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Cost assessment of the adoption of harvesting best practice (HBP)

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Abstract Using ground speeds and extractor fan speeds recommended by Harvesting Best Practice (HBP) will minimise cane loss and stool damage. While these benefits provide an incentive for growers to request contractors use HBP settings, little research based on trial data has examined the full impact on harvesting costs. Given that reduced ground speeds increase harvesting time, it is expected harvesting contractors would incur higher labour, fuel and machinery costs per tonne. To incentivise the move to HBP, additional compensation would need to be paid to harvesting contractors by growers. It is anticipated that providing growers and contractors with information about the harvesting cost implications from implementing HBP would enhance adoption. The difference in harvesting costs between conventional (standard) harvesting practice and HBP (recommended) are evaluated at nine harvesting-trial sites undertaken across Queensland in 2017 by Sugar Research Australia. The analysis draws upon the production and operational information collected during the trials along with detailed information collected from each of the nine harvesting operations. A customised economic spreadsheet was developed to model the difference in harvesting costs between standard practice and recommended settings. Harvesting costs per tonne were generally found to increase when using recommended settings, with the exception of trials that attained large reductions in cane losses due to the change in practice. The results showed that changing to recommended settings increased harvesting costs by between $11 and $101/ha. Changes per tonne showed far more variability at –67 c/t (saving) to 96 c/t (increase), where some cases showed cost increases offset by yield improvements. Moreover, harvesting costs varied among harvesting contractors due to differences in machinery-management strategies and labour-payment terms. Sensitivity analyses were also undertaken to investigate the response of harvesting costs to different scenarios.

Key words Harvesting best practice, economics, sugar loss, harvesting costs

INTRODUCTION

For the Australian Sugar Industry, Harvesting Best Practice (HBP) has been pursued in various forms since the introduction of mechanised harvesters in the 1970s. Challenges include the balance of harvester efficiencies, such as infield cane and sugar losses, against optimisation of throughput and harvesting costs (Sugar Research Australia 2014). Research, development and extension providers have continued to promote the adoption of HBP over time. More recent funding has been provided by the Australian Government and Sugar Research Australia Limited (SRA) through the Rural Research and Development (R&D) for Profit program to investigate the impact of HBP on harvesting losses across a broad cross section of industry. The program includes the project *Enhancing the sugar industry value chain by addressing mechanical harvest losses through research, technology and adoption,* which involved several harvesting trials across Queensland.

During the 2017 season, 43 harvesting trials were conducted as part of the project led by Sugar Research Australia (Patane *et al.* 2019). The revenue implications from implementing HBP, in comparison to standard harvesting practices, across all 2017 trial sites are presented in Patane *et al.* (2019). While improved yield though reduced harvesting losses and resultant revenue benefits of HBP are well understood, there is a lack of information available on the associated harvesting cost implications. To address this gap in knowledge, the project included a comprehensive investigation of harvesting cost comparisons associated with implementing HBP. It is believed that with an improved understanding of these differences, both growers and contractors would better accept the current economic uncertainties of HBP adoption. This is anticipated to raise adoption levels for Industry and reduce harvesting loss.

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 different 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 different 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). Interestingly, Agnew *et al*. (2002) examined harvesting cost changes through adoption of HBP at both paddock and regional level. They identified an average increase of 50 c/t for additional hours required at optimum economic machine settings.

Despite the HHM providing a good foundation, a challenge for our 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, we developed an economic spreadsheet (model) 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. This paper examines 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 in the findings are a cost-change range and the key cost inputs having greatest influence on overall costs.

METHODOLOGY

To assess cost changes associated with HBP adoption, we drew on data from nine harvesting trials along with detailed information about the harvesting operations that undertook the trials. Information specific to each operation was collected including costs 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 typically lasted up to 4 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, we developed a cost comparison model (Model). Its initial development drew heavily on the HHM for underpinning harvester and haulage cycle calculations as well as several other formulae. Key contributions of the HHM included the time-cycle-based interactions between the harvester and haulouts, determination of elevator pour rates and overall changes in harvesting time such as cutting and waiting times. Some of the original assumptions of the HHM were accounted for with trial data, making the calculation of costs specific to both the harvesting group and the characteristics of the trial paddock.

A challenge for the project was to accurately estimate differences in harvesting costs among different harvester settings, whilst including the impact on fixed costs. The four harvester settings of the trials included both ground speeds and primary extractor fan speeds as follows:

- Control: slow ground and fan speeds, commonly set at 3 km/h and 600 rpm, respectively;
- Recommended: targeted HBP settings as determined by past research provided by SRA (this included the use of the SCHLOT[1] harvesting optimisation model and SRA Harvesting Ready Reckoner[2]). Fan speed was in most cases set at 700 rpm although more aggressive models of extractor fans required lower speed settings (i.e. 600–650 rpm);
- Contractor's standard settings (standard): historically normal harvester settings as determined by the harvesting group;

[1] Sugarcane Harvesting and Logistics Optimisation Tool. A commercially available harvesting logistics optimisation tool.
[2] A tool developed by SRA for determining best practice settings on a harvester by optimising machine flow/pour rates.

- Aggressive: high ground and fan speeds set above the contractor's standard settings, commonly set at 7–8 km/h and 900 rpm but initially targeting an increased flow rate and fan speed increase of 20 t/h and 150 rpm, respectively.

As the HHM did not incorporate certain economic interactions among 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 paid by the tonne in North Queensland regional analyses, 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 t, undertaking a minor service every 250 h 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 among 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.

Different 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 when modelling the cost of harvesting.

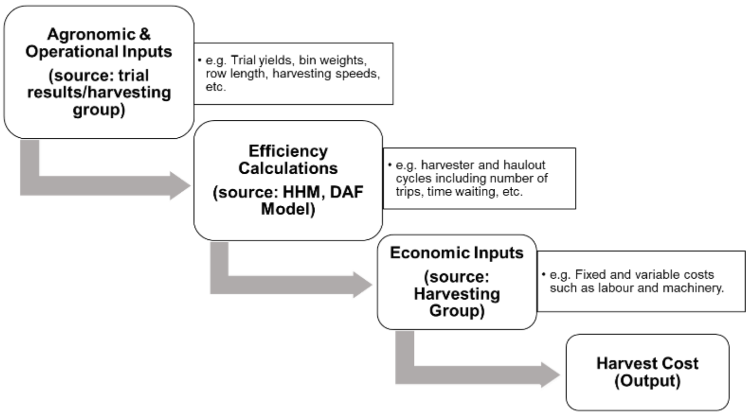

Figure 1. Harvesting cost modelling process.

We considered nine sites from the 2017 harvesting trials 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 cane-growing 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. 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 (Patane *et al.* 2019).

A wide variety of information was needed to accurately calculate harvesting costs and differences in harvesting costs among 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 in that 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 calculation of depreciation, interest and repairs and maintenance are detailed below.
  - $\text{Depreciation} = \frac{(\text{Purchase Price} - \text{Salvage Value})}{\text{Life (years)}}$;
  - $\text{Interest (opportunity cost)} = \text{interest rate} \times \frac{(\text{Purchase Price} + \text{Salvage Value})}{2}$;
  - 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 (L/h) while harvesting, turning or idling for the harvester, and consumption (L/h) while laden, empty or idling for the haulouts);
- Overhead costs (general fixed costs such as insurance, accounting, registrations, telephone, printing and stationary, 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.

RESULTS

Harvesting costs

Table 1 highlights some of the among the nine harvesting operations, trial sites, harvester settings and obtained yields that we observed. Crops harvested annually varied considerably for the harvesting groups from 58,000 to 134,000 t. Average row length at the trial blocks varied between 340 and 1,100 m, with row spacing varying between 1.6 and 2.4 m. 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/h, harvester yields between 70 and 125 t/ha and elevator pour rates between 75 and 106 t/h.

Table 1. Differences among 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 2 – all costings include fuel and both harvester and haulage allowances. Harvesting costs ranged from $6.65 to $10.13 per tonne, highlighting the substantial cost variation among 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 2. 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.

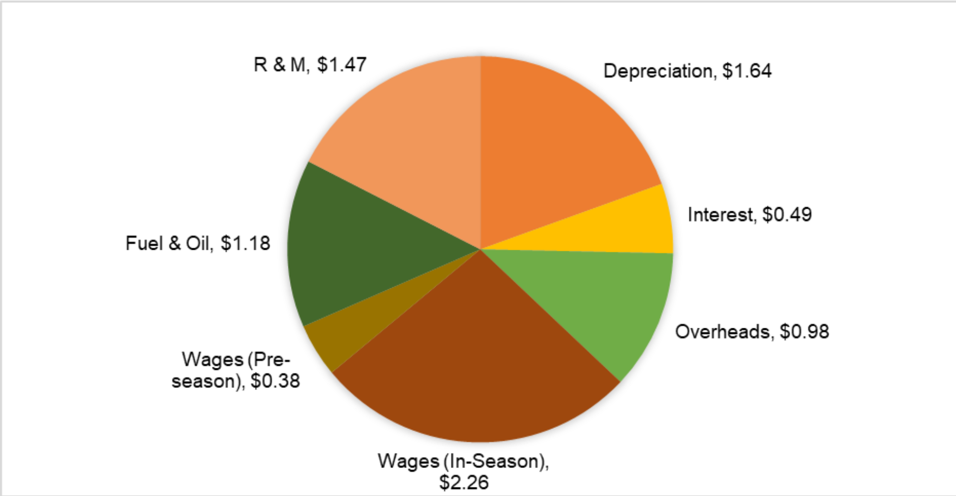

Figure 2. Breakdown of harvesting costs per tonne.

Harvesting costs were 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 assumptions: that the harvester maintained the same ground speed, and that 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 t cane/ha 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/h, higher cane losses were also expected. On the other hand, if the harvester maintained the same pour rate by reducing ground speed from 5.1 to 4.1 km/h, then harvesting costs would only decrease from $8.71 to $7.90/t, although cane losses may not increase. The same trend occurred for a row 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.

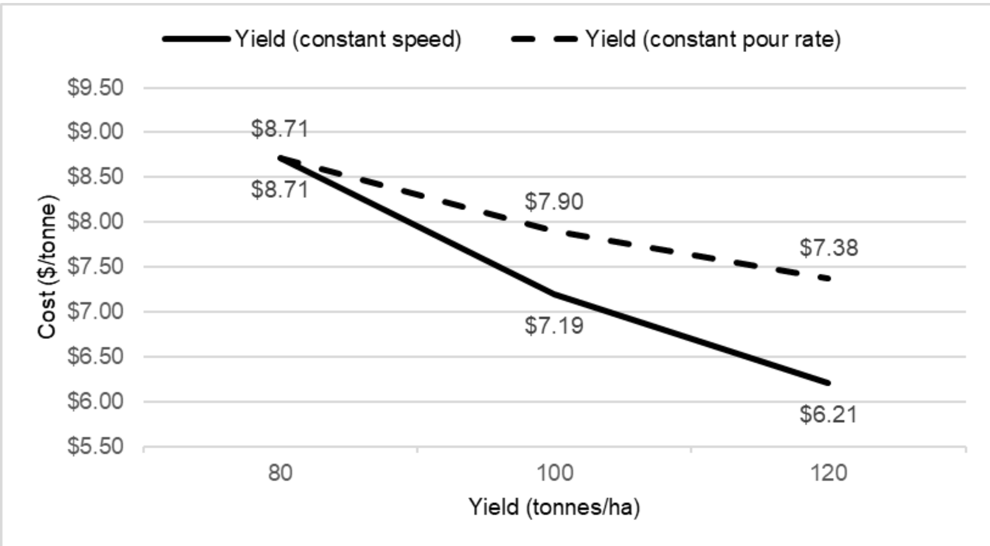

Figure 3. Impact of change in yield on harvesting costs.

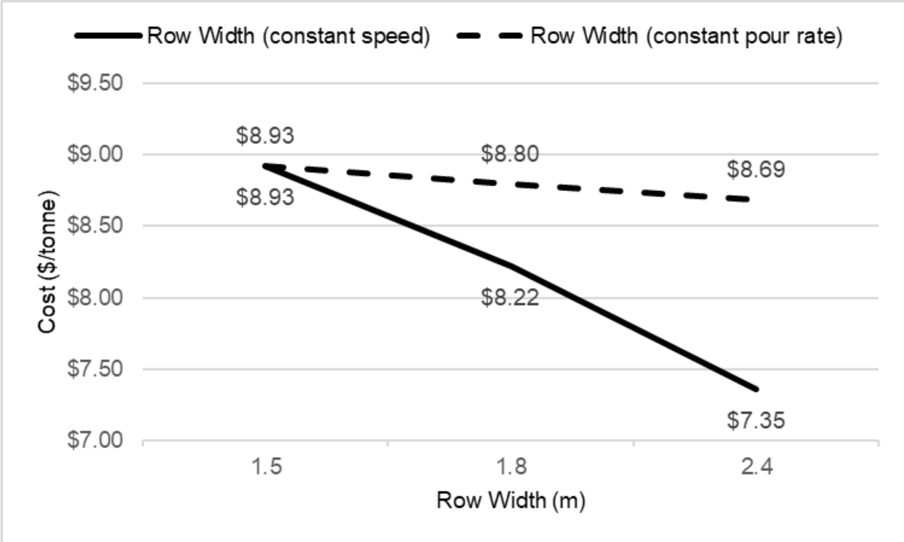

Figure 4. Impact of change in row width on harvesting costs.

The impacts of row length, ground speed and group size changes on harvesting costs are given in Table 3. 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 m was 31 c/t. Adding a further 200 m for a row length of 1,000 m only reduced costs by a further 6 c/t, 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 t, respectively. Decreasing ground speed from 7 to 6 km/h increased harvesting costs by 26 c/t, while the marginal cost increase was greater at lower speeds (due to the larger proportional change).

Table 3. Input sensitivities.

Input change	Row length (m)			Ground speed (km/h)			Group size (tonnes/year)		
	400	800	1,000	7	6	5	80,000	100,000	120,000
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

Cost comparisons

Table 4 outlines the difference in ground speed, fan speed, elevator pour rate, yield and harvesting costs between the contractors' standard settings and the recommended settings for the nine trials. Ground speed, fan speed, elevator pour rate and cane yields were all factors that were considered in 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/h and 69 rpm, respectively, resulting in an average change in elevator pour rate of 12 t/h. 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 6.7% more cane yield across the trials.

The difference in harvesting costs per hectare between the contractors' standard settings and the recommended settings ranged between an increase of $11 and $101/ha, with an average change of $61/ah across the nine evaluations (Thompson *et al.* 2019). It is important to note the range of harvesting cost differences showed more variability on a per tonne basis than per hectare, given yield change influences. The differences in harvesting costs per tonne ranged between a decrease of 67 c/t and an increase of 96 c/t with an average increase of 10 c/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 occur in circumstances where small changes in ground speed are combined with significant decreases in fan speed. This would improve yield but not substantially increase harvesting times, a big driver of cost when changing harvester settings. For South 2, the trial result showed little change in yield among 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.

Table 4. Cost differences between recommended and standard settings for the nine trial sites.

Harvesting group	Ground speed difference (km/h)	Fan speed difference (rpm)	Elevator pour rate difference (t/h)	Yield difference (%)	Cost difference ($/t)
South 1	–1.4	0	–20	9.8	0.20
South 2*	–0.7	–100	–16	–0.7	0.28
South 3	–1.2	–150	–11	8.3	0.25
South 4	–1.0	–100	–15	3.4	0.20
Central 1**	–0.9	–130	–3	18.6	–0.67
North 1	–0.8	–40	–9	7.0	0.02
North 2*	–1.2	0	–11	9.0	–0.06
North 3*	0.0	–100	4	5.1	–0.31
North 4	–1.6	0	–29	0.2	0.96
Mean	–1.0	–69	–12	6.7	0.10

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

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 5.4% average identified across all the 2017 harvesting trials (Patane *et al.* 2019). 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 5.4% 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 33 c/t decrease to a 68 c/t increase with an average of 21 c/t (Figure 5).

Table 5. Breakdown of average harvesting costs and differences between standard and recommended settings.

Cost item	Standard cost ($/t)	Recommended cost ($/t)	Change*	
			$/t	%
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 and oil	1.18	1.23	0.05	4.2
R & M	1.47	1.43	–0.03	–2.2
Total	8.39	8.46	0.07	0.8

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

Table 5 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. Although, 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 among 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.

Yield-response sensitivities

As shown in Table 4, the percentage increase in yield from the contractor's standard settings to recommended settings varied substantially among 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 96 c/t, while the trial that obtained an 18.6% improvement had a 67 c/t lower cost.

Given the change in cane yield had a considerable impact on the cost difference per tonne, it is informative to examine the sensitivity of harvesting costs to various yield changes when shifting from the standard to recommended settings. Based on the trial results, the yield change impacts on cost are explored through application of the most extreme yield changes measured by the harvesting groups (i.e. –0.7% as the lowest yield change and +18.6% as the highest yield change). These yield changes were then applied to all nine cases and the two most extreme cases presented in figure 5 (dark lines). Figure 5 also presents the cost change ranges (dotted lines) at different yield changes using the two most extreme cases (dark lines) as the outermost boundaries.

Limited by the two most extreme cases, Figure 5 shows the harvesting cost difference assuming a 5.4% yield increase. This was measured across all trials in the 2017 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 33 c/t saving to a 68 c/t increase for the nine trial sites (represented by the dotted line intersection with the outermost boundary lines).

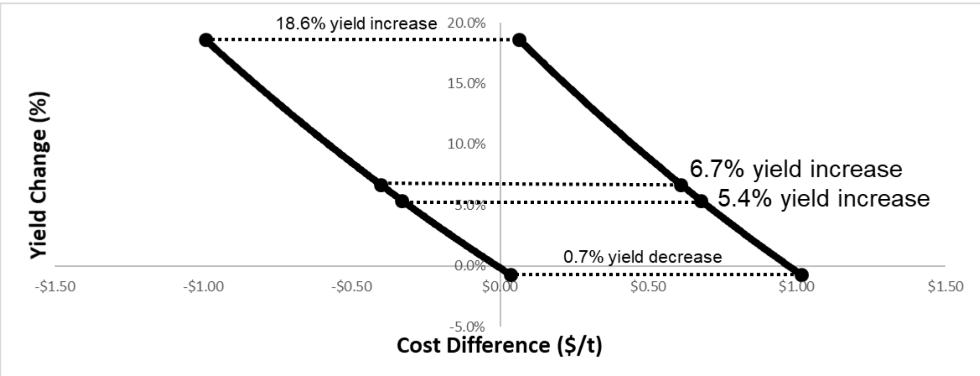

Figure 5. Range of yield changes to cost differences for the nine trial sites.

DISCUSSION

Results from our harvesting cost comparisons showed that using the recommended settings instead of the contractor's standard settings increased harvesting costs by between $11 and $101/ha. The results varied more widely per tonne given that yield improvements from the difference in settings varied greatly among trial sites. 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 c/t) than the trial site that had the largest yield increase of 18.6% where harvesting costs decreased by 67 c/t. The trial that resulted in a yield decrease showed a lower cost increase of 29 c/t given ground speed changes were marginal. Another key driver of harvesting costs 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. 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 among the harvesting operations (types of harvesters and haulouts, wages, number of haulouts used). We 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 our 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 6 shows 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 63 c/t ($54/ha) with a 0.7% decrease in yield. With an 18.6% increase in yield the resulting cost reduced by 57 c/t but still increased by $78/ha.

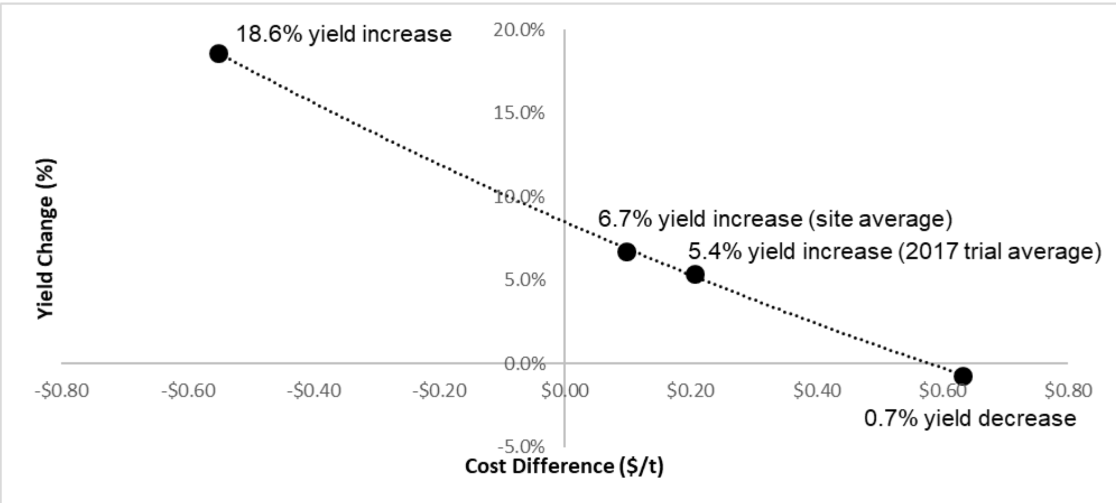

Figure 6. Yield change to cost difference sensitivity for the nine trial sites.

Patane *et al.* (2019) found an average yield increase of 5.4% in moving to recommended settings for 26 trials which is also reflected in Figure 5. Application of this yield increase to the selected case studies gave an average 21 c/t increase in cost. This included a range of –33 to 68 c/t at the outmost trial bounds. The cost increase per hectare range was $12 to $108. Given these results only reflected a proportion of the trials undertaken by the harvesting project in 2017, it cannot be assumed that these numbers are representative of the wider sugarcane industry.

Elevator pour rate changes had significant influence on the overall cost. The lower the pour rate, the higher the additional cost incurred by harvesting groups. This close relationship is reflective of the combined influence arising from ground speed, fan speed and yield changes. It is therefore critical that yield estimates are accurate or targeted pour rates would be missed. This is important given HBP targets are based on pour rates linked to the ability of harvester chambers to effectively clean the total quantity of cane and extraneous matter flowing through the machine.

CONCLUSIONS

It is important to identify the cost implications of HBP adoption for both harvesting groups and growers. The need to not only measure the benefits and costs of adoption but also to use more accurate and specific costing information in the negotiation process is key to improving acceptance of HBP by stakeholders. Our results showed that shifting from the contractor's standard settings to the recommended settings increased harvesting costs by between $11 and $101/ha. The harvesting cost changes varied considerably more per tonne due to wide variations in cane yield improvement between the trial sites (from using the recommended settings). Harvesting costs would have decreased by 57 c/t for the trial with the largest yield improvement (18.6%), while they would have increased by 96 c/t for the trial with the second lowest yield improvement (0.2%). The average yield increase across the nine trials was 6.7%, which is higher than the 5.4% average across all 2017 harvesting trials. Applying the lower yield increase of 5.4% to the nine harvesting cost evaluations identified that harvesting cost changes were between –33 to 68 c/t ($12 to $108/ha). This showed an average increase of 21 c/t.

The most important cost changes occurred with depreciation, fuel and in-season labour. These were driven largely by changes in ground speed, and the resultant increase in harvesting time. Elevator pour rate had a strong relationship with overall harvesting cost, which could be useful in future harvesting cost difference predictions.

It is proving important for contractors and growers to have access to reliable harvesting cost information relating to adoption of HBP settings. The lack of access to this information may be a significant barrier to adoption for industry. Further harvesting cost evaluations will be undertaken over the course of the harvesting project to better strengthen insight into harvesting cost differences arising from the adoption of HBP.

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REFERENCES

Agnew J, Sandell G, Stainlay G, Whiteing C (2002) Increased sugar profitability through harvesting best practice. *Proceedings of the Australian Society of Sugar Cane Technologists* 24: 8 pp.

Antony G, Prestwidge D, Sandell G, Higgins A (2003) Scope for cost savings from harvesting rationalisation in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists* 25: 8 pp.

Barker F (2007) *An Economic Evaluation of Sugarcane Combine Harvester Costs and Optimal Harvest Schedules for Louisiana*. Master's Thesis, Louisiana State University. https://digitalcommons.lsu.edu/cgi/view content.cgi?referer=https://www.google. com.au/&httpsredir=1&article=1220&context=gradschool_theses.

Higgins A, Prestwidge D, Laredo L, Sandell G (2006) Integrated sugarcane transport and harvesting efficiency models. *Proceedings of the Australian Society of Sugar Cane Technologists* 28: 1 p.

Meyer E (1998) A model to estimate combine harvester and infield transport performance and costs. *Proceedings of the South African Sugar Technologists' Association* 72: 58–60.

Patane P, Landers G, Thompson M, Nothard B, Norris CA, Olayemi M (2019) Adoption of practices to mitigate harvest losses: 2017 results. *Proceedings of the Australian Society of Sugar Cane Technologists* 41: 488–496.

Ridge D, Hobson P (2000) *Analysis of Field and Factory Options for Efficient Gathering and Utilisation of Trash from Green Cane Harvesting.* Final Report SD00011. Bureau of Sugar Experiment Stations, Indooroopilly.

Ridge D, Powell J (1998) *A Management Assistance Package for Optimising Harvester/Infield Transport Productivity*. Final Report SD98005. Bureau of Sugar Experiment Stations, Indooroopilly.

Sandell G, Prestwidge D (2004) Harvest haul model – the cost of harvesting paddocks of sugarcane across a sugar milling region. *Proceedings of the Australian Society of Sugar Cane Technologists* 26: 10 pp.

Sugar Research Australia (2014) *Harvesting Best Practice Manual*. https://sugarresearch.com.au/wp-content/uploads/2017 /02/Harvesting-Best-Practice-Manual-FINAL-LR.pdf.

Thompson M, Nothard B, Patane P, Landers G, Norris CA (2019) Economic evaluation of sugarcane harvesting best practice (HBP). *Proceedings of the Australian Society of Sugar Cane Technologists* 41: 507–511.