FINAL REPORT 2016/955

Adoption of practices to mitigate harvest losses

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ABSTRACT

Harvesting Best Practice (HBP) is predicated by two essential objectives:

1. Determining the critical point where harvesting losses can be minimised and delivered yields improved to achieve the best economic return for the grower and harvesting operation; and
2. Improved cane quality, which is determined by sound billet quality with an acceptable level of Extraneous Matter (EM).

Despite significant research into the impact on harvested cane yields of higher harvester pour rates and fan speeds, use of HBP recommendations prior to the commencement of the adoption program across the industry was relatively low. Full HBP adoption across the Australian Sugarcane industry could substantially increase industry revenue with no necessity for horizontal expansion (increase in cane land).

In order to educate industry of the significant yield gains, 95 replicated harvesting trials and workshops were undertaken in the 2017 and 2018 harvest seasons across 12 sugarcane regions between Harwood and Mossman. The performance of settings recommended by HBP was compared with each harvesting operation's standard practice by assessing yield, CCS, bin mass, extraneous matter (EM), fibre, sugar loss and revenue. To highlight the strong relationship between cane loss and excessive pour rates and fan speeds, treatments with higher pour rates and fan speeds 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. Cane loss, production and revenue data from the fully replicated and randomised trials were analysed to identify differences between industry standard harvesting practices and those recommended by HBP.

Project learnings suggest that harvesters are typically operated at ground and fan speeds that are on average 0.9 km/hr and 95 rpm above those recommended under HBP parameters. The higher ground speed delivered an additional 21 t/hr of cane into the machine on average, which overloaded the cleaning capacity of the harvester. Consequently, fan speeds are increased to remove the additional EM entering the machine, which unfortunately removes additional cane through the extractor. This cane usually disintegrates in the process, making it invisible to the naked eye.

The trial process indicates the average sugar loss out of the extractor increases by 0.15 t/ha when compared with HBP settings. However, there is no significant improvement in EM or bin mass. As a result of cane loss through the extractor, less cane per hectare is delivered to the mill. Mill analysis across all trials identified cane and sugar yields for the recommended practice were 4.9 t/ha (cane yield) and 0.7 t/ha (sugar yield) higher than standard practice. Neither CCS nor fibre levels were significantly different. Reduced pour rates (i.e. lower ground speeds) also increased the cost of harvesting. To improve adoption rates, growers would need to consider compensating contractors for these additional costs. The increased cane and sugar yields generated by the recommended practice implies an increase to grower gross revenue of $181/ha. Reduced ground speeds also increased the cost of harvesting by $61/ha. To incentivise the move to HBP, additional compensation would need to be paid to harvesting contractors by growers. Subtracting the additional harvesting costs (including fuel and levies) from the additional grower revenue leaves a net benefit of $115/ha for the grower. Extrapolating these findings across the Australian green-cane-harvested area, full adoption of the recommended practices could deliver an additional 1.2 million tonnes of cane and 164 thousand tonnes of sugar valued at over $69 million for industry.

EXECUTIVE SUMMARY

Research dating back to the 1990s substantiates the significant gains to the sugar industry value chain when cane is harvested within Harvesting Best Practice 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 resulting in juice loss through increased cuts per stalk.

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.

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). In order to address these constraining forces, growers, contractors and millers must work together.

To gain adoption of HBP, milling companies require further support to fully investigate the impact on logistics, cane quality and sugar production. It is anticipated that the delivery of cane and cane-quality must be monitored to determine the effect (if any) on milling processing requirements.

Regional working groups comprising of representatives from all three sectors of the value chain are needed to support the implementation of economically beneficial HBP and limit or reduce the constraining forces in adopting HBP parameters.

In July 2016, Sugar Research Australia (SRA) commenced a major research, development and adoption program to improve the efficiency of the Australian sugarcane harvesting sector and address the issues previously outlined. The project, *Enhancing the sugar industry value chain by addressing mechanical harvest losses through research, technology, and adoption*, comprised significant contributions from the Queensland Department of Agriculture and Fisheries (DAF), other industry advisory bodies, milling companies, harvester operators and growers. Total investment in the project comprised $3.55 million from the Australian Government (Department of Agriculture) and $1.85 million from SRA. SRA Project 2016/955, *Adoption of practices to mitigate harvest losses*, formed part of this wider project.

Project 2016/955 engaged approximately 10% of harvesting groups in 2017 (43 groups- excluding burnt-cane regions) and another 10% in the 2018 season (including burnt-cane regions). Each group participated in a demonstration trial to determine the impact of harvesting operations on cane and sugar loss. Trials were conducted by SRA using the Infield Sucrose Loss Measurement System (ISLMS) together with 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, and amounts of sugar and biomass left in the field.

Harvesting costs were evaluated for nine of the 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.

On average across nine trials, harvesting costs were estimated to increase by $61/ha from use of HBP. The cost change per tonne was sensitive to the cane yield improvement. While harvester setting changes for the nine trials resembled those across all trials, the average cane yield improvement from using HBP was larger; 6.7% across the nine trials compared to 5.2% across all trials. Costs were estimated to increase by 10c/t with a 6.7% yield increase and 22c/t with a 5.2% yield increase. This included harvester and haulout costs to the siding but not any rail/road transport or milling costs.

Results from the green cane trials showed that reducing flow rate by 21 tonnes/hr (ground speed by 0.9 km/hr) and primary extractor fan speed by 95 rpm increased cane and sugar yield by 4.9 t/ha (5.2%) and 0.7 t/ha (5.0%) respectively. This translated into an increase in grower gross revenue of $181/ha (4.8%). As mentioned, initial costings indicate this would increase harvesting costs by an estimated $61/ha, excluding any additional incentive payments to the contractor. Preliminary results in burnt cane indicate an improvement of $207/ha in grower gross revenue with lower fuel costs for the contractor through reduced primary extractor fan speeds under good burn conditions. Further research is needed to validate these results. Based on the green cane results, full adoption of HBP could improve annual industry revenue by $44 million for growers at an additional cost of $17 million for harvesting (excluding incentives). Milling revenue would also improve by $25 million per annum but this does not account for additional milling or transport costs.

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1. BACKGROUND

Historically, the benefits of Harvesting Best Practice (HBP) have been extensively promoted to the Australian sugar industry. Research in the 1970s identified substantial losses of both cane and sugar from mechanical harvesting, particularly in green-cane harvesting. Hurney *et al.* (1984) identified cleaning losses of 5-8 t/ha in burnt cane, while Ridge and Dick (1988) analysed a wide range of losses relative to harvesting practice, field conditions, varieties and time of harvest. Linedale and Ridge (1996) reported on a "successful campaign to minimise harvesting losses" over the period 1992 to 1995. Agnew *et al.* (2002) conducted a series of comprehensive trials and workshops from 1997 to 1999, supervised by Whiteing and Paton (2002). These harvesting trials (approximately 50 in total) investigated the impact of pour rate and fan speed on cane loss and cane quality. Key findings included:

- Harvester cane loss is strongly correlated to extractor fan speed;
- Extraneous Matter (EM) is influenced by harvester pour rate and field conditions.

These findings informed the BSES Harvesting Best Practice Manual for Chopper-Extractor Harvesters (Sandell and Agnew, 2002), which was updated in 2014 by Sugar Research Australia. Industry interest in harvesting losses regained focus in 2013 with a value chain analysis of the industry prepared by John Pollock (Pollock, 2013), which demonstrated the beneficial impact of adopting HBP across the entire industry. Larsen *et al.* (2017) highlighted that the profitability of the growing, harvesting and milling sectors is intrinsically linked to the material produced by the harvester operation. The fundamental issue has been finding a balance between minimising cane and sugar loss, maintaining cane quality and optimising throughput to manage harvesting costs (Sugar Research Australia, 2014). Sources of cane loss in the harvesting process include gathering and pick-up losses (1-10% of weight), chopper loss (2-8% of weight) and primary and secondary extractor loss (5-25% of weight). Primary extractor loss is the greatest source of loss (Agnew *et al.* 2002).

Past research has identified that using HBP settings can minimise cane loss and stool damage, which increases the amount of revenue obtained by growers and the wider industry. However, using HBP settings generally entails reducing ground speeds below those commonly used by industry, which increases the amount of time spent harvesting and, in turn, increases harvesting costs per hectare. The key issue for growers and industry is how these higher revenues compare against the additional harvesting costs, and whether there is sufficient benefit to encourage HBP adoption.

Past published research has examined the additional revenue obtainable by adopting HBP (Agnew *et al.*, 2002; Sugar Research Australia, 2014). Previous models have also been developed to estimate changes in harvesting costs (Ridge and Powell, 1998; Antony *et al.*, 2003; Sandell and Prestwidge, 2004). However, there has been limited research to evaluate the full harvesting cost implications (e.g. the full array of costs including depreciation, R&M, fuel, etc.) of HBP adoption on a broad scale (across multiple sites) using detailed harvesting cost information specific to each harvesting contractor (Nothard *et al.*, 2019). This paper builds upon this methodology by quantifying both the harvesting costs and additional revenue from nine replicated harvesting trials to evaluate the net economic benefit from using harvester ground and fan speeds recommended (based on HBP) by SRA.

Despite past research, when the current project commenced in 2016 there was little evidence that HBP was adopted in the industry and incentive-based schemes for contractors were not prevalent. Deterioration in many parameters of cane quality was noted by Larsen *et al.* (2016). Keeffe (2017) conducted a survey of harvester operators and growers, seeking their views on the need for, and impact of, improvements to harvesting equipment. Participants (harvester operators and growers) who responded to the survey reported the following:

- 42% of contractors felt growers were not providing the best possible conditions to harvest their cane;
- 33% of growers felt their contractor was not providing the best possible harvesting service.

The reasons for slow uptake of HBP are complex, however, and include.

1. Lack of recognition of the scale of losses and opportunity to minimise them through improved practices. It has been stated that current machines are very good at disguising the "evidence" of harvesting losses. It is important that losses are rephrased as "yield gains" in order to avoid the assumption that it is harvest operators' poor performance that results in yield losses.
2. Harvester owner expectations that there will be extra harvesting costs from changes to practice and a perceived inability to recoup them.
3. Lack of communication between the harvester operator and the farmers in the group concerning HBP.
4. Pressures on harvesting groups to harvest at high product flow rates to ensure bin allotments are filled and area is covered.
5. The concern that large contracts, which already need to harvest over a significant part of the working day, do not allow for lower product flow rates.
6. Pressure to maximise bin weights, leading to a perceived need to shorten billet lengths in an effort to increase bulk density.
7. Concern that reducing fan speed would lead to an increase in EM and a subsequent loss of CCS.

Overcoming these issues needed a different approach. With some exceptions, past efforts to reduce losses had 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.

The harvesting adoption project '*Adoption of practices to mitigate harvest losses*' was initiated in 2016 and commenced demonstration trials and workshops in the 2017 season. Uncertainty around burnt cane trial methodology restricted trials being undertaken in burnt-cane regions (Burdekin and NSW) until the 2018 season. The project aimed to undertake trials and workshops with approximately 10% of all harvesting groups in each area covered in 2017 and 2018.

2. PROJECT OBJECTIVES

The key project objectives include the following:

- To work closely with at least 10% of harvesting groups in the industry year on year to demonstrate losses in cane harvesting for each group and assist with decision support regarding an appropriate practice change response to capture additional value.

- By the end of the project (2019 off season) 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:
    - At least 70% of harvester operators and 50% of growers aware of these outcomes;
    - Structures in place to continue to promote and motivate change in harvesting practice;
    - Provide timely advice to harvester groups of outcomes of "Equipment" and "Tools" projects.
- 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.

3. OUTPUTS, OUTCOMES AND IMPLICATIONS

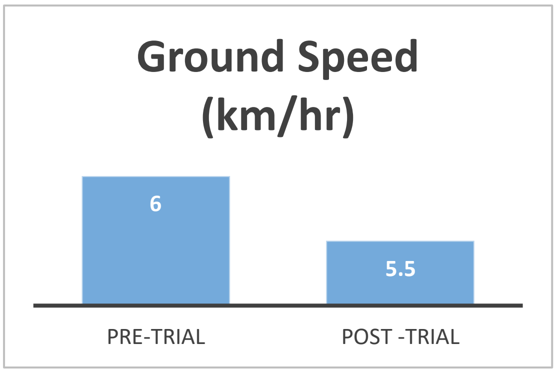
3.1. Outputs

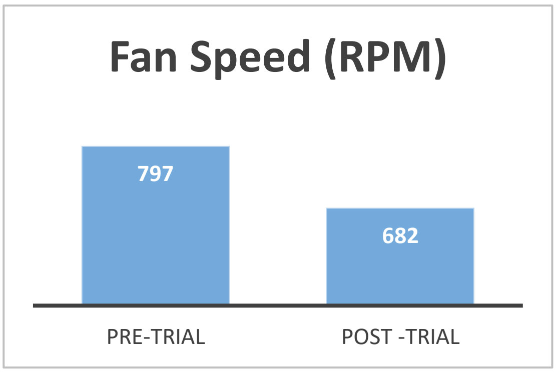
1) Harvesting groups that have acknowledged the reality of harvest losses and that are working within the groups (growers and contractors) to minimise them.
2) Productivity evaluations from 95 demonstration trials evaluating sugar and cane loss from a suite of harvester settings, including HBP.
3) Thirteen economic evaluations of HBP, nine of which estimated the harvesting cost change and net benefit from using HBP instead of standard practice.
4) A proven methodology for bringing about practice change for HBP.
5) An economic model for detailed economic analysis of harvesting costs.
6) Key messages for HBP, including fact sheets and communication materials (see Section 4.1).

3.2. Outcomes and Implications

Outcomes for engaged harvesting groups

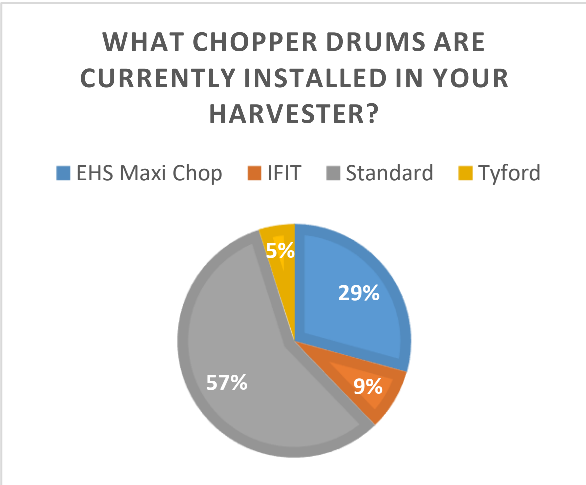
After completion of the program there has been a reduction in ground speed and fan speed by the contractor groups involved, with the expected benefit of reduced cane loss.



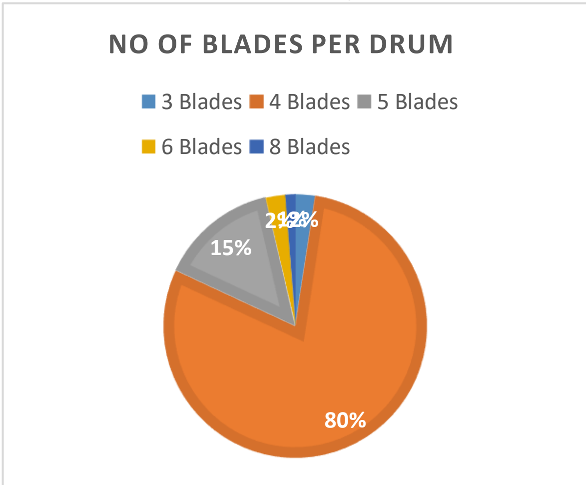


Since the completion of the program, there have been more low-loss chopper drums installed (see graph below) by harvesting contractor groups involved in the program. Simultaneously, there has been a reduction in average number of blades per chopper drums with an expected reduction in chopper losses due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

Chopper drums

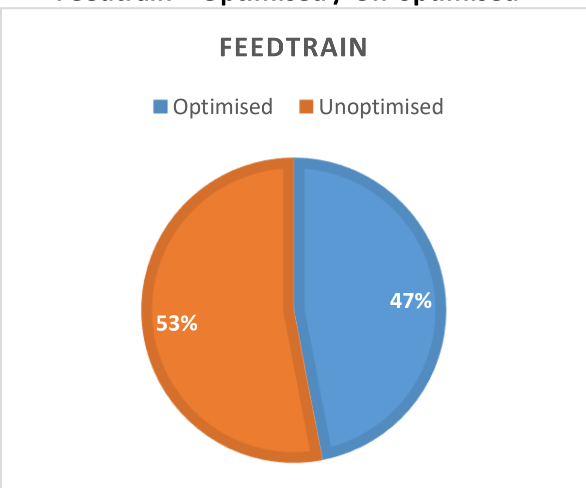


Number of blades per drum

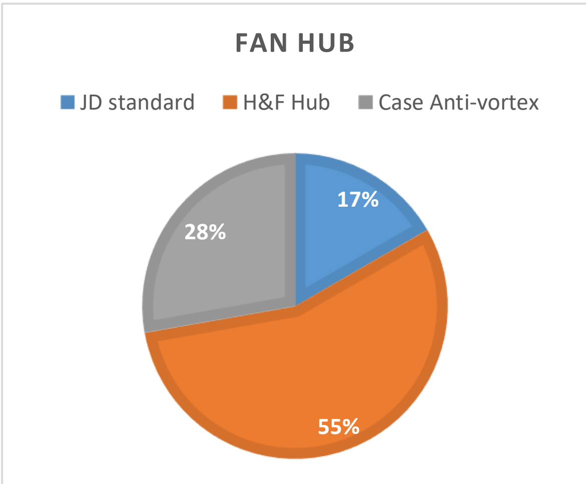


Before the program commenced, there were a limited number of optimised feedtrains on participant's harvesters. There is now an increased awareness of the value of machinery modifications (see graphs below).

Feedtrain – Optimised / Un-optimised

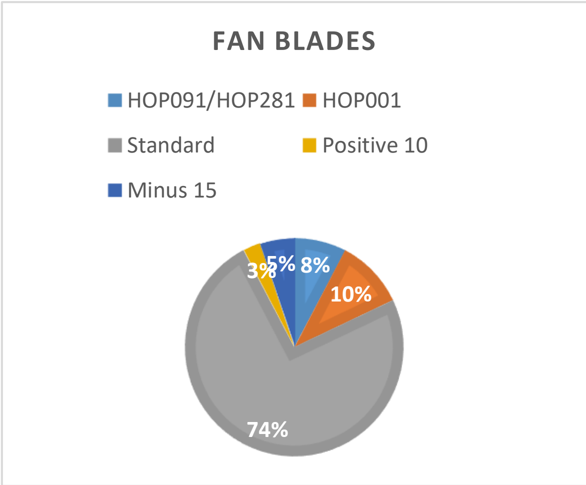


Fan Hub

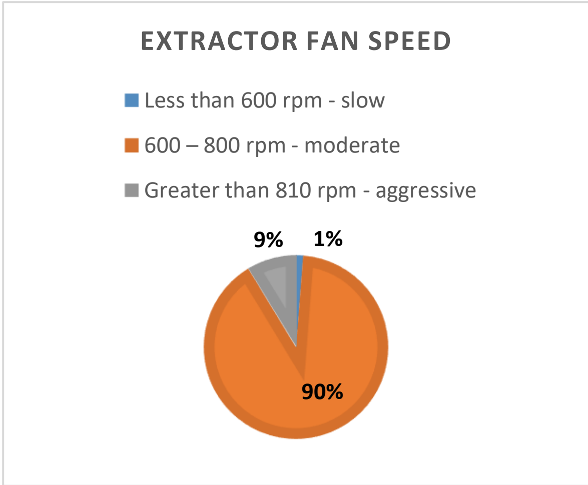


There has been an increase in moderate fan speeds used after the program and a reduction in aggressive fan speeds.

Fan Blades

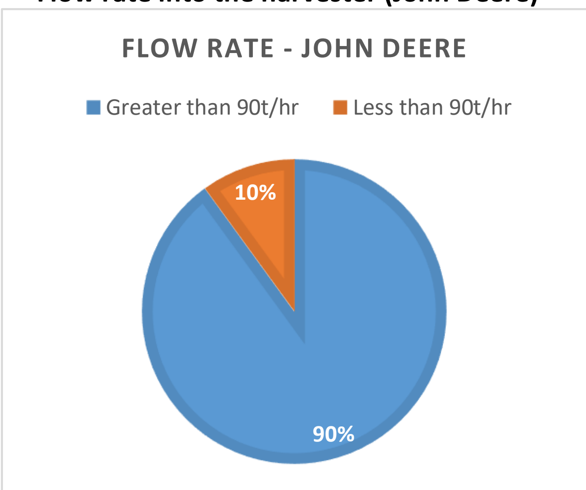


Extractor Fan Speed

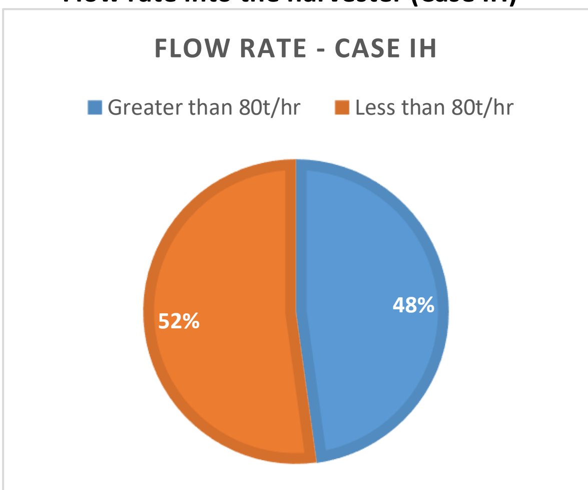


The graphs below indicate flow rate entering into the harvester for both John Deere and Case IH harvesters after program completion. The recommended flow rates are up to 90 t/hr for a 5'cleaning chamber (John Deere) and 80 t/hr for a 4'3" cleaning chamber (Case IH). The amount of material entering the 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 (SCHLOT Live) and decision-support tools to allow growers and their contractor to negotiate an appropriate payment (plus incentive) for HBP.

Flow rate into the harvester (John Deere)

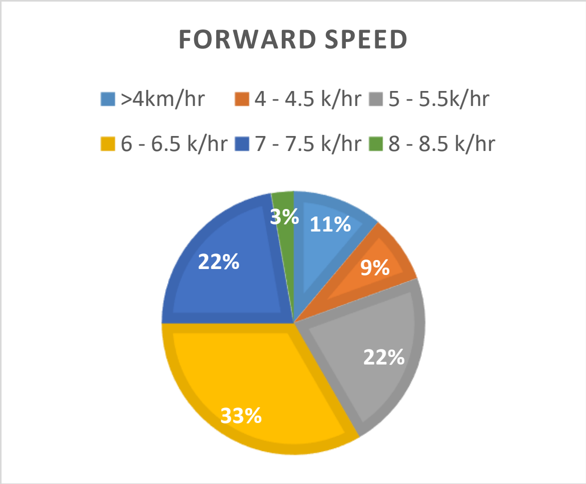


Flow rate into the harvester (Case IH)



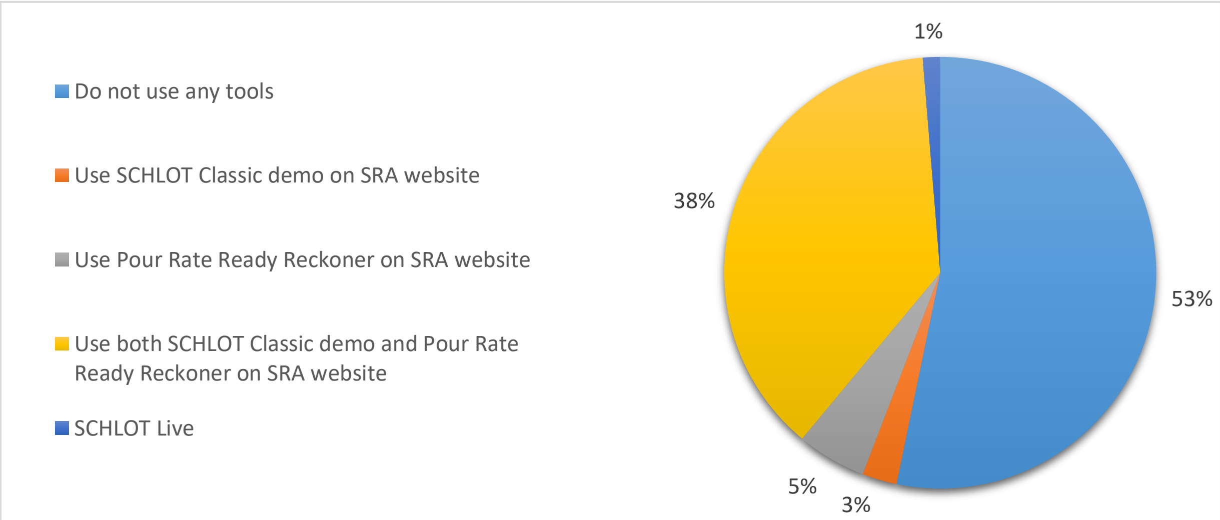
The graph below indicates post trial/ workshop average forward speed of the contractor groups involved in the program. As noted earlier, there was a reduction in average harvester forward speed over the course of the program.

Harvester Forward Speed



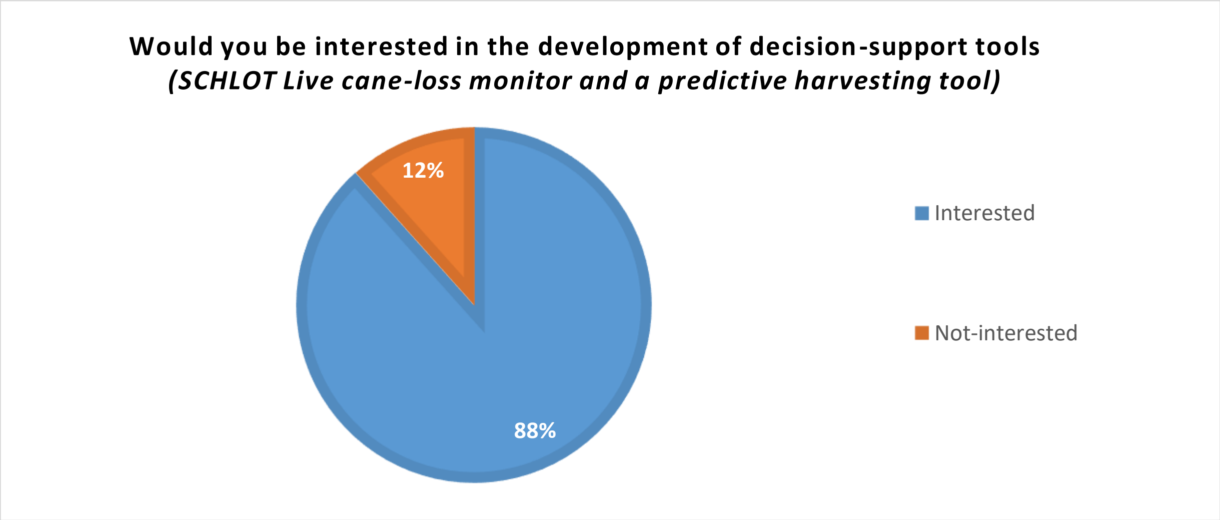
The graph below indicates the usage of decision-support tools by participants after the completion of the program. 38% of participants utilise both a demonstration version of SCHLOT Classic and the SRA Pour Rate Ready Reckoner.

Decision support tools



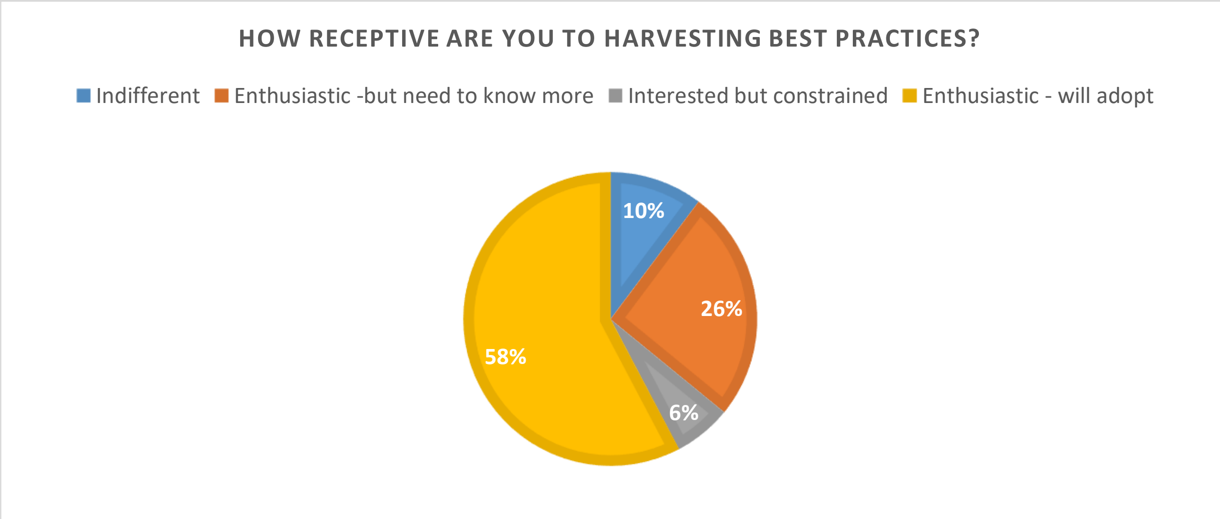
However, 88% of program participants would like a predictive tool and a live cane-loss monitor to improve HBP (see below).

Decision support tool interest



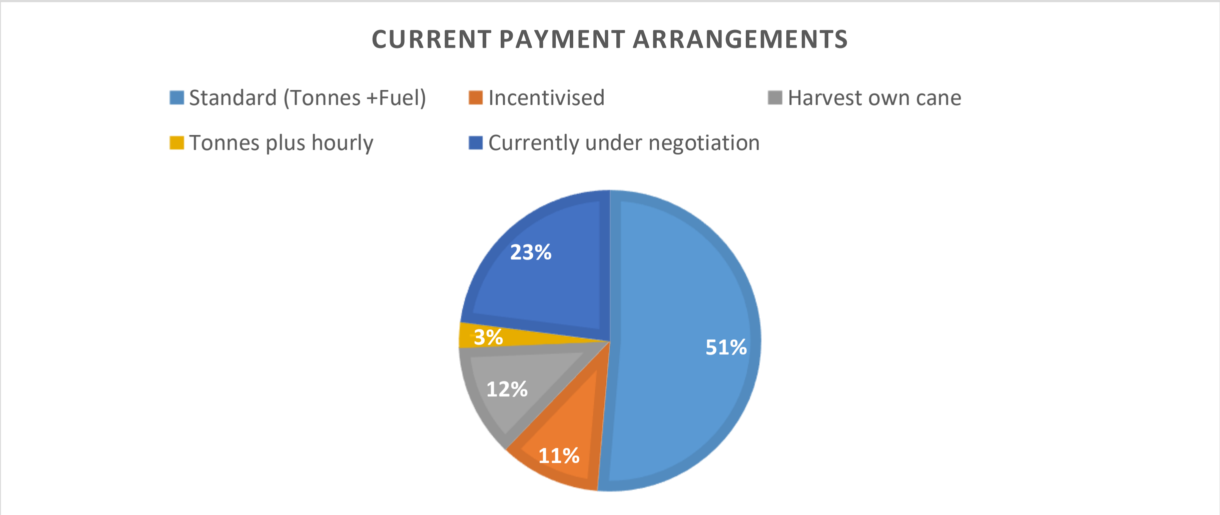
58% of participants were enthusiastic regarding HBP at completion of the program and intend adopting it in some form.

Receptiveness



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

Payment arrangements



4. INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1. Industry engagement during course of project

The project team implemented a communication strategy specifically designed to address the diversified needs of the value chain (Grower, Contractor, 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 dissemination of information.

Key Messages:

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 (yield, ground speed, row width).
	• Reduced loss = function (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 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 (yield, ground speed, row width).
	• Reduced loss = function (extractor fan and ground speed).
	• It is essential industry adopts the use of decision-support tools, live monitoring and validation tools.
	• Cultural change is necessary in the sugar industry value change, requiring collaboration to diagnose solutions to barriers to adoption.

Target Audience

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

- To deliver a communication program that enhances and supports the adoption of harvesting best practice:
  - Clearly communicate the vision for the Harvesting Best Practice Adoption project;
  - 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”.
- To 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 (2017/18).

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 practices. Facilitated discussion, enquiry and adoption.
Appropriate and targeted Social media activity throughout the duration of the project – publicising industry forums, field activities (trials, field days, research and adoption updates published in other media (cane clip 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 amongst the value chain.
Graphic design of event invitations, hand-outs, survey questionnaires and communication materials.	Growers; contractors; industry; government; journalists and community.	Ensured consistent branding across SRA, whilst acknowledging SRA project partners (Australian Government – Department of Agriculture and Water Resources; and 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 the 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 whilst 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.

Industry Engagement activities:

The project *Adoption of practices to mitigate harvest losses* has 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.

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

Presentations to Industry Stakeholder Groups:

- 4 x Presentations to Herbert River Canegrowers;
- Canegrowers Executive (in Brisbane, accompanied by Ian McBean SRA Exec. Mgr.);
- 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 (from mid- to late-2017 to mid-2019);
- 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 Forums 2018

- NSW Harvesting Forums (Condong, Broadwater & Harwood)
- Maryborough & Isis Forum
- Bundaberg Forum
- Proserpine Forum
- Burdekin or did Phil just go to the grower update…?
- Mackay & Plane Creek Forum
- Herbert Forum
- Tully Forum
- Wet Tropics Forums (Mulgrave and Mossman)

Harvest Forum 2019

- Proserpine

During consultation with SRA Executive Manager of Adoption, a decision was made to shift focus towards grower updates for the 2019 harvest season. This was a combined result of harvester operator apathy to attend forums and the need identified by the project team to present to growers the importance of understanding the required consultation, costs and gains of implementing HBP. Therefore, in 2019 only a single forum was run, in Proserpine, at the request of Wilmar Sugar, Sugar Services Proserpine and SRA Executive Manager – Regional Delivery.

Conferences

ASSCT – 2018 – Exhibit at the SRA booth

ASSCT – 2019 – Presentation of five papers:

- Harvesting groups − the key to improving harvesting practice
- Adoption of practices to mitigate harvest losses: 2017 results
- Economic evaluation of sugarcane harvesting best practice (HBP)
- Cost assessment of the adoption of harvesting best practice (HBP)
- Assessing cane and sugar losses utilising world-class methods

Refer to section 3.2 Outcomes and Implications for the project adoption metrics.

5. METHODOLOGY

5.1. Harvesting trial methodology (Patane *et al.*, 2019)

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 own voluntary trial that were: relatively even to mitigate the impact of yield variability; a minimum of 400 t of cane for replication purposes; and a single variety. The four harvesting treatments for the 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'.

For the green cane trials, the 'control' treatment was designed to provide the best possible post-harvest estimate of total biomass available in the paddock utilising the ISLMS (Infield Sucrose Loss Measurement System) and mass-balance yields. Harvester ground speed for the control treatment aimed to maintain a 60 t/h flowrate into the machine dependent on the grower's yield estimate for the block. The primary fan speed was set at less than 600 rpm, subject to harvester extractor fan and blade type, and the secondary fan was turned off. The 'recommended' treatment targeted an HBP flow rate of 80-90 t/h, subject to cleaning chamber size, which was derived from research by Ridge and Hobson (1999), who determined an optimal material flowrate of 69 t/h through a 1.37 m (4'6") diameter cleaning chamber. Like the 'control' treatment, ground speed was set to maintain the targeted flow rate (generally observed with a tolerance of plus or minus 1 km/h). The recommended fan speed varied between 650 and 750 rpm, subject to cane variety, field conditions (wet or dry), and fan blade and hub type. The 'contractor's standard' practice was the operator's nominated harvester settings for the particular block and conditions. The 'aggressive' practice was designed to demonstrate the impact of more aggressive harvesting practices. The contractor's standard pour rate was increased by 15 t/h or higher and the primary extractor speed was increased by a minimum of 100 rpm.

For the burnt cane trials, the 'control' treatment was designed to deliver total biomass available in the paddock. The primary and secondary extractor fans were turned off. Due to not having the issue of overloading the cleaning chamber as would occur in a green cane scenario, ground speed remained constant across all treatments. The 'moderate' treatment targeted a similar ground speed as the control but fan speed was operated between 550 – 650 rpm depending on fan blade and hub type, variety, field conditions and burn quality. The 'aggressive' treatment consisted of the same ground speed as the 'moderate' treatment with an increase of 200 rpm on the primary extractor. The secondary extractor was on for both 'moderate' and 'aggressive' treatments.

Cane yields were assessed using the conventional mass-balance protocol including mill weighbridge, NIR and ISLMS (Whiteing *et al.*, 2016). ISLMS was only applied to green-cane trials. 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 (Whiteing *et al*., 2016). The 'control' treatment was taken to be the best possible estimate of total biomass in the field. In the green-cane trials, operating the harvester with all fans off would be a better estimate of total biomass but this is impractical, as EM levels would then be too high to allow mill feeding. Cane loss in other treatments was estimated by inference from the mass balance results. 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 (recorded in the next subsection).

5.2. Harvesting cost evaluation methodology (Nothard *et al.*, 2019)

To assess cost changes associated with HBP adoption, nine trials were considered for further analysis. Operational 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, 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 BSES Harvest-Haul Model (HHM) for underpinning harvester and haulage cycle calculations as well as a number of 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 the trial paddock.

A challenge for the project was to accurately estimate differences in harvesting costs between different harvester settings, whilst including the impact on fixed costs. The four harvester settings are detailed under the harvesting trial methodology section. As the HHM did not incorporate certain economic interactions between different harvester settings, the Model required further development to enable this functionality. Given the harvesting cost evaluations were being undertaken across numerous regions, the Model also needed flexibility to incorporate inherent differences. For example, drivers were being paid by the tonne in North Queensland while in the South they were paid per hour. Consequently, the model was revised to enable users to select which payment method was being used to accurately reflect each individual harvesting operation. Other revisions included a much stronger emphasis on repairs and maintenance (R&M) requirements that enabled each specific item to be allocated costs based on either the number of hours, days or years spent harvesting or the quantity of tonnes harvested. For example, users could allocate R&M costs based on their experience of changing a set of chopper drum blades every 6,000 tonnes, undertaking a minor service every 250 hours or servicing their elevator once a year. This enabled R&M costs closely related to either harvesting time or tonnage to be calculated accordingly. These changes were particularly important when evaluating the difference in costs between harvester settings to ensure costs were allocated correctly, given that HBP adoption generally entailed increased harvesting times likely to increase R&M costs per hectare.

Various agronomic inputs (e.g. yield, row width, etc.) and machinery time cycle interactions (between harvester and haulouts) form the basis of algorithms used to derive harvesting costs. Figure 1 includes a summary of the steps undertaken in modelling the cost of harvesting.

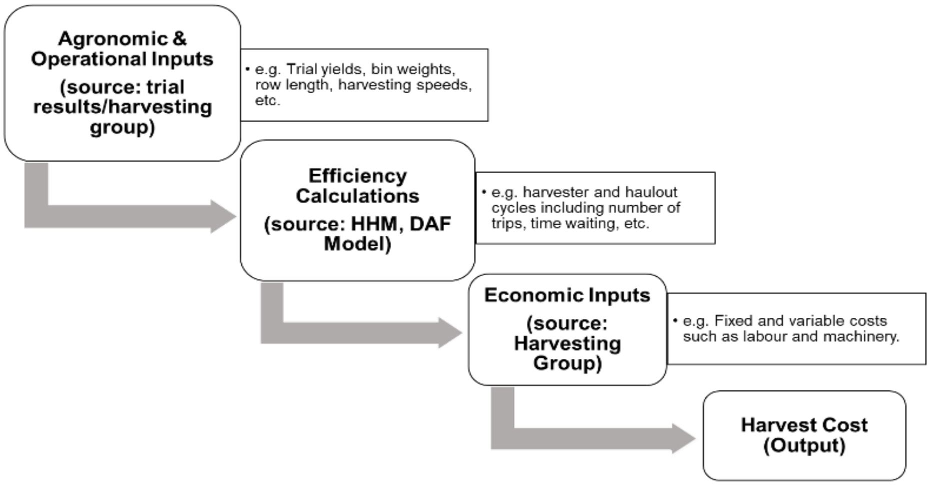


Figure 1. Harvesting cost modelling process.

Nine sites from the 2017 harvesting trials were considered in the development of nine separate harvesting cost evaluations for which detailed information was collected directly from the harvesting group. These included four costing evaluations of trials and harvesting operations located in the Southern Queensland canegrowing region, one from the Central region and four from the Northern region. The selection allowed for inclusion of different regions where contracting groups had agreed to participate. A further four costings were completed during 2017 but were excluded from the analysis given their trial results were not reflective of a change from standard to recommended practice. This was largely the result of incorrect block estimates on which the trial harvest settings had been based. For discussion purposes, results compared the contractor's standard setting and the recommended settings as these two were the most relevant for industry. The control and aggressive settings were both commercially impractical but remained relevant for the trials from a trend validation perspective (refer Patane *et al., 2019)*.

A wide variety of information was needed to accurately calculate harvesting costs and differences in harvesting costs between settings. Required information included results from each trial, characteristics of each trial block and information about each harvesting operation. For each harvesting cost evaluation, average ground speeds, fan speeds, harvested yields and bin masses were required for each harvester setting per trial. Information on the characteristics of each trial block was also needed on row lengths and widths, turnaround times, one- or two-way cutting, haulout distances and speeds, and the number of haulouts used. Trial information and data were collected during the trials and from the mill. Cost information specific to each harvesting operation was collected during face-to-face interviews and included detailed questions pertaining to:

- In-season and pre-season labour costs (including wages paid both hourly or per tonne, penalty rates, Superannuation, payroll tax, worker's compensation, annual leave loading, allowances, and rostered days off);
- Harvester, haulout and equipment costs (including depreciation, interest (opportunity cost), repairs and maintenance on harvester, haulouts, service vehicles and equipment such as compressors and tools). The calculations of depreciation, interest and repairs and maintenance are detailed below.
  - $Depreciation = \frac{(Purchase\ Price - Salvage\ Value)}{Life\ (years)}$;
  - $Interest\ (opportunity\ cost) = interest\ rate \times \frac{(Purchase\ Price + Salvage\ Value)}{2}$;
  - *Repairs and maintenance of the harvester, haulouts, service vehicles and equipment such as compressors and tools. These costs are calculated based on time (e.g. once a year or every X hours) or throughput (e.g. every Y tonnes) relationships.*
- Fuel and oil costs (consumption/litres per hour while harvesting, turning or idling for the harvester, and consumption/litres per hour while laden, empty or idling for the haulouts);
- Overhead costs (general fixed costs such as insurance, accounting, registrations, telephone, printing and stationery, Fixed Wages (management, administration and sub-contractor payments), etc.).

Other information also collected included harvesting group size (tonnes per annum), machine rosters, haulout bin capacity, bin emptying times, and average times spent moving, servicing and waiting for bins.

5.3. Net benefit methodology

An evaluation was undertaken to determine the net economic benefit from using HBP settings instead of the contractor's standard settings at nine of the trial sites (all trials with harvesting cost evaluations). The net benefit was calculated by subtracting the difference in harvesting costs from the difference in grower revenue per hectare (net benefit = Δ grower revenue – Δ harvesting costs). The net benefit is confined to the grower and harvesting operation and only takes into account changes in grower revenue and harvesting and transport costs up to the siding or pad (including levies and allowances). The analysis does not weigh up the wider benefits and costs for the whole supply chain (e.g. mill).

5.4. Statistical analysis methodology

Trial data collected during the 2017 and 2018 harvest seasons across 12 sugarcane production regions in Queensland 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 (SAS Institute, 2013). The model applied to the data for each harvest output was:

Trait ~ Treatment + Location (Replicate) + Grower/contractor + Ɛ,

where Trait was the harvested output of interest. Treatment (control, recommended (HBP), contractor's standard and aggressive) was considered a fixed effect and replicate nested within location was treated as a random effect in the model. The error term Ɛ represents the deviations from our predictions due to random factors that we cannot control experimentally. The random component effect was grouped by block/contractor to account for the variation due to each 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%.

From the 95 harvesting trials, 51 complied with the trial protocols and met the requirements for the statistical analysis. The remainder were excluded on the grounds of poor crop yield estimates prior to trials (which affected the selected product flow rates through the harvesters), insufficient replication, poor adherence to trial protocols, or contractors already operating at, or very close to, recommended practices (of which there were very few). The excluded trials also referred to trials assessing different criteria such as chopper drum comparisons.

5.5. Workshop strategy (Patane *et al.*, 2019)

Field teams conducted demonstration trials 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 of one of the grower members, the adoption team conducted a mass balance trial together with the Infield Sucrose Loss Measurement System (ISLMS) (Whiteing, 2013) 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).
- QDAF economists and SRA met with 13 of the harvesting contractors to collect detailed costs specific to each operation and trial block in order to evaluate the difference in harvesting costs from using HBP instead of standard practice.
- Trial data were analysed, and economic analyses undertaken to showcase the relative performance of each treatment trialled.
- 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 that harvester operators were to blame for losses. Options put forward included:

- Reducing pour rate and fan speed
- Use of available decision tools, such as the ready reckoner included in the HBP Manual (Sugar Research Australia Limited, 2014) and the SCHLOT program, which can be found on the SRA web site (Sugar Research Australia, 2018)
- Feed train optimisation
- GPS monitoring of ground speed
- Low loss chopper drums and reducing the number of blades
- Timing of maintenance of chopper and basecutter blades to ensure sharpness
- Changing payment arrangements
- Improving field conditions for presentation of crop

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 adoption team reviewed the publication "How to Use Persuasion Skills to Drive Technology Adoption" by C-Qual Agritelligence (2012) prepared for the 2013 Sugar Advisory Services Development Program. The following were taken as principles for facilitating the workshops:

- Establish clear objectives – such as "Reduce losses and ensure that incentives are appropriate"
- Know your product
- Identify well-defined benefits and provide sound and credible evidence – the trial results provided this
- Keep it simple and clear and focus on clarity not detail, providing enough data to support the goals
- Propose specific actions – discussed above
- Ensure practical implementation – from the facilitator's experience
- Shrink the change – reduce expectations, build on current practice, break the change into steps and recognise successful steps.

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.

The demonstrations and trials were designed to address the impediments to adoption listed above:

1. Recognition of the scale of losses and the opportunity to minimise them through changed practices. *This was addressed in the demonstration trial, where the participants noted the different distances the haulouts needed to travel to fill a bin under different treatments. It was then confirmed with the detailed reports at the workshops*.
2. Operator expectations that there will be extra harvesting costs from changes to practice and a perceived inability to recoup them. *This was addressed by the format of gathering the group together and the transparency provided by the economic analysis of the trial.*
3. In some groups, lack of communication between the harvester operator and the farmers in the group. *Also addressed by bringing the group together.*
4. A feeling of pressure to harvest at high rates to ensure bin allotments are filled. *The economic analysis can assist in demonstrating the returns from reducing loss and increasing income, thereby allowing the harvester to be compensated for extra costs.*
5. The concern that large contracts, which need to harvest over a significant part of the working day, do not allow for lower flow rates. *Apart from the point above, the economic analysis considers time spent waiting for bins; slower rates can minimise this, allowing a smaller reduction in the daily offtake.*
6. Pressure to maximise the bin weights, leading to shortening of billets in an effort to increase bulk density. *This is not addressed during the individual trial, but the results of the overall trials can be used to demonstrate the fallacy of this assumption.*

These approaches have been successful in generating change. SRA has recorded the responses of each group and updates these records as groups report new activity. Data has been gathered from group responses and from logged data, where available.

6. RESULTS

6.1. Green cane trial results

Table 1 shows the mean harvester settings, elevator pour rates and flow rates for each of the four treatments (from all conforming trial[1] sites undertaken in 2017 and 2018). 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[2] (see Table 2).

Furthermore, Table 1 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	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

*Common letters within a row indicate no statistically significant differences among treatments ($p = 0.05$).
**Estimated flow rate using results from the ISLMS and delivered product.

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 sugar/ha were then determined to give an indication of harvesting sugar loss. 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).

[1] Conforming criteria explained in statistical methodology in section 5 METHODOLOGY
[2] This provides an estimate of the total amount of pre-harvest biomass in the paddock, which is needed to calculate total biomass in the block.

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

*Common letters within a row indicate no statistically significant differences among treatments (p = 0.05).

The mean production and revenue results for each harvester treatment setting are outlined in 3. There were significant differences 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. In particular, 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. 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

*Common letters within a row indicate no statistically significant differences among treatments (p = 0.05).
**Grower revenue minus average harvest costs, fuel costs and levies.

6.2. Burnt cane trial results

Table 4 shows the mean harvester settings, fuel burn, elevator pour rates and flow rates for each of the three treatments from three conforming burnt cane trials undertaken in 2018. Compared to the aggressive treatment, primary extractor fan speed for the moderate treatment was lower by 200 rpm while the control treatment had the fan turned off. Ground speeds were the same for all three treatments across two of the three trials, but ground speed for the control treatment for one trial was 2 km/hr lower than the remaining treatments. This lowered the average speed by 0.6 km/h. Due to the lower fan speed, the moderate treatment had a lower fuel burn than the aggressive (by 3.2 L/hr); while the control treatment had the lowest fuel burn due to both lower fan and ground speeds (almost 10 L/hr 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 (see cane yield results in Table 5).

Given that 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 much lower bulk density than cane, a minor increase would not have a significant impact on reducing bin weights, although bin mass for the control was only 0.2 t per 10 t bin (or 1.9%) lower than the aggressive. As with pour rates, bin fill rates were similar between the treatments.

Table 4. Average harvester performance under different practices (burnt cane).

Parameter	Practice		
	Control	Moderate	Aggressive
Ground speed, km/h	6.3	6.8	6.8
Primary fan speed, rpm	0	609	809
Fuel burn, L/hr	41.5 c	48.1 b	51.3 a
Elevator pour rate, t/h	136.4 a	140.8 a	137.4 a
Flow rate*, t/h	138.5 a	146.8 a	145 a
Extraneous matter, %	4.7 a	5.8 a	4.0 a
Average bin mass, t/10-t bin	10.2 b	10.3 ab	10.4 a
Bin fill rates, bins/h	9.2 a	9.6 a	9.3 a

*Estimated flow rate using results from the ISLMS and delivered product.

The mean production and revenue results for each harvester treatment setting are outlined in Table 5. There were significant differences between the treatments with the control treatment delivering significantly higher cane yield than the aggressive treatment (by 5.1 tc/ha), while cane yield for the moderate treatment increased marginally (by 1.3 tc/ha) against the aggressive treatment. Mean CCS for the control treatment was slightly lower than the other two treatments but the difference was not found to be statistically significant. Differences in mean fibre levels were found to be statistically significant, with the control treatment having fibre levels around 1% 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 (-$115/ha) and aggressive (-$207/ha) treatments. Net grower revenue followed a similar trend with the moderate and aggressive treatments obtaining $82/ha and $148/ha less than the control treatment, respectively.

Table 5. Mean production and revenue results for each treatment (burnt cane).

Parameter	Practice		
	Control	Moderate	Aggressive
Gross cane yield, tc/ha	128.4 a	124.6 ab	123.3 b
CCS, units	15.48 a	15.65 a	15.71 a
Fibre levels, %Cane	14.02 a	13.08 b	13.00 b
Sugar yield, ts/ha	20.88 a	20.53 a	20.40 a
Total grower revenue, $/ha	$6,098 a	$5,983 a	$5,892 a
Net grower revenue*, $/ha	$5,027 a	$4,946 a	$4,879 a

*Grower revenue minus average harvest costs, fuel costs and levies.

6.4. Harvesting Costs Calculated for 2017 Selected Trials (Nothard *et al.*, 2019)

In calculating harvesting costs, work done by Ridge and Powell (1998) and Ridge and Hobson (2000) provided an Excel-based harvesting cost spreadsheet tool commonly referred to as the BSES (Bureau of Sugar Experiment Stations) Harvest Haul Model (HHM). This tool incorporated various harvester haulout configurations, harvest organisations (e.g. bin sizes, sidings and shifts) and various inputs relating to field presentation and crop conditions. Although many forms of harvesting cost analysis have been done internationally, e.g. Meyer (1998) and Barker (2007), the HHM has been widely used in Australia by various research groups including Agnew *et al*. (2002), Antony *et al*. (2003) and Sandell and Prestwidge (2004). It has also been used in conjunction with other models such as the Transport Capacity Planning and Siding Roster models developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Harvesting Solutions groups (Higgins *et al*., 2006). Agnew *et al*. (2002) examined harvesting cost changes through adoption of HBP at both paddock and regional level. They identified an average increase of 50c per tonne for additional hours required at optimum economic machine settings. This was a number observed to be in the mind of industry stakeholders during costing discussions.

Despite the HHM providing a good foundation, a challenge for the project was to accurately estimate harvesting cost changes between four different harvester settings, whilst including the impact on fixed costs. For the purpose of the project and to complement past harvester costing work, an economic spreadsheet (model) was developed by DAF to evaluate certain economic interactions between different harvester settings. The model required an account of specified harvesting inputs and costs to determine the difference in harvester setting costs. The following sections examine the basic workings of the custom economic model, key inputs to the model and economic outputs and trends from nine different harvesting cost evaluations. Included are a cost change range and the key cost inputs having greatest influence on overall costs as measured during 2017.

6.4.1. Harvest Cost Results

Table 6 highlights some of the differences between the harvesting operations, trial sites, harvester settings and obtained yields that were observed in the nine harvesting cost evaluations. Crops harvested annually varied considerably for the costed harvesting groups from 58,000 to 134,000 tonnes. Average row length at the trial blocks varied between 340 and 1,100m with row spacing varying between 1.6 and 2.4m. The table also outlines the range of ground speeds, harvested yields and elevator pour rates observed for the contractors' standard settings at the trial sites. Standard ground speeds ranged between 3.9 and 6.5 km/hr, harvester yields between 70 and 125 t/ha and elevator pour rates between 75 and 106 t/hr.

Table 6. Observed differences between nine harvesting operations, trial sites, settings and yields.

	Annual Tonnage	Row Length (m)	Row Spacing (m)	Ground Speed - Standard Setting (km/h)	Elevator Pour Rate - Standard Setting (t/h)	Harvested Yield - Standard Setting (t/ha)
Minimum	58,000	340	1.6	3.9	74.6	69.9
Mean	96,000	619	1.9	5.3	91.8	98.1
Maximum	134,000	1,100	2.4	6.5	106.0	125.0

The average harvesting cost per tonne, per hectare and per hour when using the contractor's standard settings are shown in Table 7[3]. Harvesting costs 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.

Table 7. Average Harvesting Cost (contractor's standard settings).

	Per tonne	Per hectare	Per hour
Minimum	$6.65	$589	$416
Mean	$8.04	$781	$512
Maximum	$10.13	$979	$686

Figure 2 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.

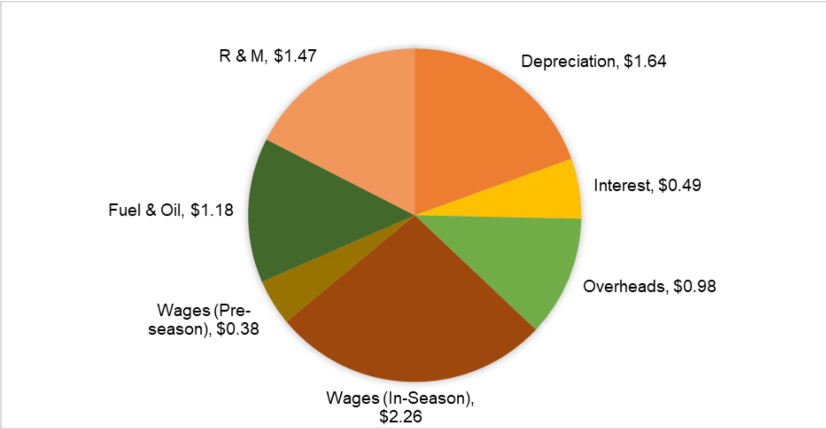


Figure 2. A break-down of harvesting costs per tonne.

Harvesting costs were found to be sensitive to changes in cane yield, row spacing, row lengths and contractor group size. Figure 3 shows 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 significant influence on harvesting costs. For example, if yields increased from 80 to 100 tch and the same ground speed maintained, then harvesting costs would decrease from $8.71 to $7.19/t. With the elevator pour rate having increased from 76 to 95 t/hr, 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/hr, 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 spacing change from 1.5 to 1.8 m (see Figure 4) with harvesting costs decreasing substantially less if the same elevator pour rate were maintained.

[3] *All costings include fuel and both harvester and haulage allowances.*

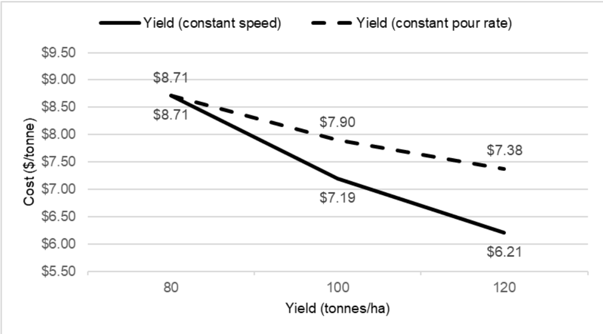


Figure 3. Yield change impact on harvesting costs

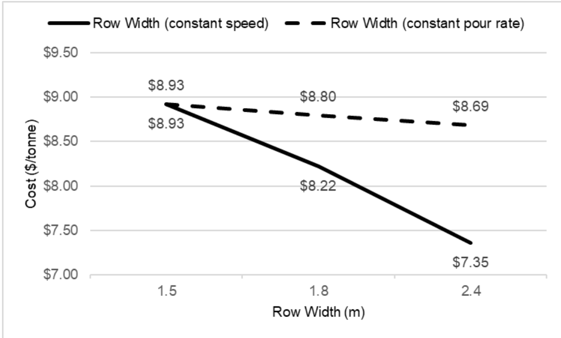


Figure 4. Row width change impact on harvesting costs

The impacts of row length, ground speed and group size changes on harvesting costs are presented in Table 8. Fixed pour rate sensitivities are excluded as both row length and group did not influence pour rate. Ground speed would also require a change in either yield or row width which was deemed unnecessary for sensitivity purposes. The average cost reduction when doubling row length from 400 to 800 metres was 31c per tonne. Adding a further 200 metres for a row length of 1,000 metres only reduced costs by a further 6c per tonne indicating that marginal cost savings declined with longer row lengths. Group size increases showed significant reductions in cost 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/hr 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 8. 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

6.4.2. Cost Comparison and Net Benefit Results

Harvesting cost evaluations were undertaken for nine different harvesting trial sites and the respective harvesting operations. Table 9 outlines the difference in ground speed, fan speed, elevator pour rate and yield between the contractors' standard settings and the recommended settings. Ground speed, fan speed, elevator pour rate and cane yields were all factors that went into the harvesting cost evaluation, but each provide guidance around what drove the harvesting cost differences. The average reduction in ground speed and fan speed was 1 km/hr and 69 rpm respectively, resulting in an average change in elevator pour rate of 12 tonnes per hour. North 3 was the only case to have an increase in elevator pour rate given ground speed between settings were unchanged but higher yields were obtained (due to relatively lower fan speeds and less cane loss). Using the recommended settings instead of the contractors' standard settings delivered an average of 6 tc/ha (or 6.7%) more cane yield across the trials.

Table 9. Differences in ground and fan speeds, pour rate and cane yield between the standard and recommended settings.

Harvesting Group	Ground Speed Difference	Fan Speed Difference	Elevator Pour Rate Difference	Cane yield difference	Cane yield difference
	(km/hr)	(rpm)	(t/hr)	(tc/ha)	(%)
South 1	-1.4	0	-20	10.8	9.8%
South 2*	-0.7	-100	-16	-0.9	-0.7%
South 3	-1.2	-150	-11	6.6	8.3%
South 4	-1.0	-100	-15	3.9	3.4%
Central 1	-0.9	-130	-3	13	18.6%
North 1	-0.8	-40	-9	6.8	7.0%
North 2*	-1.2	0	-11	8.1	9.0%
North 3*	0.0	-100	4	5.1	5.1%
North 4	-1.6	0	-29	0.2	0.2%
Average	**-1.0**	**-69**	**-12**	**6**	**6.7%**

**The trial result showed little difference in yield response between standard and recommended settings*

Table 10 highlights the differences in mean grower revenue and harvesting costs and shows the overall net economic benefit to grower and harvesting operations. Grower revenue and harvesting costs per hectare were higher for the recommended treatment at every site except for South 2 where yields reduced at the recommended settings (North 4 was close to break-even). 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 amongst the 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 the 'Central 1' harvesting cost evaluation, harvesting costs per tonne decreased substantially due to the recommended settings obtaining considerably higher yields than the contractor's standard settings (+18.6%). On a similar note, harvesting costs per tonne for 'North 3' 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. Results 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 cost when changing harvester settings. For 'South 2' the trial result showed little change in yield between settings. This may have been due to paddock yield variability and is contrary to the trend found in most of the 43 trials conducted during 2017. It is important to note that, with no yield response, the 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. Harvesting costs differences would likely vary for other blocks or harvesting operations. 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. To put this into perspective, an additional analysis was completed using the 5.2% average cane yield increase to estimate the difference in harvesting cost for each of the nine harvesting cost evaluations. Results identified harvesting cost differences from a 33c decrease to a 69c increase per tonne with an average of 22c (see Figure 5).

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 10. Observed differences in mean grower revenue, harvesting costs and net benefit from using the recommended harvester settings (versus standard).

Trial/ Harvest Group	Grower revenue difference	Harvesting cost difference		Net benefit (additional revenue less costs)	
	($/ha)	($/ha)	($/tc)	($/ha)	($/tc)
South 1	$334	$101	$0.20	$233	$2.11
South 2	-$109	$29	$0.28	-$138	-$1.10
South 3	$241	$72	$0.25	$169	$2.12
South 4	$153	$50	$0.20	$104	$0.91
Central 1	$627	$54	-$0.67*	$572	$8.19
North 1	$212	$70	$0.02	$141	$1.46
North 2	$311	$69	-$0.06	$242	$2.69
North 3	$155	$11	-$0.31	$144	$1.43
North 4	$92	$95	$0.96	-$3	-$0.04
Average	$224	$61	$0.10	$163	$1.97

**The cost difference per tonne reduces in these cases given the high increase in yield relative to the change in ground and extractor fan speeds.*

Table 11 shows a breakdown of the harvesting operations average costs per tonne (excluding harvesting or haulage allowances) in order 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 11. Breakdown of average harvesting costs and differences between standard and recommended settings ($/tonne).

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 in Table 11 exclude the impact of harvest and haulage allowances available to the harvesting operations.*

Table 12 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 12. 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 in Table 12 exclude the impact of harvest and haulage allowances available to the harvesting operations.*

6.4.3. Yield Response Sensitivities

As shown in Table 9, the percentage increase in yield from the contractor's standard settings to recommended settings varied substantially amongst the nine trials, i.e. between -0.7% and 18.6% for the recommended setting. Making comparisons between the size of the yield difference and the harvesting cost difference identified a strong negative relationship between these two measurements. For instance, the trial that produced 0.2% additional tonnes had a harvesting cost increase of 96c per tonne, while the trial that obtained an 18.6% improvement had a 67c lower cost.

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 5 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 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, Figure 5 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).

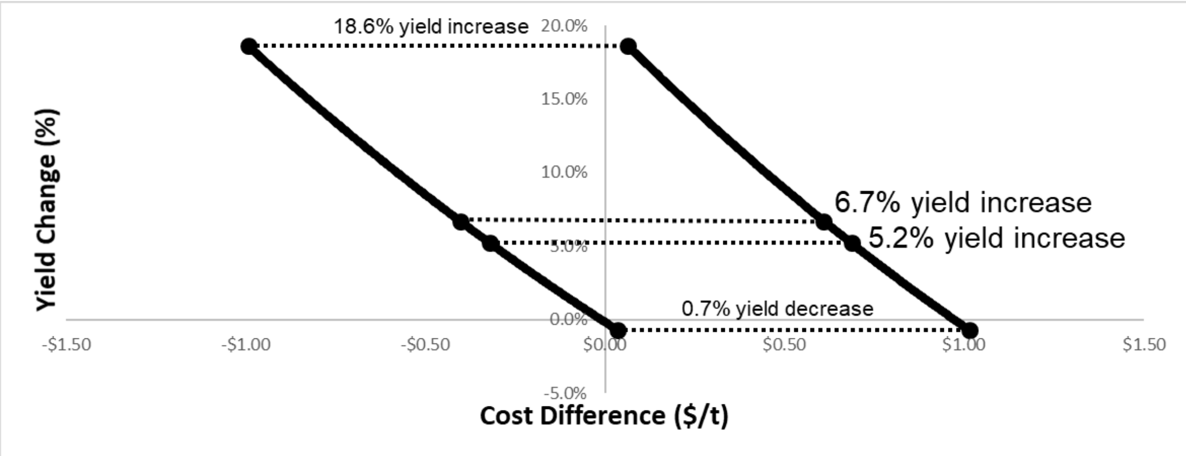


Figure 5. The range of yield changes to cost differences for the nine trial sites.

6.4.4. Ground Speed and Cost Change Relationship

Figure 6 presents the relationship between a change in ground speed and the change in harvesting cost per hectare for each of the nine trials. With a strong negative correlation (-91%), it is evident that lower ground speeds had a strong influence on increased costs when using recommended settings (HBP). This related primarily to the influence a lower ground speed had on overall harvesting times.

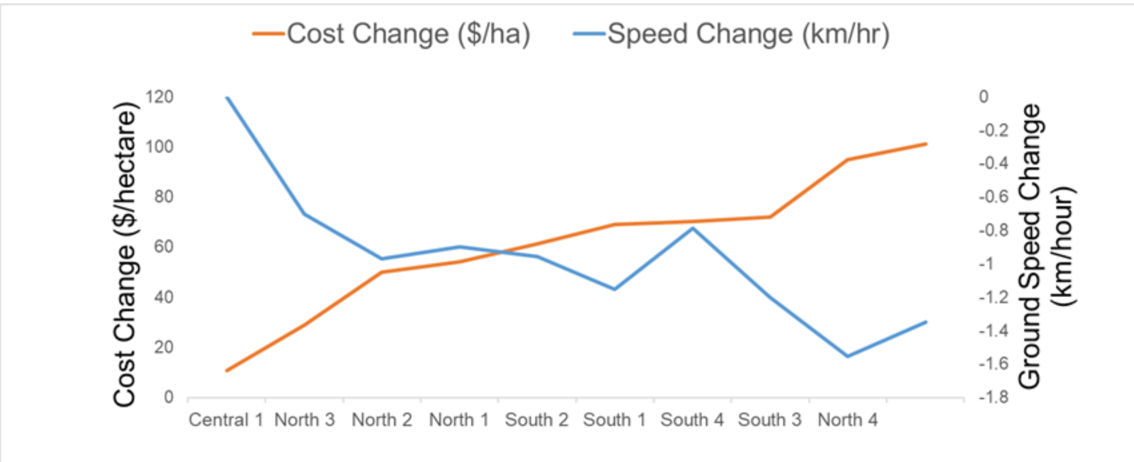


Figure 6. Change in ground speed and harvesting cost per hectare.

7. DISCUSSION

7.1. Green cane trials

Past research has identified that the size of harvester cleaning chambers influences their capacity to extract EM above a certain flowrate threshold (Ridge and Hobson, 1999). However, harvesting is commonly undertaken at ground speeds that deliver flowrates above the threshold, overloading the chamber and limiting its ability to extract EM effectively. Ordinarily this would increase EM levels but, in an attempt to offset this, operators typically increase extractor fan speeds above recommendations. While EM levels are generally offset, the higher fan speeds also extract cane, although these unintended cane losses are not visible as they are shattered by the fan blades on discharge.

Figure 7 graphically depicts differences between standard and recommended practice in terms of ground speed, fan speed, flow rate, sugar loss, elevator pour rate and cane yield. Compared to standard harvester settings, using recommended settings required operators to reduce ground speeds by an average of 0.9 km/h and decrease primary extractor fan speeds by 95 rpm.

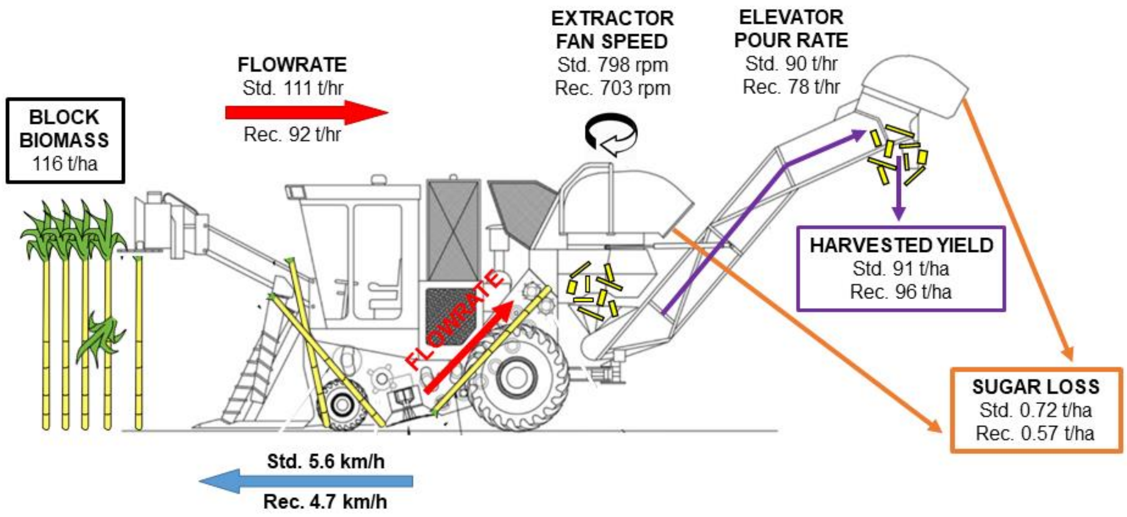


Figure 7. Graphical depiction of different speeds, flow rate, sugar loss, pour rate and cane yield between standard (Std.) and recommended (Rec.) settings.

The harvesting trials identified that reducing harvester ground speeds from current industry practice to the recommended speeds decreased the flowrate of material to be 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 the 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. This was also shown to have no detrimental impact on EM levels, fibre levels or CCS, and no significant effect on nominal bin mass. These results support previous research by Whiteing (2002). Given no difference in CCS, the improvement in sugar yield and grower revenue followed a similar trend to cane yield with recommended practice obtaining 0.7 t/ha more sugar and $181/ha more total grower revenue than standard practice.

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 (0.15 ts/ha or 21.6% increase) than recommended practice. Furthermore, in-field testing identified that significantly less material was extracted from the cleaning chamber when using recommended practice (against standard practice), also confirming additional cane loss (given there was no negative impact on EM, fibre or CCS in delivered cane). In-field tests were carried out by laying tarps next to the moving harvester, which enabled a sample of the material extracted from the harvester cleaning chamber to be collected before mulching and measuring the amount of sugar it contained (for each treatment replicate). This type of test also 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 growers to verify the increased sugar loss first hand.

Using 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. 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 (see harvesting cost results sections for results and discussion on harvesting cost changes).

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 (by -4.8 tc/ha and -0.56 ts/ha, respectively). Alternatively, using ground and fan speeds lower than recommended practice did not significantly increase cane or sugar yield (on average +1.5 tc/ha and +0.17 ts/ha, respectively). They were, however, shown to significantly increase fibre and EM levels (by +0.41% and +2.7%, respectively) as well as significantly decrease CCS and nominal bin mass (by -0.23 units and -1.47 t/10 t bin, respectively). The significantly 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. From a cane-quality perspective, both fibre and EM levels were found to be negatively related to CCS and nominal bin mass.

To provide guidance on the impact of industry-wide adoption of recommended harvesting settings, Figure 8 shows the estimated changes in cane tonnages, sugar tonnages, total grower revenue and industry revenue from full adoption. 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 are obtained across the entire Australian green-cane harvested area. Mackay PRS values were converted to CCS using a factor presented in Pollock *et al.,* (2007). A weighted-average mill constant (70.2 c/t) and 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 (an added $1.81/t of cane).

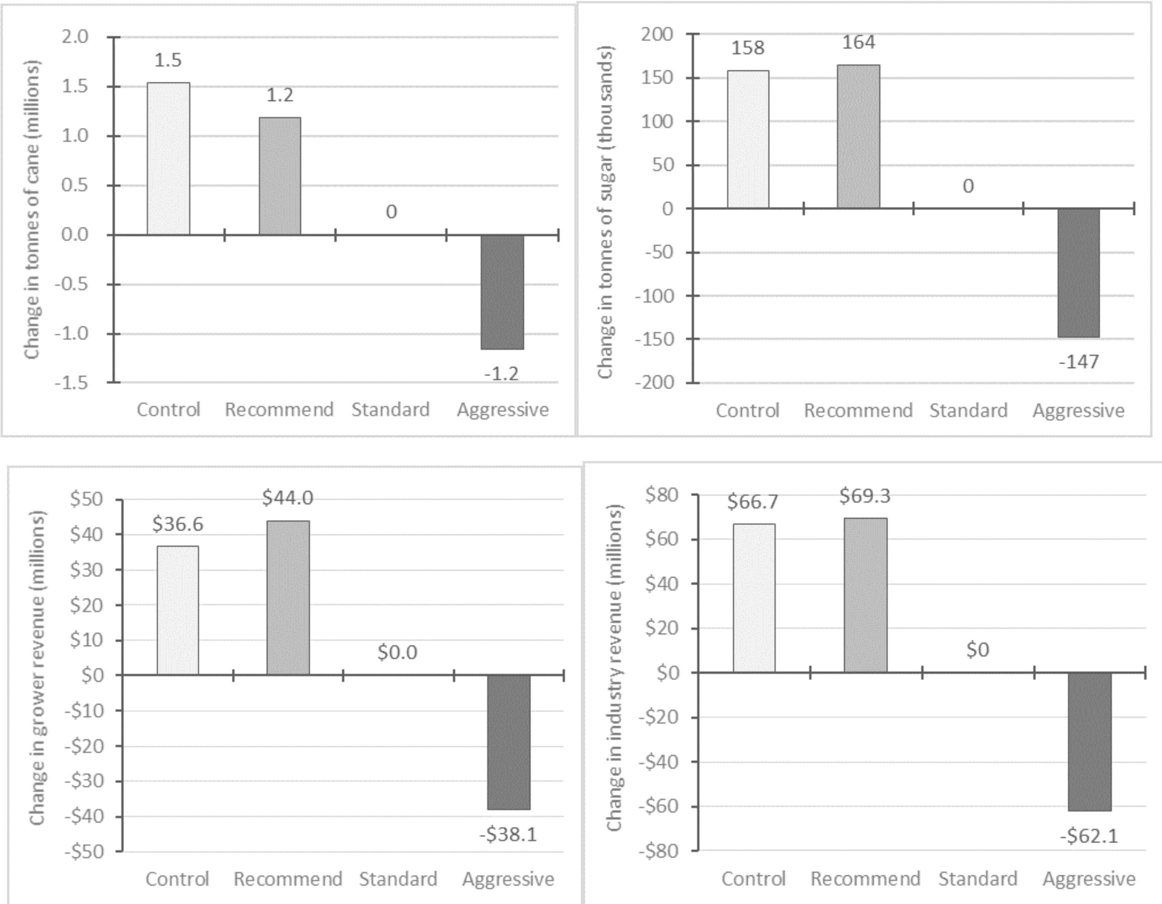


Figure 8. Impact across industry to cane and sugar production as well as total grower and industry revenue from adopting recommended harvesting practices.

The sugar price that growers and millers receive determines their revenue, which consequently influences the revenue benefit from using recommended harvesting settings. While more stable over a crop cycle, sugar prices can vary substantially from year to year. As harvester settings are tailored to requirements on any given day, it is informative to understand the revenue implications at various sugar prices. While the preceding analysis used the 5-year average sugar price, Table 13 identifies the grower and industry revenue implications at a broad range of sugar prices. In isolation, a high sugar price would generate a relatively larger revenue benefit, while a low price below would obtain a smaller benefit.

Table 13. Changes in total grower and industry revenue at various sugar prices.

Parameter	Sugar value, $/t					
	350	390	424	430	470	510
Change in total grower revenue, $millions	36.7	40.8	44.2	44.9	49	53
Change in total industry revenue, $millions	57.6	64.1	69.7	70.7	77.3	83.9

7.2. Harvesting costs and Net Benefits (Nothard *et al.,* (2019) and Thompson *et al.,* (2019))

Results from the harvesting cost comparisons 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. For the trial site that had the second smallest yield increase (0.2%), harvesting costs increased by far more (96 cents per tonne) than the trial site that had the largest yield increase of 18.6%, where harvesting costs decreased by 67 cents per tonne. The trial that resulted in a yield decrease showed a lower cost increase of 29c per tonne given ground speed changes were marginal.

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 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 9 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.

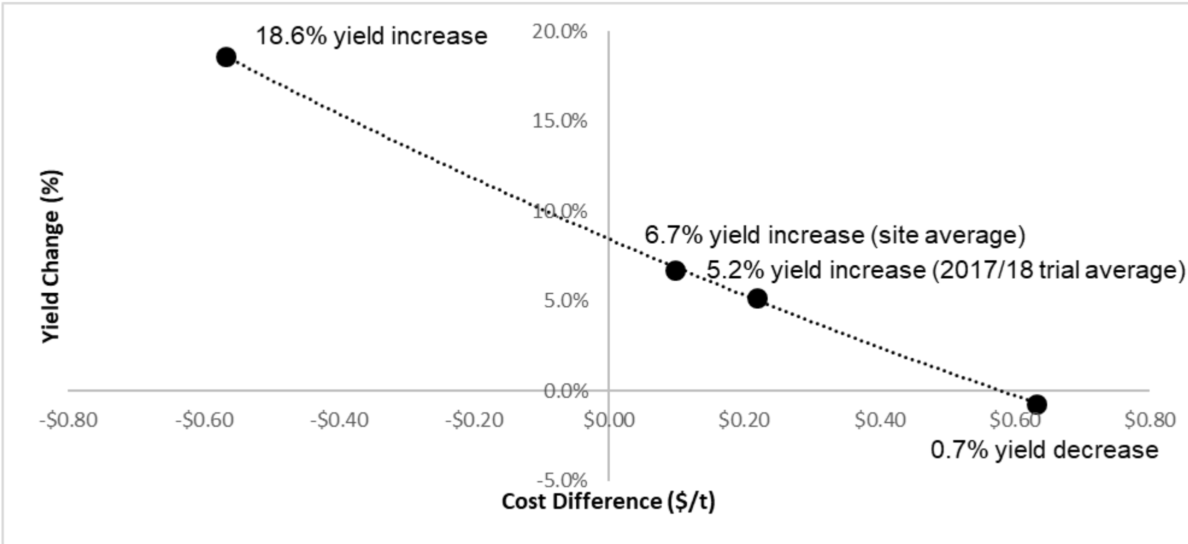


Figure 9. Yield change to cost difference sensitivity for the nine trial sites.

Patane *et al.* (2019) found an average yield increase of 5.2% in moving to recommended settings for 51 trials which is also depicted in Figure 9. Application of this yield increase to the selected case studies gave an average 22c per tonne increase in cost. This included a range of -32c to 69c per tonne at the outmost trial bounds. The cost increase per hectare range was $11 to $107. As these results only reflected a proportion of the total number of trials undertaken by the harvesting project during 2017 and 2018, it cannot be assumed that these numbers are representative of the wider sugarcane industry.

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 the harvesting project (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, Table 14 examines a range of different sugar prices. At lower sugar prices the net benefit is lower, while higher sugar prices generate higher net benefits.

Table 14. Grower net benefit from using the recommended harvesting settings at a range of sugar prices.

Sugar price ($/t)	$350	$390	$421	$430	$470	$510
Net benefit ($million)	$18.5	$22.6	$25.8	$26.7	$30.8	$34.9

The net benefit was also calculated for a 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.

7.3. Burnt Cane

Although there was no recent literature identified that related to burnt cane HBP, there were publications addressing the comparison between burnt and green cane harvesting practices (e.g. Sugar Research Australia, 2014). Literature indicated that cane loss was less of a concern under burnt conditions when compared to harvesting green cane. This is understandable given the far lower EM levels found in burnt cane. However, initial trial results suggest that losses may be an important factor to consider in burnt cane, particularly in relation to extractor fan speed.

Results from three ‘good burn’ cane trials gave 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 no-fan scenario, the five tonne per hectare improvement in cane yield (which is supported by a report published by Hurney *et al.* (1984) which identified cleaning losses of 5-8 t/ha in burnt cane) translated to an additional $206/ha in grower gross revenue ($1.66/t improvement). This signified a significant economic return from a marginal change in the overall harvesting operation.

Harvester elevator pour rates from the burnt cane trials ranged from an average of 136.4 t/h for the control to 140.8 t/h for aggressive treatments. The reduction in flow rate for the control treatment was primarily due to the drop in average ground speed. This reduction was attributed to a single trial within the limited dataset where a lower ground speed was applied in the control treatment. It is likely that a constant ground speed between treatments would increase the elevator pour rate from when a reduced fan speed is applied. This was evident in the move from an aggressive to moderate fan speed setting.

In the absence of burnt cane harvesting cost data, harvesting group information and trial data for burnt cane was applied to the green cane cost comparisons. While it drew on repairs and maintenance, labour, and other harvesting cost information from the green cane calculations, the change in cost gave indication of the benefits gained through a reduction in fan speed. This related particularly to fuel savings at between $3 (aggressive to moderate) and $11 (aggressive to control) per hour. Some of the fuel savings were offset by a reduction in bin weights that increased the number of haulout trips. On average, an additional $46/ha (22c/t) was gained by the contractor on the three trials for the 'no-fan' setting. In moving from an aggressive to 'no-fan' setting the increase in grower gross revenue was $207/ha. Incorporating changes in harvesting costs, fuel and levies, the average total net benefit to the grower was $202/ha. 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.

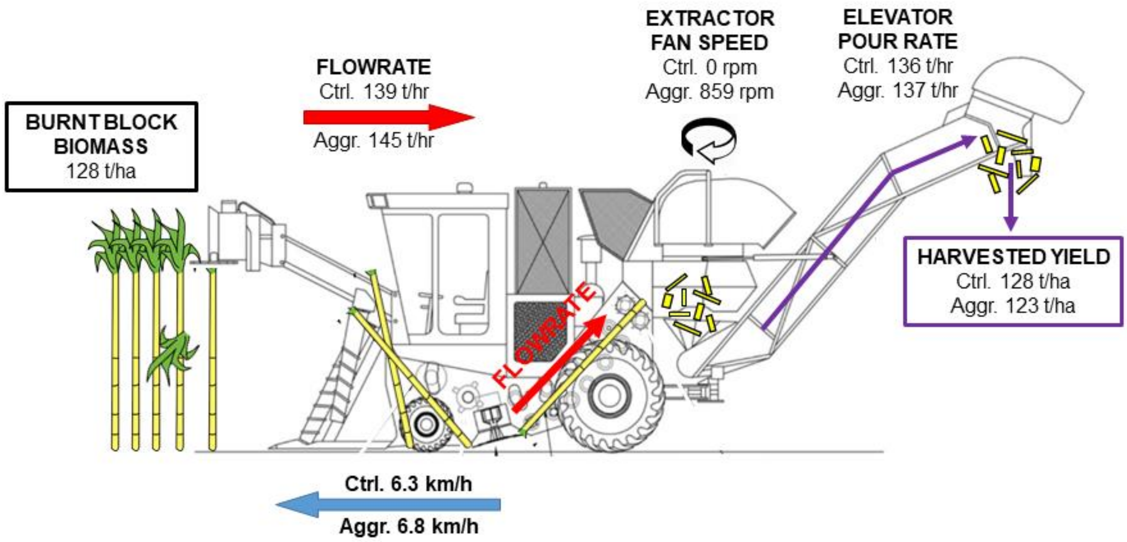


Figure 10. Graphical depiction of different speeds, flow rate, sugar loss, pour rate and cane yield between control (Ctrl.) and aggressive (Aggr.) settings in burned cane.

7.4. Barriers to Adoption of HBP

The benefits of HBP are well established and documented in research dating back to the 1990s but, as we show here, the industry continues with poor and costly harvesting practices (e.g. increasing flowrates, 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; 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. Each region has unique drivers (e.g. payment arrangements between growers and contractors and between contractors and their operators) and pinch points (operating hours, bin fleets, number of contractors). In order 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 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 implementation of economically beneficial HBP implementation and better address perceived barriers through alleviating current limitations.

8. CONCLUSION

The project demonstrated the production and revenue gains of HBP to the industry along with the associated estimated harvesting cost changes for selected trials. For green cane regions, reducing the average harvester flowrate by 21 t/hr (or groundspeed by 0.9 km/hr) and primary extractor fan speed by 95 rpm, increased cane yield and sugar by 4.9 t/ha and 0.7 t/ha respectively (or 5.2% and 5.0%). The yield gain delivered a $181/ha (or 4.8%) increase in grower gross revenue. These gains were all significantly different from current standard practice. However, the cost of these gains must not be forgotten, “there is no gain without paying”.

The perceived notion that HBP negatively impacts cane quality and bulk densities proved largely unfounded in the trial results. There was no significant deterioration in cane quality or bulk density. EM levels remained constant with no statistically significant difference, with the same observed in both CCS and fibre levels. As a result, bin mass did not significantly decrease when adopting HBP. These results confirm that HBP delivered more cane per hectare to the mill without significantly impacting quality, a gain in production to industry.

The reduction in material flowrate into the harvesters reduced by 18.8% (or 21 t/hr) with the resultant reduction in bin fill rate at the siding or pad proving notably lower at 8.2% (or 0.6 bins/hr at 10-t nominal bin capacity). The impact of this change would vary at a mill regional level and could impact cane supply logistics if full district adoption of HBP is achieved. This requires further investigation and consultation with individual mills.

The reduction in flowrate into the harvester did, however, impact harvesting costs. The severity of the cost change was driven by the size of the flowrate reduction but dampened by the resultant yield gain associated with reduced extractor fan speed. On average, harvesting costs increased by $61/ha or 22c/t at the average yield increase (5.2%) measured in the trials. These were the breakeven cost changes and growers would still need to consider incentives when negotiating new payment terms.

Assuming full adoption of HBP across the whole green cane industry, the growing sector is estimated to gain an additional $44 million annually in gross revenue. After subtracting the additional harvesting costs from implementing HBP ($17 million), along with the extra levies from increased cane yield ($1 million), growers are left with an annual net benefit of $26 million. The milling sector would also gain approximately $25 million per annum in gross revenue but the additional transport and milling costs that would be incurred are unknown.

Further research is required in burnt cane regions, but preliminary indications are that appropriate extractor fan speed selection can improve harvested yields by up to 5.1 t/ha and reduce fuel consumption by 9.8 L/h. These results culminate in an estimated grower net benefit of $148/ha.

The barriers to HBP adoption are best summarised by a lack of communication and understanding of HBP both between and within the three sectors. Growers must understand that there is “no gain without payment” and that contractors require the added harvesting costs be covered to maintain profitability. Additional contractor incentives may be required for change, given the potential for longer working hours. Contract harvesters also need to understand the impact of HBP and its impact within their operational limitations.

9. RECOMMENDATIONS FOR FURTHER RD&A

9.1. Further assessment and data mining of 2017 & 2018 trial database

A substantial amount of data was collected during the 2017-18 harvesting trials. So far, the data has been statistically analysed to determine the broad impact of using HBP. However, this data could potentially be utilised to determine if there are interactions between the benefit of using HBP and other factors such as specific cane varieties, the quantity of cane in a block, field conditions, crop presentation for harvest, etc. Results could potentially identify where there are relatively larger or smaller gains from HBP adoption, which could help to refine HBP recommendations and extension activities and enable these to be better targeted to maximise industry gains.

9.2. HBP cost change guidance tool

While nine harvesting cost evaluations were completed in the project, undertaking more of these would help extension providers to inform harvesting operations of the cost changes and promote HBP adoption. Also, collecting more data around harvesting operations will help with the development of tools and inform communication activities.

9.3. HBP net benefit decision making tool

One key barrier to adoption is that presently growers and harvesting operators 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. 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 2017-18 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 the proposed 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).

In development of such a tool, further costings would need to be done in order to validate the model algorithms. Given the difference in costs per tonne between settings, an important contributor to the model would be accurate estimation of yield responses linked to ground and fan speed changes.

9.4. Impact to milling logistics and efficiencies

Further investigation into the cost and implications to the milling and transport sectors, with a particular focus on cane supply logistics and milling efficiencies, is required. During informal discussions at ASSCT 2019, QUT/SRI expressed an interest in exploring these costs and efficiencies further. Millers and regional industry leaders acknowledged this needs investigation to understand the impact of adoption of HBP across a whole mill supply region.

9.5. Harvester operator training workshops

After the completion of the project workshop, it was identified that there was a lack of harvesting operator training programs to industry. It is important that this gap be addressed through the development of an industry-accredited training program.

9.6. Burnt cane loss assessments

The limited number of burned cane trials highlighted the opportunity to reduce fuel costs and increase harvested yields through appropriate extractor fan speed selection. The long-held belief that burned cane harvesting produced minimal losses through the cleaning chamber extractor fans is being mistakenly applied to aggressive and often unnecessary cleaning practices in burnt cane and requires further investigation to establish the opportunities to increase harvested yields with appropriate fan speed selection.

9.7. Impact of HBP on crop ratoonability

The impact of reducing harvester groundspeed is expected to have long term benefit on ratoonability, although this would need the support of longer-term trials. The current 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*" is expected to provide some more insight into ratoonability, however the project will only present its findings in 2020.

9.8. Equipment design changes

Harvester primary extractors are the largest proponent of green cane harvesting losses. There is an increasing sentiment from growers and harvesting contractors to reconsider the design and configuration of the harvester extractor chamber.

10. PUBLICATIONS

Five publications to the Australian Society of Sugar Cane Technologists (ASSCT) were accepted for paper presentations at the 2019 ASSCT Conference. These publications are listed below and refer specifically to the 2017 season results. Further papers are planned for the 2020 ASSCT Conference which will conclude the final results from both harvest seasons 2017 and 2018. Patane *et al.,* (2019) received the prestigious President's Medal for the best research paper for the presentation and submission.

- Patane P, Milford B, Landers G, Thompson M, Nothard B, Norris CA, Venables C (2019) Harvesting groups – the key to improving harvest practice.

- Patane P, Landers G, Thompson M, Nothard B, Norris CA, Olayemi M (2019) Adoption of practices to mitigate harvest losses: 2017 Results.
- Nothard B, Thompson M, Patane P, Landers G, Norris CA (2019) A cost assessment of harvesting best practice (HBP) adoption.
- Thompson M, Nothard B, Patane P, Landers G, Norris CA (2019) Economic evaluation of sugarcane harvesting best practice.
- Patane P, Landers G, Norris CP (2019) Assessing cane and sugar losses utilising world-class methods.

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- Regional Canegrowers organisations
- Plane Creek Productivity Services
- Mackay Area Productivity Services
- Sugar Services Proserpine
- Herbert Cane Productivity Services Ltd

The productivity boards and services were instrumental in supporting the identification and approaching of growers and harvesters to participate in the program. Their support continued through trial execution, workshop feedback sessions and finally to the facilitating of presentations to regional industry boards, decision makers and Canegrowers organisations.

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- Sunshine Sugar
- MSF Sugar
- Isis Central Sugar
- Bundaberg Sugar
- Wilmar Sugar
- Mackay Sugar
- Tully Sugar

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13. APPENDICES

13.1. Appendix 1. Additional Specialist Trials

During the execution of the project, SRA executed additional trials at the request of grower groups for the following comparisons:

- Optimised vs. Unoptimised Harvester Feedtrains
- Four vs. Five Blade Chopper Drums
- Low Loss After Market Drums vs. Ex-Factory Chopper Drums
- Secondary Extractor Fan Cane Loss in Burned Cane

13.1.1. Optimised vs. Unoptimised Harvester Feedtrains

A trial was conducted in the Mossman region using a CaseIH 8800 harvester to demonstrate the impact of feedtrain optimisation. The harvester feedtrain was optimised prior to the trial. The CaseIH harvester requires hydraulic plumbing changes to achieve optimisation and this was completed prior to the trial. Once the hydraulic changes are complete the feedtrain is set to run at 100% speed setting. The unoptimised feedtrain setup was simulated by reducing the feedtrain speed ratio to 65% as per its original settings. The four trial treatments consisted of control and standard practice harvester settings, each run with an optimised and unoptimised feedtrain setting (Table 15).

Table 15: Harvester settings for four trial treatments

Parameter	Practice			
	Control - Unoptimised	Control - Optimised	Standard - Unoptimised	Standard - Optimised
Ground speed, km/h	3.0	3.0	6.0	6.0
Primary fan speed, rpm	800	800	800	800
Feedtrain Speed ratio, %	65	100	65	100

Table 16 lists the results of the trial for each treatment. The treatment fanspeeds all remained within 12 rpm of each other, while the groundspeed was increased above the control treatment setting to achieve standard practice flowrates for the standard treatment. The limited trial size produced no discernible trend in EM changes and more replicates are required to reduce the variability in the results. Average bin masses decreased for optimised feedtrains, however a marked improvement in gross cane yield was observed in the range of 10.3 tc/ha at standard practice. The CCS and sugar yield of the optimised treatments improved against unoptimised feedtrain settings. This is directly attributed to the increase in billet length (refer to Table 17). Sugar losses measured in the field decrease for optimised feedtrain treatments. Gains in grower and harvester revenue were noted for optimised feedtrains in the region of $130/ha and $74/ha respectively, under standard practice.

Table 16: Summary of optimisation trial results

Parameter	Practice			
	Control - Unoptimised	Control - Optimised	Standard - Unoptimised	Standard - Optimised
Ground speed, km/h	2.9	2.9	5.6	5.4
Primary fan speed, rpm	813	825	825	819
Extraneous matter, %	18.3	15.3	12.8	16.8
Average bin mass, t/10 t bin	10.4	9.5	9.6	9.0
Gross cane yield, tc/ha	109.5	113.5	99.4	109.7
CCS, units	8.4	8.6	8.0	8.2
Sugar yield, ts/ha	9.2	9.7	7.9	8.9
Total biomass left, t/ha	26.1	21.4	21.6	22.5
Sugar loss, ts/ha	1.32	0.73	1.45	0.94
Total grower revenue, $/ha	1,904	2,031	1,550	1,777
Net grower revenue, $/ha	880	970	621	751
Harvester revenue, $/ha	794	823	721	795

Billet length and quality results are listed in Table 17. The optimised harvester feedtrain running at 100% speed ratio produced a billet length increase of 20.3 mm. The proportion of sound billets for the unoptimised feedtrain was unusually high compared to past and current research. This result highlights the importance of conducting a comprehensive trial with two harvesters of the same make, model and setup bar the feedtrain. Reducing the speed ratio of an optimised feedtrain does not accurately reflect the performance of an unoptimised feedtrain. SRA has observed this before in other harvesting trials where the feedtrain speed ratio was adjusted for an optimised harvester. Another consideration was the condition of the crop. The trial notes recorded an erect crop which lends towards good product feeding conditions through the harvester.

Table 17: Cane quality results

Parameter	Practice			
	Control - Unoptimised	Control - Optimised	Standard - Unoptimised	Standard - Optimised
Average Billet Length, mm	145.8	166.1	145.8	166.1
Sound, %	81.4	83.3	82.6	85.2
Damaged, %	14.4	11.3	13.2	11.0
Mutilated, %	4.2	5.4	4.2	3.8

<u>Conclusion</u>

For conclusive results on the production and revenue benefits associated with optimised feedtrains, a trial protocol should have two harvesters of the same make and model being used in the same block, with the only difference being their feedtrain setup, optimised vs unoptimised. The overall findings of the trial support the previous research by Davis and Norris (2002) and Hockings *et.al* (2000). Optimised feedtrains improve billet length, cane and sugar yields, grower and harvester revenues with no impact on time in the block harvesting the crop. Due to the limited trial size, no statistical analysis was completed.

13.1.2. Eight- vs. Ten-Blade Chopper Drums

A trial was conducted in the Tully region using two John Deere 3520 harvesters to demonstrate the impact of cane loss associated with replacing eight-blade chopper drums with ten-blade chopper drum assemblies. This was a repeat of a previous trial to satisfy harvester operators that two different hectare measurement protocols, GPS tracked row meters and cutting strip trials, supported the same trend of decreasing harvested yields with shorter billet chop lengths (associated with an increase in number of blades per drum). The harvester feedtrain settings of both harvesters were checked and recorded prior to the trial start to ensure comparable feedtrain setup. The six trial treatments consisted of the same control, recommendation and standard practice harvester settings for each harvester (fitted with either eight- or ten-blade chopper assemblies). These harvester settings are listed in **Table 18**.The two harvesters started at either end of the field and worked in a circular arrangement so that alternate drills were harvested by a different harvester across the entire paddock.

Table 18: Harvester settings for chopper drum comparison trial treatments.

Parameter	Practice					
	Control 10Blade	Control 8Blade	Recommend 10Blade	Recommend 8Blade	Standard 10Blade	Standard 8Blade
Ground speed, km/h	3.0	3.0	5.5	5.5	5.5	5.5
Primary fan speed, rpm	550	550	600	600	700	700
Blades per drum	5	4	5	4	5	4

Crop variability was noted in the block during harvesting and the first replicate was removed from the dataset during analysis. While the control treatments did not deliver the expected highest yield, the eight-blade chopper drum assembly consistently produced a higher yield than the ten-blade chopper across all treatments. This is a result of fewer chops per meter length of stalk and thus less mass and sucrose loss. By comparison, the eight-blade chopper produced lower EM levels except for the standard treatment. The ten-blade chopper produced a higher bin mass and left more biomass and sugar in the block. The eight-blade chopper consistently delivered higher gross and net revenues for the grower and harvesting contractor in comparison with the ten-blade chopper.

Table 19: Summary of results from chopper drum comparison trial

Parameter	Practice					
	Control 10Blade	Control 8Blade	Recommend 10Blade	Recommend 8Blade	Standard 10Blade	Standard 8Blade
Ground speed, km/h	3.0	3.0	5.5	5.5	5.5	5.5
Primary fan speed, rpm	550	550	600	600	700	700
Extraneous matter, %	20.6	19.1	19.8	15.0	15.5	16.3
Average bin mass, t/10-t bin	9.5	8.3	9.3	8.8	9.7	9.1
Gross cane yield, tc/ha	99.2	104.0	105.8	109.3	100.6	103.5
CCS, units	13.7	13.7	13.8	13.7	13.9	13.4
Sugar yield, ts/ha	13.6	14.2	14.6	15.0	14.0	13.9
Total biomass left, t/ha	23.5	19.1	21.7	19.3	24.1	22.2

Sugar loss, ts/ha	0.59	0.45	0.63	0.39	0.67	0.58
Total grower revenue, $/ha	3,787	3,943	4,072	4,178	3,914	3,820
Net grower revenue, $/ha	2,873	2,985	3,097	3,171	2,986	2,866
Harvester revenue, $/ha	719	754	767	792	730	750

Table 20 lists the comparative cane quality data for the eight- and ten-blade chopper drum assemblies. The eight-blade chopper produced a longer billet (12 mm, or ½ inch) and consistently produced higher levels of sound billets, especially in the contractor's standard practice. The eight-blade chopper drums produced lower levels of damaged and mutilated billets.

Table 20: Summary of cane quality from chopper drum comparison trial

Parameter	Practice					
	Control 5Blade	Control 4Blade	Recommend 5Blade	Recommend 4Blade	Standard 5Blade	Standard 4Blade
Average Billet Length, mm	164	178	164	178	164	178
Sound, %	82.0	89.9	83.7	85.9	70.2	85.4
Damaged, %	10.0	4.8	7.5	5.8	13.6	7.9
Mutilated, %	8.0	5.3	8.8	8.3	16.2	6.7

Conclusion

The results of the trial conclusively demonstrated the benefit of retaining an eight-blade chopper assembly configuration over a new ten blade configuration. Fewer blades per drum resulted in fewer chops per meter length of stalk. The net result was improved cleaning (EM extraction), increased cane and sugar yield, and increased revenue for both the grower and contract harvester. Cane quality improved with fewer mutilated and damaged billets. These combined benefits outweighed the reduced bin mass.

As a result of this trial, the contractor agreed to supply their eight-blade harvester to cut all the participating grower's blocks in each round of the 2018 harvest, to allow the grower to assess the performance across the whole farm.

13.1.3. Low Loss After-Market Drums vs. Ex-Factory Chopper Drums

The NSW region requested comparison trials of low-loss after-market chopper drums compared with ex-factory fitted drums. SRA conducted completed trials in both John Deere and Case recent model harvesters, JD3520 and CaseIH8800 respectively. In each trial, two harvesters of the same make and model where used to cut a block. One of the harvesters was fitted with after-market low-loss drums while the other still contained the factory-supplied chopper drum. Both sets of drums had the same number of blades.

The trial consisted of four treatments. Each harvester cut two treatments, a control treatment with low fan speed and a standard practice treatment with nominal operating speeds. The low and nominal fan speed settings were the same for both harvesters. Table 21 lists the aggregated results of both drum comparison trials. Material flowrate into the harvester remained the same across all treatments and harvesters. The first trial crop had a poor burn quality and hence a control treatment fan speed of 600 rpm was chosen, while in the trial with a good burn quality a 0 rpm setting was used for the control treatment. The standard practice treatment utilised nominal fan speed settings for the conditions. Marginally higher EM levels were observed in the after-market low-loss drums compared to the ex-factory drums. As a result, the bin bulk density and masses of the low loss drums were lower than the ex-factory drums. The low-loss drums consistently delivered higher cane yields of 7.9% (or 12-13 t/ha) compared to the ex-factory drums. CCS levels remained largely unchanged between the drum types. The low-loss drums consistently produced higher sugar yields of 7% (or 1.4 t/ha). The grower gross and net revenue from the low-loss drums was consistently the highest.

Table 21: Summary of trial comparing after-market low loss chopper drums and ex-factory drums.

Parameter	Practice			
	Control – Low-Loss Drums	Control – Factory Drums	Standard – Low-Loss Drums	Standard – Factory Drums
Ground speed, km/h	5.2	5.3	5.1	5.1
Primary fan speed, rpm	284.9[4]	270.9[5]	958.1	953.4
Extraneous matter, %	11.2	10.0	11.0	8.0
Average bin mass, t/10-t bin	7.7	8.0	8.7	8.7
Gross cane yield, tc/ha	177.6	164.7	164.9	152.8
CCS, units	11.7	11.8	12.13	12.17
Sugar yield, ts/ha	20.9	19.5	20.0	18.5
Total grower revenue, $/ha	5,250	4,911	5,026	4,666
Net grower revenue, $/ha	3,649	3,341	3,540	3,289

Table 22 lists the comparative billet quality data for the low-loss after-market and ex-factory drum assemblies. The ex-factory drum produced a marginally longer billet (6mm, or ¼ inch), however the low-loss drums consistently produced higher levels of sound billets, especially in the contractor's standard practice. The ex-factory drums consistently produced the highest levels of damaged and mutilated billets.

Table 22: Summary of cane quality from chopper drum comparison trial

Parameter	Practice			
	Control – Low-Loss Drums	Control – Factory Drums	Standard – Low-Loss Drums	Standard – Factory Drums
Average Billet Length, mm	178.4	184.4	178.4	184.4
Sound, %	56.4	53.9	64.0	52.7
Damaged, %	35.6	39.6	29.8	41.7
Mutilated, %	8.0	6.5	6.2	5.6

Conclusion

[4] This is an aggregated speed for both trial's control treatments. One trial having a fan speed of 0 rpm while the other had 600 rpm attributed to the poor burn.

The low-loss after-market drums consistently produced the highest cane and sugar yields, billet quality and revenue. Sunshine Sugar has implemented an incentive scheme to encourage harvesting co-operatives to install low-loss after-market drums into harvesters. This is a result of the SRA trials corroborating their own previous independent evaluation trials.

13.1.4. Secondary Extractor Cane Loss Trial

A NSW harvesting co-operative requested a trial to evaluate the impact of secondary extractor fan performance on cane loss. The trial design consisted of three treatments, control, aggressive with no secondary fan and aggressive with secondary fan on. Table 23 lists the harvest settings for the three treatments. A consistent material flowrate was maintained through the harvester across all treatments. The secondary extractor fan remained off

Table 23: Harvester settings for secondary extractor trial's three treatments

Parameter	Practice		
	Control	Aggressive & Secondary Off	Aggressive & Secondary On
Ground speed, km/h	5.0	5.0	5.0
Primary fan speed, rpm	0	900	900
Secondary Fan	Off	Off	On

Table 24 lists the results of the secondary extractor trial. The groundspeed and material flowrate remain constant across all treatments. The primary extractor fan speed for the comparative aggressive treatments remained constant at around 900 rpm. As expected, the control treatment produced the highest EM level as both extractor fans were off. The aggressive treatment with no secondary fan actually produced the lowest EM level, leading to the deduction that the secondary extractor is removing a higher proportion of cane billets than EM by comparison with the primary extractor on a proportional basis. Bin masses remain consistent across all treatments, suggesting the bins had additional volume capacity and are limited by on-road axle loading limits. The control treatment produced the highest cane yield as expected but the difference between aggressive treatments with secondary fan on and off is of interest. The secondary extractor fan accounted for a yield loss of up to 6.7 t/ha. CCS levels across the three treatments remained relatively consistent. Sugar yields for the control and aggressive with no secondary fan were the same. This is attributed to the 0.2 unit increase in CCS in the latter. The use of the secondary fan in the aggressive treatment resulted in the lowest sugar yield for no apparent improvement in cane quality (EM levels). Grower and harvester[5] revenue decreased with more aggressive extractor fan speeds and was highest in the aggressive treatment with secondary fan on.

[5] Harvesting in NSW is dominated by harvesting co-operatives and not pure harvesting contractors. This figure is purely for interest in other burnt cane regions.

Table 24: Summary of secondary extractor fan trial results

Parameter	Practice		
	Control	Aggressive & Secondary Off	Aggressive & Secondary On
Ground speed, km/h	5.7	5.8	5.8
Primary fan speed, rpm	0	903	900
Extraneous matter, %	12.1	8.0	9.3
Average bin mass, t/10 t bin	9.1	9.1	9.0
Gross cane yield, tc/ha	166.5	163.2	156.5
CCS, units	13.0	13.2	13.3
Sugar yield, ts/ha	21.6	21.6	20.8
Total grower revenue, $/ha	5,931	5,895	5,701
Net grower revenue, $/ha	4,627	4,618	4,476
Harvester revenue, $/ha	1,166	1,142	1,096

Conclusion

The results of the trial gave preliminary indication that operating the primary extractor fan reduced delivered yields (increased losses) without improvements in either cane quality or bin weights (or reduced fibre levels). In a move from an aggressive with the secondary fan operating to a no-fan scenario, the 10 tonne per hectare improvement in cane yield translated to an additional $230/ha in grower gross revenue. Additionally, operating the secondary extractor fan with the primary extractor fan in a good burn lost 6.7 tonnes per hectare and $194/ha gross revenue to the grower.

13.2. Appendix 2. Surveyed trial participant responses

The following includes qualitative comments made by about 70 survey respondents regarding their noted “barriers to adoption”:

1. “Sugar Price - grower is willing to pay more but is constrained by the sugar price at times”.
2. “Contractor size - Large contract size. Crop size”.
3. “Machinery price and sugar price. Large groups to keep the price down”.
4. “Sugar price and cost of harvesting. Need to get a fair price for the product”.
5. “Crop size, sugar price, contractor price. If the grower gets paid a higher price for the product, he could afford to pay the contractor more.”
6. “Harvesting price - trying to keep cost down. Trying to get extra money out of the growers”.
7. “Belief in data and price of harvesting”.
8. “The crew wanting to go home early – need to educate the crew”.
9. “Communication between harvester drivers and research presented and the growers”.
10. “Communication between grower and contractor. People keeping an open mindset”.
11. “Belief in the data. Need to be guaranteed you will get that money back”.
12. “The biggest issue is making sure the crop is there and that the growers are assisting in HBP (wide headlands, weed control etc.)”.
13. “Not enough people have seen the results in other districts. More tours of other districts. Live loss measurement system. Measuring individual fibres”.

14. “Need to know more information in a burned cane region”.
15. “Lack of harvester numbers in the Herbert, mill needs NIR”.
16. “Varieties”.
17. “People think that it is all about slowing down, which will then cost them more in harvesting cost”.
18. “Harvester drivers learning to drive slower”.
19. “The conditions of harvest vary too much to implement just a single standard HBP. What it comes down to is a on the day practice. If it’s damp and trashy you slow down. Dry and good chop and no stool damage clearly you not going to cut at 4km per hour”.
20. “The price of sugar, so the per tonne the harvester gets”.
21. “Too low a pour at times”.
22. “Contractors having invested huge amount of money in their business's based on tonnes through their machine and payment scheme not linked to best harvest practice (but this also needs the farmer convinced of harvest best practice)”.
23. “Operators view harvesting cane as something to be completed quickly and the sooner finished the more efficient the operation. High bin weights and clean cane samples are more important than cane loss”.
24. “Grower info and uptake”.
25. “As long as contractor is getting a premium open to adoption”
26. “Parameters in NSW are different due to all harvesting groups being co-ops”

13.3. Appendix 3. METADATA DISCLOSURE

Table 25 Metadata disclosure 1

Data	Green Cane Harvesting Loss Trials Statistical Report and Source Data
Stored Location	Sugar Research Australia Server
Access	Data is available upon request.
Contact	Phil-Anthony Patane, Sugar Research Australia; +61 (0)7 3331 3333

Table 26 Metadata disclosure 2

Data	Burned Cane Harvesting Loss Trails Statistical Report and Source Data
Stored Location	Sugar Research Australia Server
Access	Data is available upon request.
Contact	Phil-Anthony Patane, Sugar Research Australia; +61 (0)7 3331 3333

Table 27 Metadata disclosure 3

Data	Optimised vs. Unoptimised Harvester Feedtrain Trial Source Data
Stored Location	Sugar Research Australia Server
Access	Data is available upon request.
Contact	Phil-Anthony Patane, Sugar Research Australia; +61 (0)7 3331 3333

Table 28 Metadata disclosure 4

Data	Four vs. Five Blade Chopper Drums Source Data
Stored Location	Sugar Research Australia Server
Access	Data is available upon request.
Contact	Phil-Anthony Patane, Sugar Research Australia; +61 (0)7 3331 3333

Table 29 Metadata disclosure 5

Data	Low Loss After Market Drums vs. Ex-Factory Chopper Drums Source Data
Stored Location	Sugar Research Australia Server
Access	Data is available upon request.
Contact	Phil-Anthony Patane, Sugar Research Australia; +61 (0)7 3331 3333

Table 30 Metadata disclosure 6

Data	Secondary Extractor Fan Cane Loss in Burned Cane Source Data
Stored Location	Sugar Research Australia Server
Access	Data is available upon request.
Contact	Phil-Anthony Patane, Sugar Research Australia; +61 (0)7 3331 3333