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Adoption of practices to mitigate harvest losses: 2017 results

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Abstract Harvesting Best Practice (HBP) recommends that harvesters maintain pour rates of 80-90 t/h, depending on make and model, and recommends extractor-fan speed guidelines that ensure minimal cane loss with low extraneous matter (EM). Exceeding the recommended pour rate overloads the cleaning capacity of modern harvesters and increases EM in the cane supply. To attempt to counterbalance the EM issue, it is usual to increase fan speeds above those recommended, resulting in greater cane loss. Use of HBP recommendations across the industry is low and full HBP adoption would substantially increase industry revenue. To address this, 43 replicated harvesting trials and workshops were undertaken in the 2017 harvest season across 12 sugarcane regions between Maryborough and Mossman. The performance of settings recommended by HBP were compared with each harvesting operation's standard practice by assessing yield, CCS, bin mass, 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 28 replicated and randomised trials were analysed to identify differences between industry standard harvesting practices and those recommended by HBP. We found that harvesters are typically operated at ground and fan speeds that are on average 1 km/h and 95 rpm above those recommended. The higher ground speed delivered an additional 22 t/h of cane into the machine on average but overloaded the cleaning capacity of the harvester. While the higher fan speed helped to remove the additional EM entering the machine, it also removed additional cane through the extractor with most being disintegrated, making it invisible to stakeholders. Testing indicated that mean sugar loss out of the extractor was increased by 0.15 t/ha compared with HBP settings, while there were no significant differences in EM or bin mass. Due to the additional cane being lost, less cane was delivered to the mill per hectare. Mill results across all trials identified that mean cane and sugar yields for the recommended practice were 5 t cane/ha (5.4%) and 0.8 t sugar/ha (5.7%) higher than standard practice. Neither CCS nor fibre levels were significantly different. The increased cane and sugar yields generated by the recommended settings boosted mean total grower revenue by $220/ha, equating to $173/ha after subtracting the additional harvesting costs (including fuel) and levies. Extrapolating these findings across the Australian green-cane-harvested area, full adoption of the recommended practices could deliver an additional 1.3 Mt of cane and 202,000 t of sugar valued at over $86 million for industry ($57 million in additional revenue for growers alone).

Key words Harvesting best practice, cane loss, fan speed, pour rate

INTRODUCTION

Profitability of the growing, harvesting and milling sectors is intrinsically linked to the material produced by the harvester operation (Larsen *et al.* 2017). Since mechanised harvesting commenced in 1970, the Australian sugar industry has sought to improve its efficiency. 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).

Research in the 1970s identified substantial losses of both cane and sugar from mechanical harvesting, in particular in green-harvested cane. Hurney *et al.* (1984) identified cleaning losses of 5-8 t/ha in burnt cane, while Ridge and Dick (1988) identified a wide range of losses depending on harvesting practice, field conditions, varieties and time of harvest. Shaw and Brotherton (1992) reported an average cane loss of 8.2 t/ha in green cane in the Mulgrave region.

From 1997 to 1999, Whiteing and Paton (Sandell and Agnew 2002) conducted over 50 harvesting trials that investigated pour rate, fan speed, 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.

Larsen *et al.* (2017) surveyed cane quality delivered to the Herbert, Burdekin and Proserpine mill regions, determining percentage of EM (leaf, tops, dirt and roots), billet quality (sound, damaged and mutilated) and billet length delivered to the mill. Their survey highlighted an increase of EM, dirt and roots since the 2000s and found EM comprised 5-32% of the cane supply in the Herbert, Proserpine and Plane Creek regions, and 4-12% of the cane supply in the Burdekin burnt-cane region. Tops were 36-55% of the median extraneous matter in the cane supply and it was evident that harvesters were routinely not topping cane, even when it was erect.

In July 2016, Sugar Research Australia (SRA) commenced a major research and adoption program to improve the efficiency of the Australian sugarcane harvesting sector. This included significant contributions from the Queensland Department of Agriculture and Fisheries (QDAF), other industry research bodies, milling companies, harvester operators and growers. Across the project, investment included $3.55 million from the Australian Government (Department of Agriculture and Water Resources) and $1.85 million from SRA. SRA Project 2016/955, *Adoption of practices to mitigate harvest losses*, formed part of the wider project *Enhancing the sugar industry value chain by addressing mechanical harvest losses through research, technology, and adoption*.

We recruited about 10% of harvesting groups in 2017 (43 groups), except for burnt-cane regions, to the project. Participants were involved in demonstration trials to show the impact of harvesting operations on cane losses for each group. Trials were conducted by SRA using the Infield Sucrose Loss Measurement System (ISLMS) as well as 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.

METHODOLOGY

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 cultivar and crop class. A randomised replicated trial design was developed with up to four harvesting treatments. A minimum of four replicates were executed for each treatment, depending on block size, yield and bin allocation from the mill. The four treatments were labelled 'control', 'recommended' (HBP), 'contractor's standard' and 'aggressive'.

The 'control' treatment was designed to provide the best possible post-harvest estimate of total biomass available in the paddock together with 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 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.

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

Total grower revenue was calculated using the cane payment formula[1] 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'. 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 85 c which were deducted per tonne of cane.

Data collected in the 2017 harvest season across 10 sugarcane production regions in Queensland were statistically analysed to assess the effects of four harvesting treatments 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:

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

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 ε represents the deviations from our predictions due to random factors that we cannot control experimentally. The random component effect was grouped by block/contractor 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 family significance level of 5%.

From the 43 harvesting trials, 28 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 (which affected 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).

RESULTS

The mean results from all conforming trial sites for each harvester treatment setting are given in Table 1. For the shift from standard to recommended harvester settings, ground and primary extractor fan speeds on average reduced by 1 km/h and 95 rpm, respectively. Due to these changes in speed, the elevator pour rate decreased by 14 t/h which was partially offset by reduced cane loss. Total biomass in the block prior to harvest was estimated using the ISLMS field biomass measurements for the control treatment along with the production results from the mill. This in turn was used to calculate the actual throat pour rate (flow rate), which is the total quantity of material (cane and extraneous matter) entering the harvester feed train. Shifting to the recommended settings significantly reduced this flow rate by 21 t/h.

[1]Cane payment formula (except Mackay) = (0.009 x sugar price x (ccs – 4) + mill constant) x cane yield. Mackay cane payment formula = [(prs% x sugar price x recoverable sugar index) + ((fibre% - (ash% - 0.45%)) x fibre price) + (molasses% x molasses price)] x cane yield.

Table 1 also shows the EM levels in delivered cane, bin fill rates and average bin masses (based on a nominal 10-t rail bin). Whilst the control treatment had significantly higher EM levels than standard practice by 3.0%, there was no significant difference between the recommended and standard practices. The recommended practice filled 0.9 fewer bins per hour (-11%) than standard practice (a significant difference), which could potentially affect cane supply logistics in some regions. While the control treatment had significantly lower bin mass than the standard practice by 1.1 t per 10-t bin, there was no significant difference between recommended and standard practice. This followed the trend for extraneous matter levels.

Table 1. Average harvester performance under different practices.

Parameter	Practice			
	Control	Recommended	Standard	Aggressive
Ground speed	3.0	4.4	5.8	6.6
Primary fan speed, rpm	598	709	804	954
Elevator pour rate, t/h	55.3 a	72.9 b	86.6 c	91.7 d
Flow rate**, t/h	65.8 a	88.2 b	109.6 c	121.6 d
Extraneous matter, %	14.7 a	12.4 b	11.7 b	10.7 c
Bin fill rates, bins/h	6.6 a	7.4 b	8.3 c	8.5 c
Average bin mass, t/10 t bin	7.66 a	8.66 b	8.77 b	9.10 c

*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 shows the mean results of in-field residue measurements. The ISLMS quantified the total biomass (t/ha) of trash blanket extracted from harvester extractor chambers and determined the total sugar content of the field residue. The total tonnes sugar/ha could then be calculated to give an indication of harvesting loss. The recommended practice had a 0.15 t/ha significantly lower in-field sugar loss than standard harvesting practice. There was no significant difference in field biomass between recommended and standard practice, but there was among the control, recommended and aggressive treatments in line with the sugar-loss results.

Table 2. In-field residues under different practices.

Parameter	Practice			
	Control	Recommended	Standard	Aggressive
Sugar loss, t/ha	0.37 a	0.57 b	0.72 c	1.17 d
Total biomass, t/ha	10.7 a	14.9 b	15.8 b	20.5 c

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

Table 3 gives the mean production and revenue results for each harvesting treatment setting. There was a significant yield difference among treatments. The control treatment had the highest mean yield followed by the recommended, standard and aggressive practices. In particular, the recommended practice had a significantly higher yield than standard practice by 5 t cane/ha (5.4%). There was no significant difference in CCS or fibre levels between the recommended and standard practice. The sugar yield produced by the recommended practice was significantly higher (by 0.8 t sugar/ha or 5.7%) than standard practice, driven largely by increased cane yield.

Total grower revenue was calculated by accounting for yield, CCS, the sugar price and respective cane payment formula, while net revenue subtracts harvesting costs, fuel costs and levies from total revenue. Results identified statistically significant differences among the aggressive, standard and recommended settings. In particular, the recommended settings generated $220/ha more total grower revenue than the contractor's standard settings. A similar result was found with net grower revenue, where the recommended settings showed $173/ha more than the standard setting.

Table 3. Mean production and revenue results under different practices.

Parameter	Practice			
	Control	Recommended	Standard	Aggressive
Gross cane yield, t/ha	99.6 a*	96.3 b	91.3 c	86.9 d
CCS, units	13.95 c	14.12 ab	14.00 bc	14.16 a
Fibre levels, %Cane	15.2 a	14.8 b	14.9 b	14.7 b
Sugar yield, t/ha	14.8 a	14.6 a	13.8 b	13.3 b
Total grower revenue, $/ha	4,049 a	3,977 a	3,757 b	3,633 c
Net grower revenue**, $/ha	3,041 a	3,001 a	2,828 b	2,745 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.

DISCUSSION

Figure 1 provides a graphical representation of differences in ground and fan speeds, flow rate, sugar loss, elevator pour rate and cane yield between standard and recommended practice. Using the recommended instead of standard harvester settings required operators to reduce ground and extractor fan speeds by an average of 1 km/h and 95 rpm, respectively. The impact to industry would be an increase in harvesting time, requiring an increase in harvesting hours per day and/or an increase in season length. Harvesting time increased by an average 15 minutes for every 100 t of cane harvested using the recommended settings. This additional time would increase fuel consumption, labour hours, machine depreciation, and wear and tear per hectare (Nothard *et al.* 2019).

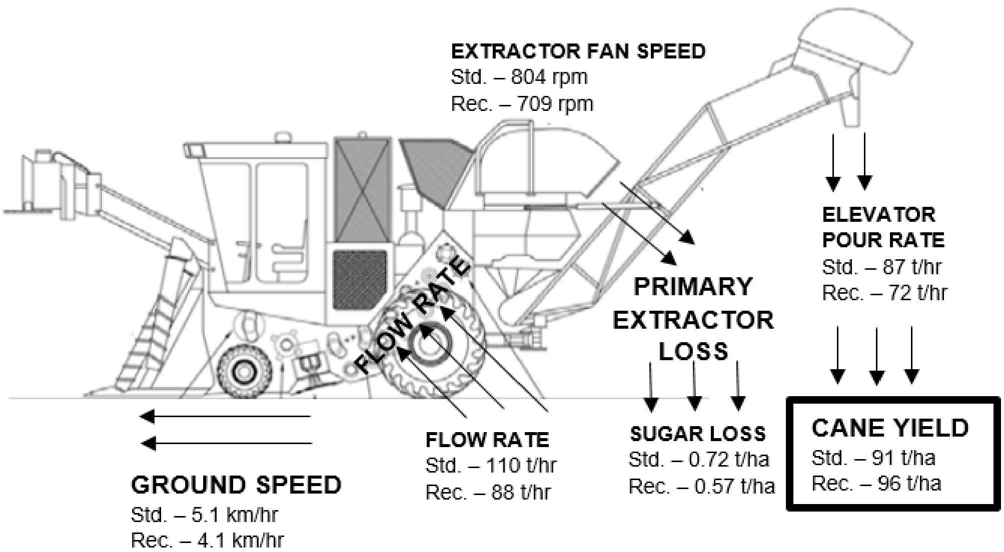

Figure 1. Graphical representation of differences in speeds, flow rate, sugar loss, pour rate and cane yield between standard (Std.) and recommended (Rec.) practices.

Reduced extractor fan speeds had a statistically significant impact on reducing cane loss but not EM. This supports the work by Whiteing (2002). As a result, there was no significant change in bin mass. Although overall fuel costs increased per hectare, savings were made per hour given the reduced fan speed.

Reducing the speed of the harvester impacted the flowrate into the machine and elevator pour rate exiting. The lower flowrate through the harvester extractor lowered the proportion of clean cane being lost via the primary extractor fan. The net result showed no significant change in EM levels delivered to the mill but an increase in total tonnes of cane per hectare. There was also no statistically significant difference in nominal bin masses arising from no significant change in EM. The reduced groundspeed driven by the flowrate change significantly impacted overall harvesting time and the bin fill rate on the siding or pad. Depending on bin fleet capacity of the mill region, this could impact the ability to deliver bins efficiently.

In-field testing measured a significant reduction in sugar loss of 0.15 t/ha when moving to the recommended setting. This was supported by the experience of growers who on the day observed increased sucrose levels of the ISLMS mulched tarp samples associated with more aggressive harvesting practices (increased fan and ground speeds). The sugar left in the field was from the undelivered cane, representing the effective cane loss from the harvester extractors. There was no significant difference in biomass extracted by the harvester and left in the field, but the significant difference in sugar levels demonstrated that the harvester extractor continued to remove EM from the product stream with reduced cane loss. The outcome was that more clean cane was delivered to the mill, suggesting that the harvester extractors were operating more efficiently at the recommended lower flowrates.

The combination of reduced flowrate and fan speed contributed to an increased cane yield of 5 t/ha. Our results show significant differences among the treatments, indicating flowrate and fan speed had a critical impact on harvested cane yield. The aggressive treatment delivered significantly less cane than the standard practice which made this operation commercially unviable. Furthermore, while the control treatment delivered significantly more cane yield than the recommended, this was also accompanied by significantly lower CCS and would come at substantially increased harvesting costs. This is analysed in more detail in Nothard *et al.* (2019). Thompson *et al.* (2019) further examines the additional revenue less harvesting cost with a shift from standard to recommended practice. A shift from standard practice to recommended and consequent improvement in cane yield (5 t/ha) indicated that average profitability would increase for both the grower and industry.

From a cane-quality perspective, significant differences in CCS levels among treatments were likely a function of the negative relationship between CCS and EM. The control treatment had significantly higher levels of EM and significantly lower CCS by comparison to recommended practice. There was also no significant difference between recommended and standard CCS results due to the same relationship between their EM levels. Fibre levels had a positive relationship with EM. The significantly higher levels of EM for the control treatment would have implications for transport logistics, mill crush rates and recoveries. This would make the control treatment impractical for adoption despite the observed gains in yield.

Figure 2 shows the change in cane tonnage, sugar tonnage, and total revenue for grower and industry across the Australian green-cane-harvested industry when shifting from standard harvesting settings. The increase in revenue from using recommended settings is calculated assuming that the same cane yield and CCS improvements we measured in the trials are obtained across the entire Australian green cane sugar industry. Five-year average green-cane production, average CCS[2] and total harvested area data were used to determine average annual industry revenue (SRA 2018). A weighted average mill constant of 70.2 c/t was used to calculate grower revenue across the industry. For milling revenue, an average 1.02 coefficient of work was applied, understanding that this would differ slightly among milling companies.

Extrapolating per hectare results across the Australian green cane harvested area shows that an extra 1.3 Mt of cane would be gained by industry-wide adoption of the recommended settings. Considering the trial CCS results, this translates to 202,000 additional tonnes of sugar valued at over $85 million for the industry (an extra $3.72/t of cane). For the grower, this amounts to an additional $57 million in gross revenue (an extra $2.50/t of cane).

The price growers and the wider industry receive for their sugar has a substantial impact on the benefit from implementing HBP. While the preceding analysis used the 5-year average sugar price, it is informative to understand the revenue implications at various sugar prices. Table 4 shows the changes in total grower and industry revenue at various sugar prices from shifting to recommended harvesting settings. A low sugar price would reduce the revenue benefit from using recommended practice, while a high sugar price would increase the revenue benefit.

Table 4. Changes in total grower and industry revenue at different sugar values.

Parameter	Sugar value, $/t					
	350	390	424	430	470	510
Change in total grower revenue, $/t	2.07	2.30	2.50	2.53	2.76	3.00
Change in total industry revenue, $/t	3.08	3.43	3.72	3.78	4.13	4.48

[2]Mackay PRS results were incorporated after converting to CCS using a factor based on Pollock *et al.* (2007).

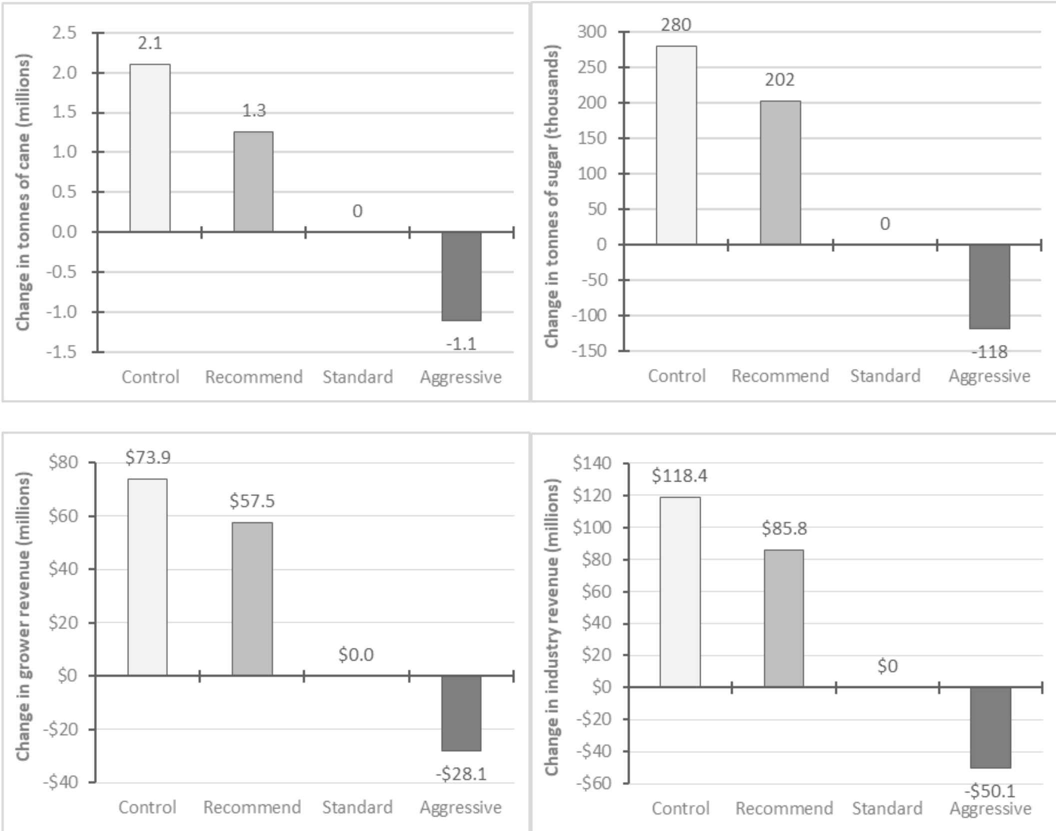

Figure 2. Impact across industry to cane and sugar production as well as grower and industry revenue from changing the harvesting practices.

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 cultivars.

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.

CONCLUSIONS

We have identified that using HBP instead of standard harvesting practice across the Australian sugarcane industry would increase industry revenue and improve industry sustainability. Our findings indicated that, compared to standard practice, the recommended settings delivered significantly lower sugar loss (-0.15 t sugar/ha, -21%), higher sugar yield (+0.8 t sugar/ha, 5.7%) and higher revenue (+$220/ha, 5.9%). When extended across the whole Australian green-cane industry, our results suggest that full adoption would increase industry revenue by around $86 million.

Replicated trial data needs to form the foundation of a wider adoption strategy as well as more detailed harvesting cost information, innovative communication offerings and tools that make the adoption process easier and more transparent for all involved. Regional working groups comprised of representatives from all three sectors (grower, harvester and miller) are needed to support and assist in alleviating limitations to full implementation.

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