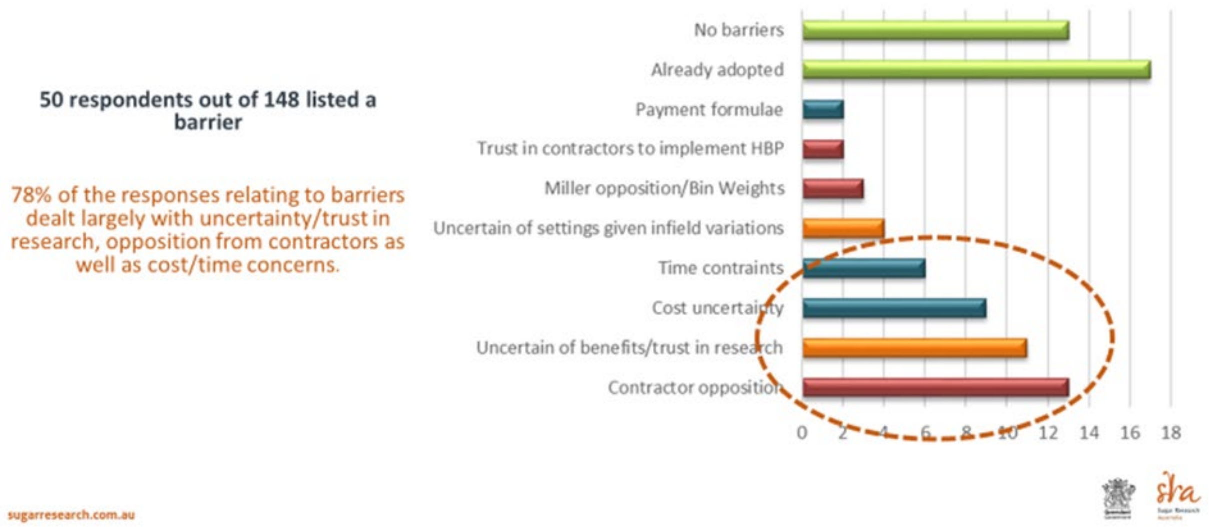
In late 2019, the SRA and DAF Harvesting Team conducted a whole-of-industry survey of growers, contractors, millers, farm managers and contractor employers (148 responses) to understand industry sentiment towards the adoption of HBP. Responses were not limited to project participants. Analysis of the data indicated that 59% of customers were growers who didn't own a harvester while 37% owned harvesters either for their use or for contracting purposes.

65% of total respondents, and 72% of growers not involved in harvesting, indicated they would be interested in implementing HBP. Interestingly 23% (18% of growers) indicated that they had already adopted HBP.



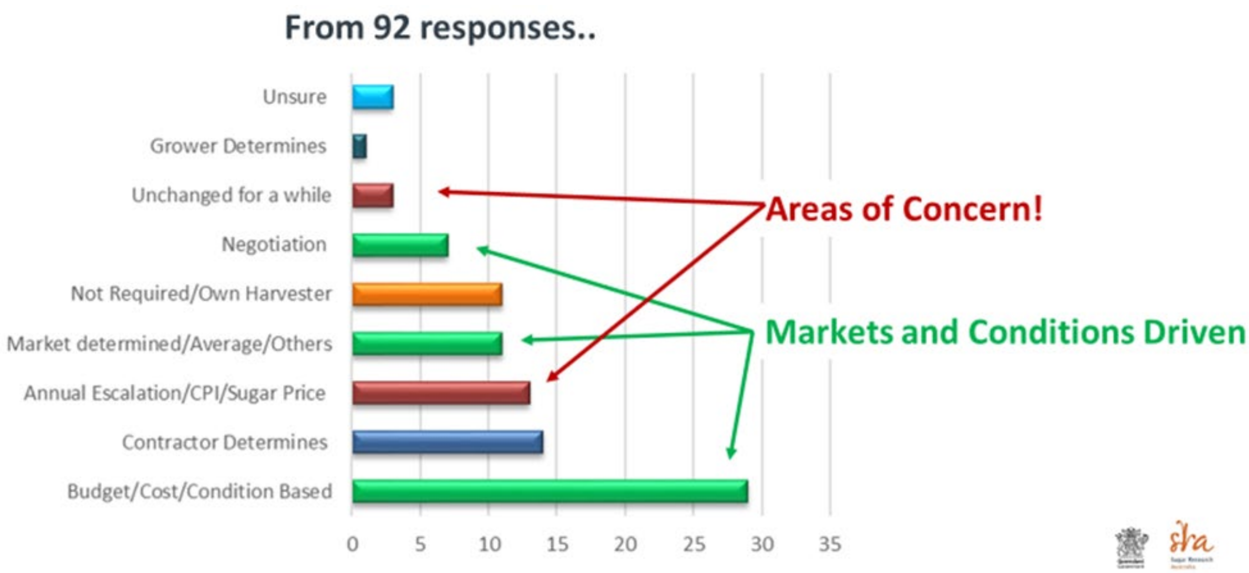
50 of the 148 participants named barriers to adoption of HBP, with 78% identifying the most significant barriers to be:

- Contractor opposition and resentment (industry perception that contractors are doing a bad job)
- Uncertainty of the benefits/trust in research ("What's in it for me?"/lack of mentoring and coaching in research outcomes)
- Cost uncertainty (lack of decision-support tools to support economic outcomes)
- time constraints (social and economic impact to contractors)



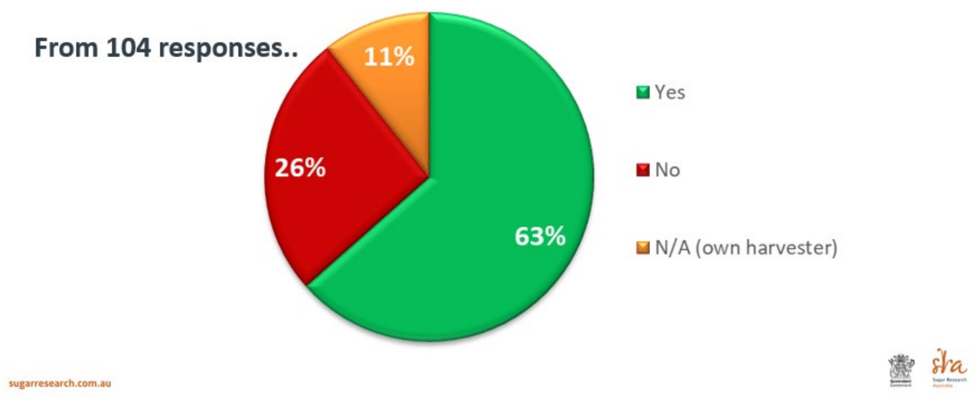
From 92 responses, it is apparent the payment system lacks appropriate frameworks to negotiate contractor and grower arrangements.

How are harvesting charge rates being determined?



Of 104 participants, 63% indicated that they would be interested in a decision-support model to assist with their decision making. However, this percentage will represent early industry adopters. It is believed once acceptance of research increases through coaching and mentoring, this ratio would likely increase.

Do you think a tool would be useful in assisting you to determine a harvester charge rate to implement HBP, which might help to inform negotiations?



Discussion

The benefits of HBP are well established and documented in research dating back to the 1990s but the industry continues with poor and costly harvesting practices. The barriers to adopting HBP have become more apparent over time and include two important factors: (1) the industry has a limited understanding of the impact of harvesting cost changes and the importance of incentives; and, (2) poor implementation of HBP results in no significant production or economic benefit. Adding to the complexities of adoption are regional differences and requirements. To address these added barriers, growers, contractors and millers must work together. There is an increasing demand for decision-making tools to assist growers and contractors to negotiate harvesting payments (economic impacts) and better understand the operational impacts of HBP. Live harvest monitoring will allow contractors to extract optimum cost-effective performance from their machines as well as enable growers to confirm that agreed harvesting parameters are being met. There is also a need to continue the investigation into the extractor cane-loss relationship with billet length and diameter to develop improved HBP fan speed guidelines for different crop varieties. There may also be legal limitations on working hours where full adoption of HBP is constrained.

To gain adoption of HBP, further support to milling companies is required to fully investigate the impact on logistics, cane quality and sugar production. There likely is a need to monitor cane-quality impacts so as not to adversely affect milling processing requirements. Regional working groups comprised of representatives from all three sectors are needed to support the implementation of economically beneficial HBP implementation and better address perceived barriers through alleviating current limitations.

3.1.3 Activity B4 − Integrated loss-measuring tools and harvester telemetry systems

Project 2016/951, Development of an intelligent tool to allow real-time evaluation of harvesting practices as part of a framework for improved harvester payment systems

3.1.1.6 The developed decision-support tool and user interface (KPI 7.6)

The initial concept for the decision-support tool now known as SCHLOT Live involved providing real-time economic feedback of the harvesting process, along with automatically acquiring the physical properties of the crop from existing GIS systems.

Following extensive consultations with potential users, and large amounts of indirect industry feedback from others in contact with larger sections of the industry, it was found that:

- There was a lot of interest in an in-cab cane loss monitor, with the ability to then see cane loss mapped on a field retrospectively
- There was little interest in collating and/or providing the level of financial information (harvesting and transport costs and sensitivities) that would be required to generate meaningful economic impact estimates

- There was not currently a lot of interest in anything more detailed than an instantaneous in-cab cane loss, as most potential users consulted suggested that simply reducing cane loss would have the most significant economic impact
- None of the GIS systems in use in Australia currently store all of the required SCHLOT parameters or information that would allow SCHLOT to derive those parameters, and it was generally suggested that this information would be better input by the harvester operator

Ultimately, the continued development of the system has been towards a less complex system with reduced functionality but more in line with what the market currently wants. Notwithstanding, software and hardware have been developed and selected to allow the increased functionality to be incorporated at a later date without major changes being required.

The in-cab display is ethernet-capable and can be paired with a GPS-equipped Gateway (at a cost of around $1000) to allow the system to determine its location and query the GIS system as a later addition if this is desired.

Reliability of the system is essential for it to meet users' needs, and cane harvesters are a notoriously harsh operating environment for electronic equipment. All hardware selected for the system had to be of appropriate industrial quality. There are large amounts of electronic devices on the market that would offer greater functionality and lower cost than the selected hardware, however, no such hardware that was also sufficiently robust was identified during the project. Attempts were made to use simpler IoT-type hardware, however, this type of hardware is generally not packaged robustly enough for this duty, and the stability of the firmware (ability to continually operate, restart, reset etc with power interruptions and fluctuations) did not appear to be suitable in testing.

This system requires several analogue and frequency inputs, which significantly reduced the pool of suitable hardware. There are large numbers of GPS tracking units, displays and IoT systems, but the vast majority are not equipped with the type and number of data inputs required for this system.

This system involves a collection of primary data over nearly the entire length of the harvester. Initial attempts at aftermarket instrumentation and control on harvesters demonstrated the challenges in adding large amounts of electrical cable on long runs in harvesters, especially into the confined cab. The adoption of a CANBUS system has allowed the volume of wiring to be significantly reduced, especially between the main sensor hub and the display, both of which were initially in the cabin. The utilisation of the CANBUS system has allowed the sensor hub to be moved to the engine bay, further simplifying the wiring and reducing clutter in the cabin. CANBUS communication between the sensor hub/computer (mounted adjacent to the hydraulic pumps) and the display (in the cab) significantly reduced the amount of wiring required to the cab, as well as making the system more modular. Finding suitable CANBUS-ready equipment was a further constraint on system development.

An initial objective, supported by potential user feedback, was to develop a system that could use a commercial off-the-shelf tablet as the in-cab interface. As many harvesters currently already have some kind of tablet in the cab for GIS/Consignment purposes, this would have allowed this existing hardware to have been used without adding another screen in the cab. At first glance, this appeared to be a logical approach, however, it quickly became apparent that there was no readily available hardware to provide the interface between the sensors and the display. Discussions with the operators indicate that having the cane loss display as a discrete unit is in no way an obstacle to adoption.

The entire interface, including the hardware used for the in-cab interface, was redesigned from a clean sheet during the final phase of the project. The current interface improves on an initial prototype by:

- Being based on a higher specification in-cab display, with touch screen, hardwired USB interface (for updates and logging), additional analogue inputs and network/internet connectivity
- Being based on updated firmware for this display, which allows greater functionality, improved aesthetics, and a longer product life (the previous firmware version has been superseded)
- Incorporating feedback from users of the prototype in-cab cane loss monitors, as well as feedback received from potential users who had viewed the SRA CaneClip on the monitor or had seen NorrisECT video of the monitor
- Improving the navigation and physical appearance of the interface to make it more user-friendly and intuitive

Continued development of the interface led to a re-evaluation of the most suitable hardware for the in-cab interface. The previous iteration of the in-cab interface used the Wachendorff A3 Standard display, which was suitable for the application. However, the A3 'Full' display, despite being more expensive, provides greater functionality and greater capacity for future improvements. The A3 'Full' Display has, in addition to the A3 'Standard', 4 analogue Input/Output ports, a hardwired USB receptacle (vs. the 'aftermarket' receptacle required with the 'Standard'), a touch screen, and an ethernet port to allow it to communicate over the internet.

The unit is supplied with the operating program for the particular machine which it will be fitted to, e.g.:

- JD CH 570,
- JD 35xx with standard extractor fan
- JD 35xx with H&F fan assembly
- Case 8000 series

Different programs are required because of different pressure/power characteristics on different machines.

Figure 20 shows the front page of the revised in-cab interface. The screen and colouring have been simplified in line with feedback from users, and the number of buttons on the front screen has been reduced to declutter the screen and allow a slightly larger primary indicator. Two new counters, total estimated cane lost since reset and total area harvested since reset, have been added to this front screen. These counters give the operator a running tally of the total estimated tonnes lost, total estimated hectares harvested and estimated average cane loss per hectare since reset, in addition to the near-instantaneous value on the primary indicator. The running and average figures can be reset or hidden if desired by the operator in the settings pages.

The operator can set the scale (maximum value) of the primary cane loss indicator, as well as set the thresholds at which the indicator changes colour to indicate 'very low', 'acceptable' and 'very high' cane loss. These loss ranges are coloured green, amber and red, respectively. Target values for the gauge display are adjusted in the Gauge Properties page.

Figure 20. In-cab interface main screen of SCHLOT Live

The navigation buttons on this screen allow the user to enter the Settings page, dim/undim the display and reset the Estimated Tonnes Lost and Estimated Hectares Harvested counters.

The revised interface has more user settings and moving to a dedicated settings screen from which all other settings are accessed has decluttered the main screen and makes navigation simpler. The settings screen also shows the version and release date of the software installed on the monitor. From the main Settings page, users can navigate to each of the detailed settings pages, including:

- Crop Physical Properties
- Sensor Calibration
- Time and Date
- Sensor Setup
- Display

Users can also navigate to the log management page.

Online mapping of cane loss is an addition to Agtrix's existing online interface and is commercially accepted. Agtrix's online interface showing a cane loss map of a field is shown in Figure 21.

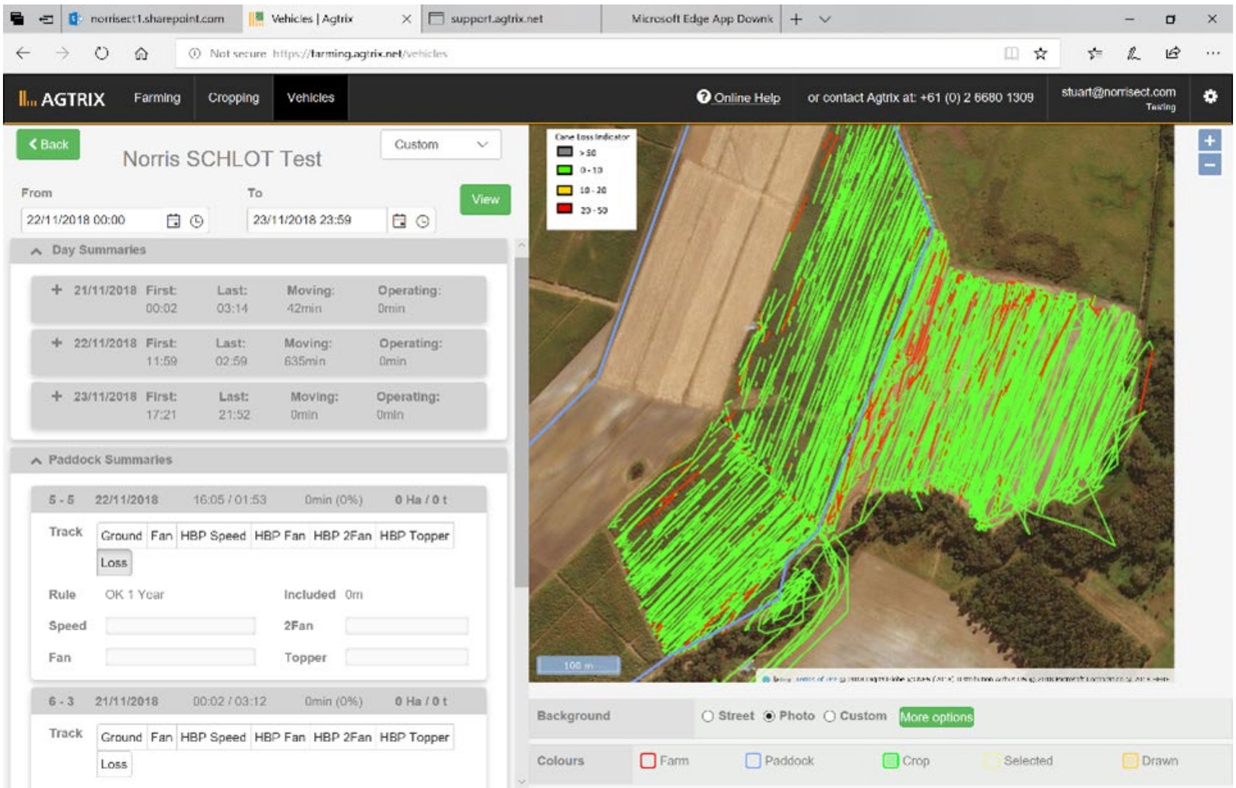


Figure 21. Agtrix online cane loss monitor interface

3.1.1.7 Field trials for the decision-support tool (KPI 7.7)

Field trials were undertaken during the 2016 and 2017 harvest seasons to measure on-ground cane loss under different operational conditions and establish relationships with corresponding harvest sensor measurements to develop cane loss algorithms. Trials were conducted in New South Wales at Condong and in Queensland at Rocky Point, Childers, Bundaberg, Ingham and Tully. Results are not presented here but are in the report of SRA Project 2016/951.

After the development of the dedicated SCHLOT cane loss monitoring unit, replicated trials were undertaken at Rocky Point and Ingham to ground-truth the instrument and the algorithms utilised in it for determination of cane loss. The logging period, logging sequence and internal equations used in the processing of data were the same as utilised for the processing of the data captured by the data logger in the initial trials. Actual cane loss was determined utilising the In-Field Sucrose Loss Measurement System (ISLMS).

Strict protocols were utilised to ensure maximum accuracy of the data from the system, based on the experience of Norris ECT in the use of this protocol. These modifications were designed to improve the accuracy and repeatability of the final sample and the determination of the Brix of the material collected on the tarpaulin, and included:

- Changes to the shredding protocol: The standard ISLMS protocol involves a single pass through the shredder of approximately 30% of the material collected off the tarpaulin, and the laboratory analysis sample is then taken from this material. The modified protocol involved the initial shredding, followed by thorough mixing. Approximately half the shredded material is then retained and re-shredded a second time before the final sub-sample is taken. This protocol modification results in a very significant increase in the visual preparation index and sample homogeneity while only marginally increasing time requirement for the shredding operation. As per standard protocols, the small samples were then taken and frozen for later determination of Brix.

- The laboratory shredding of the sub-sample before determination of Brix of the sample was also modified and an initial dry-shredding process undertaken. This improves the sample particle size range before the correct amount of water is added for final disintegration.

During the field trials, the time when the back of the harvester passed over the groundsheet was recorded to allow correlation between the ISLMS data and the logged data from the SCHLOT cane loss monitor. Further demonstration of the value of these changes has been the very high correlation of sugar loss between each of the pairs of tarpaulins taken at each harvester setting.

Rocky Point Trial

The overview data for the Rocky Point trial is presented in Table 14. It indicates good agreement between averages of the SCHLOT output reading and ISLMS measurements.

Table 14. ISLMS measurements at different extractor fan speed settings and associated SCHLOT estimate at Rocky Point

Speed Setting	t/ha extracted	Brix	Tc/ha ISLM	Tc/ha SCHLOT
680-695	25.6-26.7	1.6	8.8-9.2	6.7-8.2
770-800	32.8-33.5	1.9-2.0	14.6-15.3	11-15
800-840	40-44	1.75-2.1	16-26	12-20

Relevant sections of the logged data set (Fig. 22) indicate a good relationship between the ISLMS measurements and the raw (undamped) SCHLOT readout data for the same time period.

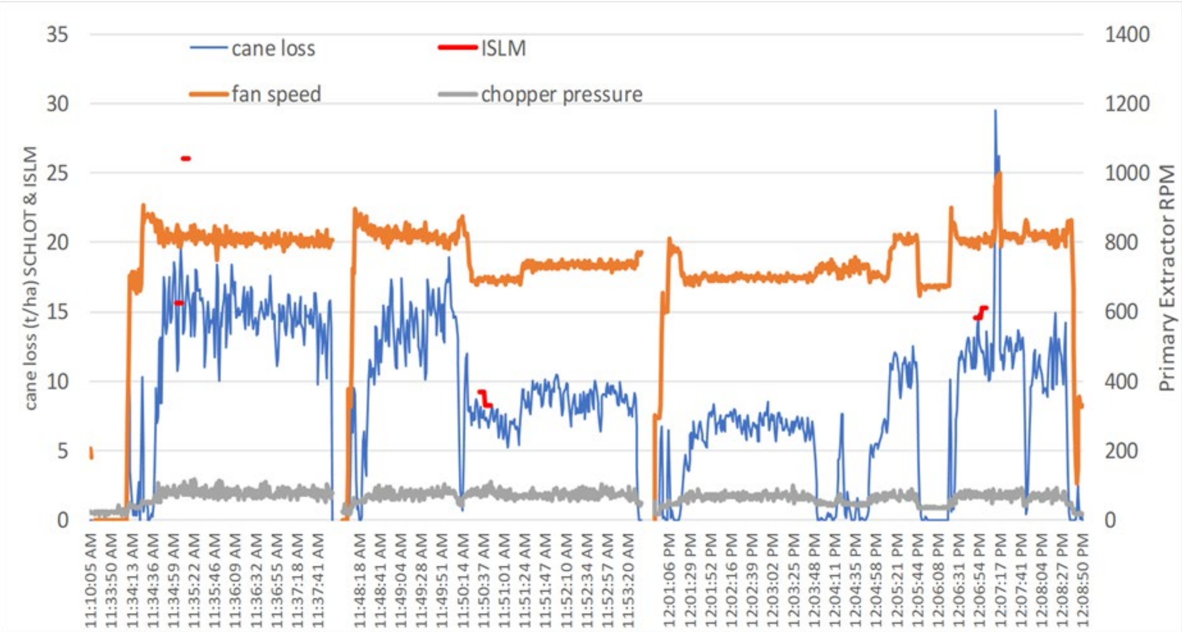


Figure 22. Sample of fan speed and derived cane loss at Rocky Point showing SCHLOT-estimated cane loss (continuous blue line) against ISLMS cane loss, the latter indicated by the red line at the time the harvester passed the ground sheets that collected cane loss and trash. (Fan speed and Chopper pressure included for reference)

Considerations from this data set include:

- Using standard calibration factors, the SCHLOT cane loss reading shows good consistency with ISLMS data (modified protocols)
- Further increases inaccuracy will be achieved by refinement of calibration factors for the particular crop
- Better correlation of the interval between the harvester passing the tarp and the placement of material on the ISLMS tarpaulins would also improve the accuracy of correlation

Given the constant variability of cane loss due to changing conditions in the field, the general correlation between the derived cane loss and the ISLMS loss numbers are of sufficient accuracy to demonstrate the usefulness of the system as a decision-support tool.

Discussion with the driver and harvester owner indicated they found the output of the SCHLOT cane loss monitor to be “realistic and very useful”. The availability of the feedback significantly changed the operating strategies of the harvester driver. Whereas typical operating practices were resulting in indicated cane loss of up to 20 t/ha in larger crops, the driver was able to target a cane loss of <10 t/ha. The credibility of the SCHLOT data was dramatically enhanced because the SRA Harvest Adoption Group had recently conducted Cane Loss Trials with the group and high cane loss was identified as an issue.

Ingham trial

This trial was conducted in a lighter crop of Q200. No modifications were made to the SCHLOT program except for the standard data input during calibration and setup. As both the Rocky Point harvester and the Ingham harvester were similar machines (both with the same chopper and extractor fan options), the same harvester parameters (program variables relating to machine characteristics) were used for both machines.

A sample of the logged data is presented in Figure 23. The typical commercial operating fan speed was 625-650 RPM, with the fan speed being increased for a period as the harvester passed over the groundsheets for the ISLMS assessment at the selected fan speed.

Figure 23. Sample of fan speed and derived cane loss at Ingham showing SCHLOT-estimated cane loss (continuous blue line) against ISLMS cane loss, the latter indicated by the red line at the time the harvester passed the ground sheets that collected cane loss and trash. (Fan speed and Chopper pressure included for reference).

Both the SCHLOT output and the ISLMS data track the changes in harvester settings in the anticipated patterns. Note also that increasing ground speed reduced cane loss as the extractor chamber became overloaded, while EM levels in the delivered material increased significantly under these operating conditions which would have a negative impact at the mill.

Discussions with the operator again indicated the usefulness of the system in managing harvester operation. Different operating strategies were developed for morning and afternoon harvesting to manage cane loss.

3.1.1.8 Demonstration trials with industry focus groups (KPI 7.9)

All development and trial work in SRA Project 2016/951 was done with commercial harvesters in collaboration with the contractor and the harvesting group (i.e. growers). Post-installation feedback from both machines that have been fitted with the final version of SCHLOT Live has been incredibly positive. This is even more impressive given that both machines were selected for other reasons, and neither group had been actively seeking the system. Both groups have stated that they have made significant changes to the way they operate the harvester since the system has been installed.

Project 2019/951, Adoption of practices to mitigate harvest losses – Phase 2

Additional demonstrations of SCHLOT Live were undertaken by Project 2019/951. SCHLOT Live units were fitted to commercial harvesters and used by the harvester operators. To provide additional validation for the units, SCHLOT Live cane loss monitor results were compared with measurements from the ISLMS. Demonstrations were run in six different regions, Tablelands, South Johnstone, Herbert, Proserpine, Mackay and Plane Creek. Three different models of harvesters were utilised to assess SCHLOT Live calibration concerning agronomic information from five different varieties, four different crop classes and six different crop yields. Unfortunately, two trials were unable to be analysed due to logfile download protocol issues at Mackay and incorrect fitting of the SCHLOT Live unit at Plane Creek.

Figure 24 indicates the correlation of SCHLOT Live and ISLMS data using a John Deere CH570 harvester in the Tablelands region. SCHLOT Live pre-calibration for CH 570 gave similar values to the ISLMS. As fan speed increased, so did cane loss as measured with both methods, however, SCHLOT tended to give higher values at the highest fan speed setting. The ISLMS system relies on capture of material on a tarpaulin, and at higher fan speed setting losses off the tarpaulin can be significant because of windage effects. The ISLMS is, therefore, less reliable at higher extractor fan speeds, and the SCHLOT reading very probably more accurately represents cane loss at the higher fan speed settings.

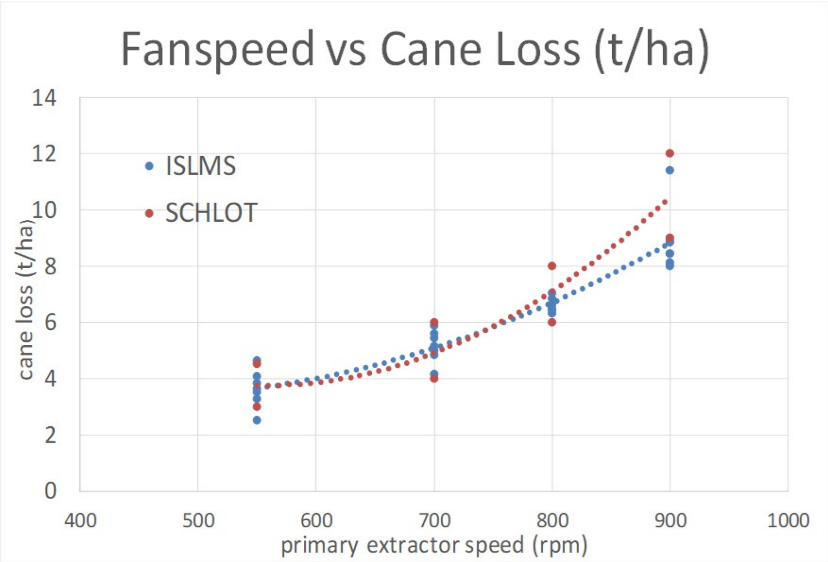


Figure 24. ISLMS compared to SCHLOT Live Cane loss monitor – JD CH570

Figure 25 indicates the correlation of SCHLOT Live and ISLMS data with a Case IH 8810 in the South Johnstone region. SCHLOT Live pre-calibration for Case IH 8810 followed the same trend as ISLMS. Similarly, as fan speed increased so did cane loss, however, SCHLOT Live tended to overestimate cane loss. This may be due to the limited number of trials with the Case IH 8810 and calibration factors are still being refined for this machine.

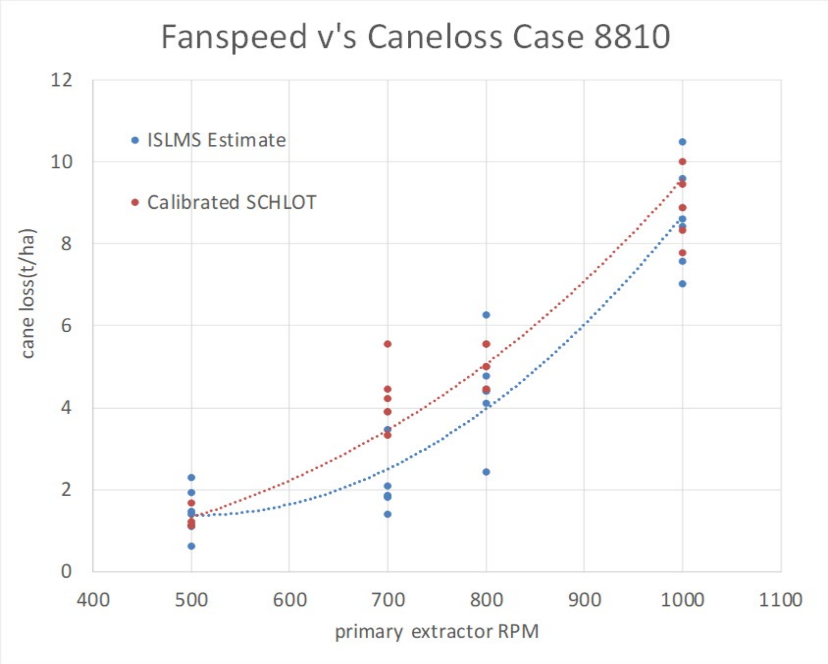


Figure 25. ISLMS compared to SCHLOT Live cane loss monitor - Case IH 8810

Figure 26 indicates the correlation of SCHLOT Live and ISLMS data with a John Deere 3520 in the Herbert region. SCHLOT Live pre-calibration for John Deere 3520 gave similar values to the ISLMS. As can be seen, as fan speed increased so did cane loss measured with both methods.

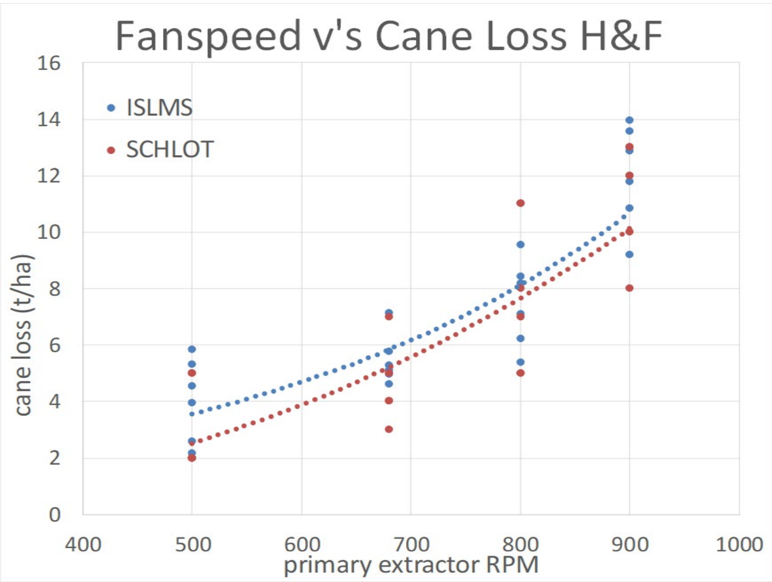


Figure 26. ISLMS compared to SCHLOT Live cane loss monitor - JD3520

Figure 27 indicates the correlation of SCHLOT Live and ISLMS data with a Case IH 8800 in the Proserpine region. SCHLOT Live pre-calibration for Case IH 8800 followed the same trend as ISLMS. Similarly, as fan speed increased so did measured cane loss, however, SCHLOT Live tended to underestimate cane loss. This may be due to the limited number of trials with Case IH 8800 and calibration factors are still being refined for this machine.

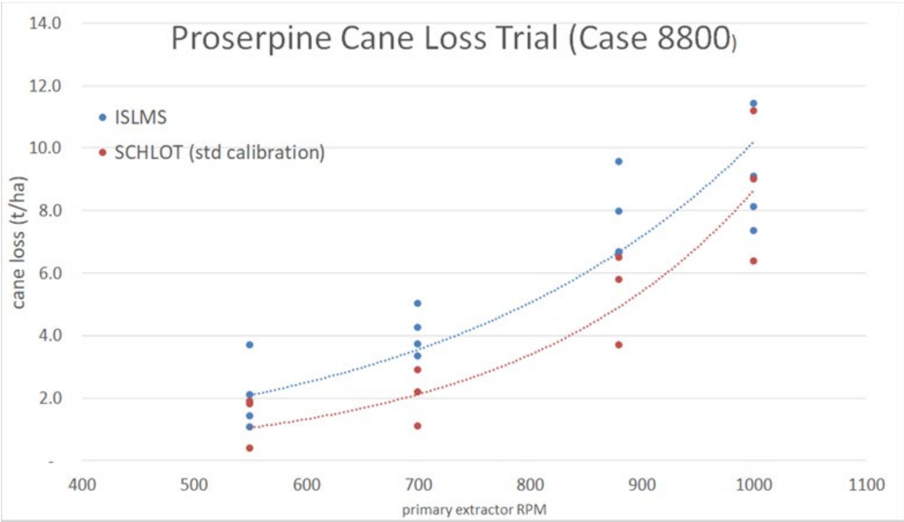


Figure 27. ISLMS compared to SCHLOT Live cane loss monitor - Case IH 8800

Figure 28 depicts ground speed, fan speed and cane loss from the primary and secondary extractor from replicate two and three of the Proserpine SCHLOT Live trial. As fan speed and ground speed changed throughout the trial, measured cane loss changes simultaneously.

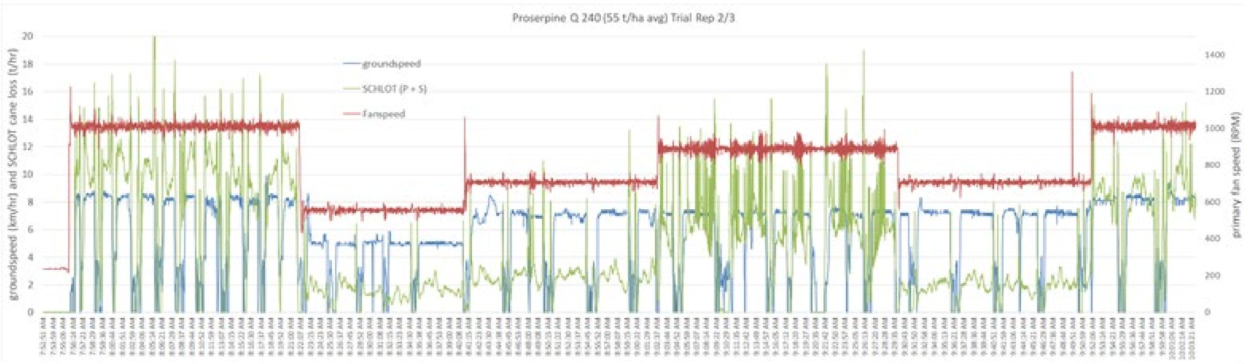


Figure 28. Harvester parameters of replicate two and three - Proserpine trial (Case IH 8800)

Analysis of electronically logged datasets indicates that repeatability of cane loss values derived by SCHLOT Live under typical harvesting conditions is high when correlated with ISLMS estimates. Where variance was observed between estimates, in particular with the Case IH 8800 series harvesters, SCHLOT Live algorithms can be adjusted with the support of the data. In operation, the SCHLOT Live cane loss monitor gave highly useful feedback to the operator and so drove significant changes in harvester operation.

3.1.1.9 Identification of harvest-quality sensors and algorithms (KPI 7.8)

Project 2016/954, Sensors for improved harvesting feedback: a feasibility study

A summary of sensing technologies and their application in agriculture is presented in the project's full technical report, covering GPS guidance, radar and spectroscopic- and optical-based systems.

All sensors considered for use in the harvesting environment must be insensitive to or protected from vibration, moisture and dust. Mostly, systems can be purchased that are rated against these factors as they are designed for use in factory environments. Additionally, advances in technology tend to result in fewer moving parts and improved cooling systems in equipment to facilitate these properties.

Resolution and speed of data collection vary depending on the instrument and will need to be considered in testing. These are strong influencers of price and developers should aim for a 'just enough' mentality. For example, basecutter height control will need continuous measurement to allow adjustments at the rate the harvester operator prefers. However, loss measurements can probably occur at much lower frequencies if required. The LLA Instruments GmbH uniSPEC systems are reported to capture data on a conveyer belt operating up to nearly 11 km/hr. These systems should provide sufficient processing speed to operate as pushbroom systems on a harvester, which is optimally moving at 6 - 8 km/hr. The spectral wavelength regions optimal for specific measurements will change based on the analytic target and the sample presentation. Some instrument manufacturers, such as Ocean Optics, lease or loan a filter camera to allow proof-of-concept evaluations and assist in wavelength selection for multispectral cameras. In the absence of this service, researchers or developers may need to complete their investigative work on expensive, high-quality equipment, with the view of reducing the specifications of the eventual commercial system to only those that are required. This should ensure that the appropriate technology is developed but can be presented in a package that is cost-effective for the industry.

Telemetry and mapping of the data that is generated from the sensors may only be required on some occasions. For example, mapping of ground height for basecutter control is probably not useful once the basecutter has passed over the spot. Alternatively, mapping of sucrose loss may be useful spatial information and could capitalise on existing telemetry systems.

Possible applications for sensing technologies within the harvesting environment are outlined below. Note that literature references have been removed from this report in the interests of brevity but are available in the full report of SRA Project 2016/954 that is available in the SRA e-library.

Toppers

Toppers are responsible for removing the green cabbage from the top of the crop, with the primary motivation of reducing extraneous matter (EM). Tops comprise up to two-thirds of EM in a green crop. Inclusion of tops in the cane supply results in increased extractor losses due to saturation of the cleaning chamber.

If the cane is not cleaned effectively in an attempt to minimise these losses, the mill supply suffers through reduced tonnage and bin weights, low CCS and increased fibre, as well as additional losses due to poor bagasse extraction and molasses exhaustion. Sugar quality is affected through increased ash, colour and reducing sugar levels.

In an erect crop, topping is a relatively simple exercise and 50% of contractors identified that they always top erect cane in the survey. The most common reason not to top cane is due to presentation issues such as lodging (56% of contractors), followed by direction from a grower (16%). Other minor factors included fuel costs, safety (e.g. wind blowing tops back into the windshield) and non-belief in the benefits of topping.

Both the growers and the contractors ranked topping poorly for impact on cane loss, quality and yield; however, contractors identified that it was a parameter that is easy to adjust in the harvester. Neither growers nor contractors felt that sensors to assist in the automation of topping would be useful or valuable to the industry. This was in direct disagreement with industry researchers, who felt that the losses and quality impacts were significant and easily minimised through practice change, with little or no cost to any party.

This disconnect was discussed during the workshops and the issue of crop presentation was frequently cited as the reason for the lack of interest. In general, the appetite for sensing in this area remained low. Most contractors felt their crops were not able to be topped. Instead of automation in this area, further research is required for better feeding or crop presentation mechanisms to allow some level of topping in lodged crops.

Due to the industry feedback, it is suggested that sensors for toppers are not developed at this time, but continued education in the value of topping where possible is critical to reducing the EM levels at the mill.

Feeding system

The feeding system for a sugarcane harvester is a complex mixture of spirals and rollers designed to gather the cane and align it for cutting and transition through the harvester. The basecutters are also considered to be part of the feeding system but will be discussed further in the next section. Research indicates that the feeding system impacts the quality of the cane supply and results in losses in the field of up to 5 t/ha in poor conditions. Key losses are associated with cane stalks left in the field, impacts on machine performance through glut/ starve feeding, and poor ratooning due to compression and stool damage (cane snapping and tear-out). The position of the floating sidewalls and crop-lifter spirals also have an impact on the dirt levels in the cane supply.

Several factors influence the quality and loss impacts of the feeding system and are a mixture of farming practice, poor communication, harvester design issues and social pressures. Crop presentation has a significant impact on how well the cane feeds into the harvester. Highly lodged crops, with poor filling in of the planting furrow and inappropriate mound shape, will result in higher losses and significant damage to the ratooning crop. This is further affected by harvester design which operates with a fundamental mismatch between the speeds and positions of the feeding elements of the machine, ground speed and the crop.

Pickup losses (which included basecutters) were ranked as the number 1 impact on yield by 52% of growers. Poor pickup is a very visible loss for the grower, but there is little data to reflect the true yield loss associated with whole sticks and high stubble left in the field. Similarly, there is an anecdotal recognition that poor basecutter height optimisation causes poor ratoonability and stool rip-out, reducing the yield in subsequent seasons. Approximately 70 % of growers ranked the pickup system highly for impact on losses.

Contractors prioritised crop pick up lower than growers for its impact on losses. However, approximately 46 % ranked it highly for impact on cane quality. The contractors also identified that the feeding systems were relatively easy to control or adjust for improvements to cane quality and reduction in yield.

In the past, engineering adjustments to the crop dividers and rollers have been attempted to improve the feeding and reduce pickup losses, but these are often retrofits by local contractors or on-farm adjustments. Despite this, a large number of survey respondents reported that their harvesters were fitted with trimming saws (71%), adjustable fronts (41%) and hydraulically adjustable knockdown rollers (57%).

From the information in the survey relating to the impact of the feeding system on cane quality and harvest losses and the ease of control for the feeding components, the feeding system was ranked second priority for the development of sensing technology. Further interrogation of this through the survey and workshops identified that sensing and automation around the basecutters was the driving requirement from the industry.

Basecutters

Losses associated with basecutter blades are difficult to quantify, however, losses are believed to exist both immediately, in juice and stalk loss with each cut of the stalk, and long-term, through poor ratooning due to stool tear-out, shattering and biological/disease damage. Biological damage also impacts the sugar content of shattered cane sent to the mill. Damaged and mutilated billets are much more susceptible to the biological breakdown of sucrose because of the greater surface area of the entry points.

During the 1990s, significant research was conducted into the causal factors of cane supply quality and loss associated with basecutter blades. Primarily, they include basecutter RPM, which splits the billets and shatters the stool due to excessive blade contact at low RPM or tearing at high RPM; basecutter feed rate, which causes stepped and partial cutting leading to splitting as well as stool knockdown due to stool-disk contact; basecutter angle; blade thickness, which influences the cutting capacity of the blade and causes cane and stool shattering at high levels; blade shape, which influences the quality of the cut, often shattering or splitting the cane or stool; basecutter depth, which influences the amount of soil in the cane supply and can cause stool damage at deep settings or cane loss and stool shattering when set high; basecutter blade wear, which allows the cane to be pushed aside instead of an efficient cut; and the relationship between the basecutters and the knockdown roller, which influences cane snapping and splitting.

Discussion around operational activities during the focus groups identified that basecutter height adjustment to minimise dirt in cane and losses associated with high cuts are one of the most frequent adjustments a contractor makes in the field. Many survey and focus group participants had trialled basecutter height controllers or had them on their harvesters, but few were in routine use. Typically, the systems were not used due to a belief that they did not work, with long response time being the most frequently cited reason. Despite this, there was a strong appetite for research to continue in this area.

Research on automation of basecutter height has focussed on the development of hydraulic, ultrasonic, acoustic and microwave sensors. Each suffered from the interference of the trash blanket and harsh environment of the cutting zone, although, this was minimised in later trials by mounting sensors on the outside of the crop dividers. Variance in operation on different soil types was also frequently observed. The technology used by Case IH and John Deere systems is proprietary and little specific information is provided. Typically, all of these sensors rely on some kind of field-based calibration where the minimum and maximum levels of the basecutter height are evaluated and the contractor sets a preferred cutting height as zero point.

A key observation regarding the design and implementation of basecutter height controllers is the location of the sensor. The sensors are typically extremely sensitive instruments and cannot withstand the harsh environment in the throat of the machine. Additionally, they cannot impede the material flow through the harvester.

There are several potential options for the development of new sensors to improve the basecutter automation or feedback for height control. The key is to appropriately distinguish between living plant material, dead plant material and soil so that the crop/soil interface can be determined. In particular, the sensor also needs to be able to distinguish between soil level and material on the surface of the ground (e.g. horizontal stalks and trash build-up), as the latter are easily misinterpreted as ‘ground level’, causing the autonomous height systems to raise the basecutters prematurely.

Both spectral and radar technologies will provide solutions for evaluating the crop/ soil interface and the topography or the distance between the row profile and the harvester chassis. Advancement in technology means that some of the techniques that have already been tested may be worth revisiting. Possibly the most variable aspect is the presentation of the sample to the sensor, or rather, what is to be measured and how. Variation in measuring angle can be used to optimise different techniques or improve on existing research. Side-view reflectance imaging of the crop/soil interface is likely to be useful for both types of technique, by allowing clear delineation between the soil bed and the plant. Combined spectral and LiDAR analysis could provide a comprehensive 3D mapping of the row profile, trash layer and base of the stalks. However, the technique is very expensive and the additional resolution provided is not likely to be required.

An alternative orientation for monitoring basecutter height control is the more traditional top-down approach, but using the newer, microwave FCMW radar technologies and GPR technology. The transmission depth of microwave-based radar could be tuned over short-range to provide 3D mapping (vertical and horizontal) of crop layer, trash layer and soil surface and sub-surface layers as each will have a vastly different dielectric permittivity. Microwave radar operates very well in dusty and wet environments and is often considered superior to spectroscopic techniques in this respect. Potentially, this technology could also be used to monitor a reduction in compaction long-term as growers move to the modern farming systems and full GPS guidance.

Feedtrain and chopper system

The feedtrain and chopper system are closely linked apparatus and will be discussed as a single unit. The feedtrain comprises the butt-lifter, which is responsible for guiding the cane into the feedtrain, butt first, following cutting by the basecutters, and the roller train, a series of 9 - 10 additional rollers designed to feed the cane to the chopper box in a single, consistent mat. The chopper system comprises two parallel drums fitted with a fixed number of blades, although the number of blades can vary between machines. The blades experience wear with use and the chopper drums are designed to allow easy blade replacement.

Ultimately, many of the factors that impact quality and loss in the feed train and chopper system are controllable and relatively static: maintaining sharp chopper blades, reducing the number of blades per drum (or possibly, using EHS chopper drums, which anecdotally reduce billet damage), optimising feedtrain roller tip speed to chopper tip speed and maintaining a low pour rate.

There was strong recognition from Growers and Contractors about the considerable losses, quality issues and yield impacts associated with choppers, with it typically ranking as a high priority. However, both Growers and Contractors consistently ranked the feedtrain mid-range for the same questions. This shows a lack of understanding between the fundamental relationship between the feedtrain and the chopper systems. The survey identified there was a moderate appetite for sensors around billet damage and cane loss at the chopper system, but discussions during the focus groups identified that this would not be particularly useful as minimal action can be taken once the harvester setup is optimised.

Sensing options suggested around blade health monitoring was received similarly to that of basecutters. They are fairly easy to check during breaks, but an image-based system would be useful if provided at a low cost.

Due to the industry feedback, it is suggested that sensors for the feedtrain and chopper systems are not developed at this time, but continued education in the value of optimising the harvester set up to improve cane flow and reduce the number of billet cuts will be critical to minimising the significant quality and loss issues caused by these processes.

Primary extractor

It is well accepted in the industry that there is a strong need to redesign the harvester due to deficiencies in the cleaning mechanism. This was raised several times during the survey and focus groups. Approximately 52% of contractors ranked the primary extractor highly for its impact on losses in the harvester and 46% of growers ranked it number 1.

The current cleaning system design uses a large fan, placed above the mat of cane exiting the chopper system, which sucks a stream of air through the cane. Ideally, this uses the dimensionality of the cane and trash particles to extract trash and other extraneous matter (EM) from the system and leave the intact billets behind. This extraction method is high powered and very effective at removing material from the mat. However, increasing pour rates have resulted in very large cane mats and saturation of the cleaning chamber, resulting in the removal of all types of cane material through the extraction system in an attempt to provide clean cane for the mill.

The contractor must balance the EM in the cane supply and acceptable levels of cane loss. Pour rate, the major factor in extractor loss is controllable to some extent to reduce extractor losses and EM in the cane supply. Fan speed is easily controlled in the cab.

Quality indicators are received from some mills that have recently reinvigorated quality sampling in response to high fibre rates across the industry. As feedback is only received regarding one side of the equation, it is not surprising that, during recent trials, extractor losses were regularly measured at 10 - 15% and periodically up to 30%. Cane loss sensors for the primary extractor were ranked as the most valuable sensor and highly useful by contractors in the survey. This was reinforced very strongly during the focus groups, where loss monitors were frequently identified as the most important application for sensors in the harvesting environment.

Many systems have been developed in the past to measure extractor losses. Vibration and acoustic sensors were mounted on the extractor hood or fan and measured impacts from billet hits. While neither of these systems was effective for measuring cane loss, they were suitable measures for mass flow through the extraction hood. Signal to noise discrimination was a key issue for the fan-mounted sensors. Hood mounted sensors suffered because few billets were still sufficiently intact to register as a billet hit.

Several possible sensors could be used to measure extractor losses. To avoid some of the placement issues experienced in past sensor development, a direct measure of sucrose will avoid the need to evaluate whole billets that pass through the extractor fan. Previous research has shown that sucrose levels in trash correlates well with cane loss. Four novel sensors are proposed: handheld direct NIR spectroscopy, transmission NIR spectroscopy, proximal NIR spectroscopy and multi- or hyperspectral imaging.

Near-infrared spectroscopy has been used to measure sucrose (or pol) in sugarcane products for decades. The Australian sugar industry routinely analyses pol in prepared cane for cane payment and factory control by diffuse reflectance. The industry also measures pol in juice by transflectance. The South African sugar industry regularly use benchtop transmission NIR spectroscopy for analysis of sucrose in juice.

Until recently, sample presentation has been a significant issue for measuring agricultural samples by reflectance NIR, as a consistent flat surface was required. The advent of new instrumentation, such as the Light Light Solutions Inc. ReSpect 4πr, avoids this by taking advantage of a large scanning area of approximately 30 cm in diameter and an infinite depth of field, allowing measurement of variable height products from a short distance. This system has been used to measure small concentrations of sugars on cotton bales in the gin, which is a very similar application to the analysis of sugars on trash, as the host substrates are both primarily cellulosic. The ReSpect 4πr is a ruggedised instrument and could be mounted to the chassis of a haulout in the fleet, near the underside of the prime mover. The instrument read head should be pointed directly downward towards the trash blanket left by both the primary and secondary extractors of the harvester. As the haulout moves through the row, the instrument could automatically gather scans at fixed time intervals and provide predictions for short row portions, of around 5 - 10 metres.

These measures could be provided to the contractor and mapped spatially as %sucrose or sucrose loss. The position on the haulout, as opposed to the harvester, will mean there will be gaps in the information to the harvester operator along with a slight delay in feedback, but discussions in the focus groups felt this was preferable if it meant all extractor losses could be captured and not just the primary fan. A single ReSpect 4πr instrument costs approximately AUD120,000, including delivery and landing costs in Australia. The cost would probably limit the installation of the sensor to a single unit per harvester, or possibly per group. However, a cost reduction could probably be negotiated if many systems were going to be purchased across the industry.

A similar application but a lower-cost option would be the use of hand-held direct NIR spectrometers for manual measurement of sucrose on trash. A handheld Viavi MicroNIR ranges in price from AUD8,000 for a standard device to AUD40,000 for a stainless steel process device. This type of handheld system could be value-added with maturity calibrations for cane stalks to facilitate harvest scheduling due to its portable nature and ease of use.

A multi- or hyperspectral sensor may be another alternative for measuring sucrose directly on the trash blanket. As these sensors are effective at scanning over a large distance, the sensor could be mounted to the top of the harvester and look down at an angle to an area where the primary and secondary extractor outputs have settled as a trash blanket. Alternatively, it may be attached to the haulout as previously described. Multi- and hyperspectral sensors naturally sample a large surface area and would be effective at managing the heterogeneity of the trash blanket. Depending on the wavelength requirements, a low-cost multispectral system may be feasible.

Transmission measurements by NIR spectroscopy are typically performed using a cell with a specific pathlength. This forms part of the linear equation against which concentration is measured. The pathlength is typically quite narrow, in the millimetre range, to avoid detector saturation. Cane and juice passing through the extraction hood will be a combination of solids and liquids as a fine vapour or aerosol. This may allow the extractor hood to be used as a transmission cell.

By mounting the source on one internal side of the hood and the detection system directly opposite, also inside the hood, all material that flows out of the extractor hood could be measured and quantified for sucrose and potentially fibre. This type of system does not exist commercially but could be built fairly easily with off-the-shelf components. The most challenging parts would be optimising the focussing lenses for the detector. The likelihood of success for a sensor such as this is challenging to estimate, as is the potential cost. If this were to be developed as a research project, a commercial provider of the technology should be involved to ensure rapid deployment to the industry if successful.

These sensors were discussed during many of the focus groups and were well received. Due to the high priority of this measurement, these should be the first sensors investigated.

Elevator

The elevator is not recognised as having a high impact on cane supply quality and it is difficult to control or adjust. Consequently, it was not surprising that it was consistently ranked as a low priority for sensing and automation opportunities.

Despite not being a cause of cane supply quality issues and cane loss, the elevator is potentially a good site for sensors to monitor EM and general cane supply quality. The elevator has been used frequently in the past as a measurement point for yield, with weigh cells, elevator pressure signals and elevator on/off signals being used. One challenge of using the elevator as a measurement site is the secondary extractor. If the sensor is before the extractor, any changes to the cane supply caused by the secondary extractor would not be captured. However, there is little space after the secondary extractor to mount a sensor that looks at the cane on the flights. Alternatively, a sensor that looks at the falling stream of cane would be possible. Elevator pour rates or yield estimates could be provided by imaging and some novel data analytics.

Improvements in multi- and hyperspectral imaging could allow effective online monitoring of EM in the cane supply by combining textural, shape and spectral analysis of the cane supply. The sensor could either be mounted in the elevator or on the underside of the secondary extractor hood measuring the stream of cane as it is flipped into the bin. If it is measured at the elevator, an assessment of what is lost through the secondary extractor would be required or the output could be used as a guide only.

There was little appetite in the focus groups to monitor cane supply quality with sensors at the mill.

Secondary extractor

The secondary extractor operates under similar principles to the primary extractor. There is little research into cane loss specifically from the secondary extractor, although losses are less than from the primary extractor. Sensing opportunities for cane loss in the secondary extractor are similar to those for the primary extractor.

3.1.4 Activity B5 – Machinery modifications to minimise crop damage

Project 2016/952, Understanding interactions between basecutters and other forward-feed components with the cane stalk, and determining practical strategies to minimise damage as harvester speed increases

3.1.1.10 Results for the dynamic model (KPI 7.10)

Modelling initial qualitative conclusions

The dynamic model that has been developed to describe the interaction between harvester front-end components and the cane stalks is capable of predicting cane damage (as indicated by cane loss) in broad agreement with the results of the field trials undertaken at Childers. The predictions confirm that higher cane loss and therefore damage occur at relatively lower basecutter speeds regardless of forward harvester speed. The modelling predicted that these relatively larger losses are caused by the acoustic forces incurred by the impact of the blade rather than multiple cuts. The significance of the knockdown roller as a cause of cane loss also confirms the findings of the 'pre-cut' field trials although it was predicted to lessen at higher basecutter speeds.

The qualitative modelling also concluded that better understanding of basecutter damage would be gained if the soil and cane models were further improved such that the effects of non-homogenous cane material properties and more realistic soil/ root sub-models were developed.

Simulating Cutting Behaviour by modelling basecutter blade geometry and condition

The Kroes (1996)[3] bending and cutting geometry was adopted to test different blade geometries and blade conditions. Kroes tested experimentally the basecutter incline (the angle achieved with the ground by the basecutters in the harvester direction). The angles tested by Kroes were 0 degrees (blade perpendicular to stalk during the impact), 7.5, 15 and 22.5 degrees (blade facing downwards). The experimental field trials carried out in Stream 1 of this project have shown that if the stalk is not bent at all, there is significantly less damage to the stalk during cutting. That means that, if the stalk was bent less while still being able to feed, there would most likely be less damage at the cutting site. The mechanism is further complicated because some stalks will be impacted in the compression side, while others will be impacted on the tension side, and some on the side where the compression and tension are relatively balanced.

The basecutter blade geometry and condition were modelled. As it is likely that the basecutter blades would soon lose a sharp edge, two geometries were modelled:

1) A 5 mm blade thickness with a 1 mm blunt edge.
2) A 3 mm blade thickness with a 0.5 mm blunt edge (for example, a higher quality slower wearing blade material).

The approach taken was to model the combinations shown in Table 15. The performance was judged by the measured cut force, and more importantly, the predicted damage to the stalk. In this case, the number of removed slices was counted by visual inspection of the predictions. The predictions are given in the table and an example for the first scenario in Figure 29.

[3] Kroes, S., 1996. The cutting of sugarcane. PhD Thesis., Toowoomba: University of Southern Qld.

Table 15. Modelled blade geometries and predicted results

BLADE INCLINE (°)	BLADE THICKNESS (MM)	BLADE EDGE (MM)	MAXIMUM BENDING STRESS BEFORE CUT (MPA)	MAXIMUM CUT FORCE (N)	NO. OF REMOVED SLICES
0	5	1	17	840	3
0	3	0.5	19	1180	2
15	5	1	23	1150	8
15	3	0.5	19	1210	4
22.5	5	1	19	990	10
22.5	3	0.5	19	980	9

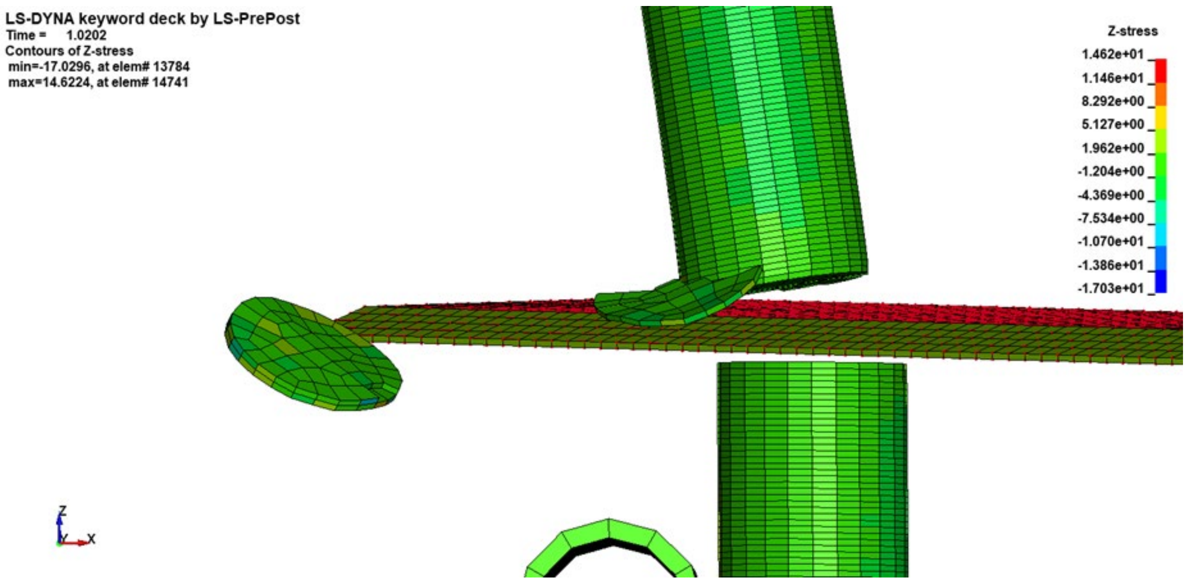


Figure 29. Predicted cut for blade incline 0°, blade thickness 5 mm, blade edge 1.0 mm

Inspection of the table shows that the 3 mm thick blade with a sharper edge of 0.5 mm was predicted to consistently cause less damage to the stalk than a blade with edge of 1 mm. This is expected: a larger impact area of the blade should cause more damage. It is also consistent with the conclusion by Kroes, that “a blunt blade increased the cutting force and energy, hence, increased the damage”. However, it is interesting to note that the predictions did not show a consistent reduction in cutting force for the thinner, sharper blade. This may be because the prediction of the cutting force requires a finer mesh for both the stalk and the blade.

The table also shows that a smaller incline angle is consistently predicted to cause less damage to the cane. Again, this would be expected: as the angle increases, the area that the stalk is impacted by increases. However, this prediction is contrary to the conclusions of the experimental results by Kroes, who stated that “increasing the incline, however, did reduce the overall damage for both varieties”. Kroes also stated that “the incline angle did not appear to affect damage to the stalks of the Q123 varieties. The minor splitting in both the stool and stalk of the vertical 82C-954 samples was reduced to major edge damage at 15° and then minor edge at 22.5”. The results by Kroes suggest that:

1) The stalk damage due to the basecutter blade incline is cane variety dependent, and

2) The current predicted failure mechanism of the stalk, when impacted by the blade (the removal of slices), may not be correct for some cane varieties.

It is noted that, during the improvement of bending predictions, there was a combination of values of material parameters that resulted in the prediction of the axial splitting of the cane stalk during bending failure. That predicted failure mechanism is shown in Figure 30. This behaviour was predicted when the values of parallel shear strength and perpendicular shear strength were changed to 5.0 MPa and 2.0 MPa while retaining other values. Follow up and adjustment of the magnitudes of these parameters while retaining the ratio may result in an improved prediction of the cutting mechanism for some cane varieties, while retaining an adequate prediction of bending. This is reinforced by observations made by Kroes of splits forming in the stalk perpendicular to the direction of impact of the basecutter blade.

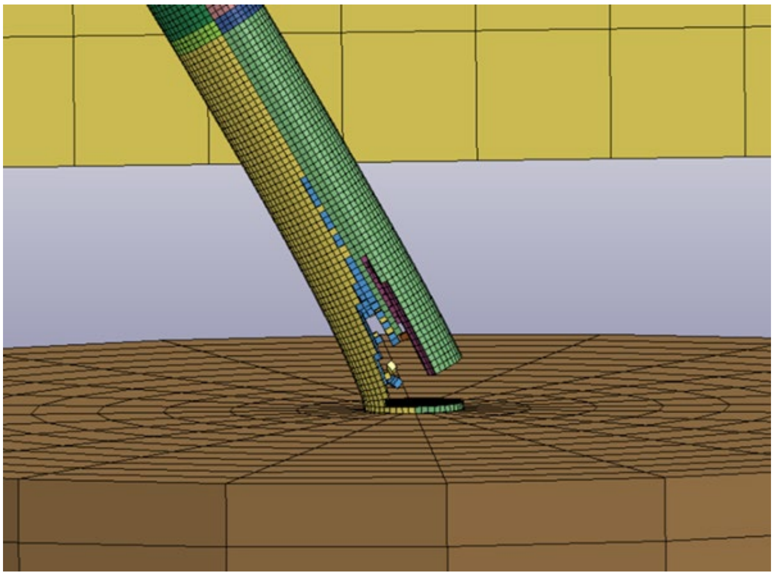


Figure 30. Predicted axial splitting of the cane stalk during bending failure

Simulation of a typical current harvester geometry (Model A)

The series below (Figs. 31-38) shows the modelled progress of a stalk of cane from the first contact with the harvester until the stalk enters the feed train.

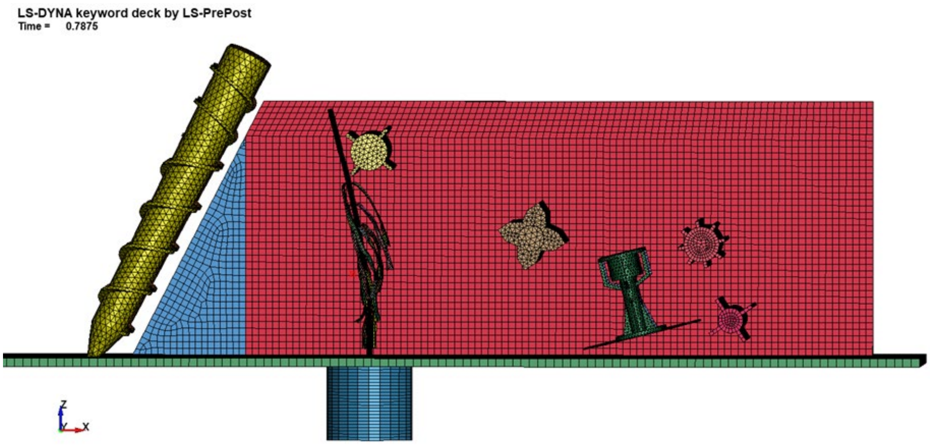


Figure 31. Model A results: stalk contacting knockdown roller

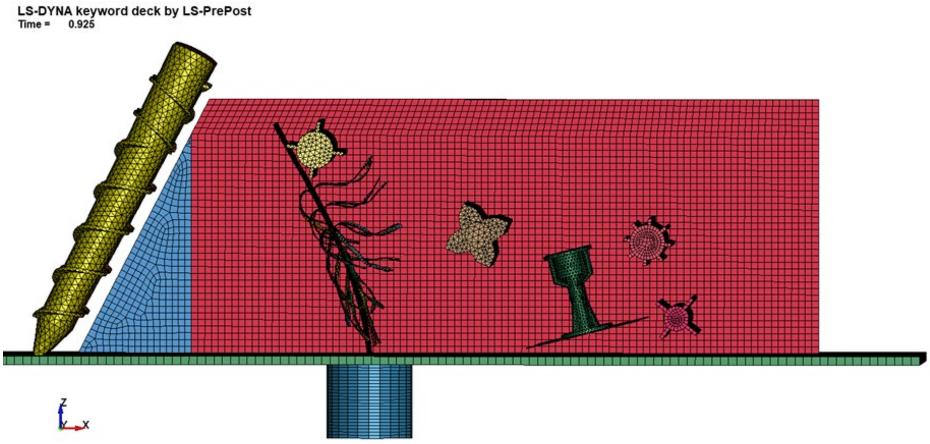


Figure 32. Model A result: stalk being pushed over by a knockdown roller

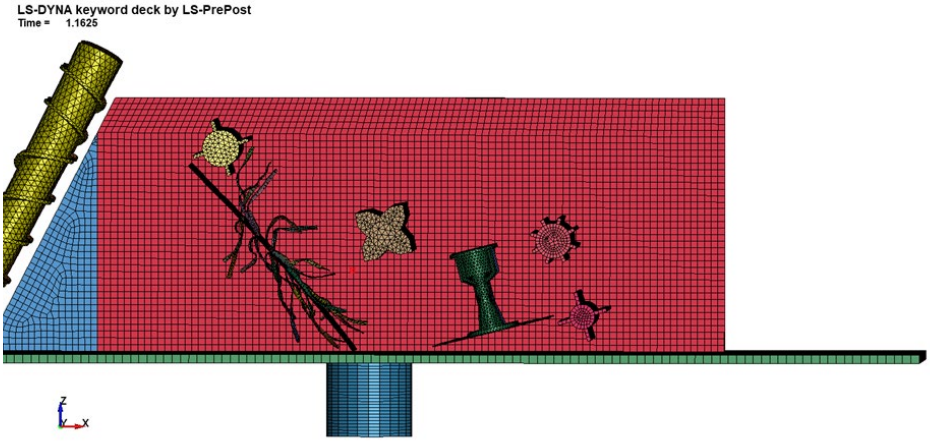


Figure 33. Model A result: stalk being broken by knockdown roller

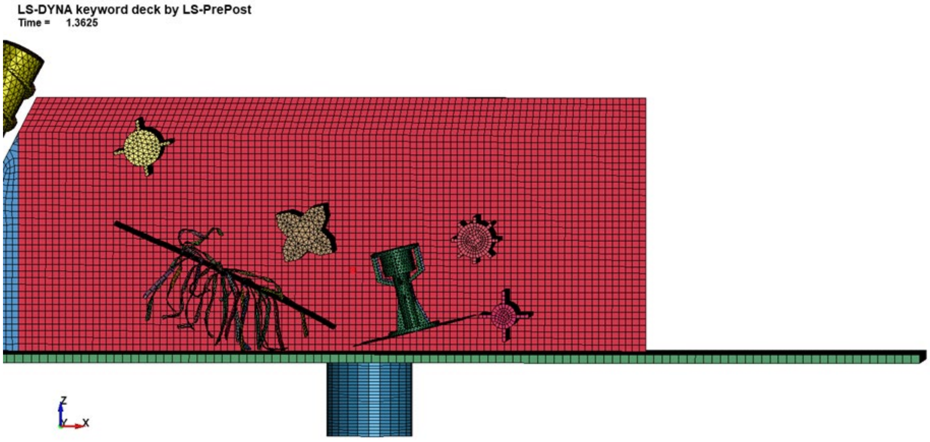


Figure 34. Model A result: stalk falling

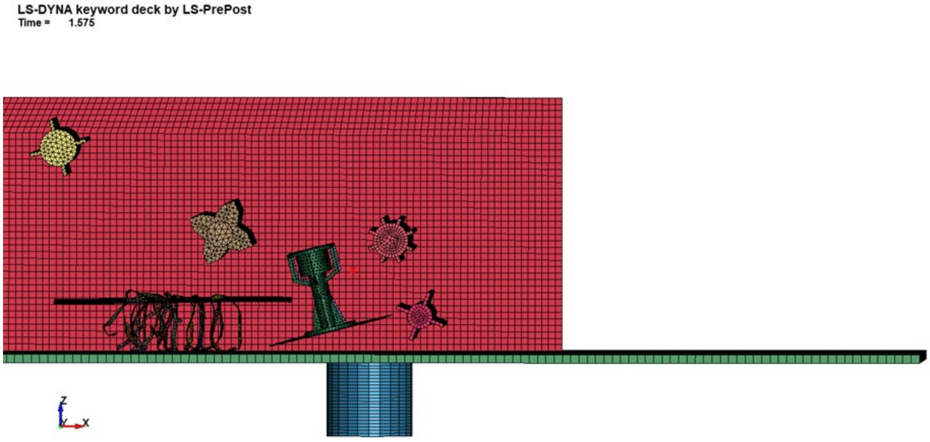


Figure 35. Model A result: stalk falling and rotating

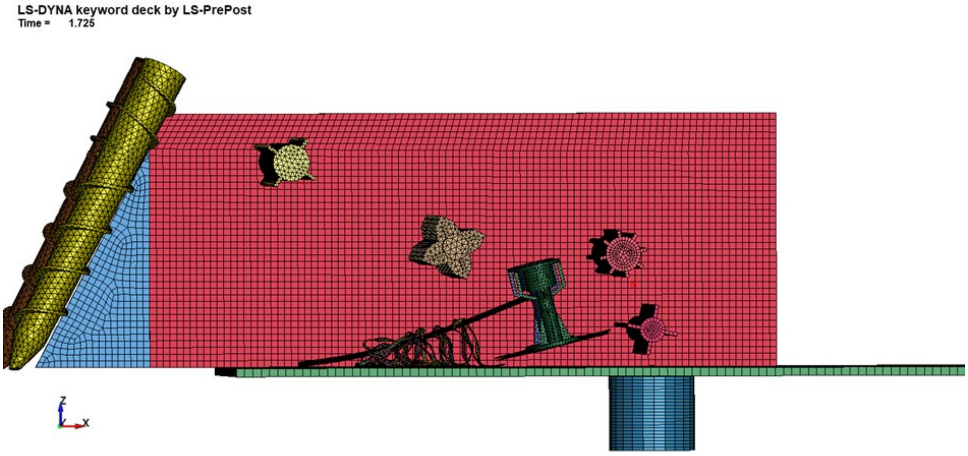


Figure 36. Model A result: stalk contacting top frame of basecutter frame

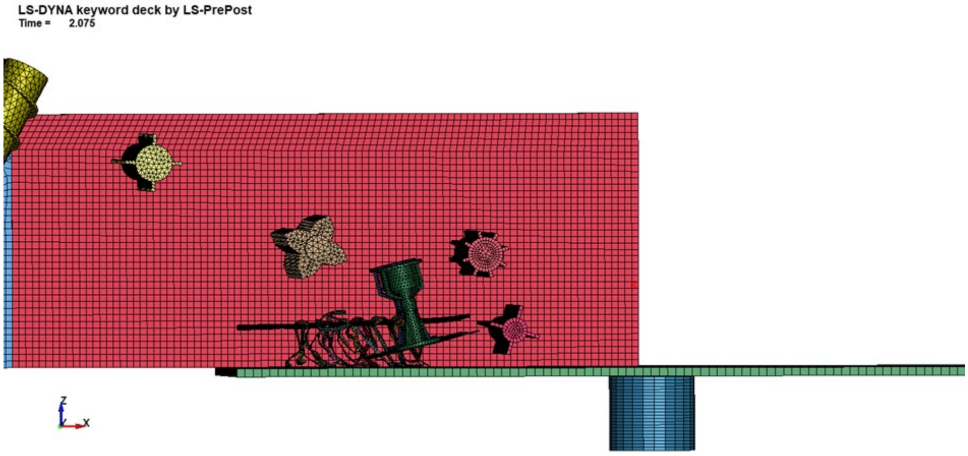


Figure 37. Model A result: stalk moving through basecutter opening

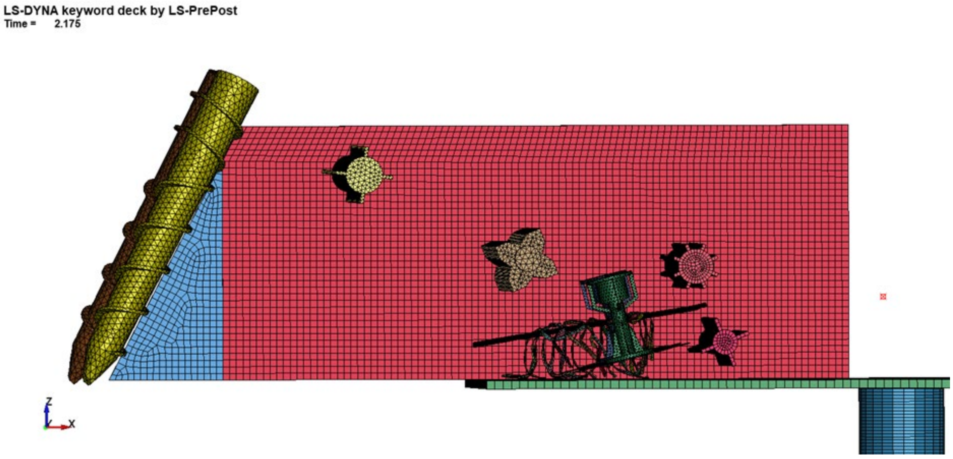


Figure 38. Model A result: stalk reaching the gap between butt lifter and top feed roller

The predictions look realistic and a good start. The spirals take little part in the simulation as the stalk and its leaves are in the middle between the spirals and there is little contact. The cane stalk is pushed, bent and broken at its base with the ground by the knockdown roller, as noted by Kroes and observed in Stream 1 field trials. The momentum of the cane stalk and the forward movement of the harvester allows the cane stalk to orientate with the basecutter opening and be fed through, reaching the butt lifter roller and the top feed roller. The finned roller is predicted to take little part in the feeding of this single stalk and leaves. In reality, the cane stalk and leaves will be supported and held back by the other stalks and leaves around it as the harvester moves through the location, and the stalk won't move horizontally as much.

The current simulation shows that there is a significant horizontal distance between the spirals and the knockdown roller, and particularly between the knockdown roller and the finned roller, which seems to be significantly underutilized. The Model A results provide a guide as to the modifications that could be carried out to the geometry.

Simulation of spiral geometries with 45° and 63.5° sideways angle with the ground

The prediction of the stalks and leaves for the five-stalk model traversing the spirals was carried out for two spiral geometries, 45° (Model C) and 63.5° (Model A) sideways angle with the ground. The sequence of Figures 39-48 shows the stalk and leaves partway through the spirals and the predicted forces on the spirals for the 45° and 63.5° simulations. The predicted forces are for three directions:

1) The harvester forward movement direction
2) Force parallel to harvester width
3) Force in the vertical direction

The forces are difficult to interpret without comparison to other harvester speeds and spiral speeds. Overall, the 45° spirals are predicted to provide higher positive forces in the harvester direction and, interestingly, in the vertical direction. If it is assumed that higher positive forces will feed the cane better into the harvester and also lift any cane lying down, then the 45° spirals' angle with the ground is predicted to provide better performance. Interestingly, both simulations show that the stalks and leaves in contact with the spirals are held back compared to the inner stalks, implying that the spirals are rotating too slowly for the current speed of the harvester.

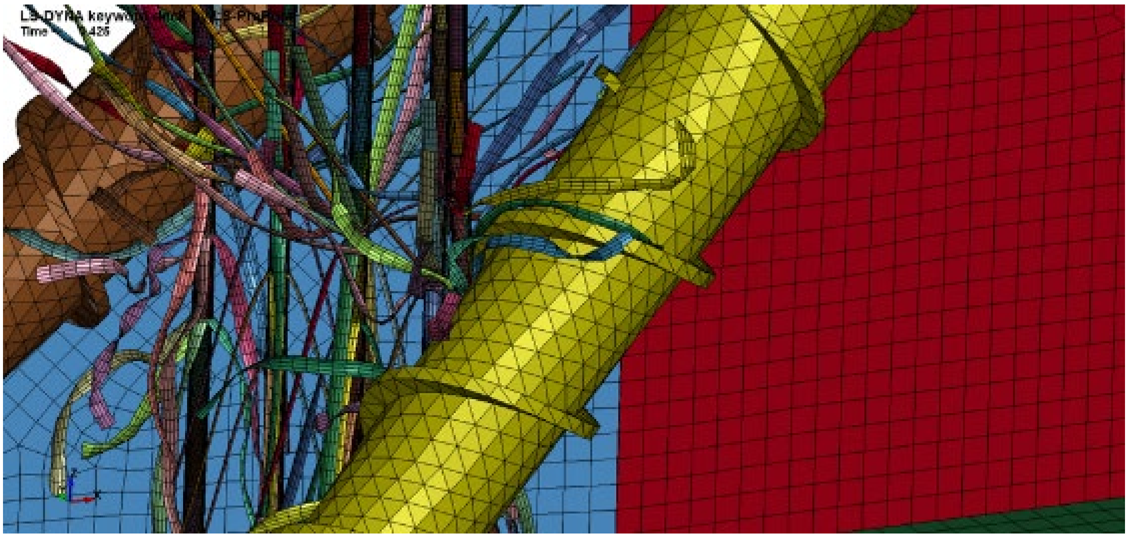


Figure 39. Model C - sideways spiral angle with ground of 45°– stalk and leaves along mid spirals

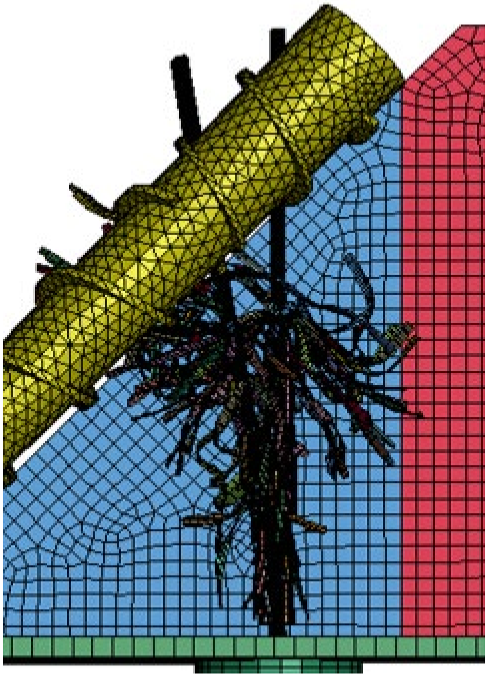


Figure 40. Model C- sideways spiral angle with ground of 45°– stalk and leaves passed spirals

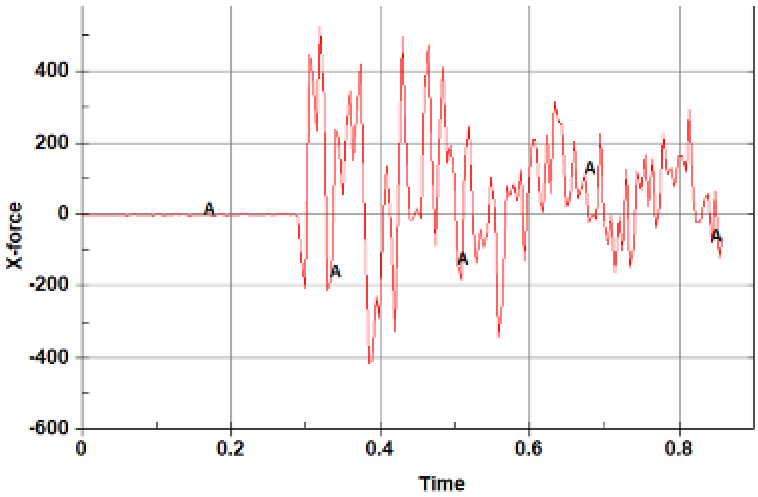


Figure 41. Model C- sideways spiral angle with ground of 45°– force (N) in harvester direction

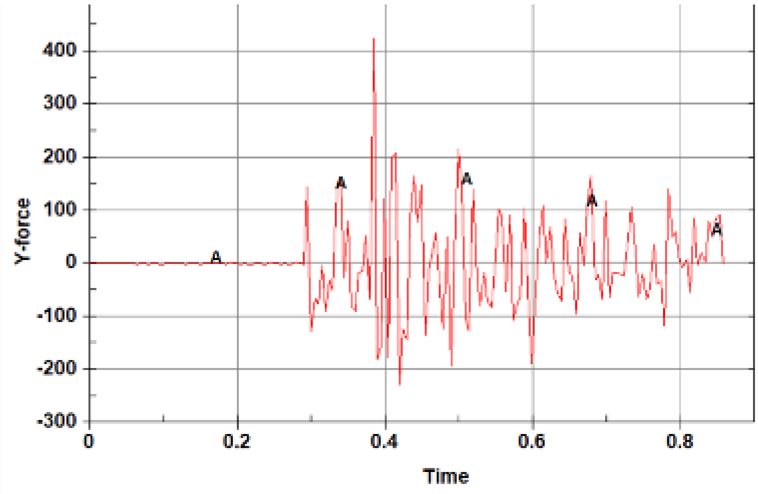


Figure 42. Model C – sideways spiral angle with ground of 45° - force (N) parallel to harvester width

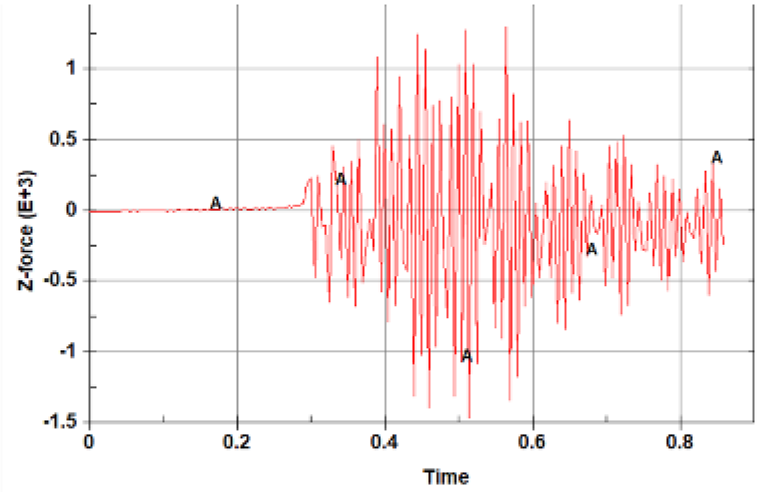


Figure 43. Model C – sideways spiral angle with ground of 45° - force (N) in the vertical direction

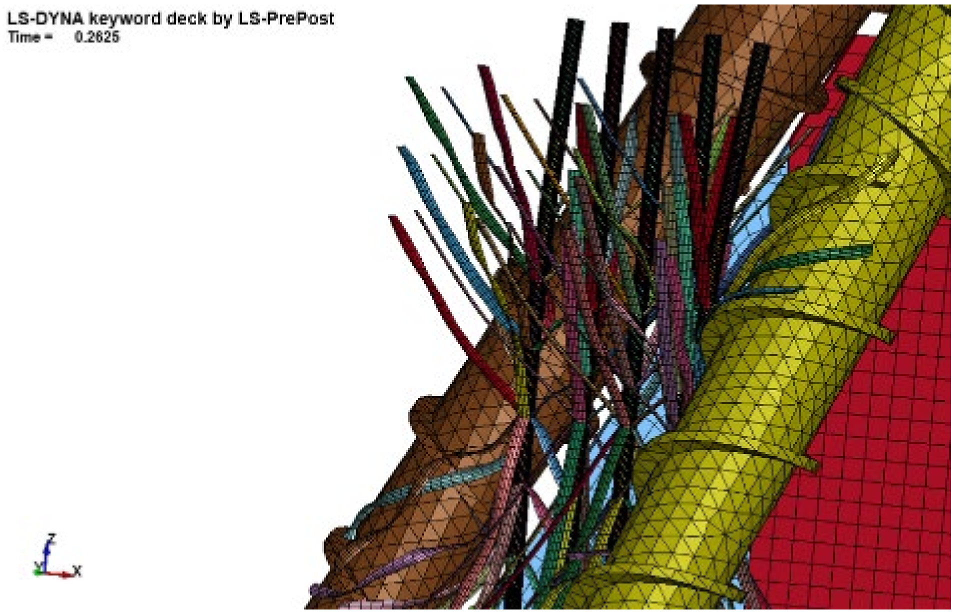


Figure 44. Model A - sideways spiral angle with ground of 63.5°– stalk and leaves along mid spirals

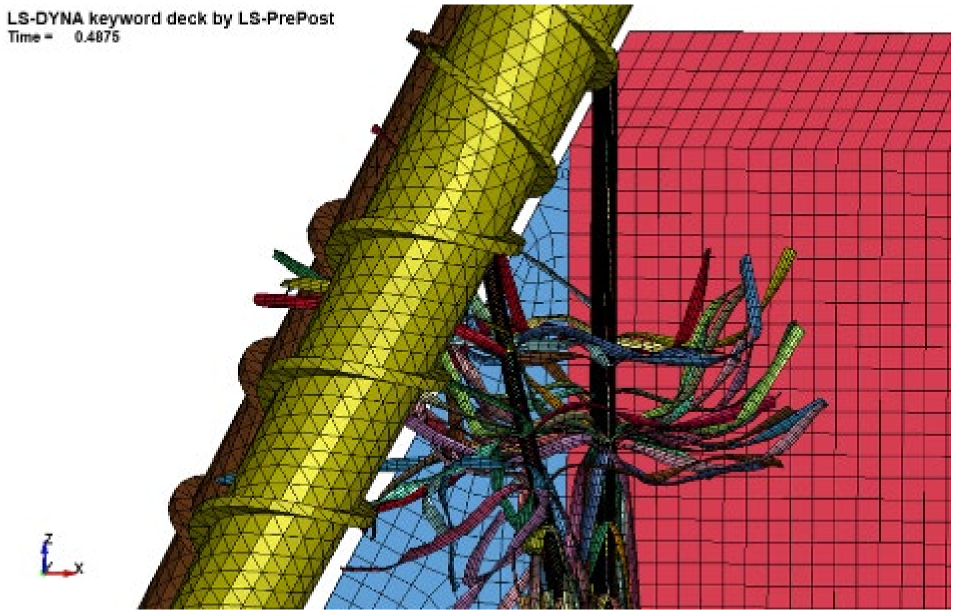


Figure 45. Model A - sideways spiral angle with ground of 63.5°– stalk and leaves passed spirals

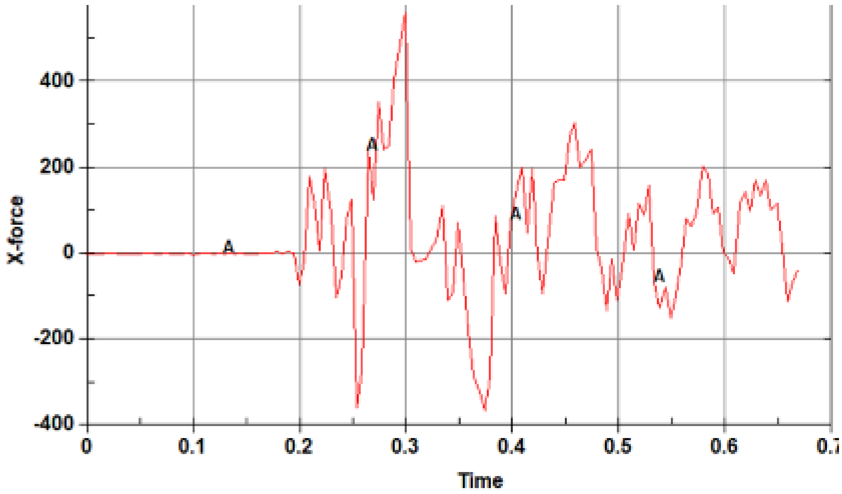


Figure 46. Model A - sideways spiral angle with ground of 63.5°– force (N) in harvester direction

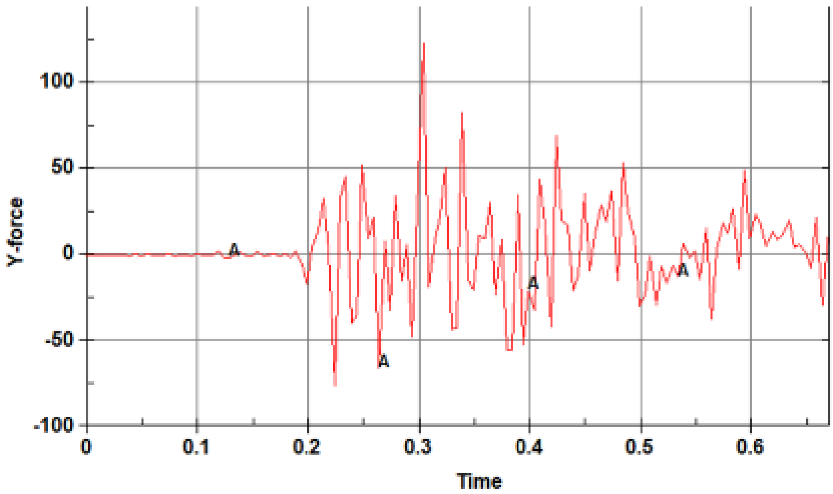


Figure 47. Model A – sideways spiral angle with ground of 63.5° - force (N) parallel to harvester width

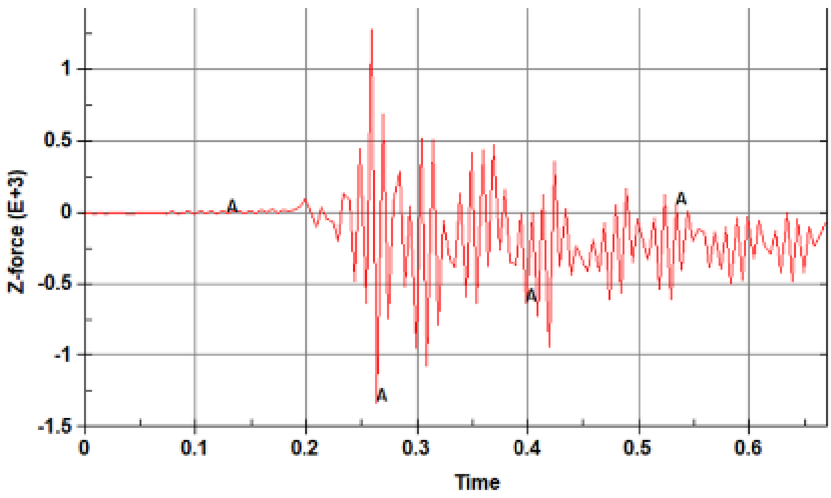


Figure 48. Model A – sideways spiral angle with ground of 63.5° - force (N) in the vertical direction

Simulation of single stalk with harvester sideways spiral angle with the ground changed from 63.5° degrees to 45°, move the knockdown roller horizontally towards the finned roller, and shorten the harvester in the horizontal direction (Model F)

Predictions for the simulation with a single stalk and geometry for Model F, which has a spiral angle with the ground at 45°, the knockdown roller moved horizontally towards the finned roller, and the harvester shortened in the horizontal direction, are described in this section.

The sequence of Figures 49-55 shows the modelled progress of a stalk of cane from the first contact with the harvester until the stalk enters the feed train.

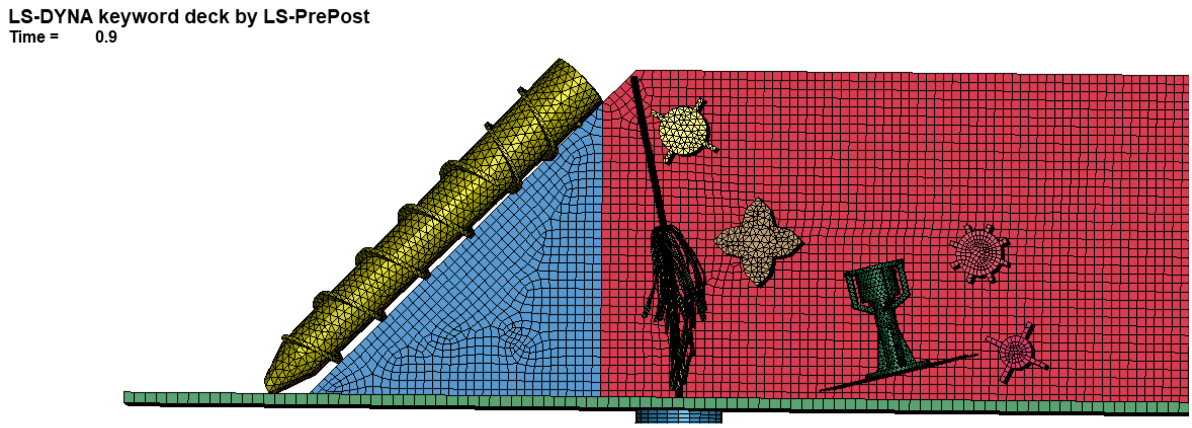


Figure 49. Model F: stalk contacting knockdown roller

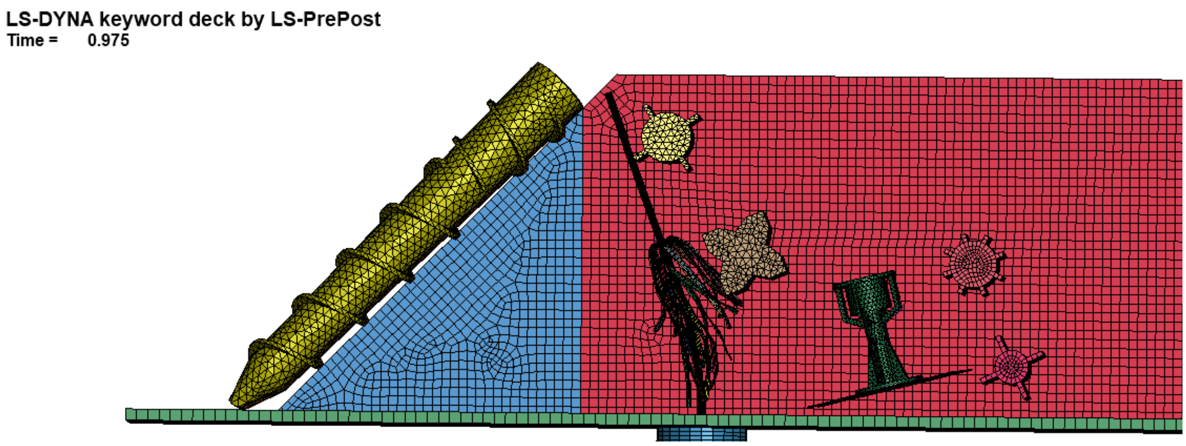


Figure 50. Model F: stalk being pushed over by knockdown roller, leaves contacting finned roller

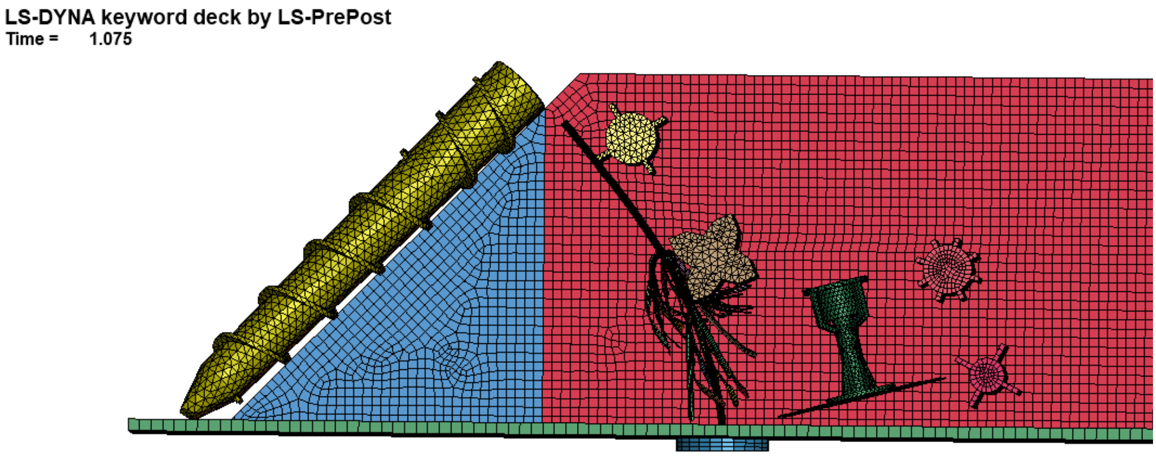


Figure 51. Model F: stalk being broken at the bottom by knockdown roller and finned roller

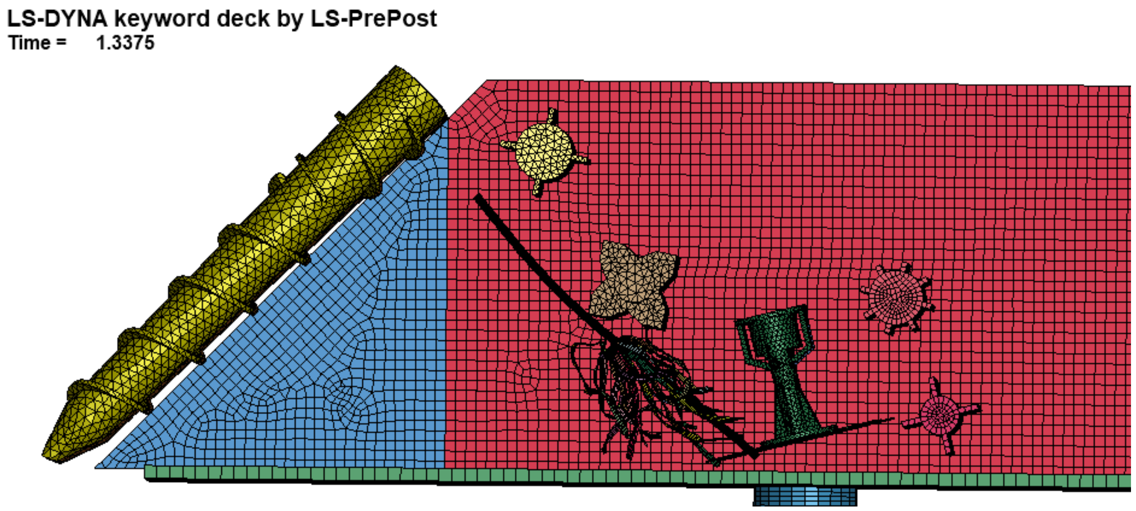


Figure 52. Model F: stalk falling and rotating, still in contact with finned roller, with bottom part of stalk entering basecutter throat area

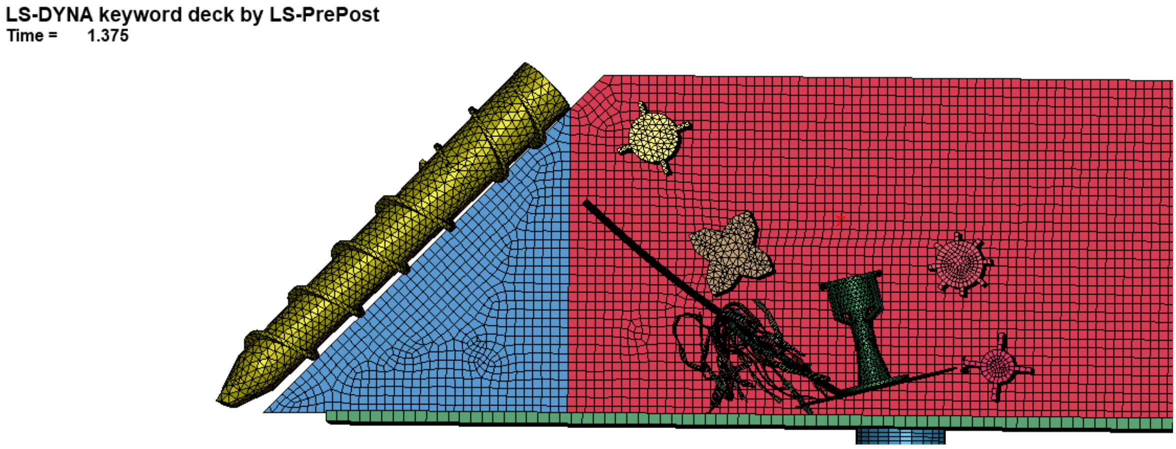


Figure 53. Model F: stalk continuing to fall and rotate, feeding through basecutter throat area, with a small part of the bottom stalk being cut off and bouncing just underneath the butt lifter roller

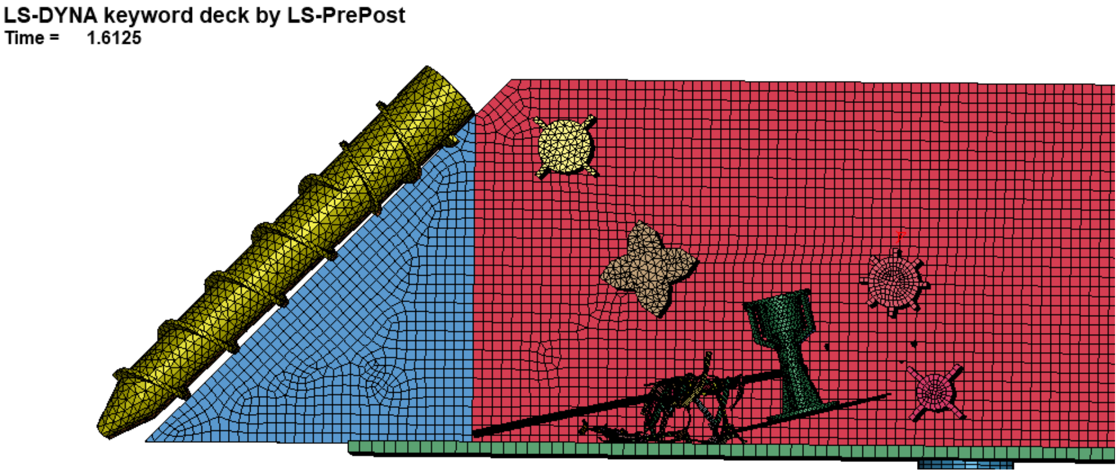


Figure 54. Model F: stalk continuing to fall and rotate, feeding through basecutter throat area

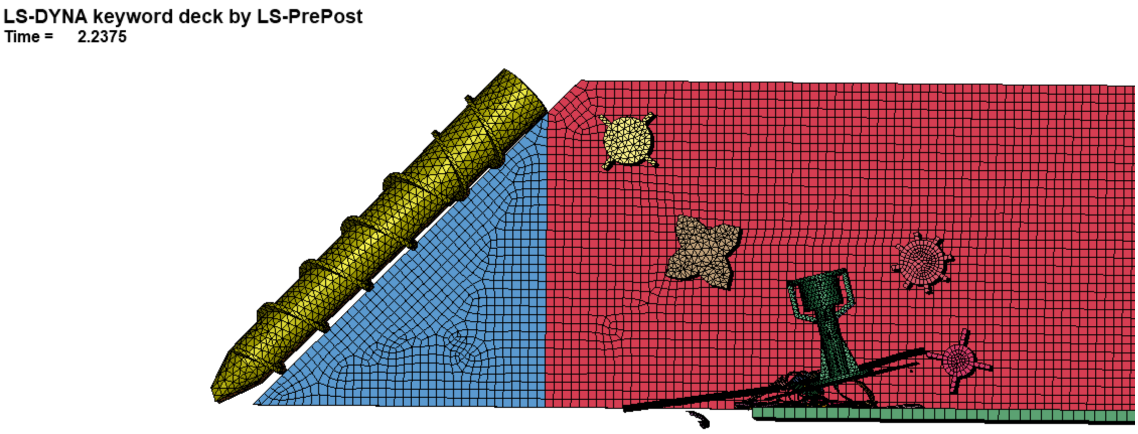


Figure 55. Model F: stalk continuing to fall and rotate, feeding through basecutter throat area and contacting butt lifter roller

It is shown that, compared with the starting geometry (geometry model A), the geometry of model F allows the knockdown roller and the finned roller to work more interactively in feeding the stalk through into the basecutter area. The reduced length of the harvester in this location should reduce the friction of the cane stalks and leaves on the sidewalls as the contact area is reduced. The cane stalk is still predicted to break at the bottom before the basecutter blades reach it, therefore there is further scope to improve the geometry and operating parameters for the knockdown roller, finned roller and basecutters to achieve bending without breaking, cutting of the stalks by the basecutter blades and subsequent feeding through the basecutter's throat. It is also concluded that the harvester described in model A can be shortened by approximately 1.2 m.

Conclusions

The modelling component of the project has introduced the LS-DYNA structural analysis software into the Australian sugar industry in a first application. The software has capabilities not seen before in other structural software, and in a single well-integrated package. In particular, it has the ability to model in real-time a relatively fast process in which there are large strains, damage, failure, contact and friction, in geometrically complicated moving and rotating equipment. This capability tool can be used to combine modifications and predict likely results, minimising the need for physical manufacture of prototypes. The modelling to date has confirmed significant deficiencies in the feeding geometry of a current harvester design and described and modelled improvements.

3.1.1.11 Report on all harvester modifications and field trials (KPI 7.11)

The first field trial of harvester modifications to match the speeds of front end components and ground speed, conducted at Childers in 2016, was undertaken primarily to refine protocols and test the machine, however, the site was maintained as part of the trial program. The results indicated that, while very significant damage was suffered by the cane stool during the harvesting operation, the differences associated with different harvesting speeds and component speeds were relatively small. The size of the crop being harvested appeared to be a very significant factor in determining damage. The variety of the crop being harvested appeared to be very significant factors in determining damage, as was the degree of moisture stress of the crop at harvest.

Table 16. Treatment details of machinery modification trials, 2017-2019

TRIAL	HARVEST YEAR	TREATMENTS (GROUND SPEED KM/H X BASECUTTER RPM)	NO-KNOCKDOWN SUBPLOTS?
BZ Farms, Condong	2017	4.5 x 500, 8.0 x 850, 4.5 x 620, 8.0 x 620	No
	2018	5 x 500, 8.6 x 850, 5 x 620, 8.0 x 620	Yes
	2019	6.0 x 620	Hand Harvested
Bouchards Rd, Childers	2017	5 x 500, 8.5 x 850, 5 x 620, 8.5 x 620	No
	2018	4.5 x 450, 8.5 x 850, 4.5 x 850, 8.5 x 450	Yes
	2019	6.5 x 850	Hand Harvested
Colonial Drive, Condong	2017	5 x 500, 8 x 800, 5 x 620, 8 x 620	No
	2018	5 x 500, 8 x 800, 5 x 620, 8 x 620	Yes
	2019	6.5 x 620	Hand Harvested
Plaths Rd, Childers	2017	5 x 420, 8.5 x 820, 5 x 820, 8.5 x 420	No
	2018	5 x 500, 9 x 820, 5 x 820, 9 x 500	Yes
	2019	7 x 820	Hand Harvested
Mona Park, Burdekin	2017	5.5 x 500, 7.5 x 850, 5.5 x 620, 7.5 x 620	No
	2018	(6 or 10 km/h x deep or shallow basecutter setting)*	Yes
	2019	8.0 x 620	Hand Harvested

* Due to issues with the hydraulic configuration on the Case harvester, the equipment to link component speed to groundspeed was removed and matched treatments replaced with shallow or deeper (more typical) basecutter depth settings

Subsequent trials used treatments as in Table 16. Changes to the 2017 treatments were primarily to better match field/crop conditions. In the 2018 harvest treatments at Childers, the second and third treatments compared “inverse” component speed/forward speed relationships, to assess if this increased the magnitude of effects.

Example of trial data: Bouchards Road, Childers

Detailed results of all trials are presented in the final report for SRA Project 2016/952. Results are presented here only for the sequence of trials conducted at Bouchards Road, Childers. These were in a crop of Q240 growing in a single row configuration at 1.83 m row spacing. The harvester used was the JD 3520 operated by Central Harvesting, in standard configuration except for modifications to achieve the variable basecutter /forward-feed component RPM and aftermarket chopper drums. The crop was harvested green with an average yield in 2017 of 108 t/ha.

The levels of billet damage observed in 2017 were consistent with expectations (Fig. 56). Billet mutilation appeared highest in the high speed/high basecutter speed treatment, but differences were not statistically significant.

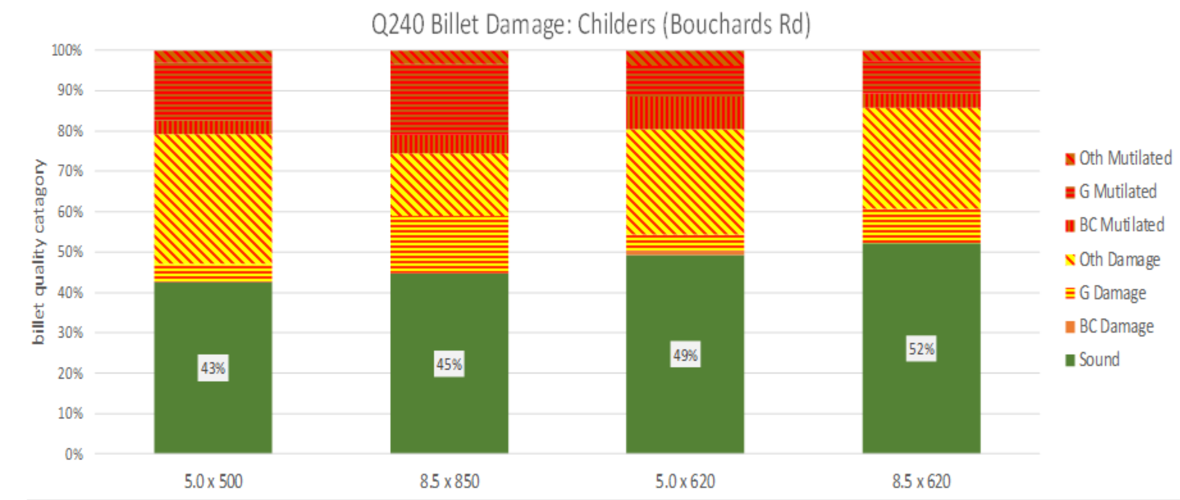


Figure 56. Billet quality for different treatments at Bouchards Rd trial (ground speed in km/h x basecutter rotational speed in rpm)

Stool damage was assessed after harvest. The average number of cut stalks which could be assessed was higher for the two matched treatments and lower for the ‘standard’ high and low harvesting speed settings (Fig. 57). Significantly, the low harvesting speed had 50% more undamaged cut stalks than the other treatments. The lowest percentage of damage of visible stumps was also associated with the low harvesting speed with linked component speeds (Fig. 58).

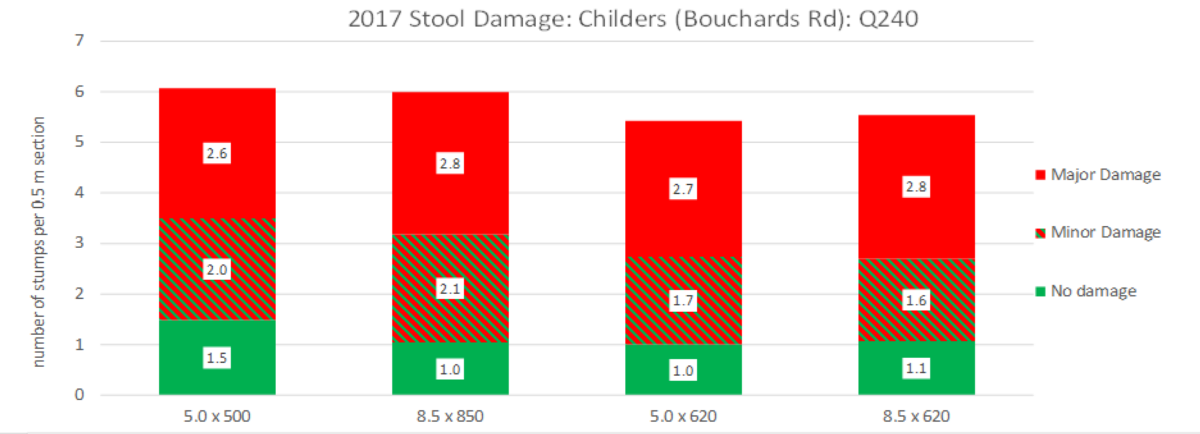


Figure 57. Stool damage assessment after the 2017 harvest at Bouchards Rd (ground speed in km/h x basecutter rotational speed in rpm)

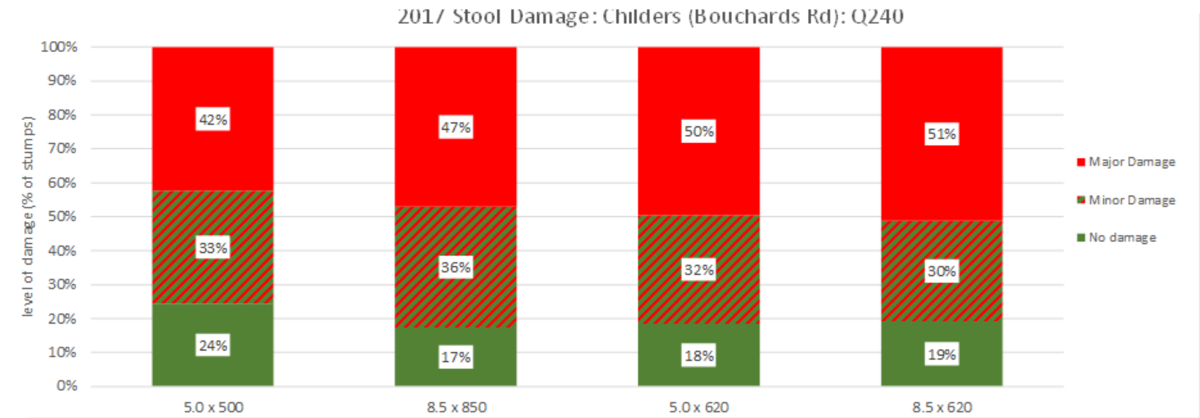


Figure 58. Stool damage assessment expressed as a percentage (ground speed in km/h x basecutter rotational speed in rpm)

The shoot count was undertaken 45 days after harvest. Significant leaf damage to the emerging plants was noted across the trial, presumably from armyworms. The post-harvest plant count and the pre-harvest (2018) millable stalk count both indicate some potential benefit in the matched component speeds (Fig. 59), however, the effect was not statistically significant.

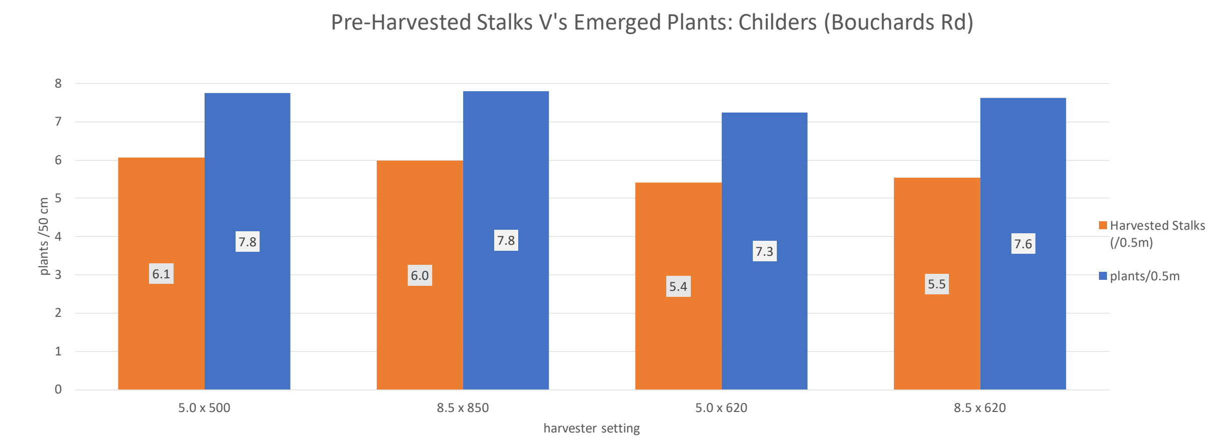


Figure 59. Emerged shoot count and pre-harvest stalk count at Bouchards Road (ground speed in km/h x basecutter rotational speed in rpm)

At the subsequent 2018 harvest, yield of Treatment 1, matched low ground speed and component speed, was significantly greater than the other treatments (Fig. 60, P=0.0054).

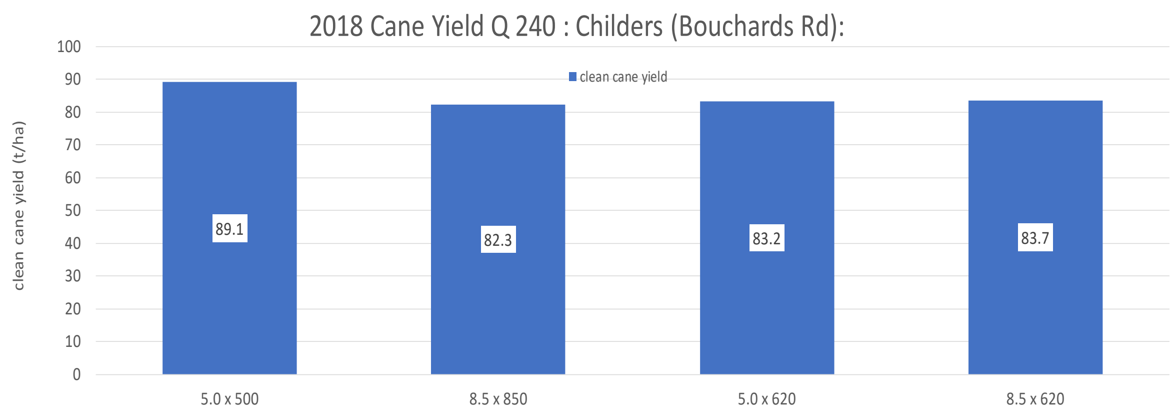


Figure 60. Cane yield at 2018 harvest at Bouchards Road (ground speed in km/h x basecutter rotational speed in rpm), 2017 treatments

The general trend was that, with the low groundspeed and matched front-end speed, the lowest stool damage (the highest proportion of undamaged stalks) and highest pre-harvest millable stalk count were associated with the highest yield. This also followed through to sugar yield (Fig. 61).

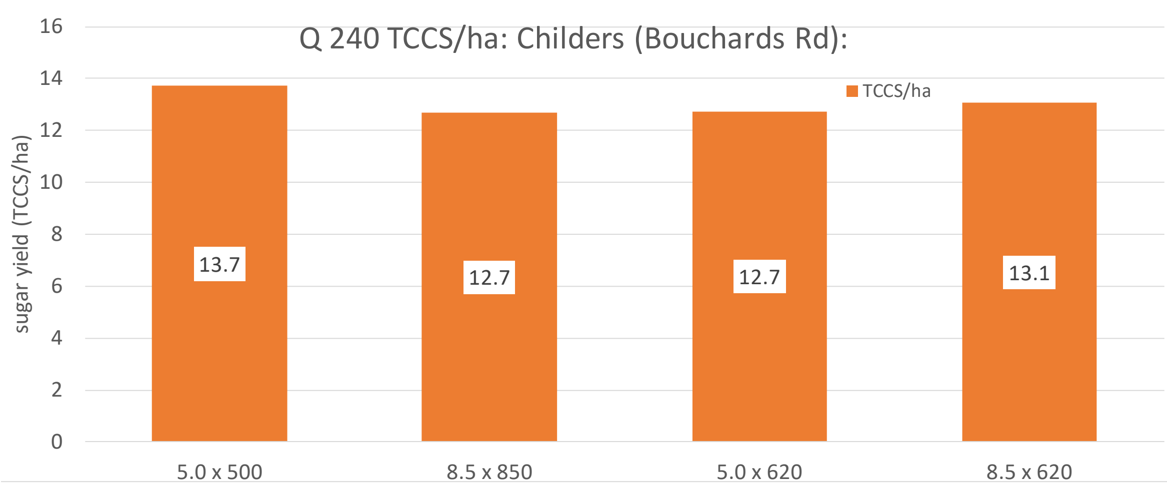


Figure 61. Sugar yield for the different treatments in the 2018 harvest, Bouchards Rd (ground speed in km/h x basecutter rotational speed in rpm), 2017 treatments

Based on the observations of the 2017 harvest data, damage to the cane stool associated with all harvest treatments was very high, with typically the post-harvest assessments indicating fewer than 20% of the stalks from the cane stool having minimal damage and with severe damage being observed on over 50% of stalks in some instances. Three clear issues needed to be addressed:

- The high levels of stool damage were sustained across all treatments
- The limited impact of the different harvester setup and operation options
- The relatively poor correlation between typical measurements relating to stool damage and crop response

Hence, to address these issues, a decision was made to introduce new treatments to separate the damage associated with gathering and knockdown from basecutting damage, as noted in Methodology.

The stool damage assessment at the Bouchards Rd trial site after the 2018 harvest is presented in Figure 62. In the standard treatments, the percentage of undamaged stool stumps averaged only 12%, as against 25% with no-knockdown. The level of major damage was also substantially lower in the no-knockdown treatments.

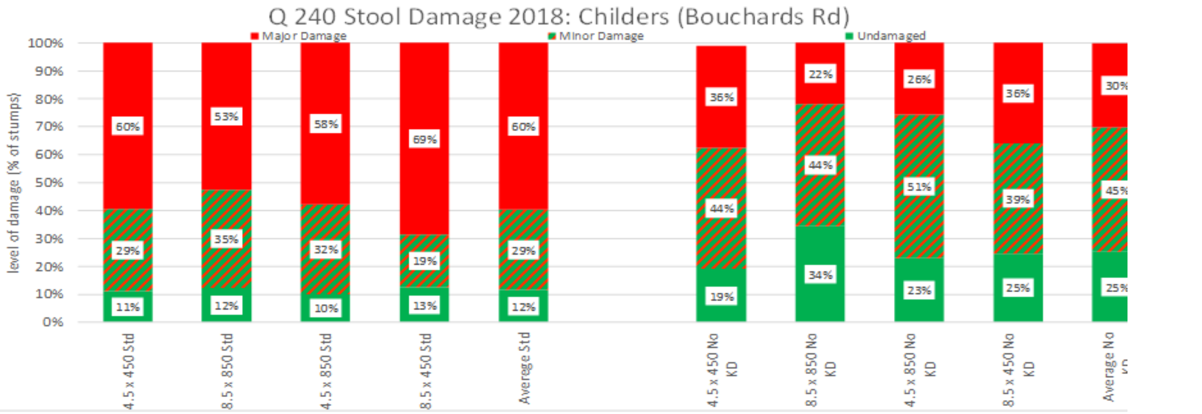


Figure 62. Stool damage for the Bouchards Rd trial (ground speed in km/h x basecutter rotational speed in rpm, with or without knockdown effect)

Emerged plant counts 67 days after harvest were lower in the no-knockdown treatments, however, assessed plant height was higher (Fig. 63).

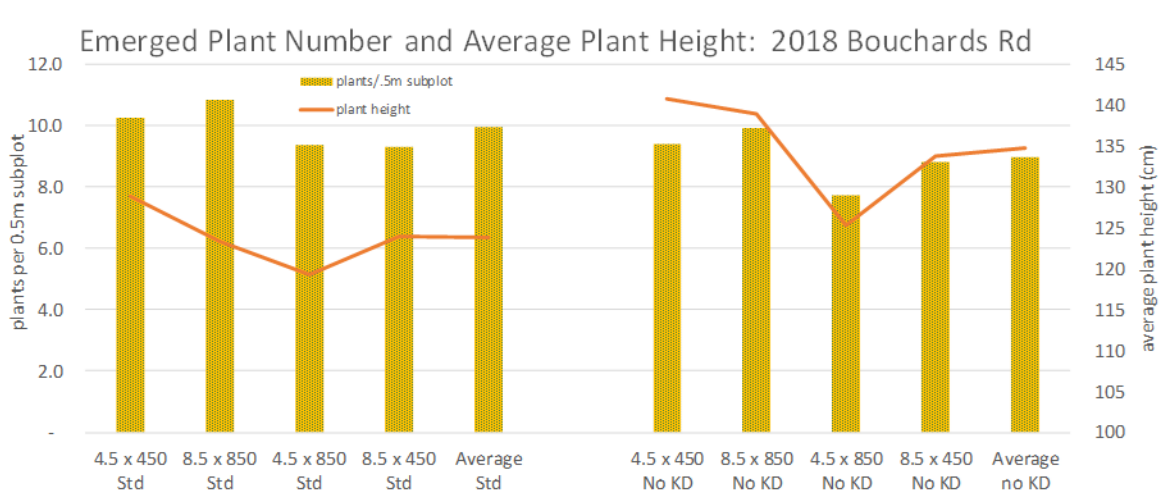


Figure 63. Emerged plant number and average plant height for the Bouchards Rd trial (ground speed in km/h x basecutter rotational speed in rpm, with or without knockdown effect)

Based on the relationships gathered between plant weight and height, the biomass for the different treatments was derived. This indicated greater biomass in the no-knockdown treatments, despite the lower plant numbers (Fig. 64).

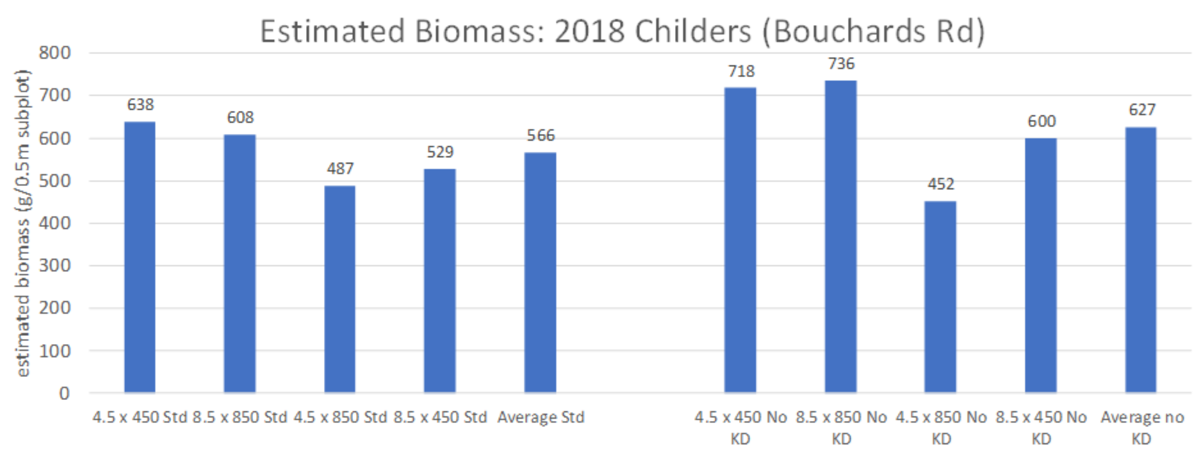


Figure 64. Derived biomass 67 days after harvest for the different treatments (ground speed in km/h x basecutter rotational speed in rpm, with or without knockdown effect)

The trial was harvested on 31/9/2019, with the subplots being manually harvested. The average yield of the standard treatments was 97 t/ha and the no-knockdown treatments averaged 108 t/ha, an increase of 11% (Fig. 65). Of interest also was that the highest yielding treatments were associated with lower component speeds.

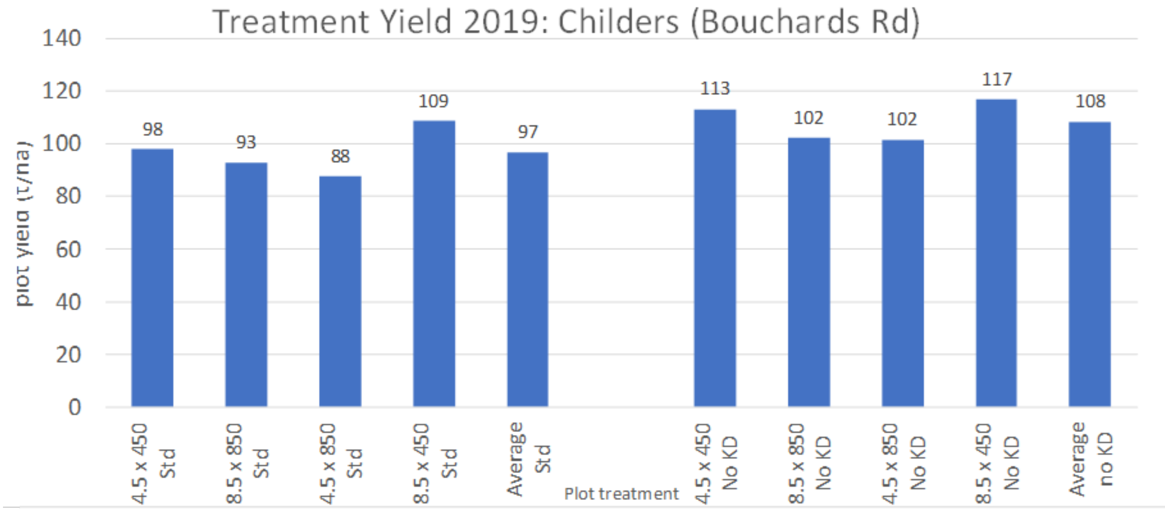


Figure 65. Treatment yield for the subplots at the Bouchards Rd trial (ground speed in km/h x basecutter rotational speed in rpm, with or without knockdown effect)

The machine-harvested yields of the full plots are presented in Figure 66. This indicates little difference between the main treatments.

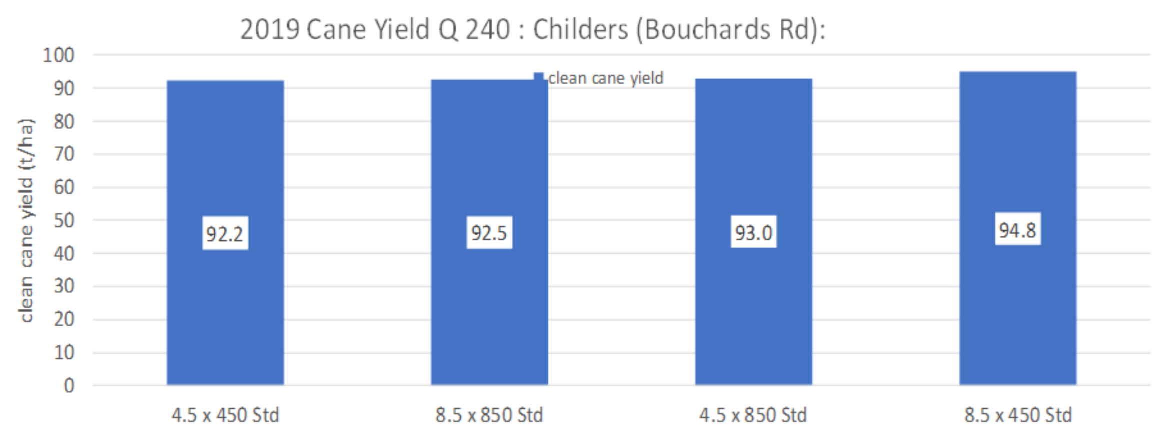


Figure 66. Machine-harvested yields of main plots at Bouchards Road (ground speed in km/h x basecutter rotational speed in rpm)

As the crop progresses through the ratoon cycle, the damage to the crop stool can be anticipated to support lower stalk numbers and greater variability in stalk placement. This effect is illustrated in Figure 67, which compares the means of the mean and standard deviations of the number of stumps in each 0.5m section of the sub-plots after the 2017 and2018 harvests.

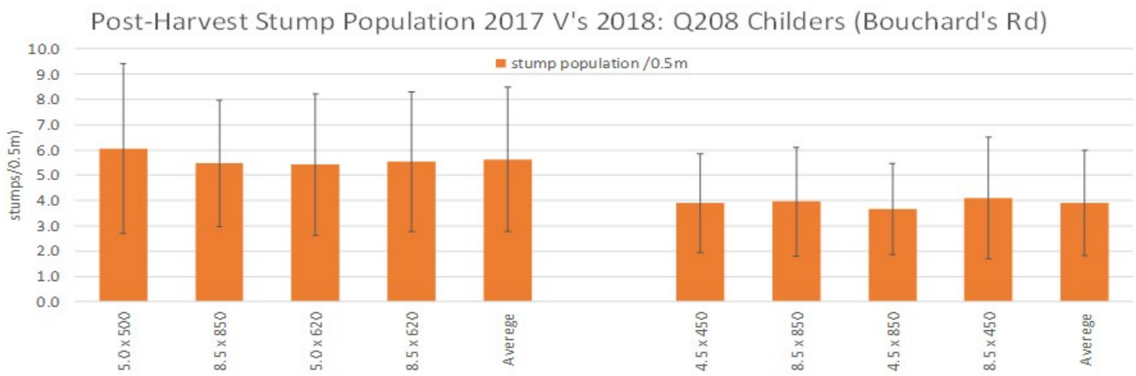


Figure 67. Change in number of cane stumps at Bouchards Road from 2017 to 2018 (ground speed in km/h x basecutter rotational speed in rpm)

The mean data indicates a reduction in stump numbers and the error bands indicate standard deviation as an indication of variability. While the standard deviation of a population in each 0.5 m section had reduced at the 2018 assessment, the probable maximum and minimum stump numbers reduced to less viable numbers.

Summary of all trial results

The most significant outcome from the 2016 and 2017 harvest events was the high levels of damage observed in all treatments. At approximately 30 days and 60 days after harvest, plant counts were undertaken. Additionally, at some sites, sample areas were harvested to assess plant weight. A weak trend linking increasing shoot numbers with increasing stool damage, and a general inverse trend linking increasing total shoot biomass with reducing stool damage was apparent. A significant impact of this observation is that shoot biomass rather than shoot number is more significant when evaluating ratoon germination and emergence performance.

To better assess the causes of damage, hand-cut sub-plots were introduced at the 2018 harvest to minimise gathering and knockdown effects, thus allowing comparison of basecutter-only and full front-end damage. The elimination of the gathering and feeding damage resulted in a very significant reduction in observed damage, as well as a small but important increase in the number of stumps which were available for damage assessment. This also then directly equated to a reduction in stump removal. This effect was noted at all sites (Table 17).

Table 17. Summary of stump damage with and without the gathering and forward-feed effects

TRIAL	STANDARD HARVEST WITH KNOCKDOWN			PRE-CUT: NO GATHERING OR KD EFFECT		
	UNDAMAGED	MINOR DAMAGE	MAJOR DAMAGE	UNDAMAGED	MINOR DAMAGE	MAJOR DAMAGE
Childers: Bouchards Rd	12%[A]	28%[B]	60%[C]	25%[A]	45%[B]	30%[C]
Childers: Plath Rd	17%[D]	43%	40%[E]	33%[D]	45%	21%[E]
Condong: Colonial Drive	21%[F]	52%	27%[G]	35%[F]	51%	14%[G]
Condong: BZ Farms	10%[H]	34%	56%[I]	29%[H]	32%	39%[I]
Burdekin: Mona Park	1%	24%[J]	75%[K]	1.5%	36.5%[J]	62%[K]
Ingham: Bambaroo	24%[L]	32%	45%[M]	30%[L]	33%	36%[M]
Average	14%	36%	51%	25%	40%	34%

For each category of damage in each trial, the differences between all pairs of values sharing a superscript is statistically significant to at least p = 0.05. The differences between pairs with superscripts A, C, E, G, I and K are statistically significant to p= 0.01.

The elimination of the gathering/knockdown effect resulted in an increase in undamaged stumps at all sites and a reduction in stumps with major damage (from 51% to 34%) overall sites. The high levels of statistical significance of the reductions in damage levels, despite the small sample sizes and significant variations due to uncontrolled factors, suggest that the knockdown geometry is a very significant contributor to observed damage levels.

Pre-harvest plant counts were also undertaken. The plant counts in the initial plots and the plots which were pre-cut indicated a positive correlation with reduced levels of damage.

At harvest, the pre-cut sections were hand-cut, stalks counted and weighed. To minimise extraneous effects such as planting rate, the direction of previous harvests, and other factors, a section in the same row immediately adjacent to the pre-cut section was also hand-cut, stalks counted and weighed. The impact of the treatments on plot yield is presented in Table 18. Stalk weight did vary across replicates, particularly at Mona Park, where yield from the highest yielding plot pair was 182% of the yield of from the lowest yielding pair of plots. However, typically, the difference in yield in any pair of plots was driven by differences in stalk number, not stalk weight.

Table 18. Summary of cane yield with and without the gathering and forward-feed effects

TRIAL	STANDARD CONFIGURATION (T/HA)	NO KNOCKDOWN (T/HA)	YIELD RESPONSE TO NO KNOCKDOWN	P VALUE
Bouchards Rd (Childers)	97	108	12%	0.095
Colonial Drive (Condong)	109	125	14%	0.031
Bambaroo (Ingham)	65	82	25%	0.007
Plath Rd Childers	78.1	89	14%	0.035
Mona Park (Burdekin)	93	101	9%	0.014
Condong (BZ) (126 t/ha avg)	13.2 stalks/m	16.6 stalks/m	25%	0.005

The highest response to the removal of the knockdown/gathering effects was noted at Bambaroo and BZ Farms, with the plot yield difference at Bambaroo being 25%, and the post-harvest stool count at BZ Farms indicating 25% higher stalk numbers. These two sites also had the highest level of significance in the difference (P=0.007 and P=0.005, respectively). Both crops had been sprawled at the 2018 harvest and so high levels of damage were expected. Both crops were the thin-diameter variety Q208.

The Plath Rd site and the Colonial Drive site both indicated a 14% increase in plot yield with the knockdown effect removed, with significances of P=0.035 and P=0.031. The variety at Colonial Drive was Q240, a thicker variety where higher levels of damage were anticipated. Whilst a significant effect, it is thought that stalk breakage above ground tends to protect the stool during harvest.

The Bouchards Rd site indicated a 12% increase in yield from the removal of the gathering/KD effect. The P=0.095 means that this was not statistically significant, however, it can still be considered to be a trend which is consistent with the results of the other trials.

The Mona Park trial indicated a yield response of 8% to the elimination of gathering and KD effects, but the P=0.137 indicates the response was not significant. As previously indicated, the yield of the highest yielding pair of plots was 182% of the lowest yielding pair of plots. This variation overwhelmed the treatment differences, despite the no-KD treatment having a higher yield in 10 of the 12 plots. Post-harvest EM soil mapping of the field indicated that large differences in yield across the plot area could be anticipated, associated with soil conditions.

The trial data demonstrate that, whilst damage associated with the basecutters is significant (given also that new- or near new basecutter blades were utilised during the trials), the issue of damage during the gathering and knockdown process is also a very significant contributor to damage and this can be directly associated with yield depression. Damage reduction from developments in basecutter configuration will be constrained because of the high level of damage before the basecutting process.

Observations during the trials also indicated that loss of stool is a major issue, as indicated by an increase in the "gappiness" of the remaining plant stand and a reduction in stump/stool numbers after each harvest. This effect is consistent with the findings of Chapman (1988)[4], who noted that the decline in yield was primarily associated with loss of population. Evenness of emerged plant spacing would be a primary driver of this effect.

Other harvest-related issues

Even though five of the six trial sites were specifically chosen with a crop row spacing that nominally matched the field equipment wheel spacing, machine placement error remains a major issue, even with highly committed and competent operators. This has two direct effects:

- The harvester basecutters are no longer aligned with the centre of the crop bed/row
- Encroachment of harvester and haulout wheels on the crop row

The offset of the harvester adversely impacts on gathering and feeding performance of the machine. More importantly, given that the distance between the centres of the basecutter discs is 600 mm, significant placement error means that the crop row is being harvested by one basecutter disc (Fig. 68).

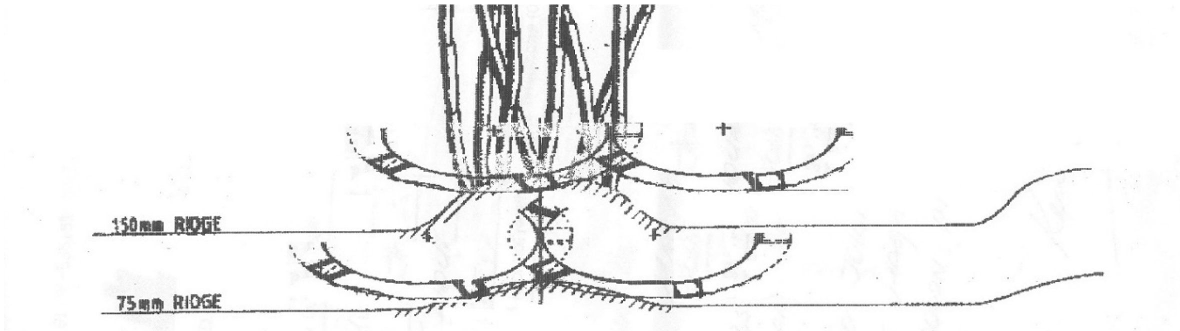


Figure 68. Illustration of the interaction between the swept path of the basecutter blades when the harvester is aligned on the row (bottom sketch) and when the harvester is "off the row" (top sketch)

If the harvester is offset, the gathering boards are less effective in lifting the cane to above the basecutters, the lowest part of the blade sweep is effectively over the centre of the crop row and so this is where the deepest cutting is occurring while the blades are cutting shallower towards the edges of the crop bed, and the blades do not effectively sweep the sides of the crop bed. These factors combine to induce the operator to set the basecutter operating depth deeper, causing more damage to the stool.

Harvester modifications

The process of gathering and aligning lodged cane stalks by the gathering spirals causes some damage to both the cane stalk and the cane stool. The damage to the cane stool is associated with tension in the cane stalks during the gathering process and to the bending and rotation associated with the re-alignment of the stalks. The more difficulty encountered by the gathering spirals in achieving the alignment of the cane stalks, the greater the anticipated level of damage. As harvesting speeds increase, the forces and associated damage can be anticipated to increase because of the reduced time available for the re-alignment process and associated increases in component accelerations.

To minimise forces associated with the gathering process requires the gathering spirals to be of appropriate design and be operating at the correct relationship with groundspeed. To date, the relationship between billet damage and groundspeed, in matched or un-matched configurations, has been limited.

[4] Chapman, L. S., 1988. Constraints to production in ratoon crops. Proc. Aust. Soc. Sugar Cane Technol. 10, 189-192.

On all machines except the Rocky Point machine, the speed control of the spirals and forward-feed rollers has been attempted by an open-loop control system. The data available indicate that this system is not achieving the targeted control of component speeds, particularly under variable field conditions. However, these machines are considered superior to unmodified machines.

The Rocky Point harvester is fitted with a closed-loop control system on the spirals and uses speed feedback from this circuit to control the oil flow to the forward-feed rollers. This machine is also fitted with spirals with modified wrap with a design ratio of 16 rpm/km h^{-1}. The performance of the Rocky Point harvester, particularly with respect to performance in large heavily lodged cane, is superior to the modified machines with only open-loop speed control, and very significantly better than machines in standard configuration. The modifications allow the harvester to very successfully harvest unburned “two-year” crops of greater than 200 t/ha. This is not possible with the standard machines.

Billet quality analysis was undertaken on product from this the Rocky Point machine as part of an SRA cane loss trial (Table 19). The crop was being harvested was a high yielding sprawled crop, and Sound billet proportions of 60-70% would have been considered good under the conditions. The very high levels of sound billets in the trial indicate that the gathering and feeding functions were being achieved with very low stalk damage.

Table 19. Billet quality analysis on the Rocky Point machine which is fitted with modified fronts

ROW LABELS	*SOUND BILLETS*	*DAMAGED BILLETS*	*MUTILATED*
Aggressive	81.9 %	14.1 %	4.0 %
Low Loss	85 %	11.6 %	3.4 %
Nominal	85.6 %	13.1 %	1.3%
Recommended	88 %	8.3 %	3.7 %
Average	85.1 %	11.8 %	3.1 %

Conclusion

The project has clearly illustrated that the design of the front end of current harvesters is resulting in very high levels of damage to the crop being harvested, reducing the yield potential for ratoon crops, and harming industry profitability. Across the thirteen field trials conducted, over 75% and up to 100% of the cane stumps had suffered identifiable damage, with major damage sometimes exceeding 60%.

The field trial program demonstrated that approximately half of the total damage occurs before the basecutters contact the cane stalk. Eliminating the initial forward-feeding damage resulted in reduced ratoon shoot numbers, but improved ratoon growth (biomass production) and an average yield increase of greater than 12% over the 60 paired sub-plots.

The project directly led to the development of functional guidelines for the technology for linking the rotational speed of key components to groundspeed. The field experience with the machines showed that active feedback on the rotational speed of all components, rather than open loop control, is necessary to achieve satisfactory speed control because of the high variability in load. The development of the matched component speed in conjunction with gathering fronts of optimised design resulted in very significant improvements in feeding performance of machines in very large crops.

Whilst the modifications undertaken to the machines for the trials to match the forward speed and rotational speed of key components did improve machine operational performance, particularly in larger crops, only limited positive impact on damage and subsequent yield was noted. More significant machine modifications reduced damage, but further development is necessary before such modifications could be commercialised.

3.1.5 Activity B6 – Commercial-scale evaluation of post-harvest cane cleaning

Project 2016/953, Commercial-scale economic evaluation of post-harvest cane cleaning to maximise the returns to the supply chain

3.1.1.12 Outcomes from cane cleaning and low-loss harvesting (KPI 7.12); Demonstration trials of cane cleaner (KPI 7.13)

Trials of post-harvest cane cleaning were conducted on commercial farms and required a large input from participating growers, harvester operators and milling companies, with some treatments proposed by the industry collaborators. As such, KPIs 7.12 and 7.13 are considered together.

The harvesting tests conducted in southern Queensland in 2017 produced cane supplies with different levels of cane quality. Statistically significant differences in cane fibre content and CCS were identified between low loss and cleaned cane supplies but not between the commercial and other treatments. Lack of statistical significance is believed to be mainly caused by the small number of tests and was remedied in 2018. The factory results showed higher sucrose extraction from the cleaned treatment than from the low loss treatment but few other significant differences.

The mobile cane cleaner received some major modifications during the off-season following the 2017 tests. These modifications included:

- New axles to carry the mobile cane cleaner for moving around the farm/district
- New cleaning chamber fitted to the machine
- Modified accelerator drum housing, a new trajectory for cane billets passing through the jet stream
- ‘Hungry boards’ on the hopper to hold more cane for the high lift tipping cane haulouts in north Queensland

The cane cleaner was then disassembled in Bundaberg and cleaned down to pass a biosecurity inspection to enable transport to the Atherton Tableland across four cane zones. Four large trials were conducted in 2018.

Trials 1-3

The first trial, conducted in plant cane of variety KQ228, consisted of 19 replicates of two treatments, normal harvesting (fan speed 800 rpm) and low loss plus cleaning (fan speed 680 rpm). Treatment 1 (normal) had a significantly higher cane and CCS yield than treatment 2 (low loss + cleaning). In-field sugar loss was measured using the ISLMS. There were more sucrose and cane lost in the field in commercial harvest treatment 1 than in the low loss treatment 2.

The second trial consisted of one replicate of three treatments. The combination of low loss harvesting plus cane cleaning appeared to result in lower cane yield than commercial harvesting, but no statistical analysis was possible.

The third trial in the same cane block consisted of 11 replicates of three treatments, commercial (fan speed 900 rpm), normal (fan speed 800 rpm) and low loss + cleaning (fan speed 700 rpm), with a ground speed of 4 km/h. The only statistically significant difference in cane properties (CCS, purity, fibre content and ash content) was in fibre content: the fibre content of the cleaned cane treatment was significantly lower than the fibre content of the two uncleaned treatments. Analysis of variance did not find that treatment had a statistically significant effect on cane or CCS yield ($P = 0.05$). The average sugar/cane loss data was gathered using the ISLMS. There were more sucrose and cane lost in the field in commercial harvest Treatment 1 than in Treatments 2 and 3.

The primary purpose of the cane cleaner is trash separation and removal. In both Trials 1 and 3, trash levels were assessed both before and after cane entered the cane cleaner. The results showed an average of 61% of trash being removed in Trial 1 and an average of 73% of trash being removed in Trial 2. The operating speed of the diesel engine of the cane cleaner was increased from 2100 rpm in the first trial to 2300 rpm in the third trial. This change proportionally increased the speed of the extraction fan on the cane cleaner resulting in greater airflow and increased trash removal.

There was a significant increase in the proportion of mutilated billets measured through the cane cleaner in Trial 3 with an average increase of about 9% of total billets damaged. There was a similar but non-significant trend in Trial 1. The cleaning chamber of the cane cleaner had been redesigned and these trials were the first usage of this new configuration. Billet damage during the cane cleaning process is an important consideration and additional measurements were included as part of future testing.

The main objective of the trials was to measure the increase in CCS yield from the low loss harvesting plus cane cleaning treatment to improve sugar income. The ISLMS cane loss measurements showed an increase in CCS yield with the low loss harvesting treatment, but there appeared to be a loss of CCS yield of about 2 t/ha in the cleaned cane supply that was not explained. As a result of this deficiency, the next trial was designed to provide more information about the cane cleaner itself.

Trial 4

The trial was in plant cane KQ228 with an estimated yield of 145 t/ha. There were 18 replicates of three treatments, commercial harvesting (Treatment 1, fan speed 900 rpm), low loss harvesting (Treatment 2, fan speed 700 rpm) and low loss plus cane cleaning (Treatment 3), each at a nominal harvester speed of 4 km/h. Cane analysis at the factory was obtained from the factory NIR-based Cane Analysis System, with the appropriate bias, as utilised for cane payment, applied to the CCS results.

Statistically significant differences were found for damaged and mutilated billet content and trash content. There were more damaged billets from Treatment 3 than from Treatments 1 and 2, and there were more mutilated billets from Treatment 3 than from Treatment 2. Statistically significant differences were found between the trash contents of all three treatments. Treatment 2 had a significantly higher cane and CCS yield than either of Treatments 1 or 3, but there was no significant difference between Treatments 1 and 3 (Fig. 69).

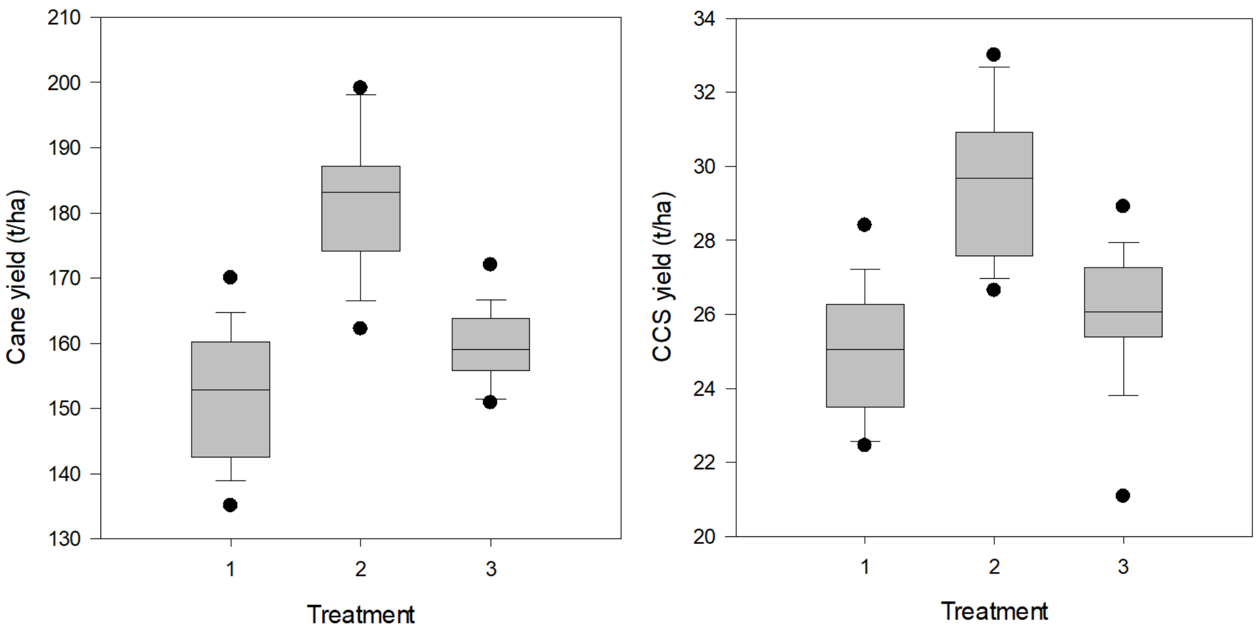


Figure 69. Summary of yield results from Trial 4

Following the completion of the first day's testing, a sufficient quantity of the cane billets surrounding the cane cleaner was collected so that an estimate of billet loss could be made. An estimated 38.6 t of billets had been processed through the cane cleaner, based on the total cane delivered to the factory, the calculated billet loss and the extraneous matter analysis. The measurements indicated that a total of about 2% of the cane delivered to the cleaner was lost during the cleaning process.

One of the biggest uncertainties from previous trials surrounded the losses from the cane cleaner since there were no mass measurements of the cane entering the cane cleaner. In Trial 4, Treatment 2 provided those mass measurements and enabled a much more certain mass balance. The extraneous matter analysis was used to calculate the billet yield from the cane yield for both Treatment 2 (entering cleaner) and Treatment 3 (exiting cleaner). The billet loss calculated from the mass balance of 6 t/ha corresponds to a cane cleaner billet loss of 4%, about twice that estimated above by collecting billets and billet fragments.

Trial 5

This trial was conducted in plant cane Q208 with an estimated yield of 125 t/ha. There were 10 replicates of four treatments: aggressive (Treatment 1, fan speed 850 rpm, ground speed 6 km/h), normal (fan speed 750 rpm, ground speed 5 km/h) low loss (Treatment 3, fan speed 600 rpm, ground speed 4.5 km/h) and low loss plus cleaning (Treatment 4).

There were significantly more mutilated billets from Treatment 4 than from Treatments 1-3. There was significantly more trash from Treatment 3 than from the other three treatments, and from Treatment 2 than from Treatment 4. Bin weight for Treatment 3 was significantly less than for Treatments 1 and 2 and bin weight for Treatment 4 was significantly greater than for Treatments 1 and 2. These results are a mirror image of the trash content results, as expected.

There were concerns about the validity of NIR cane analysis for high trash samples in previous trials. Therefore, additional cane analysis was undertaken in Trial 5. NIR cane analysis was undertaken as in previous trials. At Mossman factory, the main cane analysis parameters of focus were fibre, CCS and purity. From prepared cane and first expressed juice samples, fibre, CCS and purity could also be calculated from can fibre and the Brix and pol of first expressed juice, using the conventional laboratory analysis procedure. From the prepared cane samples, moisture, Brix and pol in cane were also calculated directly using the direct cane analysis (DAC) methodology. As an alternative method, Brix and pol in cane were calculated from can fibre rather than moisture.

No statistically significant differences between treatments were identified in the NIR CCS data. For the CCS calculated from first expressed juice analysis, statistically, significant differences were identified between Treatment 3 and both Treatments 1 and 4. Also, a statistically significant difference was identified between Treatments 2 and 4. The direct cane analysis using both methods identified the same differences as the first expressed juice analysis results, and also a statistically significant difference between Treatments 2 and 3. The trends for all three analysis methods are a mirror image of those for trash content, as expected. A comparison of results between methods showed that, compared to the standard first expressed juice-based CCS analysis, the NIR analysis was not capturing the magnitude of the high CCS samples adequately. The two alternative direct cane analysis methods gave quite similar CCS values.

Billet yield was calculated from cane yield using the extraneous matter results. CCS yield was calculated using the NIR, first expressed juice and direct cane analysis CCS results calculated using both moisture and fibre analysis. Cane yield and NIR-based CCS yield was significantly greater for Treatment 3 than Treatments 1, 2 and 4. Cane yield of Treatment 2 was also significantly greater than Treatment 1. First expressed juice-based CCS yield was significantly greater for Treatment 3 than Treatment 1. The NIR and first expressed juice-based CCS yield results appear similar, whereas the high CCS yield for Treatment 3 is absent from the direct cane analysis results.

A summary of results for billet yield and CCS yield by direct cane analysis is shown in Figure 70.

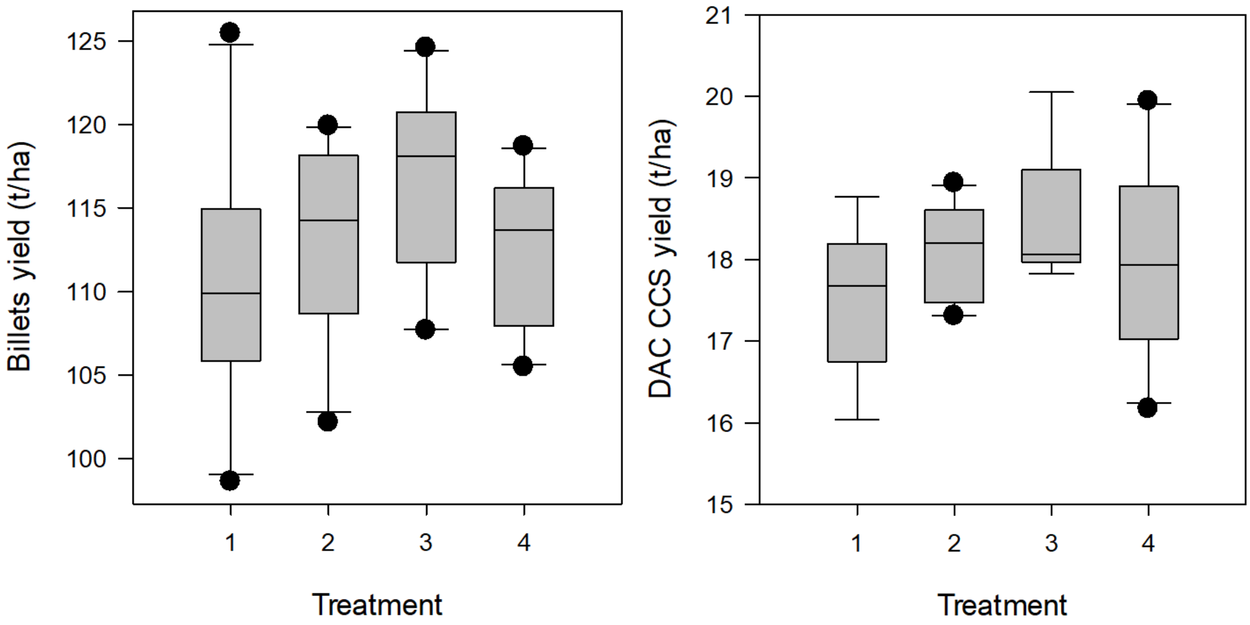


Figure 70. Summary of yield results from Trial 5

One of the biggest uncertainties from previous trials surrounded the losses from the cane cleaner. Trial 4 had addressed this issue by measuring the mass of cane into and out of the cane cleaner, and results indicated 4% of billets were lost. Using the same methodology, a mass balance around the cane cleaner was conducted for Trial

5 using the Treatment 3 and 4 results. The calculated billet loss of 4 t/ha corresponds to a cane cleaner billet loss of 4%, about the same as calculated in Trial 4 and about twice that estimated through direct measurement of billet loss in that trial.

3.1.1.13 Benefit/cost analysis and a summary of findings (KPI 7.14)

For each of the Tableland trials 3, 4 and 5, components considered for the economic analysis included transport parameters and costs, harvest parameters and gross income, harvest and haulout costs and the 'cleaning' costs. For the purpose of the study, fuel (less rebate) was set at $1.20 per litre and the wage rate was set at $35.00 per hour based on current industry payments (pers. comm. Mark Poggio and Stephen Ginns, 2019).

For each trial, trucks were used to deliver the cane to the designated mill. Each of the trials had differing parameters relating to transport capacity and cost (Table 20).

Table 20. Transport parameters and associated costs under Trials 3, 4 and 5

PARAMETER	TRIAL 3/ TMT 1	TRIAL 3/ TMT 2	TRIAL 3/ TMT 3	TRIAL 4/ TMT 1	TRIAL 4/ TMT 3	TRIAL 5/ TMT 1	TRIAL 5/ TMT 2	TRIAL 5/ TMT 4
	900rpm	800rpm	700rpm + cleaning	900rpm	700rpm + cleaning	850rpm	750rpm	600rpm + cleaning
Tonnes transported	214.9	200.2	220.0	385.05	355.64	358.0	340.0	400.0
Truck trips to mill	10	10	10	17	17	10	10	10
Trash %	4.0 %	5.0 %	2.5 %	4.28 %	1.8 %	3.86 %	6.0 %	2.0 %
Distance to mill (km)	10	10	10	10	10	81	81	81
$ per km to mill	$4.50	$4.50	$4.50	$4.50	$4.50	$4.50	$4.50	$4.50
Total cost per trial	$450	$450	$450	$765	$765	$3645	$3645	$3645
Total cost per tonne	$2.09	$2.24	$2.05	$1.98	$2.15	$10.18	$10.72	$9.11

The harvester contract rate was estimated through established harvesting cost spreadsheets developed by DAF economists working in north Queensland. Data for each of the trials was supplied to the economics team working under Project 2016/955. Where there were data gaps, the average cost of inputs provided by harvesting groups across the industry was used.

A difference between the standard practice and the introduction of the cane cleaner is the addition of an extra haul-out. Standard practice commonly utilises two trucks, one at the harvester and one in transit to or from the siding to unload. With the addition of the cleaner, two haul-outs will rotate between the harvester and the cleaner while a third will manage the clean cane from the cleaner to the siding for transport to the mill for processing. The additional haul-out increases fuel and labour costs to the contractor and the rate per tonne increases as the cost is spread over a decreased amount of cane, trash and EM exiting the cleaner. The contract rate in Table 21 shows the increased rate per tonne of cane processed through the cleaner. It was expected (but not realised) that the subsequent processing of cleaner cane at the mill would deliver an improved CCS rate to compensate for the increase in overall harvest and haul-out costs.

Table 21. Harvest and haul-out parameters and associated costs in Trials 3, 4 and 5

PARAMETER	TRIAL 3/ TMT 1	TRIAL 3/ TMT 2	TRIAL 3/ TMT 3	TRIAL 4/ TMT 1	TRIAL 4/ TMT 3	TRIAL 5/ TMT 1	TRIAL 5/ TMT 2	TRIAL 5/ TMT 4
Contract rate $/t	$5.72	$5.58	$6.39	$5.66	$6.44	$5.87	$5.80	$7.70
Number of haul-outs	2	2	3	2	3	2	2	3
Harvest cost$/t (incl. fuel)	$6.29	$6.16	$7.09	$6.25	$7.10	$6.37	$6.36	$8.47

Due to the nature of the experimental design, spatial challenges and data variability, the option to undertake long term investment analysis was limited. As such, the partial analysis observes a 1-year harvest for a farmer, with and without the cane cleaner, as part of the harvest and transport process. The operational cost for the cane cleaner was estimated at $1.49 per tonne of cane entering the machine and $1.54 per tonne for the cleaned cane exiting the machine. The cost of the mobile cane cleaner incorporated FORM (fuel, oil, repairs and maintenance), depreciation and operating labour as in Table 22.

Table 22. Operational costs for the post-harvest cane cleaning plant

PARAMETER	UNIT / COST
Fuel usage (litres/hour)	28.00
Total fuel and oil cost (per hour)	$36.96
New price	$325,000
Productive life (hours)	10,000
Repairs and maintenance cost (per hour)	$24.38
F.O.R.M (per hour)	$61.34
Salvage value	40%
The interest rate used to calculate depreciation	8%
Depreciation and interest cost (per hour)	$18.20
Labour cost (per hour)	$35.00
Total operation cost per hour	$134.04
Cleaner pour rate - average during the experiment (t/hour)	90

The cane cleaner removes trash from the harvested cane before being transported to the mill, and so there is a significant trash issue at the cleaning site. Numerous options to deal with the trash were discussed but remain un-costed or investigated, including:

- Sale of trash to Bunnings and other nursery outlets for processing and packaging as garden mulch
- Private contractor to spread the concentrated trash back over the harvested area to return organic matter and nutrients to the farm, as well as add to soil moisture preservation and weed control
- Co-generation of electricity at mill sites (requires transport).

There is a significant amount of trash that would be generated through the applied use of the cane cleaner across a sugarcane district. For example, in Trial 3 using the standard harvesting process (Treatment 1), around 8 tonnes of trash per hectare would be generated by the harvest and transported to the mill (excluding that returned as a trash blanket by the harvester). Looking at Treatment 3 of the same experiment that employs the use of the cane cleaner, 3.5 tonnes of trash per hectare would be sent to the mill as part of the harvest. Therefore, approximately 4.5 tonnes of trash are created at the cleaning site per hectare of cane that is processed. Given that southern Queensland harvests around 45,000 hectares of cane (Canegrowers Annual Report 2016-17), then theoretically (under full adoption) 180,000 tonnes of trash could be generated each year. This throws up another potential hurdle, 'adoption' if there was only small or partial adoption by industry innovators. There is potential for benefits such as reduced repairs and maintenance costs, a shift in processing capacity (less trash equals more billets), and cleaner product. Indications are that mills might not be able to respond, incrementally to this innovation due to 'choke' points along the sugar processing chain, rather it would require a significant practice change.

However, despite all the 'what ifs', the study has placed an economic cost on the trash in place of a defined trash strategy that would be able to deal with the volume of trash that could be potentially generated. For this study, the economic cost of trash was approximated using a western Queensland baling cost for large round bales (*pers. comm.* Fred Chudleigh, Principal Agricultural Economist DAF, 2018). Removal or transport of the bales off-site would need to be covered by the estimated sale price of the bales so as not to burden the farming operation further. The cost for baling one tonne of cane trash was $27, equating to 3 bales. Table 23 below outlines the trash cost for each of the trials employing the mobile cane cleaning plant.

Table 23. Approximate trash baling costs for cane cleaning trials

EXPERIMENT / TRIAL	COST PER TRIAL	COST PER HA
Trial 3 / Tmt 3	$121.77	$78.05
Trial 4 / Tmt 3	$272.12	$122.20
Trial 5 / Tmt 4	$334.80	$99.64

The summary of data collected represents three different trials under which numerous tests were conducted to examine standard harvesting and transport practice versus a process that incorporated the mobile cane cleaner. Due to the variability between experiments, each should be considered separately, and so results examined within and not between trials. The economic summary distils the data to per hectare and per tonne for comparability within experiments, as harvest areas, travel speeds and other variables were not constant between trials. Table 24 outlines the key economic parameters from the project. In each instance, the income generated in trials utilising the cane cleaner is less than each of the standard practice treatments.

Table 24. An economic summary of trial data with and without the mobile cane cleaner

PARAMETER	TRIAL 3/ TMT 1	TRIAL 3/ TMT 2	TRIAL 3/ TMT 3	TRIAL 4/ TMT 1	TRIAL 4/ TMT 3	TRIAL 5/ TMT 1	TRIAL 5/ TMT 2	TRIAL 5/ TMT 4
Gross income per ha	$6,412	$6,236	$5,816	$6,858	$7,184	$4,644	$4,447	$4,554
Cost per ha	$1,296	$1,252	$1,583	$1,245	$1,846	$793	$741	$1,291
Net income per ha	$5,116	$4,984	$4,233	$5,614	$5,338	$3,851	$3,706	$3,263
Net income per tonne	$33.22	$33.40	$30.02	$37.18	$33.43	$30.92	$31.88	$27.41

It was expected that gains in CCS may overcome any additional harvesting and transport costs generated by the inclusion of the cane cleaner in the process. Table 25 outlines the existing CCS results for the cane cleaning trials and what they would need to achieve to break even with the standard practice in each case. In summary, in all three trials for which economic analysis was completed, the treatment with post-harvest cane cleaning was found to be less attractive than the harvest-only treatments.

Table 25. CCS results from trials with the mobile cane cleaner and the CCS required to achieve a break-even result in terms of net income per hectare

EXPERIMENT / TRIAL	CCS TRIAL RESULT WITH MCC	BREAKEVEN CCS
Trial 3 / Tmt 3	15.3	16.2
Trial 4 / Tmt 3	16.3	17.4
Trial 5 / Tmt 4	14.5	15.4

3.2 Contribution to program objectives

The objective of the program is to realise significant productivity and profitability improvements for primary producers, through:

- generating knowledge, technologies, products or processes that benefit primary producers
- strengthening pathways to extend the results of rural R&D, including understanding the barriers to adoption
- establishing and fostering industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.

The project has generated significant knowledge of the factors that contribute to sugarcane harvest losses and of opportunities to maximise crop value. It has:

- Developed and implemented modifications to the front-end of commercial sugarcane harvesters that improve cane feeding in large crops
- Provided evidence of other sources of crop damage from harvesting machines that could be rectified by further R&D
- Constructed a mobile post-harvest cane cleaning plant and generated data on the costs and benefits of low-loss cane harvest followed by post-harvest cane cleaning
- Developed a decision-support tool, SCHLOT Live, that provides real-time feedback on cane losses to the harvester operator in the cabin
- Undertaken a feasibility study of sensors that may be used to reduce cane losses and improve cane quality in the harvesting environment, and that has led to further industry-funded R&D
- Conducted an extensive program of practice change to increase adoption of Harvesting Best Practice, through a combination of work with harvesting groups combined with detailed demonstration trials
- Provided an industry dollar value of harvest losses under different scenarios that have greatly increased industry awareness of the value lost cane that is invisible due to the cane billets being pulverised as they pass through the harvester extractor fans
- Provided a data set that can be mined to develop an economic decision-support tool that will allow growers and harvester contractors to negotiate a suitable harvesting payment for implementation of HBP

One of the barriers to adoption of Harvesting Best Practice, despite it not being a new concept, has been a lack of industry belief in it as a serious issue at grower and contractor level. Past industry adoption based on fact sheets and oral advice has received little traction. This project, through a process of direct engagement with the people involved, that is with the growers and harvesting contractors within the individual harvesting groups, and by measuring/demonstrating harvest losses under each group's circumstances, has achieved more in terms of adoption of HBP than many years of past extension effort. As harvest losses are largely invisible, recognition of the problem and trust in the data is required before people will make changes to their current operations.

This project has established a large range of collaborations between research organisations and particularly between organisations and different sectors of the sugarcane industry. Improvement in sugarcane harvesting requires cooperation and trust across the growing, harvesting and milling (processing) sectors. All work has been done with commercial cane growing and harvesting operations and has been highly visible. It is expected that this collaboration will continue beyond the end of project 15-02-020, with an industry harvesting RD&A program currently being developed with input from all sectors.

4. Collaboration

The collaboration between NorrisECT and Agtrix as partners in project 2016/951 capitalised on the synergies between Agtrix's commercial status and the engineering capability of Norris ECT in development of the decision support tool SCHLOT Live. Various industry participants who hosted trials or modifications to their machinery or assisted with any of the extensive field activities were crucial to the success of the project, in particular Jaistand Pty Ltd, Tweed Valley Harvesting and City View Farms, Rocky Point Harvesting, Central Harvesting, Bray Harvesting, Raccanello Enterprises, and SRA.

Project 2016/952 brought together the modelling expertise of the Queensland University of Technology (QUT) and the engineering expertise and field experience of Norris ECT. Jindong Yang from LEAP Australia provided crucial information and assistance with LS-DYNA modelling tasks Informal collaboration with EHS Manufacturing, an innovative Mackay-based company designing and manufacturing after-market harvester modifications (http://www.ehsmanufacturing.com.au/product-list/agricultural-equipment/), has brought benefits to the project. On an operational level, the following groups made the project possible: Jaistand Pty Ltd (North Farms), Tweed Valley Harvesting and Citifarms, Central Harvesting at Isis, Mark Mammino of Isis, Bruce Petersen of Isis, SJC Harvesting at Ingham, Pace Farming at Ingham, Rocky Point Harvesting, and Wilmar in the Burdekin region.

The team leading Project 2016/953, the Queensland Department of Agriculture and Fisheries (DAF) and others, was assisted by the transport and production teams at Bundaberg, Isis and MSF sugar companies. QUT provided the coordination of tests and production of liquor for sugar and molasses production estimates in the Bundaberg and Isis tests. Rajinder Singh hosted a cane cleaning trial on the Tableland and Mossman Mill provided milling support. SRA assisted with in-field measurement and cane analysis data.

In the adoption projects led by SRA, Projects 2016/955 and 2019/951, the Queensland Department of Agriculture and Fisheries provided extensive support in the auditing of all trial data and detailed economic analysis applied thorough their proprietary economic modelling algorithms. Execution of the project was made possible through the efforts and support of numerous regional organisations: Regional Canegrowers, Plane Creek Productivity Services, Mackay Area Productivity Services, Sugar Services Proserpine, Herbert Cane Productivity Services Ltd, Sunshine Sugar, MSF Sugar, Isis Central Sugar, Bundaberg Sugar, Wilmar Sugar and Mackay Sugar. It drew upon activities underway in all the harvesting projects and collaborated with all participants. Particular collaboration with NorrisECT provided valuable input into the recommendations for Harvesting Best Practice to be tested by each harvester group, based on the decision-support tool SCHLOT, but also provided a validation of SCHLOT Live based on real data. The cross-sectoral collaboration in the project was essential to demonstrate Harvesting Best Practice, quantify whole-of-industry benefit and distribute benefits (and costs) equitably.

The project Research Management Group brought together representatives from different sectors and, while they were not always in agreement, on-going interaction with the group and communication between group members and the wider industry is expected to lead to a more collaborative approach to the problem of lost industry value due to inefficient harvesting.

The leader of the adoption projects 2016/955 and 2019/951, Phil Patane (SRA), travelled to Brazil and the USA in October 2016 to undertake a tour of the Case IH and John Deere harvester factories. Phil also travelled to the USA in November 2019 to visit harvester marketing and engineering staff, accompanied by two harvesting contractors engaged in project 15-02-020. Although neither trip was part of the RuralR&D project, being funded by SRA Travel and Learning Awards, these visits have strengthened industry collaborations. Case and John Deere, which make the majority of harvesters in use in Australian and manufacture all their machines offshore, have expressed their intent to be more involved in harvester research in Australia in the future.

In summary, this project brought together a diversity of research organisations to focus on a particular high-priority industry issue. Intellectual input and operational assistance came from all sectors of the sugarcane industry. Strong support from representatives of the project Research Management Group and others at a harvesting workshop in December 2019 for development of an on-going sugarcane industry RD&A harvesting program indicates that the collaborations established in the project will be on-going.

5. Extension and adoption activities

Extension and adoption activities were undertaken by SRA's Communications unit and its Adoption team, particularly operating through the dedicated Harvesting Best Practice adoption projects 2016/955 and 2019/951. Full details of activities were provided in Sections 2.5 and 2.6 (Methods) and 3.1.2 (Outcomes). This group has also communicated results of other harvest-related projects and activities, particularly through regional harvest forums that were run each year.

One key barrier to adoption of harvesting best practice is that growers and harvesting contractors cannot confidently estimate what the benefit is from using HBP (instead of standard harvesting practice) in a particular block of cane. One practical solution to this problem would be the development of a decision-support tool that harvesting groups could utilise to estimate the grower revenue benefit and additional harvesting costs from HBP. This would require estimating cane yield and CCS impacts to enable the revenue benefit to be determined. Given the extensive amount of production data collected during the 2017-19 harvesting trials, it makes sense to utilise this data to calculate the algorithms needed for the tool. Work was also undertaken during the project to develop the network of calculations needed to evaluate harvesting cost changes, along with the collection of harvesting operational data. These calculations and data could be integrated into a tool to enable harvesting cost changes to be estimated. With both revenue and cost impacts known, the net benefit from using HBP in a particular block could be derived to help growers decide if the benefit was large enough to warrant HBP and, if so, what would be fair compensation for the harvesting operations to use HBP settings (to inform the negotiation process between grower and harvesting operation).

The results generated in this project will inform a revision of the sugar industry Harvesting Best Practice Manual. That revision is expected to take place later in 2020.

Harvest operator training is important for adoption of HBP and other harvesting improvements. Training will be based around the revised HBP Manual. One option for an entry-level harvester operator training program is to integrate harvesting best practice (HBP) into basic harvester operator training. Although a VET entry-level harvesting training module does exist, the elements of HBP are not a focus. The Australian sugarcane industry must endorse formal training which embeds HBP as a minimum entry-level skill requirement.

A training program could use an innovative on-line delivery system based on the learning management system (LMS) aNewSpring. This LMS is currently the basis of a training program being developed for mill operators, with funding from SRA.

The sugarcane industry is currently negotiating with one of the harvester manufacturers to base a harvester simulator in Queensland. This would be a very sophisticated training device with full controls, video screens instead of windows, and a realistic cabin movement. If the negotiation is successful, the simulator will provide an excellent training platform to promote further adoption of HBP.

6. Appendix - additional project information

6.1 Project, media and communications material and intellectual property

A list of research papers, extension materials, communications and activities was provided earlier under Activity B3, Communication and extension activities.

Most intellectual property subsists as a copyright in the various project reports. Project IP that may be used for future commercial developments includes:

- Knowledge of sensors and installations required to collect machine operation data for SCHLOT Live
- Methods for estimation of cane and trash extraction through the primary extractor based on harvesting rate, crop properties, extractor speed and sensor readings on the harvester (used for SCHLOT Live)
- Processed data from SCHLOT Live specific to harvest loss estimation
- The interface of SCHLOT Live and Agtrix systems
- Finite Element Models of cane-harvester interactions, and modelled behaviour with different design specifications
- New harvester front end control systems and algorithms
- The economic model for detailed economic analysis of harvesting cost equipment and assets

Assets costing more than $5,000 are:

- Mobile cane cleaning plant MCC 180
- In-field sucrose loss trailer (built up by SRA from individual components)
- Non-standard hydraulic basecutter motor for the Case 8000 harvester modified in the Burdekin as part of SRA project 2016/952

6.2 Monitoring and evaluation

6.2.1 Introduction

This project was designed to address the following programme outcomes:

Generating knowledge, technologies, products or processes that benefit primary producers

- Develop technologies, knowledge, and capacity to increase revenue throughout the sugar industry value chain by addressing losses currently caused by mechanical harvesting.

Strengthening pathways to extend the results of rural R&D, including understanding the barriers to adoption

- Understand and address barriers to the adoption of Harvesting Best Practice.

Establishing and fostering industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture

- Demonstrate the value of applied research and knowledge sharing among sugar industry sectors.

The agreement for Project 15-02-020 was executed on 24 June 2016 with a scheduled end date of 1 May 2019.

Cash contributions to the project were expected to be:

- Sugar Research Australia (SRA) $1,700,000
- Queensland University of Technology (QUT) $75,000
- Sugar Research Limited $150,000
- Grant $3,551,000

SRL was ultimately unable to obtain board approval for its planned contribution. SRA agreed to make up the missing $150,000, bringing SRA's total cash contribution to $1,850,000, and that information was relayed to DAWE on 16 September 2016.

The project, hereafter referred to as the ‘Harvesting Program’, includes the following sub-projects (‘Projects’) that were contracted with individual research providers:

1) Development of an intelligent tool to allow real-time evaluation of harvesting practices as part of a framework for improved harvester payment systems (Project 2016/951)
2) Understanding interactions between crop dividers, basecutters and other harvester forward-feed components with the cane stalk, and determining practical strategies to minimise damage as harvester speed increases (Project 2016/952)
3) Commercial-scale economic evaluation of post-harvest cane cleaning to maximise the returns to the supply chain (Project 2016/953)
4) Sensors for improving harvester feedback: evaluation of suitability (Project 2016/954)
5) Adoption of practices to mitigate harvest losses Phases 1 and 2 (Projects 2016/955, 2019/951)

These projects contributed to the activities spelled out in the Grant Agreement:

B1 Project initiation

B2 Project planning and management

B3 Communication and extension activities

B4 Integrated loss-measuring tools and harvester telemetry systems

B5 Machinery modifications to minimise crop damage

B6 Commercial-scale evaluation of post-harvest cane cleaning

A Project Plan, Communications and Extension Plan, and Monitoring and Evaluation Plan were submitted as part of Milestone 2.

The following discussion is structured around the M&E Framework and Activities in the M&E Plan, specifically the KPIs for each Achievement in the Plan.

6.2.2 Activity B1 and B2. Project initiation, planning and management

GOAL	*TO ENSURE THE HARVEST LOSSES PROGRAM ACHIEVES ITS GOALS*				
ACHIEVEMENT		**OBJECTIVES**	**KPI OR MEASURE**	**M&E METHOD YOU WILL USE TO GET THE DATA**	**ACHIEVED**
Outcome: Sugar industry productivity and profitability improved through successful Rural R&D4P Project	Governance arrangements applied	• Minimise program risks.	• Program Coordinator appointed. • Research Management Group (RMG) formed to represent industry sectors, project partners and research providers. • Individual projects agreements executed with appropriate evaluation of IP.	• All structures in place during Year 1.	✓
	Program runs on time and within budget	• Complete the agreed Project (Program) Plan.	• Milestone reports delivered to the Commonwealth, including financial statements. •	• Reports accepted by Rural R&D for Profit.	✓
	Individual project outputs delivered	• Individual projects implement agreed plans, including communications. • Individual projects achieve their milestones and achievement criteria.	• This is discussed in the detailed M&E plans for individual activities below.	• Individual project reports accepted by SRA Research Funding Unit (RFU).	✓
	Program delivers on its stated goals	• Development of new technologies and adoption of new technologies and/or Harvesting Best Practice by growers and harvester operators.	• Program focuses on industry benefits. • Outcomes communicated to industry. •	• Progress regularly reviewed by industry-representative RMG.	✓

Governance arrangement applied

Program coordinator appointed

A program coordinator, Bernard Milford, was appointed from August 2016 to June 2019. Bernard has had a long career in the sugar industry, with experience in milling, cane growing and research policy. He began his career as a Chemical Engineer in a far north Queensland sugar mill and subsequently was Chief Policy Officer for Australian Canegrowers for 24 years up until 2012. His responsibilities included miller-grower relations and research organisation and policy, and he has since provided consulting advice for CANEGROWERS and for the Fiji sugar industry. For the Rural R&D for Profit Harvesting Program, Bernard coordinated activities of the Research Management Group (see below), assisted with the preparation of industry communication materials, provided guidance to individual projects and facilitated linkages among them and with the sugarcane industry.

Research Management Group formed

A Research Management Group (RMG) was formed with representatives from all industry sectors with initial representation as in the table below.

RMG Initial Membership

Coordinator (Bernard Milford)
SRA Research Funding Panel (Gary Longden)
Millers
NSW (Ian McBean)
Isis (Paul Nicol)
Bundaberg (Simon Doyle)
Mackay (Craig Bentley)
Tully (Dick Camilleri)
MSF (Hywel Cook)
Wilmar (Ian Davies)
Contractors/growers
Contractor (Michael Deguara)
Contractor - Joe Marano
Contractor - Vince Russo
Grower - Mario Raccanello
Research providers
NorrisECT (Stuart Norris)
Agtrix (Rob Crossley)
SRA (Phil Patane)
QUT (Phil Hobson)
DAF (Steve Ginns)

The membership of the RMG was selected to represent a cross-section of the sugarcane industry: growers, harvester contractors and millers, including members of organisations that were expected to give in-kind contributions to project activities. Chief investigators of research projects were also members as well as the program coordinator and a representative of the SRA Research Funding Panel. A few names changed as people left their respective organisations, but overall industry representation remained.

The RMG met as below:

- 30 September 2016, Brisbane
- 15 May 2017 (teleconference)
- 13 March 2018, Townsville (including DAWE – Georgina Kelley)
- 30 November 2018 (teleconference)

- 18 December 2019, Brisbane (including DAWE – Paul Hopkins)

Individual project agreements executed

Agreements were executed for sub-projects as below:

1) Development of an intelligent tool to allow real-time evaluation of harvesting practices as part of a framework for improved harvester payment systems (led by Norris ECT and Agtrix) – executed 27 June 2017 as Project 2016/951.
2) Understanding interactions between basecutters and other forward-feed components with the cane stalk, and determining practical strategies to minimise damage as harvester speed increases (led by Norris ECT and QUT) – executed 24 March 2017 as Project 2016/952.
3) Commercial-scale economic evaluation of post-harvest cane cleaning to maximise the returns to the supply chain (led by QDAF) – executed 3 May 2017 as Project 2016/953.
4) Sensors for improving harvester feedback: evaluation of suitability (led by SRA) – executed 8 February 2017 as Project 2016/954.
5) Adoption of practices to mitigate harvest losses (led by SRA) – executed 8 March 2017 as Project 2016/955.
6) Adoption of practices to mitigate harvest losses – Phase 2 (led by SRA) – executed 25 November 2019 as Project 2019/951.

Work had begun by the researchers involved in all these projects before agreements were finalised.

Program runs on time and within budget

Delays to the execution of agreements for all sub-projects, brought about by the need for research providers to scrutinise and, in some cases, seek variations to clauses and intellectual property tables in the standard SRA project agreements, had serious ramifications for the harvesting program, as the cane harvest runs from June-December; field activities not completed during the 2016 harvest season could not be re-started until the second half of 2017. SRA (Peter Samson) met with the Rural R&D for Profit team in Canberra on 14 January 2017 and presented a plan for the variation to the Activity Schedule to allow the project to achieve its objectives within budget but with a delayed completion date. A variation to the project end date to 1 May 2020, and with a re-balancing of some activities and expenditure, was approved by the Commonwealth on 11 September 2017. This variation included the additional cash contribution by SRA of $150,000 to replace funding that was originally offered but not delivered by Sugar Research Limited, and additional activity to replace some prior-funded work in the area of harvest-quality sensors and decision-support tools.

A draft Project Plan was submitted to DAWE at Milestone 1. Feedback received on 1 March 2017 was that a project schedule and risk assessment be included. Project schedules and risk assessments were included for both the overall program and each of the individual projects and the re-drafted Project Plan was presented and approved at the RMG meeting on 15 May 2017. Only two minor changes were proposed, to the methodology of the machinery project (2016/952) and to the background of the adoption project (2016/955) with greater emphasis on the need to promote belief in the reality and importance of harvest losses within the industry. The final Project Plan was submitted to DAWE at Milestone 2.

Several of the intended communications detailed in the Communications and Extension Plan that was provided at Milestone 2 had not been completed on time, for various reasons (SCHLOT Live not sufficiently developed, cane cleaning unit commissioning delayed, analysis of harvest optimisation activities incomplete) while several were brought forward (machinery modifications to improve harvester performance). A Communications and Extension Plan revised according to progress during the 2017 harvest season and expected progress in 2018 was re-submitted to DAWE at Milestone 3.

All milestone reports and financial statements have been delivered to the Commonwealth on time according to the Project Agreement and been accepted by DAWE.

Individual project outputs delivered

Individual project reports have been reviewed by the SRA Research Funding Unit as detailed in their individual milestone schedules and appropriate payments made to research providers.

Program delivers on its stated goals

Program focuses on industry benefits

Every project within the program has worked directly with sugarcane industry participants across the value chain and progress has been reviewed by the RMG. Practical outcomes have arisen from the program and economic analyses have been conducted, more details are provided below under Activities B3-B6.

Outcomes communicated to industry

Outcomes have been communicated as detailed below under Activity B3.

6.2.3 Activity B3. Communication and extension activities

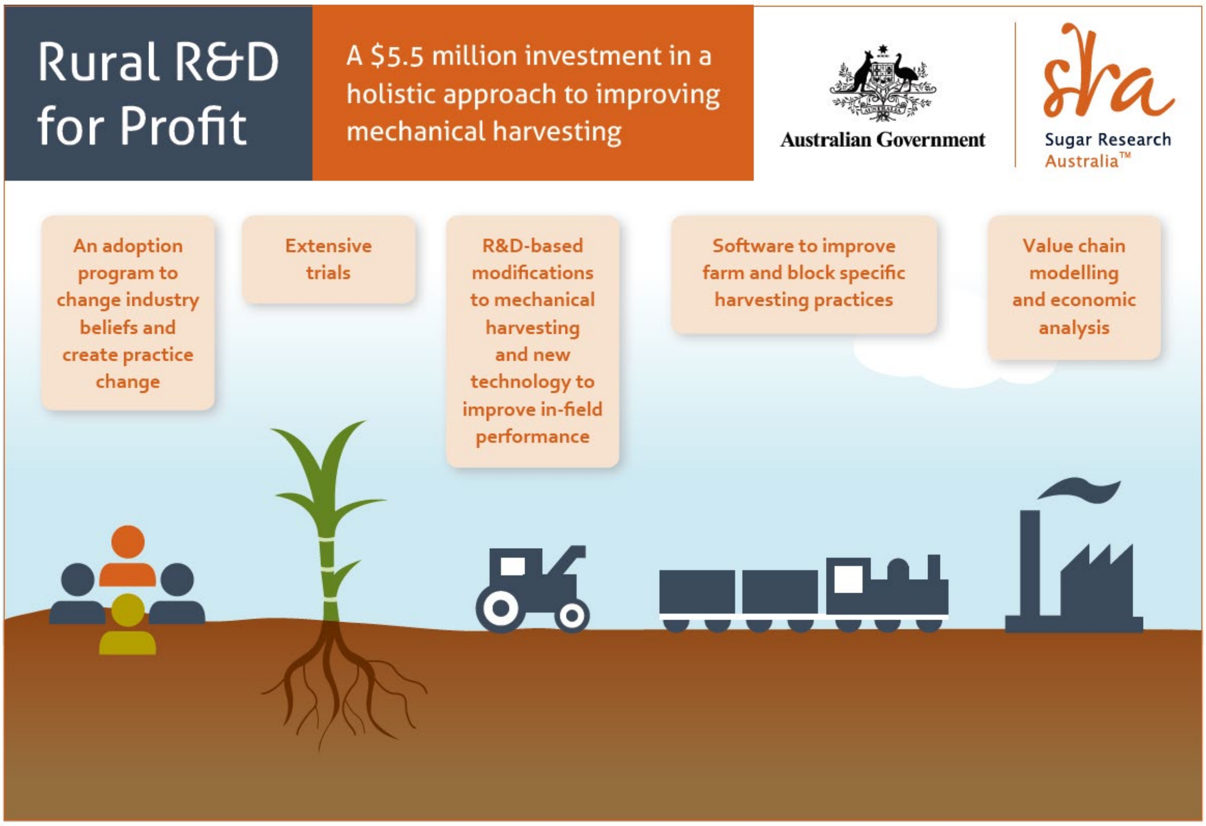
GOAL	*INFORM STAKEHOLDERS OF PROGRAM ACTIVITIES AND FACILITATE ADOPTION OF PROGRAM OUTPUTS*				
ACHIEVEMENT		**OBJECTIVES**	**KPI OR MEASURE**	**M&E METHOD YOU WILL USE TO GET THE DATA**	**ACHIEVED**
Outcome: Sugar industry productivity and profitability improved through adoption of improved harvesting technologies and practices	**Sugar industry informed of Program activities and aware of harvest-related issues**	• Deliver a communication program that enhances and supports the adoption of best practice harvesting outcomes. • Promote the activities of SRA and the various components of this project. • Leave a long-term legacy of communication material that can be used beyond the duration of this project.	• Communications delivered according to Communication and Extension Plan, including articles in CaneConnection, CaneClips, SRA eNewsletters and an access point on the SRA website. • Legacy materials developed, including a DVD compilation of Program videos and an updated Harvesting Best Practice Manual.	• Communications Plan checked off by Program Coordinator, RMG and SRA RFU.	Completed except for HBP Manual
	Benefits of Harvesting Best Practice and improved technologies demonstrated in practice	• Determine value of improved harvesting across whole value chain. • Encourage adoption of improved harvesting practices.	• Harvesting groups participated in trials in 2017 and 2018; target 10% of industry groups each year. • Economic analyses completed for each trial.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/955), with regular reports on achievement success to be reviewed by SRA RFU.	✓
	Harvester contractors/ operators provided information and training to improve industry performance.	• Develop and deliver workshop material for harvester operators.	• Materials developed for cooperating harvester groups and refined each year. • Annual harvesting forums held in each region. • Harvesting Best Practice Manual revised. • Workshops for harvesting contractors/operators run at project completion using new knowledge.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/955), with regular reports on achievement success to be reviewed by SRA RFU.	Completed except for HBP Manual and final workshops

Sugar industry informed of Program activities and aware of harvest related issues

Communications delivered

A media release on the new project was sent from SRA on 30 August 2016, together with articles in SRA publications, and an infographic was developed at the time of the announcement.

Media release - project initiation



A Communication and Extension Plan was developed by the SRA Communications group and provided to DAWE at Milestone 2.

Communication delivery vehicles included:

- the SRA magazine CaneConnection, which is sent as hard copy to all SRA members and industry stakeholders
- the SRA magazine MillingMatters, which is sent as hard copy to key milling stakeholders
- the SRA e-Newsletter, which is emailed to all SRA members and stakeholders
- CaneClips (videos), which are available on the SRA website
- The SRA e-Newsletter, which includes links to CaneConnection, Milling Matters and CaneClips

Legacy materials

A full list of extension materials is provided in Section 3.1.2. A DVD compilation of legacy materials has not been developed and is not considered necessary, all materials are available on the SRA website under 'Harvesting' at https://sugarresearch.com.au/growers-and-millers/farming-systems/.

The Harvesting Best Practice Manual has not been revised to this time. Two of the projects operating within the harvesting program that will contribute outcomes to the Manual, 'Harvester-cane interactions and strategies to minimise cane damage' and 'Adoption of practices to mitigate harvest losses – Phase 2', only finished on 1 April 2020. Revision of the HBP Manual is on the task list of the SRA Adoption Group and it will be done within the SRA core budget during 2020/21.

Benefits of Harvesting Best Practice and improved technologies demonstrated in practice

Harvesting groups participated in trials

A total of 95 harvesting groups were engaged through replicated trials in 2017 and 2018, and a further 14 in 2019 through projects 2016/955 and 2019/951. In addition, 12 growers from, another two groups were involved in large-scale demonstration trials in the Herbert River region in 2019. With a total of more than 100 engaged groups, this is close to 20% of the estimated number of groups in the industry (more than 600).

Economic analyses

Economic analyses were conducted for each trial and results presented to each harvesting group at a follow-up workshop. Figure 71 below show the economic analysis for just one of the more than 100 trials, from the point of view of the grower. In this case, by moving from the contractor's usual harvester operation in terms of ground and extractor fan speed to the recommended settings according to Harvesting Best Practice, the grower gained $267/ha in net revenue after deducting harvesting costs and levies. It will cost the contractor extra to harvest at HBP because of a lower ground speed, so there needs to be an agreement between grower and contractor to share the benefits.

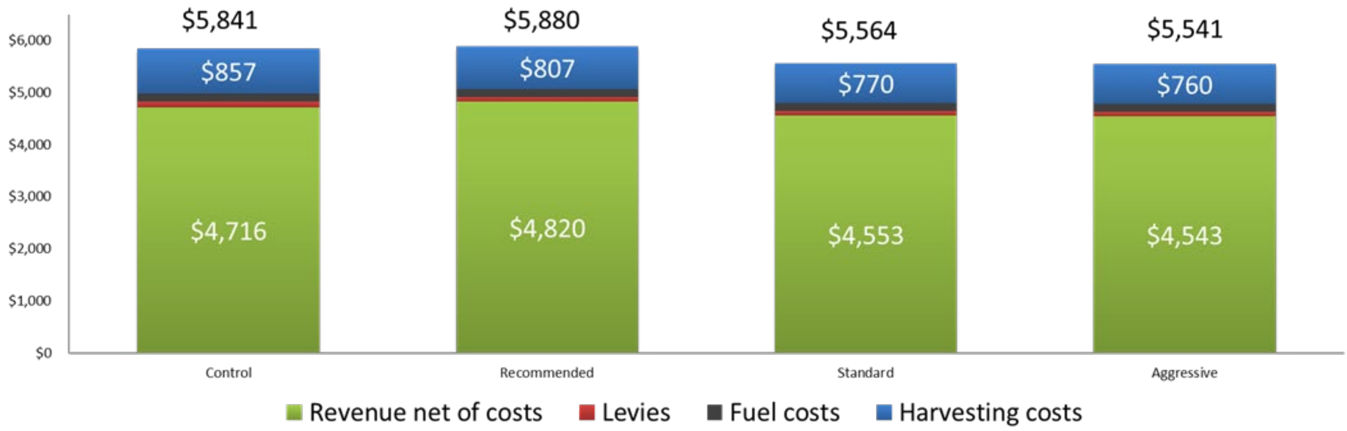


Figure71. Grower net revenue under different harvester operational settings – results from one demonstration trial

On average across the 95 trials in 2017 and 2018, increased cane and sugar yields generated by HBP increased grower gross revenue by $181/ha. Reduced ground speeds also increased the cost of harvesting by an average of $61/ha. This is a net benefit of $115/ha which, extrapolated across the Australian green-cane-harvested area, could deliver an additional value of over $69 M to the industry.

Harvester contractors/operators provided information and training to improve industry performance

Materials developed

Materials were developed for cooperating harvester groups, both individualised productivity and economic analyses as outlined above and generic HBP guides as provided to DAWE at Milestone 5 and available on the SRA website.

Annual forums

Annual forums were held to communicate project results to a wider audience across canegrowing regions. Details are provided in Section 3.1.2. Industry contact included 13 annual harvesting forums or briefings in 2018 reaching more than 400 participants, eight regional milling forums in 2018, and one milling forum and seven regional grower updates in 2019, together with a variety of presentations to industry stakeholder groups such as CANEGROWERS, boards of district productivity services, mill managers and mill cane supply and transport staff.

Harvesting Best Practice Manual and contractor/operator workshops

Contractor/operator education was embedded in the more than 100 demonstration trials conducted with harvesting groups during 2017-2019. As noted above, the Harvesting Best Practice Manual will be updated by SRA during 2020/21 and final workshops for contractors/operators will be designed around the revised Manual.

Progress towards the goal: *Inform stakeholders of program activities and facilitate the adoption of program outputs*

This work has delivered:

- Harvesting groups that have acknowledged the reality of harvest losses and that are working within the groups (growers and contractors) to minimise them
- Productivity evaluations from more than 100 demonstration trials evaluating sugar and cane loss from a suite of harvester settings, including Harvesting Best Practice
- Thirteen economic evaluations of HBP, nine of which estimated the harvesting cost change and the net benefit from using HBP instead of standard practice
- A proven methodology for bringing about practice change for HBP
- An economic model for detailed economic analysis of harvesting costs
- Key messages for HBP, including fact sheets and communication materials

Phil Patane and the SRA/DAF Harvesting Best Practice adoption team received the prestigious President's Medal for their contributions to research papers presented at the 2019 conference of the Australian Society of Sugar Cane Technologists.

Figure 72. The Harvesting Best Practice team (SRA and DAF) receiving the President's Medal at the 2019 conference of the ASSCT

6.2.4 Activity B4. Integrated loss-measuring tools and harvester telemetry systems

GOAL	DEVELOP TECHNOLOGY AND DECISION-SUPPORT TOOLS TO ENABLE INFORMED HARVESTING DECISIONS				
ACHIEVEMENT		**OBJECTIVES**	**KPI OR MEASURE**	**M&E METHOD YOU WILL USE TO GET THE DATA**	**ACHIEVED**
Outcome: Sugar industry productivity and profitability improved through harvesting decisions that benefit all sectors	**Real-time decision support tool developed, to enable informed harvesting decisions**	• Develop a web- or smartphone-based intelligent tool (Sugarcane Harvesting Logistics and Optimisation Tool, SCHLOT) to deliver real-time or near-real-time feedback on harvester performance.	• Cane loss algorithms developed using variety-specific industry data. • Decision-support tool integrated with harvester telemetry. • User interface developed in consultation with harvester operators. • Alternative payment systems evaluated for different harvesting scenarios.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/951), with regular reports on achievement success to be reviewed by SRA RFU.	✓
	Harvest-quality sensors identified to reduce crop losses and improve cane quality	• Undertake a feasibility study to identify the sensing opportunities most likely to improve sugarcane harvesting, including feasibility and likelihood of adoption.	• Sensing opportunities prioritised based on an industry survey and focus groups. • Feasibility study of sensors completed for each opportunity based on literature review and contact with suppliers. • Sub-set of sensors identified with potential to improve harvesting outcomes and that are feasible in the harvesting environment.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/954), with regular reports on achievement success to be reviewed by SRA RFU.	✓

Real-time decision support tool developed to enable informed harvesting decisions

Cane loss algorithms developed using variety-specific industry data

A decision-support tool named SCHLOT (Sugar Cane Harvesting Logistics and Optimisation Tool) was developed to provide real-time feedback to operators in the harvester cabin (SCHLOT Live). The cane-loss algorithms in SCHLOT Live use the diameter of the cane billets as one of the data inputs to predict the levels of cane loss that will result from different sensor values on the machine, which can be actual diameter in the field or average diameter of different varieties from industry data.

Decision-support tool integrated with harvester telemetry

On harvesters fitted with appropriate telemetry and software, cane loss can be categorised according to its conformation or not with HBP and displayed on a remote device. The online interface is an addition to Agtrix's existing online interface (Fig. 73).

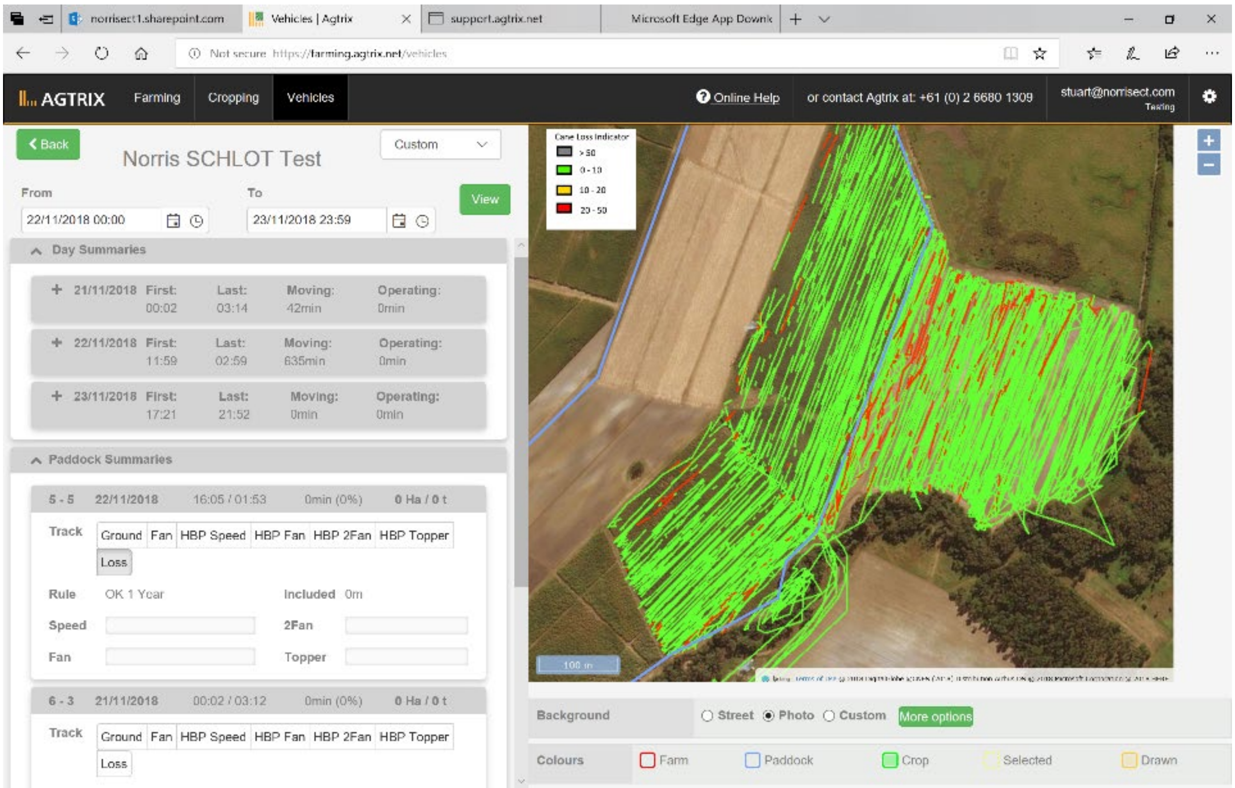


Figure 73. Agtrix display of harvester performance tracked across a field

User interface developed in consultation with harvester operators

The final interface improved on previous versions by being based on a higher specification in-cab display, with touch screen, hardwired USB interface (for updates and logging), additional analogue inputs and network/internet connectivity and updated firmware. It incorporated feedback from users of prototypes, as well as feedback received from potential users who had viewed the SRA CaneClip on SCHLOT Live. The navigation and physical appearance of the interface was improved to make it more user-friendly and intuitive, with estimated cane loss displayed as a simple rotary 'digital dial'.

Figure 74. SCHLOT Live in-cab display of estimated cane loss

Alternative payment systems evaluated

Extensive work was undertaken on the benefits and costs to HBP that apply to both growers and harvesting contractors. It has become clear that there is no simple answer to development of a payment system that will compensate and incentivise contractors to conform to HBP; in most situations it will increase their cost per hectare of cane harvested, but not all. Projects 2016/955 and 2019/951 have developed a very large data set of productivity and economic benefits and costs for different harvesting scenarios, by far the largest data set that has ever been developed in the Australian sugarcane industry. SRA's intention in 2020/21 is to mine that data set to determine the critical factors influencing the economics of cane harvesting, which are likely to included crop size, cane variety and crop condition, and develop a decision-support tool that will enable growers and contractors to negotiate an equitable payment for harvesting that is tailored to their individual circumstances.

Harvest quality sensors identified to reduce crop losses and improve cane quality

Sensing opportunities prioritised

A feasibility study was conducted through literature review, industry-wide paper and online surveys, consultation with industry experts and researchers, consultation with industry service providers (growers, contractors and millers), harvesting manufacturers, sensor manufacturers and method specialists. Ultimately, industry prioritised the following quality and loss pathways: (1) extractor losses, (2) basecutter quality (height control), and (3) cane supply quality.

Feasibility study completed

All sensors considered for use in the harvesting environment must be insensitive to or protected from vibration, moisture and dust. Resolution and speed of data collection varies depending in the instrument and will need to be considered in testing. Spectral imaging, proximal NIR spectroscopy and radar technologies were favoured solutions. Spectral imaging and radar techniques are better equipped to deal with sample heterogeneity due to their large sampling area. Direct spectroscopic applications are susceptible to presentation issues, as particle size, compression and composition all affect the scattering properties of the sample, but this can be overcome by user training and increased sampling frequency if sample preparation processes are to be avoided.

Sub-set of sensors identified to improve harvesting outcomes

Outputs can be used by researchers to define new projects that will test and develop the proposed sensing systems in the field. Specific research groups capable of continuing these activities were consulted during this project. Although no further development of these sensors was undertaken within project 15-02-020, SRA has since contracted work with the University of Southern Queensland to test some sensors in proof-of-concept field trials.

Progress towards goal: *Develop technology and decision-support tools to enable informed harvesting decisions*

This work has delivered:

- A compilation and critical review of past research on the use of sensors in the harvesting environment
- A feasibility study evaluating sensors for improved harvesting feedback
- A concise course of action for future research regarding sensors in the harvesting environment that includes sensor techniques viable for efficacy testing, pathways suitable for testing and proposed sampling points.
- A decision-support tool that provides real-time feedback to the operator in the cab and that facilitates adoption of Harvesting Best Practice and delivery of the associated industry benefits
- A tool that can provide real-time and historic information to other harvest stakeholders via the ‘cloud’

Commercialisation discussions for the decision-support tool SCHLOT Live are underway to ensure that this system is made available to the Australian sugarcane industry.

6.2.5 Activity B5 Machinery modifications to minimise crop damage

GOAL	*DEVELOP MACHINERY MODIFICATIONS THAT REDUCE CROP DAMAGE*				
ACHIEVEMENT		**AIMS**	**KPI OR MEASURE**	**M&E METHOD YOU WILL USE TO GET THE DATA**	**ACHIEVED**
Outcome: develop machinery modifications that reduce the rate of ratoon yield decline associated with current harvesting practices	**Harvester design and operation modified to reduce cane damage**	• Develop and validate improved harvester front end and basecutter designs and operation. •	• Harvesters (four in total) modified to link speed of components with harvester forward speed. • Components redesigned according to empirical tests or outputs of dynamic modelling. • All modifications validated by field testing in comparison with standard machines.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/952), with regular reports on achievement success to be reviewed by SRA RFU.	✓
	Fundamental understanding of the effect of the harvester on cane stalks	• Develop a dynamic model that can be used to inform harvester design and operation.	• Database of cane properties developed for modelling. • Dynamic model developed for interaction between harvester front-end components and basecutters, and cane stalks. • Model used to develop new machinery designs.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/952), with regular reports on achievement success to be reviewed by SRA RFU.	Achieved except for use of model to develop new designs
	Machinery modifications adopted and/or made available commercially.	• Demonstrate to industry and commercial companies the benefit of successful modifications	• Develop information packages and conduct extension activities. • Engage manufacturers to commercialise modified components and control systems.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/952), with regular reports on achievement success to be reviewed by SRA RFU.	Achieved except for commercial development

Harvester design and operation modified to reduce cane damage

Four harvesters modified

In a standard harvester, the rotational speed of the basecutters and forward-feed components is constant, irrespective of harvester ground speed. Modifications were developed to hydraulic systems, motors, electronic controls and software to allow speeds of the basecutters and forward-feed components to be varied during operation, with the intent of assessing whether matching (or mismatching) of speed with harvester ground speed affected the quality of the harvesting job. Modifications were made to JD 3520 harvesters in New South Wales (Condong) and in Queensland at Rocky Point, Childers and Ingham, and to a Case 8000 machine in the Burdekin region.

Components redesigned

A variety of machinery modifications were required to link front-end rotational speeds to harvester ground speed. These included changes to basecutter drive motors, hydraulic systems, control systems to basecutter motors and hydraulic pumps, control systems for gathering and forward-feed components, and control software. One machine (at Rocky Point) was also fitted with modified spirals developed by EHS Manufacturing in Mackay. The spirals had a “double start” design of the flights, with the pitch modified to give a design rotational speed of 16 rpm/kph forward speed. A new control system and software was fitted to accurately maintain this forward speed relationship. After the 2018 harvest season, the front end of the harvester was modified to reduce the knockdown effect by moving the lower feed roller position. Full details of these modifications and re-designs are supplied in the final report of SRA Project 2016/952.

Modifications validated

The project demonstrated that front-end damage is a real issue for the sugarcane industry, with potential gains from reduced front-end damage to the harvested crop being in the order of 15% in ratoon yield. This demonstrably also impacts on economic ratoon cycle life, with financial and environmental implications. The project also identified that simply reducing harvester speed is not a viable solution to stool damage with standard harvester configurations, as little benefit accrued in field trials. However, lower harvesting speeds in conjunction with component speeds matched to groundspeed both improved machine functionality in larger crops and reduced damage to the crop stool. Modifications to gathering spiral design in conjunction with matching of component speeds to groundspeed in an optimal relationship offers the capacity to harvest larger crops unburned at commercially viable speeds and reduce billet damage.

In 2018, very substantial damage to cane stools from the knockdown roller was measured consistently in field trials. Alleviation of this source of damage was not an objective of the current project but is an opportunity for future R&D.

Fundamental understanding of the effect of the harvester on cane stalks

Database of cane properties developed

Cane material property data available or derived from the literature suitable for direct use in the Finite Element Model were collated. Some material properties relevant to the model which had not been measured for cane were collated from the literature on other crops such as bamboo, energy cane and reed. These additional properties included compressive strength, tensile strength and breaking strength. Material property values are provided in the final report of SRA Project 2016/952.

Dynamic model developed

A dynamic model of the interaction between cane stalks and the harvester front end was developed using Finite Element Analysis rather than Dynamic Element Modelling as had been originally proposed. Both methods were assessed, various commercial software options were evaluated, and a review of their practical applications was undertaken, and a decision was reached to proceed with the FEA method. The modelling component of the project introduced the LS-DYNA structural analysis software into the Australian sugar industry in a first application. The software has capabilities not seen before in other structural software, and in a single well-integrated package. In particular, it has the ability to model in real time a relatively fast process in which there are large strains, damage, failure, contact and friction, in geometrically complicated moving and rotating equipment.

A model was developed describing the progress of five cane stalks through the harvester for various settings of basecutter thickness, sharpness and incline angle, position of the knockdown roller and angle of the gathering spirals. Qualitatively, the model predictions of stool damage match what was observed in field trials.

Model used to develop new designs

The model developed using the LS-DYNA software has the capability to combine modifications and predict likely results, minimising the need for physical manufacture of prototypes. However, due to delays in project inception noted above and particularly the lack of a proposed PhD student who was to be dedicated to the project (see below), new designs were not developed or tested based on the modelling results.

Machinery modifications adopted and/or made available commercially

Develop information packages and conduct extension activities

Industry engagement during the course of the project was regular feedback to the Research Management Group, regular communication with the SRA Harvesting Adoption group, and annual attendance at the SRA Harvesting forums. Further, the project required ongoing collaboration with a number of industry participants (growers, mills and harvesters), who had ongoing visibility of project developments.

Engage manufacturers

The combination of further development of modelling of machine-cane interactions and physical trials with modified machines offers the potential to develop retro-fit modifications to machines which can both significantly reduce the current damage levels to the crop and improve machine functional performance. However, while the modifications undertaken to the machines for the trials to match forward speed and rotational speed of key components did improve machine operational performance, particularly in larger crops, only limited positive impact on damage and subsequent yield was noted. Hence there is a limited business case for commercialisation of these modifications. More significant machine modifications did reduce damage, but further development would be necessary before such modifications could be commercialised.

Progress towards goal: *Develop machinery modifications that reduce crop damage*

Much of the modelling of cane–harvester interactions was to have been undertaken by a PhD student at QUT, but a suitable student could not be identified. Delay in appointing a student required an extension of this project's term to March 2020. Work was progressed by QUT staff and an external consultant and a sophisticated model was developed, but delays prevented the work being progressed to the point of designing and constructing components based on model outputs.

The key industry messages from this work are that:

- The interactions between the gathering, feeding and basecutting components in a modern sugarcane harvester are responsible for significant levels of damage to both the harvested stalk and the crop stool, under all harvesting scenarios investigated.
- Adjusting the rotational speed of these machine components had limited impact on the level of damage to both billets and the stool, although some benefits were noted relating to evenness of feed and ability to harvest larger crops.
- The high levels of damage are primarily associated with the configuration of the key harvester components, as approximately half of the observed damage related to the aggressive manipulation of the crop prior to the basecutting function.
- Changing operating parameters alone had little impact on observed damage, or on subsequent yield.
- Reducing stool loss and stool damage by eliminating the damage associated with the gathering and knockdown functions resulted in lower ratoon shoot numbers but higher total biomass accumulation, higher pre-harvest counts of millable stool and higher yield.
- The re-design of the front end of the harvester to minimise damage during the harvesting operation appears likely to offer potential ratoon yield increases of > 10%. Such a modification is a one-off, not a recurring cost.

The developments that have contributed to this overall output include:

- Computational modelling (FEM) that has facilitated a greater understanding of the exact mechanisms that cause the damage observed in field trials; and
- A series of field trials over multiple ratoons with modified harvesters that have generated a significant body of data on the impact of modern harvester components on future yields.

6.2.6 Activity B6 Commercial scale evaluation of post-harvest cane cleaning

GOAL	*IMPROVE INDUSTRY HARVESTING OUTCOMES BY POST-HARVEST CANE CLEANING*				
ACHIEVEMENT		**AIMS**	**KPI OR MEASURE**	**M&E METHOD YOU WILL USE TO GET THE DATA**	**ACHIEVED**
Outcome: Quantify potential industry gains through 'low-loss' harvesting in combination with post-harvest cane cleaning	**Industry harvesting practices modified to reduce cane loss**	• Demonstrate the industry gains from 'low-loss' harvesting.	• Commercial-sized in-field cane cleaning plant commissioned. • Cane losses due to conventional harvesting compared with 'low-loss' harvesting (minimal cane cleaning performed by the harvester) demonstrated on multiple farms.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/953), with regular reports on achievement success to be reviewed by SRA RFU.	✓
	Post-harvest cane-cleaning evaluated as an enabler of 'low-loss' harvesting without sacrificing cane quality	• Evaluate the economics of post-harvest cane-cleaning in combination with 'low-loss' harvesting.	• Whole-of-value-chain trials conducted (Tableland Mill). • Economic analysis conducted for demonstration and whole-of-value-chain trials.	• KPIs are Milestones and/or Achievement Criteria in the agreement with research provider (SRA Project 2016/953), with regular reports on achievement success to be reviewed by SRA RFU	Achieved except for whole-of-value-chain trial at Tableland Mill

Industry harvesting practices modified to reduce cane loss

Commercial-sized in-field cane cleaning plant commissioned

A mobile cane cleaning plant MCC 180 was constructed by Norris ECT and delivered to DAF in Bundaberg in early 2017. This plant has a nominal throughput of 180 t/h, although this flow rate depends on the trash content of the cane. A safety audit was undertaken, some equipment modifications were made, and an Operating and Maintenance Manual and a set of Safe Work Procedures were developed before use in the 2017 harvest season; these were provided to DAWE at Milestone 3. Additional modifications were made during the harvest off-season to improve cleaning performance before the plant was moved to the Atherton Tableland before the 2018 harvest season.

Cane losses due to conventional harvesting compared with 'low-loss' harvesting

Four series of tests were completed in southern Queensland in 2017. The analysis of results revealed very few statistically significant differences between the different cane supply strategies, mainly due to the small number of tests completed. Two preliminary experiments and three large experiments were conducted on the Atherton Tablelands in 2018. The main objective of the experiments was to determine the change in sugar yield that could be achieved by changes to harvesting parameters (principally extractor fan speed), with and without cane cleaning. As a basic concept, it was expected that reducing extractor fan speed would reduce cane loss, resulting in increased sugar yield but also increased trash content, and that the post-harvest cane cleaning operation would remove the additional trash, maintaining the higher sugar yield. The results did support the expectation of higher sugar yield with lower extractor fan speed, but much of the higher yield measured by low loss harvesting was lost after post-harvest cane cleaning.

Evaluate the economics of post-harvest cane-cleaning in combination with 'low-loss' harvesting

Whole-of-value-chain trials conducted

The ultimate plan for the cane cleaning trials was for MSF Sugar's Tablelands mill and associated farm infrastructure to implement project outputs across their whole operation for an extended period: manage harvester operations, manage logistics, use post-harvest cane cleaning, mill the cane and make sugar, to enable a comprehensive evaluation of the cost and benefits of post-harvest cane cleaning across the value chain. Intensive replicated trials were conducted on the MSF Tableland farm during 2018 with a total of 50 replicated measurements for each harvesting scenario. These trials required a large time input from MSF staff. However, the trials did not demonstrate a significant improvement in cane quantity delivered to the mill and showed only a small improvement in cane quality (lower extraneous matter). As a result, MSF management was not willing to commit further time to evaluate it within their normal field operations.

Economic analysis conducted

An economic analysis was undertaken on the three large Tableland experiments to assess the most economically attractive harvesting and cane cleaning strategy of the three strategies tested. The analysis considered costs associated with harvest and haulouts, transport, trash and cane cleaner operation, along with gross income based on tonnes of cane and CCS at the factory. In all three experiments, the treatment with post-harvest cane cleaning was found to be less attractive than the harvest only treatments. On one of the farms, this result was achieved even taking into account the lower transport cost in getting cane to Mossman Mill, a distance of 95 km.

Progress towards goal: *Improve industry harvesting outcomes by post-harvest cane cleaning*

The mobile cane cleaning plant that was constructed for this project required safety auditing, development of standard operational procedures, and some modifications to improve performance, before it could be used during the 2017 harvest season. Consequently, limited data was collected from the 2017 trials conducted in southern Queensland.

Further modifications were made to the cleaning plant after the 2017 harvest, particularly to the cleaning chamber, before it was moved to the Atherton Tableland.

Intensive testing was done on the Tableland during the 2018 harvest season. Results did not demonstrate the expected productivity or economic benefit and did not encourage MSF Sugar to proceed with planned whole-of-factory testing.

However, the conclusion reached, that the combination of low-loss harvesting plus post-harvest cane did not deliver an economic benefit, should be tempered by several factors:

- There was a measurable loss of cane from the cane cleaning plant
- Trials were conducted in only two sugarcane varieties, Q208 and KQ228, both of which would be considered low-loss varieties (i.e. losses are low during normal harvesting compared to some other varieties), and detailed results were obtained for only one region (Atherton Tableland)
- The extracted trash was included in the analysis as a cost, i.e. the cost of baling for removal, rather than as a potential additional revenue stream, e.g. for co-generation of electricity

Therefore, there is potential for further investigation of post-harvest cane-cleaning, using the existing cane cleaning plant possibly with further modifications to improve its performance.

6.2.7 Progress towards achievement of project outcomes

Project Outcomes as listed in the Project Plan are:

- A shared industry acceptance that harvest losses should be addressed and that harvest practices should be improved
- Reduced cane loss and improved cane and sugar quality as a result of improved harvesting practices
- Equitable sharing of the costs and benefits of changed harvesting practices across the value chain

with the following deliverables:

1) A 'next generation' intelligent tool for the harvesting sector which will allow more informed decision making
2) Recommendations for improved front-end harvester design to reduce stool damage and cane loss
3) Economic data to determine the whole-of-industry effect of different harvesting and cane-cleaning practices
4) A non-pneumatic cane cleaning unit, if initial proof-of-concept is positive
5) A feasibility study evaluating sensors for improved harvesting feedback and a course of action for future research to develop effective measurement products
6) A concerted adoption program to change industry beliefs and begin a process of substantive practice change

Most of the listed deliverables have been delivered. The exception is the non-pneumatic cane cleaning unit 4), which was investigated by QUT in a proof-of-concept project funded by SRA outside of 15-02-020. Although a small scale (20 t/h) unit was built and tested, a pilot-scale unit was not constructed due to the withdrawal of the commercial sugar industry partner, although the design and expected performance of such a unit was reported. This did not affect deliverable 3) which used a conventional pneumatic (air blast) cleaning unit to evaluate economics of post-harvest cleaning. However, due to the late start of the cane-cleaning project (2016/953) and teething problems with the cleaning plant, economic data is not sufficient for industry to assess whether this is an economic strategy in all situations or regions, particularly for cane varieties that are not considered ‘low loss’ or where harvesting procedures deviate substantially from HBP. R&D on machinery improvements indicates that there are potential modifications, particularly around design of knockdown rollers and the cleaning chamber, that are not currently being addressed.

The meeting of the project Research Management Group in December 2020 included additional industry and research participants and began the development of a sugarcane harvesting program that will continue and expand on work conducted in 15-02-020. The project has delivered significant advances in technologies and practices to reduce sugarcane harvest losses; take up of Harvesting Best Practice has been particularly strong. The sugarcane industry will continue to invest in harvesting RD&A in order to obtain maximum value from the sugarcane crop.

6.3 Budget

Financial statements shows all three projects delivered within budget