

ASSESSMENT OF SUGARCANE YIELD MONITORING TECHNOLOGY FOR PRECISION AGRICULTURE

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Abstract

WITHIN the Australian Sugar industry a number of attempts have been made to monitor yield variation across a block. These have ranged from the early yield monitoring systems based on discrete mass measurement, to the current focus of predicting yield via surrogate measurements based on chopper pressure, feed train roller displacement and elevator power. This paper describes an independent evaluation of commercially available mass flow sensors that was conducted to assess current performance of yield monitoring options while identifying opportunities for developing improved cane yield monitoring systems. Three yield monitoring systems which were commercially available in 2008 (AgGuide, TechAgro and MTData) were fitted to a BSES-owned CH2500 Cameco harvester. Trials were conducted during the 2008 and 2009 seasons in the Ingham district of North Queensland. Each yield monitoring system was assessed simultaneously to eliminate the influence of machine setup and site characteristics that would be encountered through independently assessing each unit. During the trial, the harvester was operated according to Harvesting Best Practice (HBP). In addition to yield monitoring, sugarcane yield was also measured using a weigh bin in order to determine the absolute accuracy and resolution of the respective yield monitoring systems. Weigh bin and mill weight data were used to assess the yield monitors at a range of scales including; 50 m of row, full rows, multiple rows (i.e. plot of 9 rows) and the entire field. These assessments were made with the harvester operating at both high and low pour rates. Only the TechAgro unit was found to provide results that were sufficiently accurate to be considered as a potentially viable sugarcane yield monitor. Performance of this unit was, however substantially

reduced at high pour rates and this sensor was unable to account for changing pour rates. Recommendations for further refining the devices and for additional work are included.

Introduction

During the past decade, considerable effort has gone into developing systems to allow for yield monitoring on sugarcane harvesters on-the-go (Bramley, 2009). Several different approaches have been taken to measure and predict the quantity (t/ha) of cane being harvested. Cox *et al.* (1998) tried several different approaches and ended up patenting a weigh platform that was supported by load cells in the upper section of the elevator (Cox *et al.*, 2003; US Patent No. 6,508,049 B1). The use of a similar yield sensor has been reported by Pagnano and Magalhães (2001), Cerri and Magalhães (2005), Molin and Menegatti (2004), Magalhães and Cerri (2007) in Brazil and by Benjamin (2002) in the USA. A system to monitor yield using a combination of base cutter pressure and the torsion in a deflection plate on the elevator was patented in the US in 2001 (Wendte *et al.*, 2001; US Patent No. 6,272,819 B1). Installation of instrumentation to monitor the roller opening was the approach taken by Hernandez *et al.* (2003, 2005) and Fernandez *et al.* (2007). A different approach is to use optical sensors to measure the amount of cane on the slats in the elevator (Price *et al.*, 2007).

The purpose of the research reported in this paper was to evaluate the commercial devices that have been available as yield monitors in the Australian Sugar Industry (as at July 2008). The devices included the units available from TechAgro, AgGuide and the Mackay Sugar 'MTData' unit. It should be noted that the primary function of the MTData unit is for vehicle tracking. As an add-on, Mackay Sugar has fitted pressure transducers to selected harvesters to investigate work-rate as a coarse indication of yield variation. This has allowed the MTData unit to be used out of context, as a yield monitor.

The three systems were based on different operating principles: the TechAgro unit deriving its yield estimation by sensing feed train roller opening, the MTData unit based on the change in hydraulic pressure across the chopper and roller motors, and the AgGuide unit based on the change in pressure across the elevator motor.

The investigations evaluated the performance of these yield monitors in terms of the maps produced with the collected data, the actual data values underpinning these maps, and a comparison between these data and the values obtained from weight-truck readings. The effects of various operating configurations on the yield monitor response were also assessed.

Materials and methods

Instrumentation of all three yield monitors on the same machine, a BSES-owned Cameco CH2500 harvester, enabled a side by side comparison of the various yield monitors while at the same time eliminating many external influences (i.e. crop and harvesting interactions) which would be encountered through separate evaluation of each unit. The trials were conducted in the Herbert district during 2008 and 2009.

Prior to the trial, new base cutter blades, chopper knives and extractor fan blades were fitted and the harvester was subsequently operated according to harvester best management practice (BMP) as defined by BSES. In addition to yield monitor data, a combination of BSES weigh bin and mill bin weight data was obtained to assess the yield monitors at a range of spatial scales. The field was split into plots which consisted of 9 rows of cane. The first 4 rows were harvested into a weigh bin with the harvesting operation stopped every 50 m for the mass harvested to be determined and recorded. The harvester driver used highly visible site marks that were set out at 50 m intervals prior to the harvest. The next 5 rows were also discharged into the weigh bin (so that the amount harvested could be tracked), but the harvesting operation was only stopped when the bin was full. In both cases, yield monitor data were logged simultaneously during the harvest operation. A schematic diagram of the trial layout is shown in Figure 1.

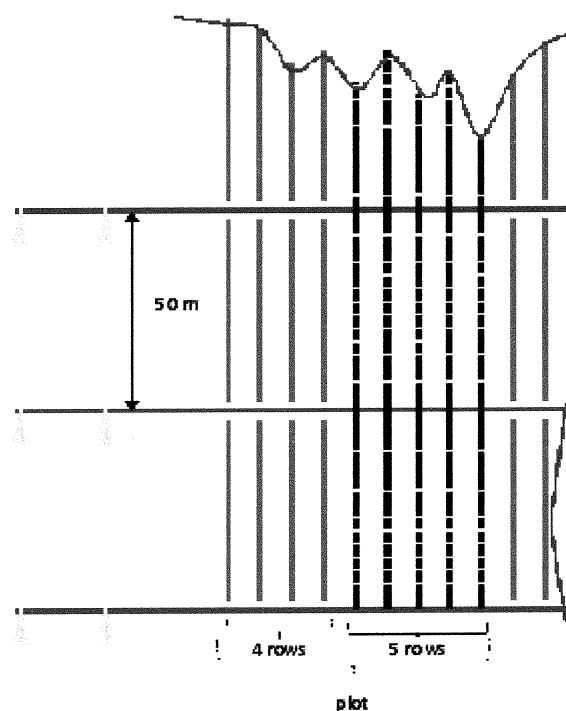


Fig. 1—Schematic representation of the trial plot layout.

The current calibration procedure for each yield monitoring system includes post processing sensor data by aligning the total predicted yield with total yield (the mill receipts for tonnes of cane) obtained for the block. It is assumed in this process that the calibration is stable over the whole block. However, this may not always be the case due to machine performance issues and crop variations driven by issues such as variety and past agronomic history. Thus, the total yield for the block is effectively distributed across the field relative to sensor outputs including (i) chopper and roller

pressure, (ii) roller opening or (iii) the hydraulic pressure of the elevator motor, depending on the cane yield monitoring system adopted.

The trial in 2008

The trial conducted in 2008 was undertaken in the Mutarnee area, south of Ingham on a single field (5.5 ha, 4th ratoon) and was harvested on 21–22 September. The trial design was as shown in Figure 1, with each plot consisting of 9 rows of cane and being 50 m in length. Due to block size and shape, the field consisted of 7 plots wide by 11 plots deep. The harvester operator was instructed to travel at a constant groundspeed of 5 km/h. Geo-referencing was achieved using low-end non-differential GPS linked to each of the yield monitors. Yield maps were generated for the TechAgro and AgGuide units only as unforeseen problems associated with the GPS data feed into the MTData unit prevented collection of sufficient data for mapping.

The trial in 2009

This trial was undertaken one kilometre west of Ingham on two fields on adjacent properties. The first field (2.2 ha, plant cane) was harvested on 23 September, with the second field (2.5 ha, 4th ratoon) harvested the following day.

The trial design was the same configuration as the previous year (Figure 1). Due to block size and shape, the field harvested on 23 September consisted of 5 plots wide by 5 plots deep, whereas the field harvested on 24 September consisted of 8 plots wide by 4 plots deep.

Due to the concerns of the project team as to the ability of the yield monitors to handle varying crop conditions—issues raised from the 2008 results—two different pour rate ‘treatments’ were imposed on both days during the 2009 trial. This was achieved by varying the ground speed of the harvester to better align with ‘real-world’ harvesting methods. Two target speeds were selected: ‘high’ being as fast as the harvester could safely operate (approximately 7–8 km/h) and ‘low’ (approximately 5 km/h and similar to last year’s speed). Our objective here was to use higher harvester speeds as a means of forcing a high pour rate. For the purposes of data analysis, we subsequently defined ‘high’ as being greater than 6.4 km/h and ‘low’ as being 6.4 km/h or slower.

Several observations were made during this trial. On the first day, the plant cane crop was higher yielding and better presented to the harvester than the crop harvested on the second day, which was a heavily lodged 4th ratoon crop. As a result, the top roller was more frequently in the fully open position due to the randomness of presentation of cane to the harvester.

Due to server difficulties, half a day’s data were lost for the MTData unit for the field harvested on the 23rd, and so the primary focus here is on the datasets collected on the 24th.

Yield maps were produced using a protocol based on that of Bramley and Williams (2001). The logged data were ‘thinned’ to the equivalent of a 3 second logging interval, and the data were then trimmed so that all recorded yield values lay within ± 3 standard deviations of the mean. Values corresponding to ‘zero’ yield, and

harvester speeds of less than 2 km/h were also discarded. Yield maps derived from yield monitor data were then interpolated onto a 2 m grid using local block kriging (10 m blocks) as suggested by Bramley and Williams (2001) using VESPER (Minasny *et al.*, 2005).

Due to the much lower number of data values, the plot-based maps were interpolated using global kriging following the fitting of exponential variograms, also using VESPER (Minasny *et al.*, 2005).

It is recognised that arguably, too few data were available for this process, but our objective here was to simply get a broad sense of the spatial structure of yield variation at the plot scale, and for this purpose, the methodology used was considered adequate. Subsequent map display and analysis was conducted in ArcGIS (ESRI 2008) using the 'Spatial Analyst' extension.

Other non-spatial analyses were undertaken on the data from the 2009 trial. These included assessment of the response of the yield monitors with time and determination of the relationship between the yield monitor values and the actual plot yields across all plots.

Results and discussion

2008 trial data

Comparison of the yield maps derived from the AgGuide (Figure 2c) and TechAgro (Figure 2d) yield monitors showed marked differences except when yields were high or low.

More importantly, the spatial structure of the yield data displayed in these maps is inconsistent, suggesting that at least one of the yield monitors does not provide an accurate measurement of yield.

Comparison of these yield monitor outputs to the 'actual' yield (Figures 2a and b), reveals consistent similarities between the TechAgro product (Figure 2d) and the plot-based yield map (Figure 2b), other than in the unmeasured portion in the north-west of the field.

This indicates some confidence in the spatial distribution of yield across the block measured by the TechAgro yield monitor.

Discrepancies in the yield values between these maps can be explained by the low sampling interval (i.e. 50 m) of the plot-based map; here we are much more interested in the spatial structure of the data.

Although the AgGuide yield monitor (Figure 2c) has sensed some of the features evident in the plot-based map (low yielding areas), differences in the spatial structure of Figures 2b and c indicate this sensor is of limited value in appropriately identifying differences in yield within the block.

Alarming, this deficiency even occurs when the classification of yield values is simplified into low, medium and high based on 33rd percentiles (Figure 3).

Clearly, the maps shown in Figures 2 and 3 could lead to markedly different outcomes if they were used as the basis for developing targeted agronomic management strategies.

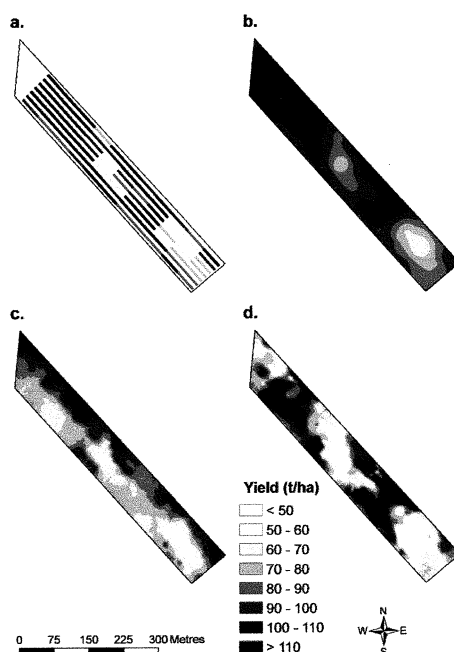


Fig. 2—The 2008 trial results showing (a) mean plot yields, and interpolated maps derived from (b) plot means and (c) the AgGuide and (d) TechAgro yield monitors.

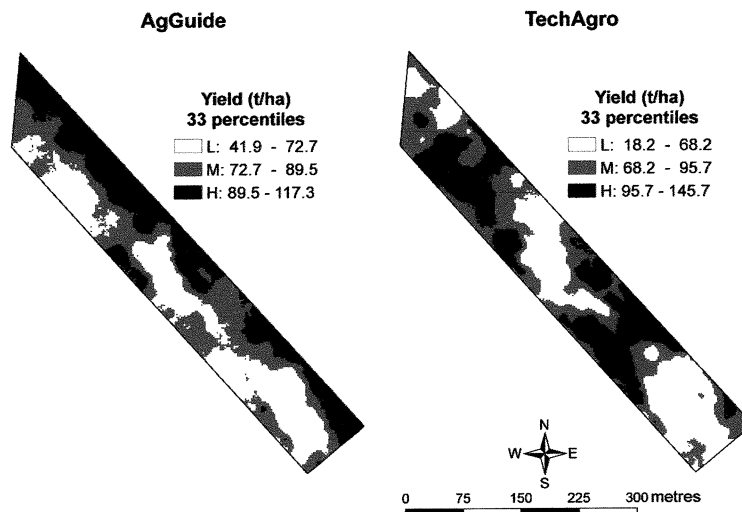


Fig. 3—Comparison of the AgGuide and TechAgro yield monitors in 2008 when yield was classified into low, medium and high, based on 33rd percentiles.

2009 trial data

In 2009, mean plot yields were again used to produce an ‘actual’ yield map (Figure 4, bottom row) for comparison with the yield monitor maps (shown in Figure 4 as the right-hand map of each pair in the top row.) In addition, we produced ‘plot-

based' yield monitor maps which were generated by interpolating the data collected by the yield monitors when harvesting along the same 50 m of row as was used for determination of the plot means. These plot-based maps are displayed in Figure 4 as the left-hand map of each pair in the top row.

Comparison of the plot map (Figure 4, bottom row) with the yield monitor maps suggests that, as with the 2008 trial, the TechAgro system does better than the other devices in describing the spatial variation. However, there is considerable stripping evident in the TechAgro map due to the pour-rate treatments.

In the matching 'plot-based' yield monitor map, there were spatial similarities with the 'actual' map suggesting that the TechAgro unit is capable of capturing the effects of spatial variation in yield. Both maps for the MTData and AgGuide units show very little, if any, spatial similarities to the 'actual' plot map.

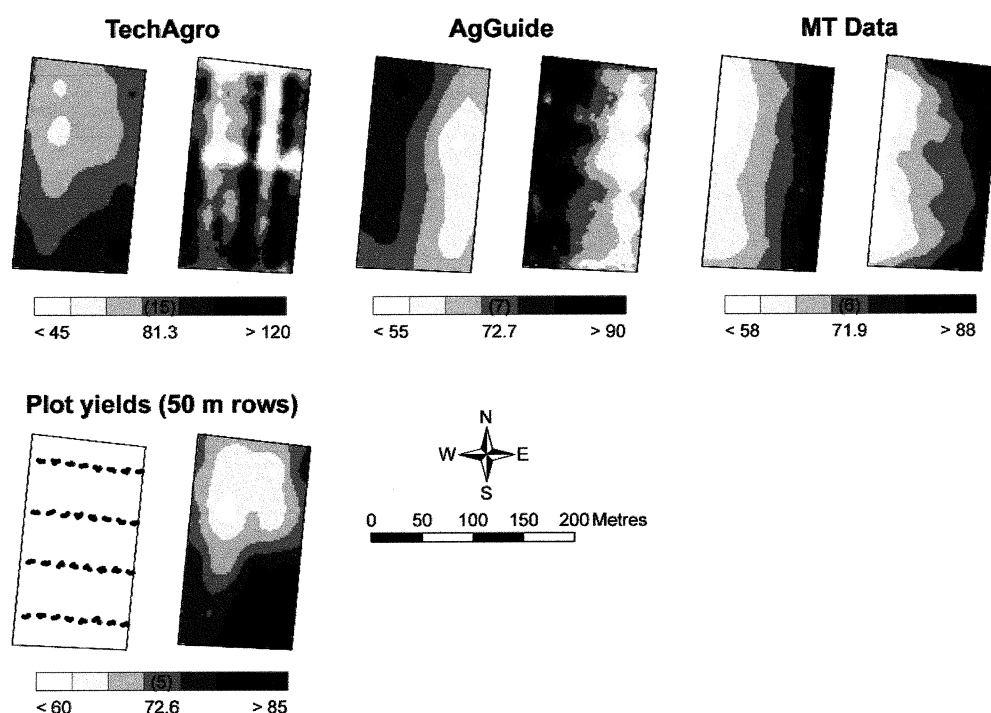


Fig.4—Results from 2009 trials showing yield maps based on: 50 m aggregated plot weights (bottom row), yield monitor data collected from the same rows as used to determine the aggregated plot weights (top row, left-hand map of each pair) and the full yield monitor-based maps derived from all harvested rows (top row, right-hand map of each pair). The legends show the upper and lower category values and the mean value for the field. The number in brackets is the width (t/ha) of the legend categories.

When the yield maps shown in Figure 4 were re-drawn using three yield classes (low, medium and high), which is arguably more consistent with their use by growers, there were large differences in the spatial distribution of yield as measured

by the different yield monitors (Figure 5). As in 2008, the application of possible agronomic strategies based on the maps derived from the different yield monitors could result in substantially different strategies for the same block—a matter of some concern.

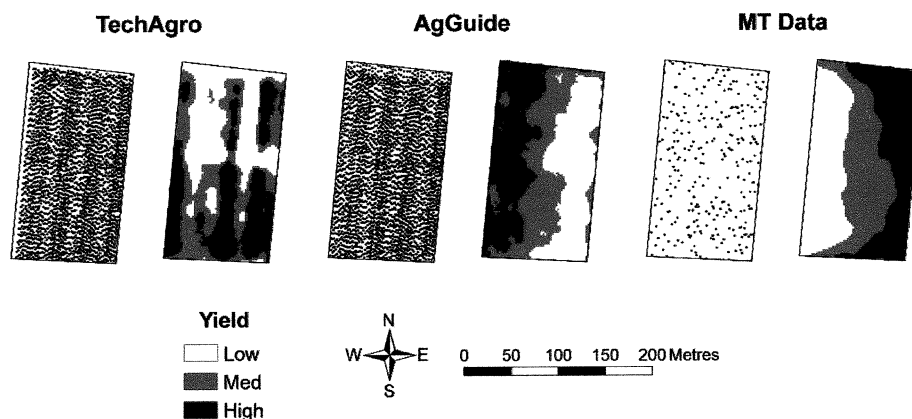


Fig. 5—The GPS dot trace of valid yield points along with yield maps generated from them when categorised into low, medium and high yields (33rd percentiles).

By constraining the harvester to operate at two differing set speeds (pour rate treatments), separate maps were produced using only the low or high pour rate data. This was done to eliminate any influences imposed on the analysis by combining the different pour rate treatments and to determine the consistency of yield maps generated from different harvester operational settings. The idea behind this analysis was that at the ‘high’ speed, the rollers were in effect forced open continuously, particularly in this lodged crop. The results are shown in Figure 6.

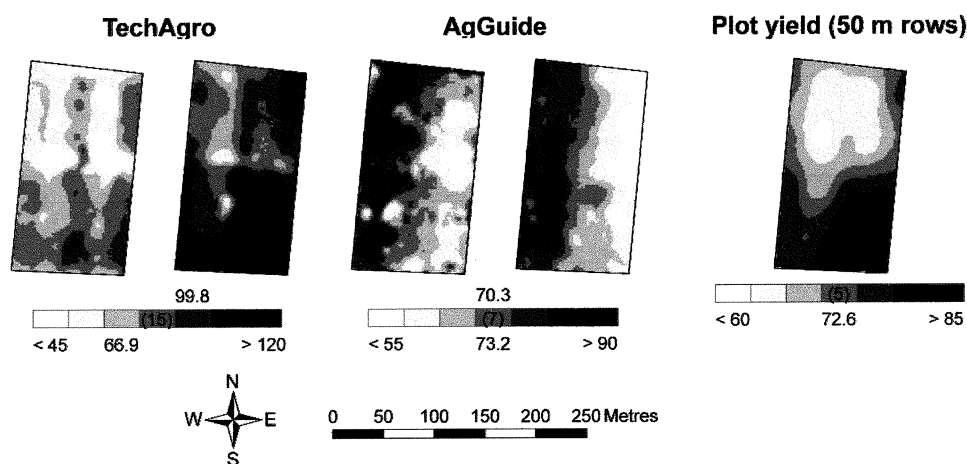


Fig. 6—Results of the pour rate comparison (low pour rate left, high pour rate right) for the TechAgro and AgGuide yield monitors. The mean value under the legend bar is for low pour rate, and that above it is for high. The number in brackets is the width (t/ha) of the legend categories.

Figure 6 shows that harvester speed has a minimal effect on the AgGuide system, although as has been noted, this system is unable to measure yield with sufficient accuracy to enable robust representation of spatial variation in yield.

However, speed clearly has a major effect on the TechAgro unit with a 33 t/ha difference in mean yield (unkriged data) between the low and high pour rates.

As a consequence of this, the TechAgro maps (Figure 6) show a shift of ± 1 legend category in mean yield depending on pour rate.

Nevertheless, there are promising similarities in the spatial patterns evident between the actual plot yield (map bottom right) and both the low and high pour rate maps produced from this sensor.

Pour rate also has an effect on the yield monitor's sensitivity. If we assume that the coefficient of variation in yield monitor data (after trimming, cleaning etc.) is a measure of instrument sensitivity, then without exception, and for both yield monitors on both days, faster speeds/pour rates lead to lower CVs; that is, less sensitivity.

The largest effect of pour rate was seen for the TechAgro yield monitor at 53.7% compared to 35.2% for AgGuide.

Overall, our map analysis suggests that the TechAgro yield monitor does a better job of capturing the spatial structure of within-block yield variation than the other sensors.

However, this device is clearly somewhat sensitive to the operating parameters of the harvester. As observed, this may markedly distort the yield map compared to the yield achieved in the field.

As a result, greater reliability through further development is required to at least accommodate changes in pour rate.

The non-spatial analyses of the data from the 2009 trial gave rise to important results.

The two data 'grabs' featured in Figure 7 detail the response of both the TechAgro and AgGuide yield monitors to differing pour-rates and to an area without cane represented by a 4 m wide drain located in the field.

The grabs (about 2 minutes of data) were extracted from a full-row harvested through the plot rather than one of the 50 m plots.

The average yield recorded for the entire length of the low-pour row was 68 t/ha and the high-pour row was 82 t/ha.

The TechAgro unit over predicted by a large margin (average 124 t/ha) in the high pour-rate row and by a smaller amount (average 78 t/ha) in the low pour-rate row.

The AgGuide unit under predicted on both the low pour-rate row (average 59 t/ha) and the high pour-rate row (average 64 t/ha).

The TechAgro unit clearly identified the drain whereas the AgGuide unit indicated this area as a low yielding (25–30 t/ha) area.

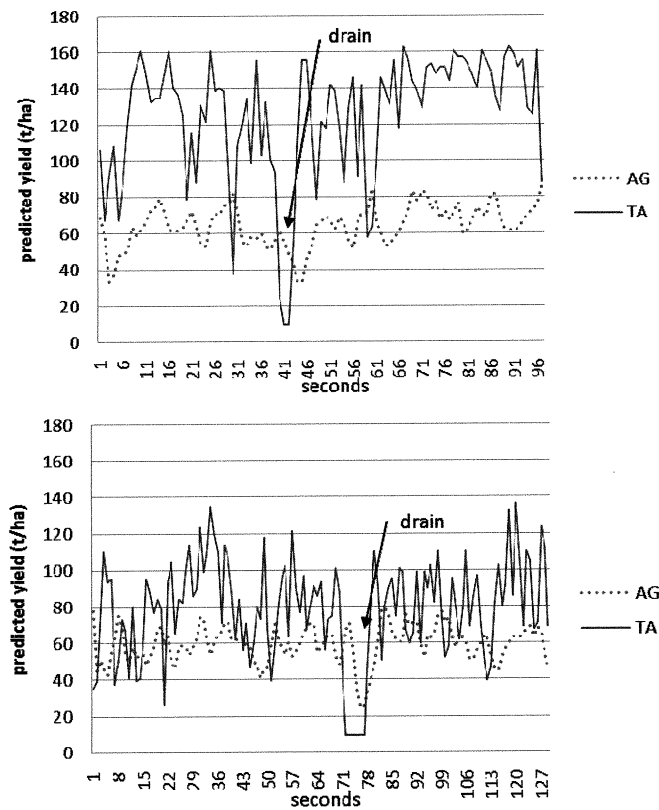


Fig. 7—The response of the yield monitors over time (high pour rate top and low pour rate bottom).

The relationship between yield monitor values and actual plot yields across all plots for the TechAgro unit are shown in Figure 8 with the AgGuide and MTData results shown in Figures 9 and 10 respectively. Only the TechAgro unit showed promising results, with an R^2 value of 0.73 for the regression between predicted and actual yield.

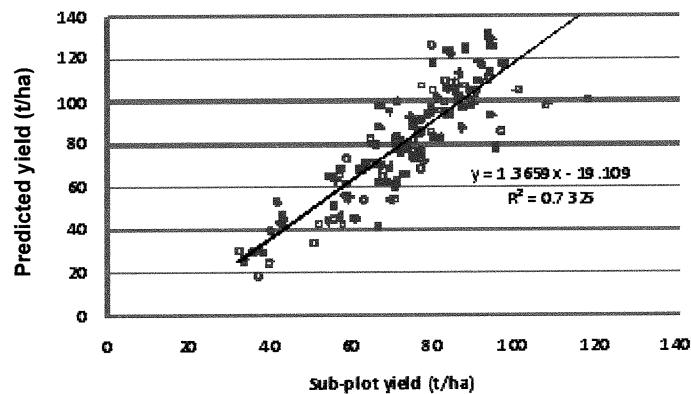


Fig. 8—The correlation between actual and sensor monitored yield for the TechAgro unit.

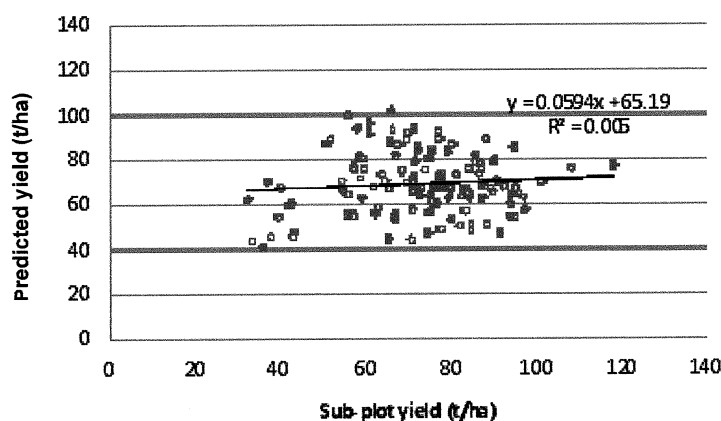


Fig. 9—The correlation between actual and sensor monitored yield for the AgGuide unit.

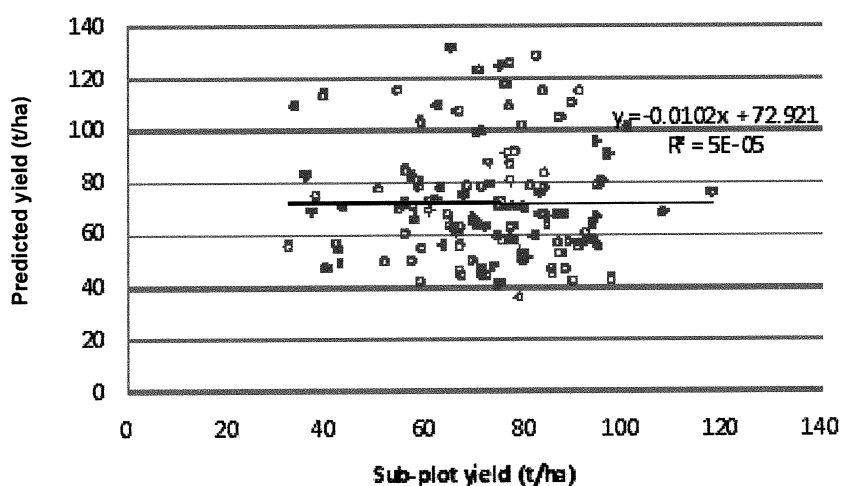


Fig. 10—The correlation between actual and sensor monitored yield for the MTData unit.

In substantiating the considerable difference between the high and low pour rate plots displayed in Figure 7, the correlations for ‘low’ and ‘high’ pour rates for the TechAgro unit are shown separately in Figure 11.

This confirms the lower pour rate produced a better correlation ($R^2 = 0.81$) than did the high pour rates ($R^2 = 0.78$).

The correlations for the low and high pour rates were individually better than that of the combined result shown in Figure 8 ($R^2 = 0.73$).

This adds weight to the recommendation that care must be taken when interpreting the yield data obtained from this unit.

Corresponding graphs for the AgGuide and MTData units are not shown given the poor correlations shown in Figures 9 and 10.

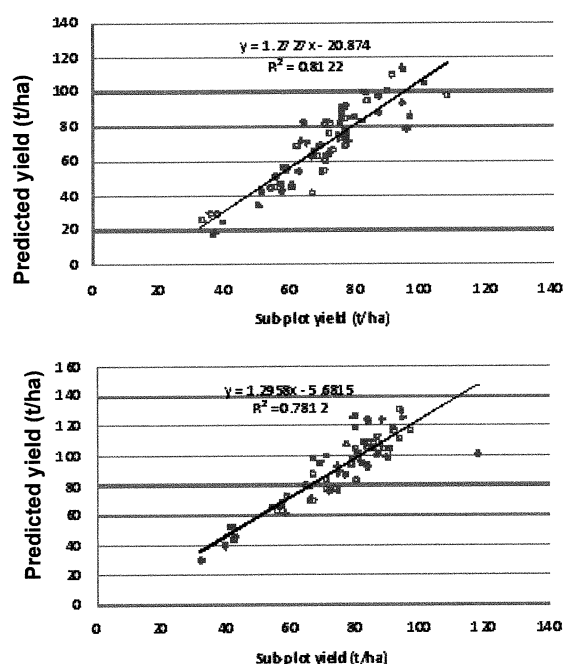


Fig. 11—The correlation between actual and sensor monitored yield for the TechAgro unit for low pour rates (top) and high pour rates (bottom).

Conclusions

The purpose of this work was to review various yield monitoring concepts that are commercially available to the sugar industry, and assess their performance. These concepts, albeit in a non-commercially available configuration, were also investigated by Cox (2002) and found to have far greater potential than was encountered in the present work.

In our assessment, the MTData unit in its current form does not adequately perform as a yield monitor. It is important to note that while there is some industry perception of it being a yield monitor, Mackay Sugar maintains that the device is effectively used for harvester tracking and management. In our view, the predictability, and therefore the reliability, of the yield information provided by this sensor is not useful in agronomic terms for precision agriculture. We make no comment as to its utility for harvester tracking but understand users to be happy with the performance when used for this purpose.

The AgGuide unit was found to perform only marginally better as a yield monitor than the MTData unit. It is important to note that the AgGuide unit is no longer supported or available as a commercial sugarcane yield monitor.

The TechAgro unit was found to provide the best result and is potentially a viable sugarcane yield monitor for precision agriculture (with some caution). However, performance was substantially reduced at high pour rates and this sensor was unable to account for changing pour rates. As a general guide, this unit should be

operated at constant ground speed and low pour rates although this does not guarantee the unit will accurately determine cane yield due to other factors influencing feeding of the crop through the harvester (such as a tangled or lodged crop). Given that the uncertainty and unpredictability of this unit is driven by conditions that would be encountered in normal harvesting operations (i.e. high pour rates; variation in machine ground speed and tangled crops), further work is required to improve this device. Without this input, the potential of this device as a valuable tool for precision agriculture will not be realised.

Overall key recommendations from this work include:

- Revisit the previous work of Cox (2002) to reinvigorate the weigh pad concept as a direct measurement of yield (as opposed to indirect measurements and limitations identified) especially in light of innovations in component technology since the late 1990s.
- Further development of the TechAgro concept to at least incorporate ground speed and changing pour rates.
- More detailed work is required on yield monitoring concepts including chopper pressure and elevator power for these to have commercial value particularly given the potential of these concepts identified by Cox (2002) to be much better than the performance encountered in this study.

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