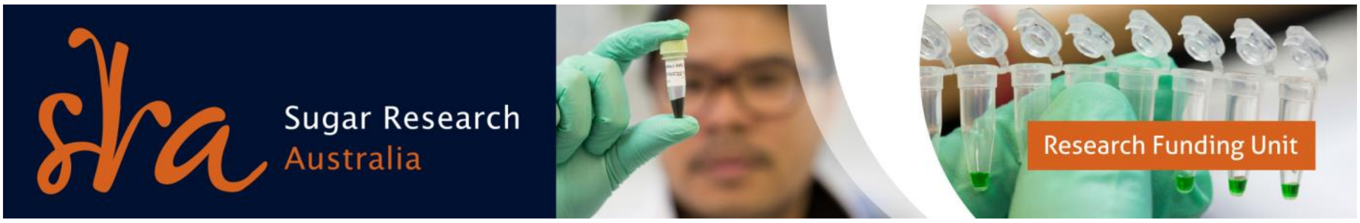


SRA Research Project Final Report

Product and profit – Delivering precision to users of Precision Agriculture in the Australian Sugar Industry - Yield Monitoring: final report 2014/028

SRA Project Code	**2014/028**		
Project Title	Product and profit – Delivering precision to users of Precision Agriculture in the Australian Sugar Industry - Yield Monitoring		
Key Focus Area in SRA Strategic Plan	Key Focus Area 4: Farming systems and production management		
Research Organisation(s)	National Centre for Engineering in Agriculture, USQ		
Chief Investigator(s)	Troy Jensen		
Project Objectives	Accurate yield monitoring has been demonstrated in CSE022. However, performance is compromised by consignment errors, and also sensor 'noise' derived from the vagaries of harvest, especially at row ends. How do we take the research outputs relating to yield mapping and monitoring to a commercially implementable product without compromising robustness? This key question will be broken down into two components; a. When we know the consignment is right, how reliable will the yield monitor data be? b. What are the key performance indicators and methods for assessing whether the data underpinning a yield map is accurate and reliable?		
Milestone Number	6		
Milestone Due Date	1/2/2017	**Date submitted**	5/4/2017
Reason for delay (if relevant)	The late collection of data in Childers in 2016, followed by attendance at the International Sugar Conference (ISSCT) in Thailand for most of December, has caused a delay in the finalisation of all materials. Inconsistencies between head agreements and subcontracts has resulted in a delay in detailing financial information, thus further delaying submission.		

Milestone Title	Submit Final Report
Success in achieving the objectives	☒ Completely Achieved ☐ Partially Achieved ☐ Not Achieved
SRA measures of success for Key Focus Area (from SRA Strategic Plan)	

Please cite as: Jensen T. 2017. Product and profit – Delivering precision to users of precision agriculture in the Australian sugar industry - yield monitoring: final report project 2014/028. Sugar Research Australia Limited.

PART A

Section 1: Executive Summary

***Issue**:*

The ability to collect robust yield data has been demonstrated in a previous SRA-funded project CSE022 (=2008/022) across a range of different yield sensing options. This same project documented a set of procedures and protocols with which to handle the data (detailed in Bramley and Jensen 2013), in order to generate robust yield maps. It was noted during CSE022 however that the ability to generate reliable maps is compromised by consignment errors (attributing the cane cut to the wrong fields), and more importantly, by how the data is converted to yield (t/ha).

Sensor 'noise' derived from the vagaries of harvest, especially at row ends/ haulout changeover/ stoppages is also an issue. How do we take the research outputs relating to yield mapping and monitoring to a commercially implementable product without compromising robustness?

This key question will be broken down into two components;
1. When we know the consignment is reliable, how reliable will the yield monitor data be?
2. What are the key performance indicators and methods for assessing whether the data underpinning a yield map is accurate and reliable?

***R&D Methodology**:*

The two instrumented harvesters used during CSE022 (in the Bundaberg and Burdekin regions) were re-commissioned for use during this project. The instrumentation included: GPS, fuel use, feed roller separation, chopper pressure and speed, elevator pressure and speed, and a load cell in the floor of the elevator. The sensing concepts were the same on both harvesters other than for the Burdekin harvester that did not have a loadcell installed. Both machines had 3G modems being to send ’15 minute’ packets of data to a centralized server. Data was collected over 3 seasons (2014-2016) with the majority of each season being captured. In addition, a low-cost yield monitoring option was evaluated on the Bundaberg harvester. An opportunity also arose to observe the prototype John Deere yield monitoring system that was installed on a new JD3520 harvester in the Childers district during the 2016 season. This same harvester was also installed with sensors to monitor feed roller separation, chopper pressure and speed, and elevator pressure and speed

A set of procedures (based on the yield monitoring protocol of Bramley and Jensen 2013) that provides a uniform and automated data manipulation method was developed to predict yield. The data from the 2014 season was run manually as the automated tools were still under development. Subsequent seasons were taken through the automated process.

Data from a range of locations and conditions were interrogated to determine the accuracy and reliability of both the data handling tool and the yield monitor sensors. This was achieved by evaluating the histograms of sensor outputs, comparing values across sensors and by comparison to known yield, both from bin monitoring and small plot experimentation (in conjunction with the NUE project). From this data, a range of maps were generated and evaluated.

Engagement with commercial providers (John Deere and Vanderfields / Greentronics) has provided insight into the operations of their commercial or near-commercial yield monitoring solution. Some of this work is, however, commercial-in-confidence, and as such, cannot be reported here. Discussions are continuing with the above two companies, along with the Herbert Cane Productivity Services (HCPSL) and AgTrix who have expressed interest in using the tool or components thereof.

The project also provided input and/or data to others interested in yield monitoring in the cane industry, in particular the NUE and MIP projects. Presentations have also been made to industry via SPAA meetings / workshops / conferences and ASSCT / ISSCT conferences.

As the collaborating farmers provided the project team with all the 'metadata' on the field of interest, they have been consulted during the project and have provided the sounding board for the maps and information generated.

The project deliverables:

The primary output of this project was the development of a suite of procedures to automate the data handling processes associated with the generation of yield maps from sugar yield monitor sensor data. These procedures have been encapsulated into a software tool. Using the tool to treat all data in the same way provides consistent results independent of the sensor used, across a range of operating conditions, provided that erroneous data (due to sensor malfunctions) is excluded prior to being processed by the tool; some simple rules have been used to help identify such data. The results compared favourably with mill records in the evaluations undertaken, provided that the amount of cane was correctly assigned to the block from whence it was cut, be that via manual or electronic methods, so that a true harvest event could be mapped. All yield sensing concepts (feed roller separation, chopper pressure, elevator pressure and load cell) provided useful data to map. For the majority of the fields, there was good consistency between maps with no sensor being more reliable than the other. There was however some differences noted on the edges of fields between the feed train sensors when compared to the elevator sensors due to operational procedures at the edges of the fields. It was noted during evaluations that, on newer machines (JD3520), the volume sensors have less sensitivity due to the increased material handling capabilities of these machines.

Although specifically designed for '15 minute' packets of data, various components of the tool have utility in general yield monitor data manipulation procedures. Enquiries about accessing the tool and components of the tool can be made to David Gobbett at the following email address: (David.Gobbett@csiro.au).

The project team has made presentations at SPAA workshops, Expos and conferences, with papers presented at Australian and International sugar conferences. Two papers detailing the project's research efforts has been accepted by the International Sugar Journal, and a paper detailing the novel technique to detrend the yield monitor data is in preparation. In addition, the project has provided data to other SRA projects as well as collaborating farmers.

Outcomes and Impacts:

Precision Agriculture (PA) offers the opportunity of enhancing the efficiency of farm management compared to the conventional uniform approach, through the targeting of inputs and/or selective harvesting of outputs. One of the pivotal data layers in the PA approach is the measure of production, with yield monitors and remotely sensed imagery being the two main methods. This project has focused on developing tools and testing these under a range of conditions so that the industry can have confidence in the ability of the yield monitor to represent production differences across the field. With this increased confidence, a grower's profitability can be enhanced either by addressing the limiting constraint and raising the level of production, or by reducing the level of inputs to match the lower production potential.

Section 2: Background

Over the past two decades, considerable effort has gone into developing systems to monitor yield on sugarcane harvesters (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 a load cell 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 a number of researchers both in Brazil (Pagnano and Magalhães (2001), Cerri and Magalhães (2005), Molin and Menegatti (2004), Magalhães and Cerri (2007)) and in the US (Benjamin (2002)). 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 differing approach is to use optical sensors to measure the amount of cane on the slats in the elevator (Price et al. 2007).

The evaluation of the commercially available devices that have been advocated as yield monitors and were available to the Australian Sugar Industry (as at July 2008) was tested in the SRA funded project 2008/022 (CSE022). These devices included the units available from TechAgro, AgGuide and the Mackay Sugar "MTData" unit.
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 motors, and the AgGuide unit based on the change in pressure across the elevator motor.

The investigations evaluated the performance of these yield monitors by comparing the yield monitor data and the values obtained from weight-truck readings. The results of this evaluation was reported on in Jensen *et al*. (2010) who suggested that there were several areas in which there was room for marked improvement. Of particular concern was how the data was handled with the proprietary software. Rather than the continued testing of the commercially available sensors, Jensen *et al.* (2012) detailed the evaluation of the fundamental yield measurement concept. These concepts included; the pressure drop across the elevator and chopper motors, a load cell in the elevator floor and the degree of opening of the top feed roller. These concepts cover those being employed in the commercial units, both past and present.

Analysis indicated that there are considerable similarities between the yield monitoring concepts in terms of their ability to measure yield. How the sensor data is recorded and managed however, is critical to the accuracy and overall performance of these concepts as yield monitors. The first step were taken by Bramley and Jensen (2013) to develop a protocol for the generation of yield maps from yield monitor data.

The next step that was needed were tools to automate the very time consuming data manipulation and handling process, and to assess the accuracy of such data. Added insight into when to be able to trust the data, and when it was non-sensible, was also desired. This was the premise for the current project.

Section 3: Outputs and Achievement of Project Objectives

Project objectives, methodology, results and discussion

Project Objectives

The following is the 'specific research objective' extracted from the original full proposal as submitted to SRA.

Accurate yield monitoring has been demonstrated in CSE022. However, performance is compromised by consignment errors, and also sensor 'noise' derived from the vagaries of harvest, especially at row ends. How do we take the research outputs relating to yield mapping and monitoring to a commercially implementable product without compromising robustness?

This key question will be broken down into two components;

1. *When we know the consignment is right, how reliable will the yield monitor data be?*
2. *What are the key performance indicators and methods for assessing whether the data underpinning a yield map is accurate and reliable?*

Methodology

The 'project methodology' detailed below has been extracted from the original full proposal as submitted to SRA. Due to contracting issues, a project variation agreement was initiated. There was no impact on project objectives, outputs or overall budget, however the project completion date was pushed back by 7 months. The opportunity for data collection over a third harvesting season, rather than the 2 seasons envisaged in the original project document, was also realised.

The words in bold in the following methodology provide the headings that will be further discussed in the subsequent section of this report. Evidence will be provided to demonstrate that the topic has been addressed, or reasoning behind why this has not been achieved. Aligned and additional areas of investigation will also be discussed.

CSE022 has demonstrated the merits of a range of concepts for sensing yield on-the-go. What is now needed is determination of which sensor or sensor combination is most suitable for commercial implementation and at what resolution/sensitivity they should be implemented without compromising performance or data utility when collected in commercial format. This issue will be progressed through negotiations with commercial providers (e.g. John Deere, CNH, Solinftec, Agtrix) as to how best yield monitoring should be delivered to industry.

The short duration of this project precludes rigorous testing of the recently released 'Brazilian Yield Monitors'. These competing developments are based on the load cell principal, which is already part of our testing regime so it will have the same inherent issues that we have already observed. We therefore consider it more important to **develop the protocol** and key performance indicators for assessing the **reliability and accuracy of the data collected** and the map generated. Note that CSE022 has already developed a robust protocol for yield map production which works well, but its efficacy is compromised by data errors which lead to poor map confidence (i.e. high confidence intervals) by comparison with yield maps in other crops.

The **yield monitoring equipment** that has been utilized during the life of CSE022 will continued to be used in this follow-on project. As it is operating in a harsh environment, the sensors however do require continual maintenance. Two of the three sites engaged during the life of CSE022 will continue to be monitored, Bundaberg and Burdekin. The existing Bundaberg site will be the focus of this work, due to its proximity to Toowoomba and for the ability to undertake development and construction work.

Data will be collected in both the Burdekin and Bundaberg regions of Queensland in the 2014 & 2015 seasons. Rather than targeting the 'PA focus blocks' used in CSE022, this project will target a range of blocks that may be further afield. In order to have a better understanding of the reliability of the data coming from the yield monitors, **all possible harvesting scenarios** need to be encountered scenarios such as (but not limited too); plant and ratooned cane, lodged, burnt and green cane harvesting, standover, considerable weed pressure, grub damage, frost, water logging, wet weather harvesting, light vs heavy soil, the effects of topping, varietal differences (trashy (Q138) vs no trash (Q208) vs thick stalk (Q240) etc.). Ideally 2 harvest events for each scenario will be investigated. The aim is for **10 harvest events to be analysed each year**.

The harvester operator will identify where conditions change from normal (date and location) so that the data from this block can be focused on. The yield for this block will be predicted (using the protocols developed in CSE022) and the individual sensor values interrogated to find signatures for the above scenarios, with at least one block for each signature being obtained. Ideally, these will be encountered in the first year, however climatic and management decisions may preclude all being obtained. The second year will be used to complete/refine the signatures.

The reliability of the yield data is also dependant on **the correlation with the mill tonnages**. Agtrix have offered one of their harvester tracking systems to facilitate this. A site in Northern NSW is also being sought where the full **electronic consignment** system is in operation. This will also provide data on 2 year old/standover crops.

Both of these sites (Bundaberg and Burdekin) overlap with the SRA project "Boosting N-use efficiency" being considered as part of this funding round. There will be **free sharing of data,** resources and manpower between these projects, as they have common goals.

The consignment/yield monitor calibration problem will be tackled at Bundaberg through collaboration with Agtrix Pty, who have developed an electronic consignment system. They are also developing a **low cost yield monitor** that they have offered to the project for evaluation purposes. Options for yield monitor calibration that are independent of the mill (load cells on haul-outs; portable weigh beds), will also be investigated.

A second site for the collection of **accurate consignment data** will also be chosen. This may be the Burdekin site or alternatively, in Northern NSW where electronic consignment has been operating now for several years. With confidence in the cane being correctly assigned to the block in which it was grown, we give ourselves the best chance in being able to accurately produce reliable yield maps.

Data collection will continue for a second year, based on existing yield monitoring equipment. Prototype consignment/yield monitoring equipment will also be evaluated against the above system. Having confidence in the sensor values, and hence the yield maps produced using this data, is the major output of this project. This will be achieved by **producing a program/app/package** that will evaluate, clean and prepare the data as input to the mapping protocol for rigorous map generation.

The yield mapping protocol combined with the new 'evaluation tool' will provide a much better understanding of the sensing options to determine when the data and believable and when it is not. Being able to accrue the full benefits as a result of adopting Precision Agriculture Technologies is dependent on having complete confidence in the layers on which the decisions are based. The research that has been conducted as part of CSE022 has shown the yield data, from a range of sensors, can reliable show the spatial patterns commensurate with other data layers. Depending on how the original sensor data is filtered, manipulated and attributed to the block from which it was cut, can have considerable bearing on the accuracy and reliability of the resultant yield maps. Without this confidence in the yield maps, all flow on decision based on this dataset are flawed.

Combining SRA agronomic knowledge, spatial and PA expertise from CSIRO and engineering and sensor knowledge from NCEA will enable this project to address the above issues and provide the understanding and knowledge on which to base PA advancement through the use of reliable and accurate yield maps.

We will also maintain our existing engagement with the PEC unit (Summer Olsen and colleagues), SRA project NCA013 and emerging consultant capability (e.g. Farmacist) to ensure effective **extension of PA procedures and practices to industry**.

Results and Discussion

The various topics identified in the methodology and highlighted in bold above, will be detailed and discussed in the following section of the report.

A. Yield monitoring equipment

The yield monitoring equipment utilised during CSE022 was refurbished and re-commissioned for data collection during the 2014 crush. Figure 1 is a schematic of a sugar cane harvester showing the various components and the yield sensing locations (displayed in blue)

Each harvester used a Campbell Scientific CR3000 data logging platform, coupled to a DGPS and a range of pressure and angle sensors. The configuration of each installed systems differ slightly, and is described below.

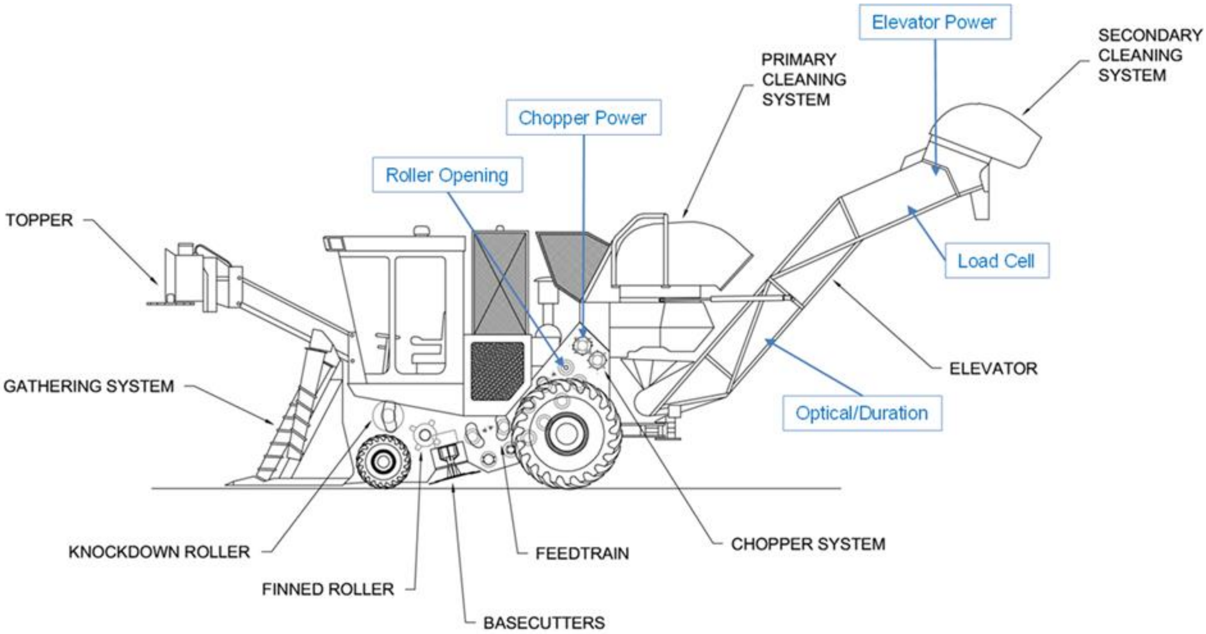


Figure 1 A schematic of the sugar cane harvester showing the location of the various yield monitoring concepts.

Bundaberg Harvester - Austoft 7000

The sensors installed on this harvester (see Figure 2) include a load cell in elevator, chopper pressure, elevator pressure, elevator speed, chopper speed, and second last and last roller opening using a rotary potentiometer. The data being recorded was sent by 3G modem back to a centralized server every 15 minutes. For backup purposes, the data was also recorded onto a CompactFlash (CF) card in the logger.

Agtrix have also specifically modified one of their vehicle tracking/HBMP units to accept yield sensor inputs (elevator pressures) that are averaged and recorded approximately every 5 seconds. Harvest progress can be tracked real time using a web-based portal. Comparisons have been made between the 'Agtrix' derived data and the data collected with the CR3000 data logger to quantify the effects of sampling rate and GPS accuracy (a low-cost non-differential GPS is installed). The evaluation of this equipment for providing the industry with low-cost yield monitoring options is discussed fully in a later section of this report (see Section J).

Burdekin Harvester - Cameco 3500

The sensors installed on this harvester (see Figure 3) included; chopper pressure, elevator pressure, elevator speed, and roller opening (using a linear potentiometer, similar to the Solinftec unit). A load cell was not installed on this harvester as the depth of the elevator floor was not sufficient to house the existing unit. The harvester was also being monitored by Solinftec (yield prediction based on roller opening sensor) during the 2014-15 season and Farmacist have a monitoring system installed looking at chopper pressures. Prior to the commencement of the 2015 season, the Burdekin harvester was also installed with the 3G modem to transmit the data back to the centralised server, with CF data backup.

Figure 2 the Bundaberg harvester in operation

Figure 3 The Burdekin harvester cutting cane.

Childers Harvester – JD3520

An opportunity arose during the 2016 season to have a harvester instrumented with a prototype John Deere sugar cane yield monitor. This was installed on the Russo's JD3520 harvester (see Figure 4) in Childers, late in the 2016 season. The JD installation was completely stand alone. The purpose of the installation was to give John Deere sight of the USQ developed yield monitoring concepts and to access these concepts against current JD product developments. As such, this work was 'commercial-in-confidence' and was undertaken outside of this project. There were however several components of the JD system that are common across all JD yield monitoring systems (i.e. the ability of flag points in the yield file) and are not confidential. This provided the project team with the ability to track haulout from the field and partnered with the bins at the siding, enabled the comparison between bin tonnage and sensor prediction reported on in section D and tracking the cane from the field to the mill reported in Section G.

In addition to the JD yield monitoring system, the standard 'USQ system' was also installed. As with the Bundaberg and Burdekin installations, the sensors installed on this harvester included; DGPS, chopper pressure, elevator pressure, elevator speed and roller opening using a linear potentiometer. The data being recorded was also sent by 3G modem back to a centralized server every 15 minutes. For backup purposes, the data is also recorded onto a CompactFlash card in the logger.

The trials conducted at this location also utilised the electronic consignment system of Isis mill. Manual consignment has previously been identified as an impediment to accurate yield maps due to human error in the consignment process. The accuracy and reliability of the electronic consignment is reported in Section G. Included in Section H, are survey results of several mills undertaken to determine the desire to move towards electronic consignment and the potential errors that may be involved in such.

Figure 4 the Childers harvester starting a row

B. Data collected

As mentioned in Section A above, yield monitor data from the harvesters instrumented was sent via modem over the 3G network to a central server. The data was transmitted every 15 minutes. During the life of the project, nearly 20,000 '15 minute' data packets have been collected. Due to contracting delays, data was collected using the CompactFlash card method from mid-August 2014 at the Bundaberg site and for all of the 2014 season in the Burdekin.

The late start to collection of data at the Bundaberg site in 2016 was due to the wet start of the season and the use of the tracked harvester, rather than the instrumented wheeled machine. Data collection only occurred later in the 2016 season at Childers due to an opportunity to collect data in parallel with a John Deere yield monitoring system.

Table 1. Details of the data files collected during the life of project 2014/028

Location	Year	Data start	Data end	Files
Bundaberg	2014	10/11/2014	5/12/2014	949
	2015	22/06/2015	17/11/2015	6950
	2016	23/08/2016	20/12/2016	5745
Burdekin	2015	26/05/2015	11/11/2015	2686
	2016	2/06/2016	24/12/2016	2844
Childers	2016	28/10/2016	25/11/2016	809

C. Develop the protocol

The yield data checking and mapping protocol developed, builds on the protocol developed through the CSE022 project (Bramley & Jensen, 2013). Additional checks have been included to verify the quality and suitability of the sensor data. Specific adaptations and refinements have been made to accommodate the specific sensors and format of the input data (in 15 minute chunks) utilised in the USQ yield monitors.

These adaptations include:

- Aggregate 15 min modem data files into individual days of yield data per harvester
- Project GPS latitude and longitude coordinates to UTM/GDA eastings and northings
- Separate daily data by sub-block – i.e. into 'Events'
    - A supplied boundary spatial dataset is used to assign data to sub-blocks
    - Data which falls outside mapped block boundaries are discarded
    - Calculate area harvested per block per day ('event' area)
    - Generate a Vesper grid for any sub-block covered by the event
- Filter the events
    - Delete data 3 seconds each side of harvester stopping
    - Remove data if harvester speed < 0.75 m/s or > 3.0 m/s
    - Remove data if elevator speed < 0.5 m/s (initially this threshold was 1.5 m/s but testing showed the higher threshold to be removing too many data points in some cases). This test is not applied in certain cases where the elevator speed sensor was known to have been faulty.
    - Remove points to ensure no closer than 2 m along the direction of travel
    - Exclude events with less than 50 data values
- Read the consigned tonnes for each event from the modified mill record CSV file (NB the record has been manipulated as all mills have different formats-a generic format has been used)
- Separate data for each sensor for further processing
    - Filter to remove non-numeric data

  - Subtract the minimum sensor value from all sensor values as approximation of the sensor zero or 'free-running' value). This simple approach could be improved if a more reliable method to derive sensor zero values were developed*.
  - Exclude the entire yield data file if sensor data CV is less than 10%. This check is to ensure there is a sensible range of variation in sensor values, and that the sensor is not repeatedly outputting on a fixed or constant value, such as can occur with a faulty sensor.
  - Calculate sensor averages and differences (e.g. CP Average from CP1 and CP2)
  - Calculate sensor 'yield index' by dividing sensor value by harvester speed
  - Normalise to a mean of zero, and a standard deviation of 1 then trim to remove data outside +/- 3 standard deviations etc.
- Combine all harvest event for each sub-block into a single file (per sub-block and sensor)
- If the sub-block has consignment data available, and the yield monitor events cover at least 90% of the sub-block area, the normalised yield index are kriged
- Kriged sub-block normalised grids are then adjusted to the average consigned yield per sub-block.

* Justification for this approach is detailed in the following section

Addressing the free running sensor values in the protocol

Different yield monitor sensors output data values over different numeric ranges which need to be calibrated to the corresponding cane yield. In doing this it is important to derive an estimate of what raw sensor value corresponds to a yield of zero. For example, a chopper pressure sensor may output values between zero and 140 bar, but values close to 50 bar occur due to the power required to turn over the chopping mechanism, but with no cane passing through the harvester. These are known as the free running values. A key step of the protocol to treat and filter sensor data is to subtract the free running values from the original value. If the resulting value is negative, that data point will be treated as noise and removed. Any resulting value greater than zero will be kept as valid data point. This step serves to establish a new zero value for the data and increase its sensitivity.

For example, if we consider original sensor values of 100 and 110 and a free running value of 50, the resulting new sensor values will be 50 and 60 (the original minus the free running value). The difference between the two original values is 10% ({110-100}/100), whereas the difference between the two new values will be 20% ({60-50}/50).

However, implementing this step automatically is not straightforward as different sensors will have different free running values for different field conditions and therefore they cannot be assigned a fixed value across all harvest events. Instead, each harvest event will have to be analysed to find its own appropriate free running value. Originally, this value was identified manually for each individual harvest event. In order to have a script capable of automatically processing every step of the protocol without human interaction it was necessary that the script would estimate the most appropriate free running value for each harvest event.

In order to do this, the script looks at the minimum sensor value of the harvest event and uses it as the free running level, or the new “zero” value. Although not the ideal approach, the benefits of having an automatic process without human interaction outweighs the potential flaws of this method. In the processing script, this check is applied after ensuring that all data points fall within a block boundary, and after filtering.

Since the free running step occurs after the threshold filtering of the data based on the yield monitoring protocol (filtered on ground speed, elevator speed and the three second gap), there is a chance that noisy data points will still remain in the data set (an example shown in Figure 5). Figure 6 displays the same yield points where the free running value was manually set and the noisy data removed. The biggest issue with this automatic approach is that the new “zero” value will be lower than ideal, diluting the benefits of zeroing the sensor. The noisy data points will, however be removed at a later step of the protocol when the data set is trimmed within three standard deviations of the mean.

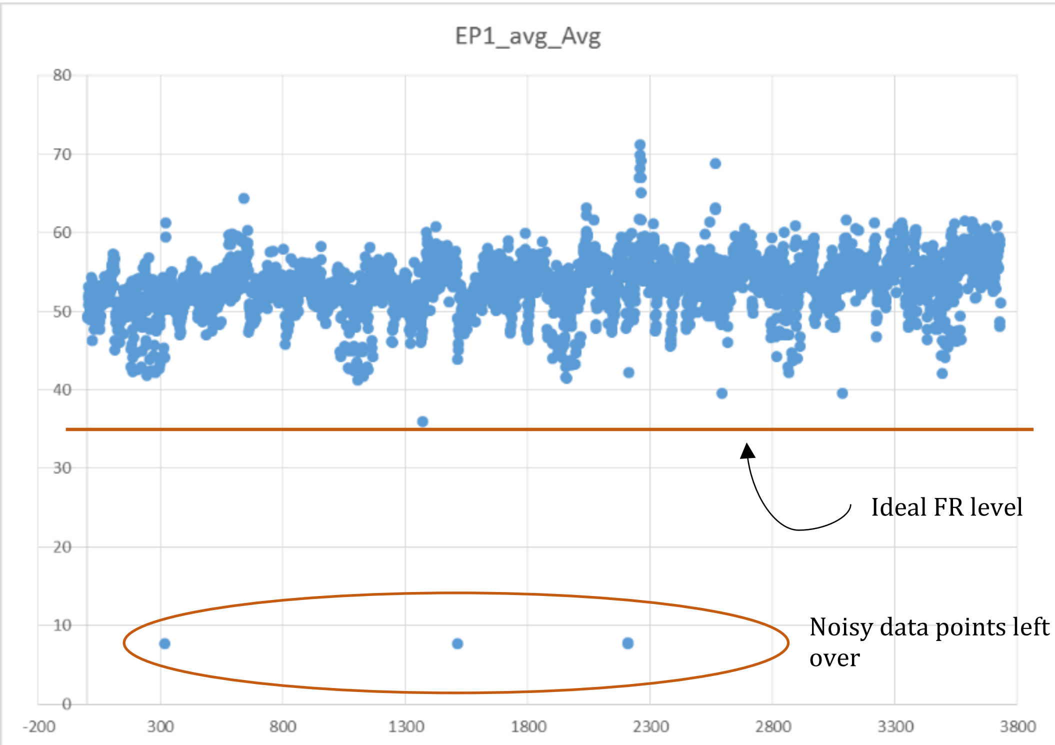


Figure 5. Elevator Pressure sensor data for Bundaberg 2016 with a few noisy data points left

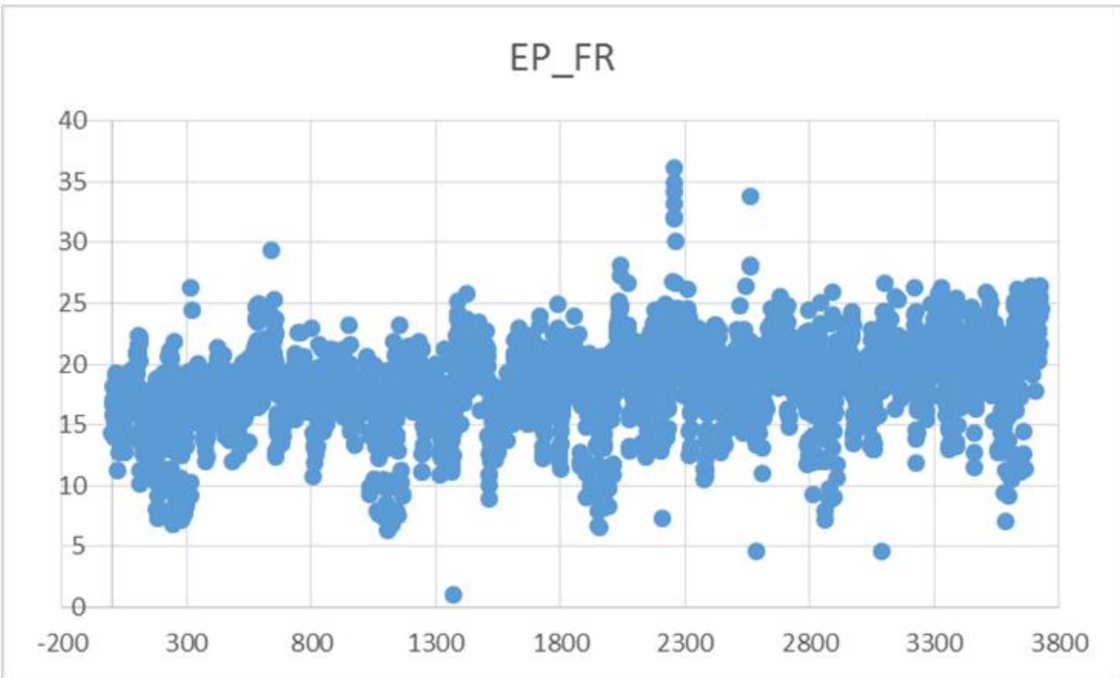


Figure 6. Elevator Pressure sensor data after Free Running values have been subtracted

The tables below show representative datasets from different regions and different years, to evaluate the value that would typically be chosen manually compared to the value that the automated script utilised.

Bundaberg 2015

Table 2. Sample of Bundaberg 2015 Free Running values selected manually vs automatically

Date	Block	Sensor	Manual FR	Automatic FR
2015-07-09	13C	CP_avg	30	29.04
		RO2_avg	75	78.46
2015-07-09	13D	CP_avg	30	31.76
		RO2_avg	75	79.28
2015-07-27	12D	CP_avg	30	28.10
2015-10-15	26C	CP_avg	30	32.44
		EP1_avg_Avg	30	37.76
2015-10-15	28A	CP_avg	25	25.06
		EP1_avg_Avg	30	21.32
2015-10-16	28A	CP_avg	25	25.10
		EP1_avg_Avg	30	33.50

Bundaberg 2016

Table 3. Sample of Bundaberg 2016 Free Running values selected manually vs automatically. Problematic sensors are highlighted.

Date	Block	Sensor	Manual FR	Automatic FR
2016-10-06	15B	CP_avg	30	29.78
		EP1_avg_Avg	35	7.64
		RO2_avg	4	3.96
2016-10-10	12D	CP_avg	25	28.06
		EP1_avg_Avg	30	34.68
		RO2_avg	4	3.84
2016-10-19	19A	CP_avg	30	27.58
		EP1_avg_Avg	30	35.68
		RO2_avg	4	4.54
2016-11-15	26C	CP_avg	30	29.84
		EP1_avg_Avg	35	7.76
		RO2_avg	5	6.64

Burdekin 2015

Table 4. Sample of Burdekin 2015 Free Running values selected manually vs automatically

Date	Block	Sensor	Manual FR	Automatic FR
2015-07-07	101_123	CP_avg	50	52.68
		EP_avg	15	15.52
		RO1_avg	30	33.36
		Roller_Angle	30	29.64
2015-07-08	101_123	CP_avg	60	56.98
		EP_avg	15	16.92
		RO1_avg	25	29.14
		Roller_Angle	25	29.06
2015-08-22	101_131	CP_avg	40	40.02
		EP_avg	15	15.94
		RO1_avg	20	25.12
		Roller_Angle	20	24.12

Burdekin 2016

Table 5. Sample of Burdekin 2016 Free Running values selected manually vs automatically

Date	Block	Sensor	Manual FR	Automatic FR
2016-06-11	101_355	CP_avg	70	74.80
		EP_avg	20	15.32
		RO1_avg	40	24.06
		Roller_Angle	30	23.94
2016-08-08	102_622	CP_avg	80	81.20
		EP_avg	15	15.32
		RO1_avg	20	24.12
		Roller_Angle	20	23.90
2016-09-19	101_125	CP_avg	40	43.24
		EP_avg	15	14.64
		RO1_avg	25	29.22
		Roller_Angle	20	25.06

In general, over different districts and years, the automatically derived free running values are close to the values that would be selected manually, with the added benefit that the process does not involve human interaction. In some cases, however, there are a few noisy data points that can remain after the first filtering steps. When this happens, the selected free running values can be distant from the ideal value.

However, it must be noted that in the example of Bundaberg 2016 where there are some data points below the free running value, the elevator speed sensor was not working and therefore the data set was not able to be filtered against this criterion, and likely contained data points that would normally have been removed during the normal filtering protocol. In the cases where the elevator speed sensor is working properly (vast majority of cases), the likelihood of having noisy data points retained is very low.

Some considerations to improve this approach:

- Before identifying the free running value for a harvest event, the script could check for elevator speed sensor performance. If the elevator speed is not working, it is assumed that there could be noisy data points left over and the free running value should be checked manually.
- When the elevator speed sensor is working properly, the selected free running value could be 90% of the minimum value to avoid discarding potentially valid data.
- Alternatively, the free running step could be delayed until after the three standard deviation trimming is completed. This would help to ensure that there are no outliers in the data set. However, this would require recalculating the predicted yield to subtract the free running value from the original sensor value, increasing the complexity of the script.

D. Reliability and accuracy of the data collected

Several approaches were taken to access the accuracy of data collected. These approaches are detailed below:

Tool quality checks

Included in the protocol detailed above in section C. are specific checks that have been implemented to determine the suitability of data for mapping. These checks and outputs include:

- exclude data from faulty sensors, using the CV of the sensor values in a harvest event
- exclude mapping of sub-blocks with incomplete coverage by harvest events (90% threshold)
- availability of consignment data
- calculate the mean point density of valid sensor data per yield map.

Additionally, a brief summary report is generated for each map to help ensure the quality of the data processed and aid in the interpretation of the yield map. The summary file includes the mean point density of yield data per sub-block which will typically be in the range 1500 to 3000 points/ha. Yield monitor point densities below 1500 points per hectare may indicate the possibility of areas of sparse data that may result in lower confidence in the maps generated. However, interpretation of this is affected by factors such as row width, and whether the sparse data areas are widely scattered or concentrated in specific parts of the sub-block.

An example summary report is as follows:

```
2016 Bundy yield from subblock: 00895-03-A
    Sensor:CELL
    Processed 19/01/2017 16:01
    Subblock area     : 5.200 ha.
    Area of yield data: 5.236 ha (approx).
    Consigned tonnes  : 389.1 tonnes.
    Kriged yield was adjusted to a mean yield of: 74.3 t/ha
    Yield data points (after cleaning): 8950
    Yield data point density          : 1721 points/ha
```

Comparison between bin tonnage and sensor prediction

The following figures compare the yield predicted by the yield monitor with that obtained from the mill bin records. It should be noted here that this analysis was conducted in parallel with the electronic bin consignment investigation. Although the harvester was equipped with a roller opening sensor (see Section A - Childers 2016), the high material throughput of this new harvester (JD3520) combined with very heavy feed rollers resulted in only small changes in the separation distance of the final feed rollers when compared to late 1990's machines instrumented previously. As such, the roller opening separation is a poor sensor location choice on these new machines. With the roller fully closed, the sensor was reading 0.949 (see Figure 7). As the linear potentiometer had a travel of 200 mm, and the maximum sensor value was 0.39 (note readings go from high to low) which equated to an opening of 112 mm. As the roller had approximately 175 mm of opening, this indicated that during the cutting of this field, the final feed roller was never fully open.

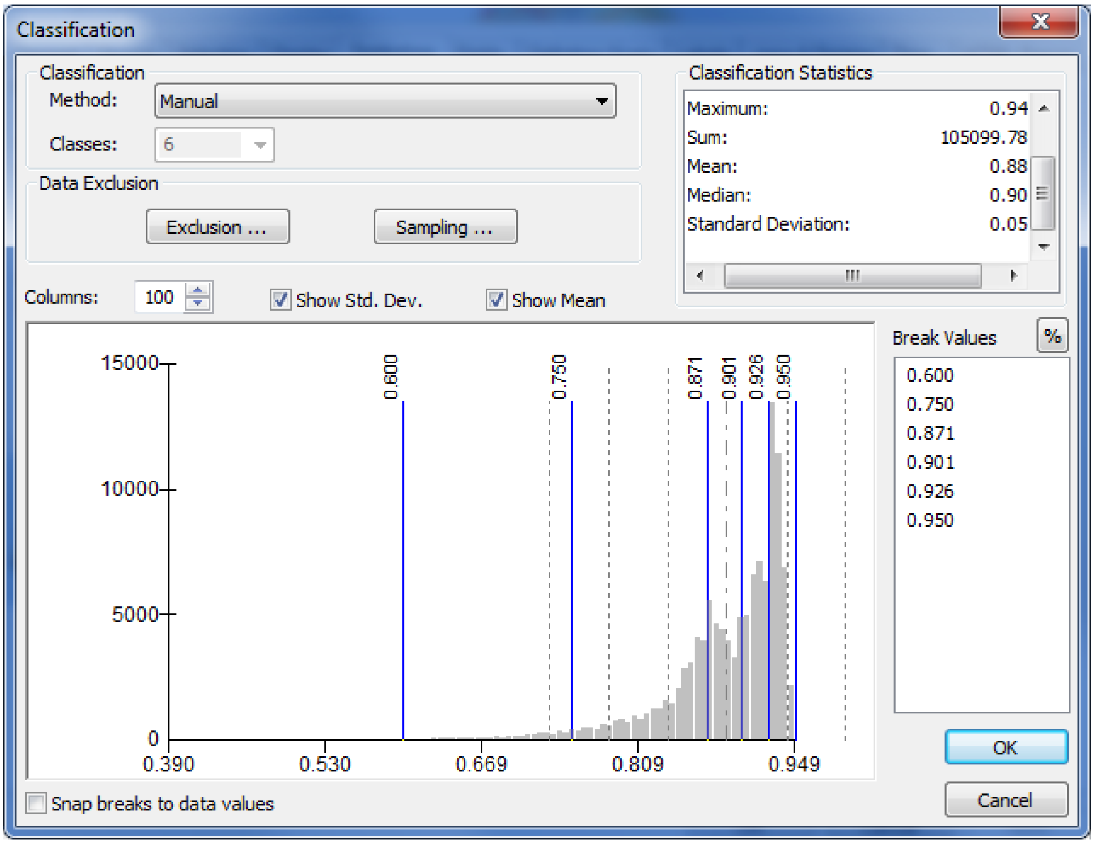


Figure 7 a histogram of sensor values for the Roller Opening on a JD3520 harvester

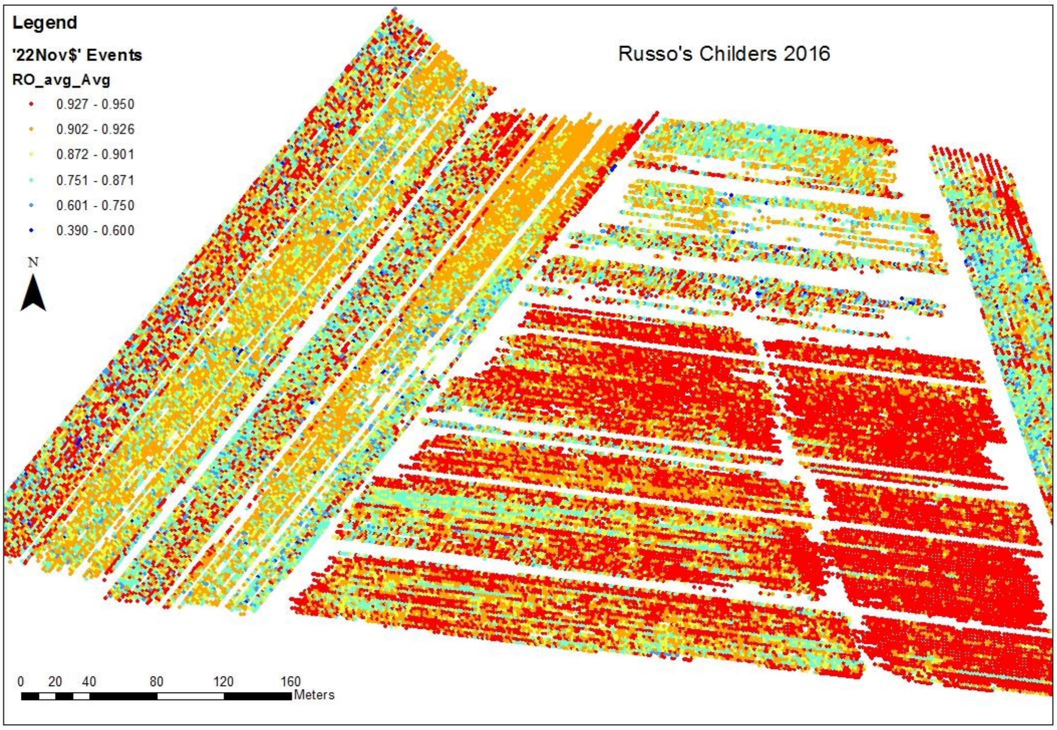


Figure 8 The RO sensor value map for the JD3520 harvester showing the narrow range of values (Note: this map has not been processed using the protocol described above but rather is a 'dump' of sensor values.

In fact, the difference between the red-orange-yellow on the above sensor map (which equates to more than half of the data points in this map) corresponds to only 15 mm change in the roller opening, or 10 % of its range. This means there is plenty of reserve feed train capacity on the new JD3520 (and one would assume the CH570) harvesters.

As such, only the Chopper Pressure sensor (CP_Yield) and Elevator Pressure sensor (EP_Yield) are evaluated here, and compared with the actual yield as measured by the mill for every pair of bins harvested (BinYield), i.e. per load. The CP and EP yield predictions per load are based on harvest event-level calibration (as per Protocol guidelines).

The CP and EP sensors as well as the BinYield have the same average yield value for the whole harvest event. However, each load will have a value above or below this average depending on the natural variability of the field and changing field conditions. Data collected over 4 days (whilst undertaking the consignment investigation) is displayed in Figures 9-12.

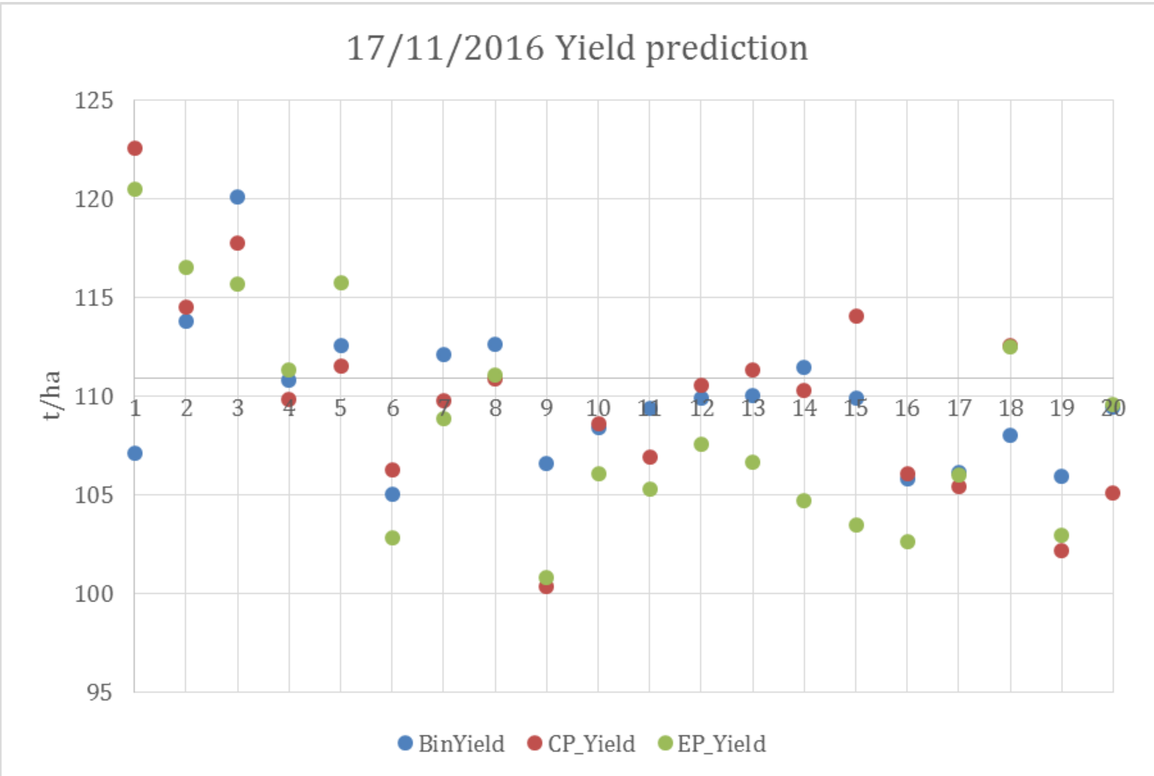


Figure 9. Yield prediction for the block harvested on 17/11/2016. Average yield (horizontal line) is 111 t/ha.

For the block harvested on 17/11/2016 (Figure 7) the CP sensor in particular follows the BinYield (average yield for that load) trend relatively well. This indicates that the natural in-field variability represented by the BinYield value is picked-up by the sensor. This harvest event had a total of 38 loads, of which only 20 are available for analysis. This reduction in numbers is mainly due to one of the haul-out vehicles (the McLean bin – discussed in

Section G) being used was not capable of unloading the cane evenly in the rail bins, therefore mixing cane from different parts of the field. Those bins had to be discarded for this analysis.

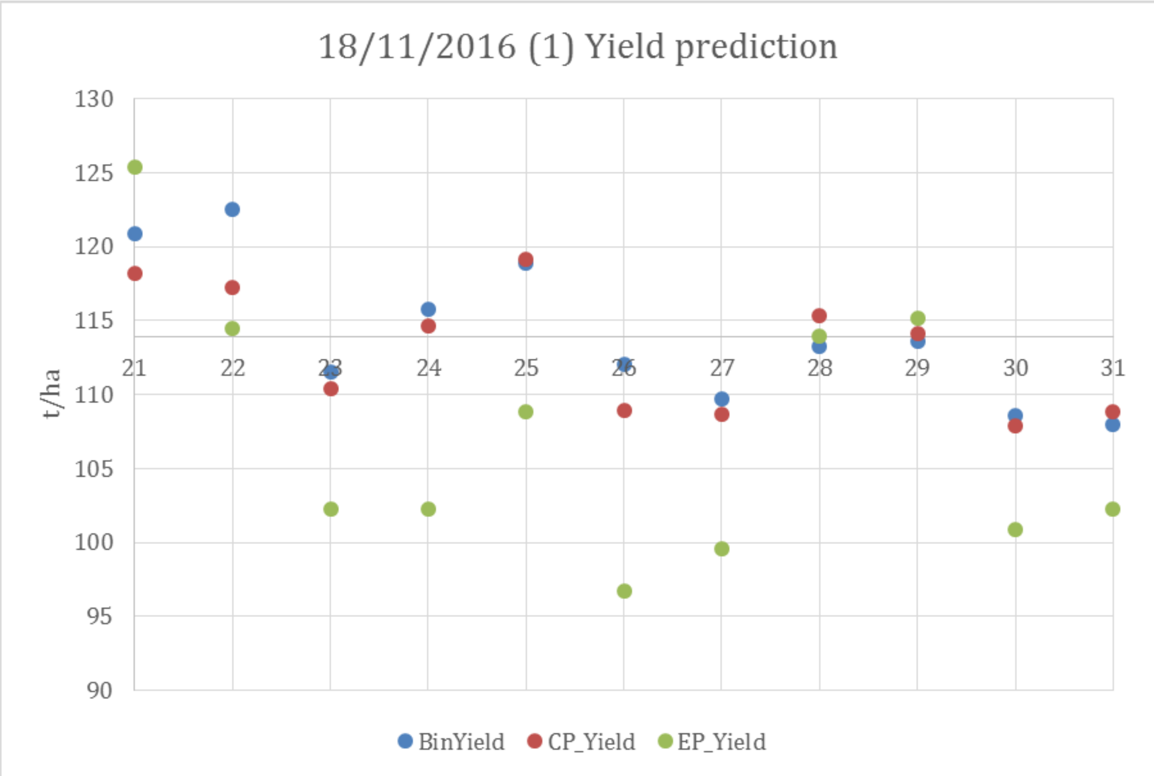


Figure 10. Yield prediction for the first event on 18/11/2016. Average yield (horizontal line) is 113.9 t/ha.

Figure 10 represents the yield prediction for the first event harvested on 18/11/2016. Again, the CP sensor picks up the in-field variability represented by BinYield. EP sensor follows the trend but it underestimates the yield for the loads for which data is available. Data is available for 11 loads out of the 16 that there are in total for this harvest event.

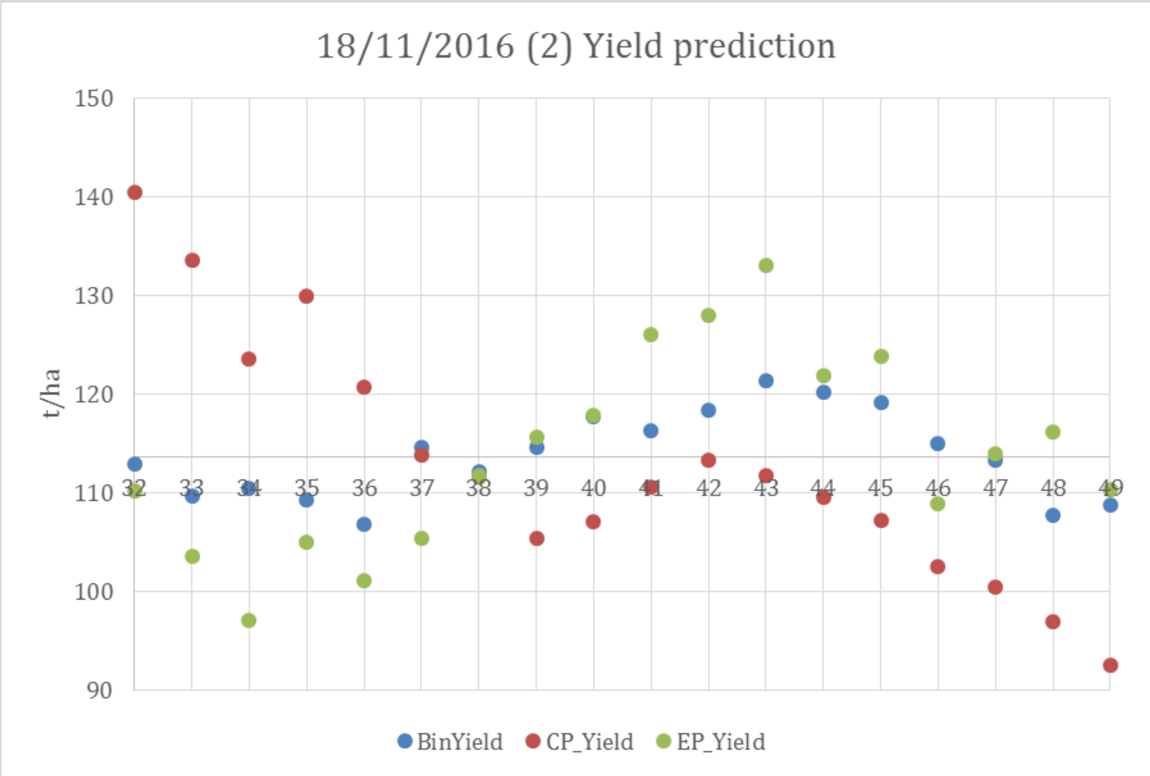


Figure 11. Yield prediction for the second event on 18/11/2016. Average yield (horizontal line) is 113.6 t/ha.

Figure 11 shows some interesting results. From load 32 to 36 the CP sensor seems to be overestimating the yield. Then, from load 37 onwards it follows the trend remarkably well, although underestimating. The only known factor affecting this trend change is a 50 minute break in the harvest between load 36 and 37. If a change in the harvester operator was involved during this break, it is likely that this could be the cause behind the change in sensor behaviour. Figure 11 includes 18 out of the 19 loads for the harvest event.

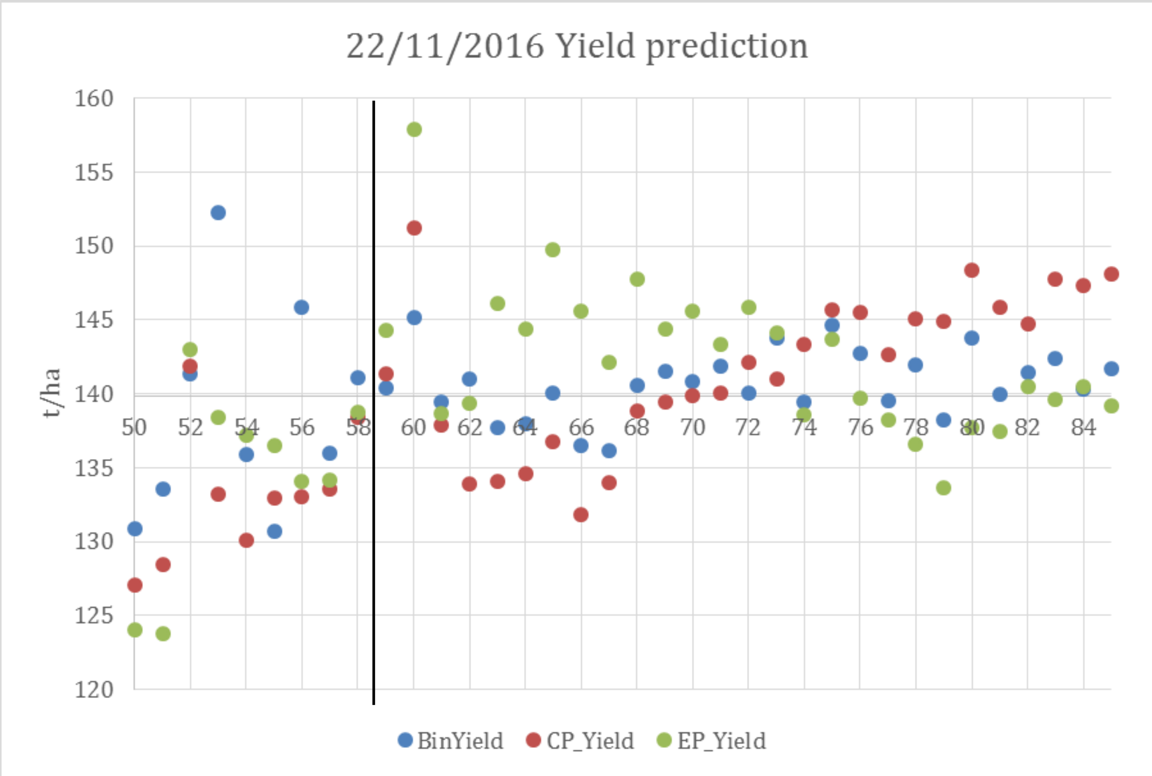


Figure 12. Yield prediction for the block harvested on 22/11/2016. Average yield (horizontal line) is 139.8 t/ha

Figure 12 offers a glimpse into a reasonably large harvest event on the 22/11/2016. During the first quarter of the event both the CP and EP sensors show a larger standard deviation from the BinYield value than can be seen during the second part of the event. In this case again, a break after load 58 was followed by a change in harvester operator. It is evident that personal preferences for machine settings has caused changes in the sensor relationships with bin yield. Speed maps generated for this harvest event (Figure 13) also show a clear speed change that is attributed to the operator change. As the speed effects the pour rate of material through the harvester, this has impacted on the range of sensor values and hence yield predictions. This dataset includes 36 out of the 41 loads that make up the harvest event.

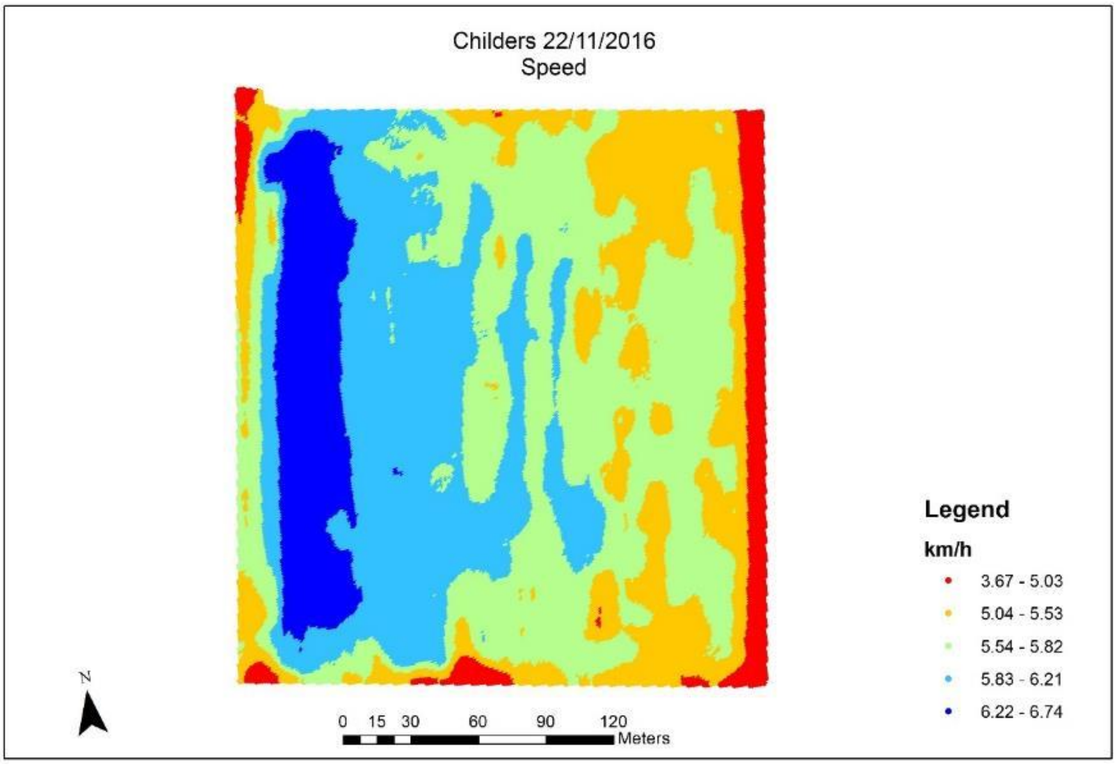


Figure 13. Speed map of the harvest event on the 22/11/2016 showing a clear difference in harvester speed. This difference is attributed to harvester operator change around the middle of the event (note block harvested from west to east).

According the Protocol developed during project CSE022, a harvest event is defined as "a period of harvesting cane of the same variety/age within a single cane block or management unit; assuming an overnight break, a harvest event cannot last for longer than one day."

The results shown above indicate that this definition of harvest event could need to be adapted. Within the current definition of harvest event, a change in harvester operator can affect how the sensors behave due to a different harvester speed, basecutter blade height, or even a change of chopper blades. Being cognisant of these considerations when applying the protocol would provide greater accuracy of the data.

Potential for micro calibrations and e-consignment

Just as there is district level average yields, there are farm level average yields and block level average yields, down to plant level yield. The more specific the data, the easier it will be to identify variability at a finer resolution, which is the goal of Precision Agriculture. The yield monitor data manipulation protocol calibrates the sensor data against a harvest event average yield. In any one block there could be just one harvest event or there could be several, depending on the size of the block and the days taken to harvest it.

Figure 14 represents the difference between the individual load's yield (mill-derived) and the harvest event average yield (also mill-derived). The higher definition allows for more accurate yield prediction. The blocks were harvested from 17/11/2016 to 22/11/2016, the same block as discussed above.

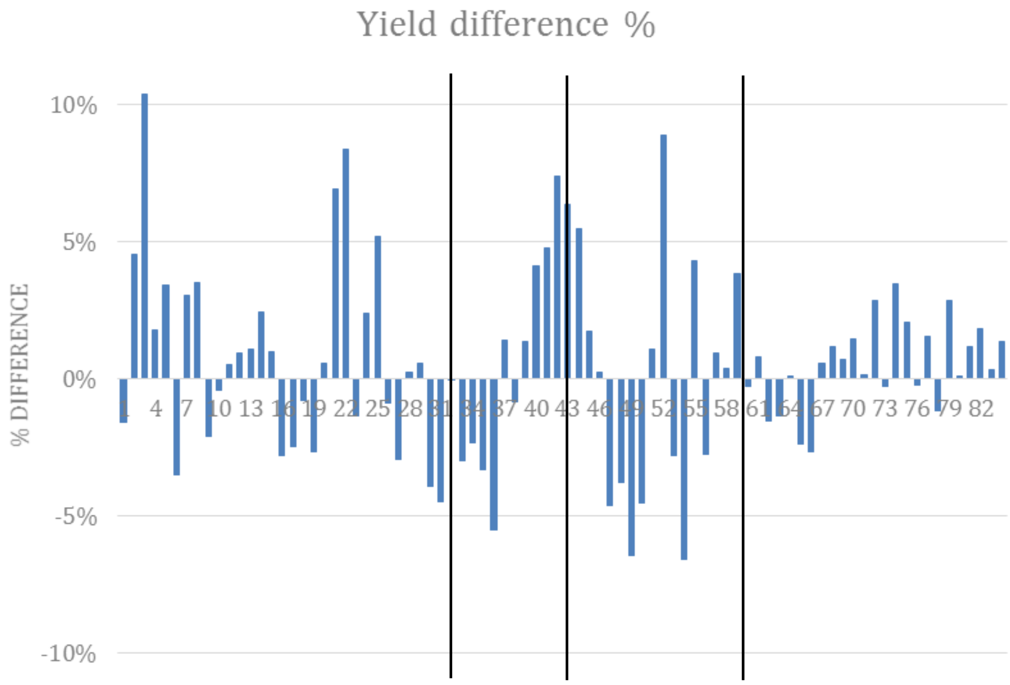


Figure 14. Yield differences in percentage between block average and bin average. There are four harvest events included (separated by vertical bars)

The total average difference across the eighty plus bins was zero. However, as yield varies throughout the block (and hence a different calibration is used for every load), so does the predicted yield for that load. It is to be expected that the predicted yield will be more accurate with load-level calibration as compared to harvest event-level calibration, just as it is more accurate to use harvest event-level calibration than district-level calibration.

This level of detail is unusual, and currently it is not possible to obtain more than harvest event-level of information for commercial cane. However, with the increased implementation of electronic consignment that is spatially aligned with harvest data, this level of detail could be further investigated to advance Precision Agriculture in the Australian sugar industry.

As discussed above, there is an impact on sensor behaviour from changing operators as they adapt the harvester settings to their individual style (harvester speed, fan speed, chopper height, use of the topper, etc.). These changes should be minimised to reduce the impact on predicted yields. Being able to micro-calibrate the sensor readings to account for these changes would likely improve the accuracy of the predicted yield. To implement electronic consignment in such a way that micro-calibrations are possible, it would be necessary to be fully autonomous to avoid human interaction and error. This error has been detected in the load experiment above where the operator had to manually push a button at every load change, resulting in a significant amount of misses, repeats or invalid load calibrations due to lack of confidence.

Furthermore, the first and last bins of a harvest event are likely to carry an error and should be discarded. A new harvest event might unload the cane on a bin that was not completely filled from the previous event, therefore assigning tonnage from a different field on the new harvest event's first load. Similarly, at the end of a harvest event it is likely that the bin will not be completely filled and that the bin will be topped up with the harvested cane of the following event. The other option is to send half-filled bins to the mill, but there have been derailment issues, and should be avoided.

From the 85 bin combinations detailed above (totaling 170 six ton bins as bins were in pairs) the following predicted t/ha yield monitor data was generated using the standard harvest-event protocol for both the chopper and elevator pressure sensors. The predicted yields are compared to the bin generated yields, with the results being shown in Figures 15 and 16. There is a very good relationship between the predicted vs actual yields. As all collected bin data is displayed in these graphs, there are some noticeable outliers that coincide with entering a new block or change of operator. Removing 8 associated points from Figure 13 (chopper pressure) increased the R^2 value from 0.769 to 0.920. There are fewer outliers in Figure 14 (elevator pressure) with only 4 being remove resulting in an increased the R^2 value from 0.864 to 0.891. Both yield predictions were able to explain more than 90% of the variation in the fields tested.

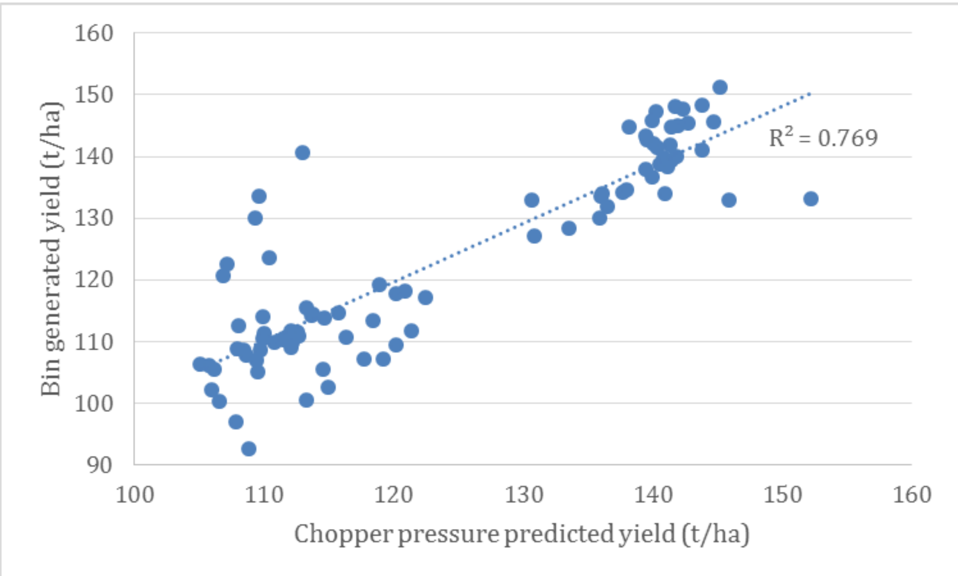


Figure 15. Comparison of the actual yield (calculated from bin totals) verses chopper pressure predicted yield from the yield monitor

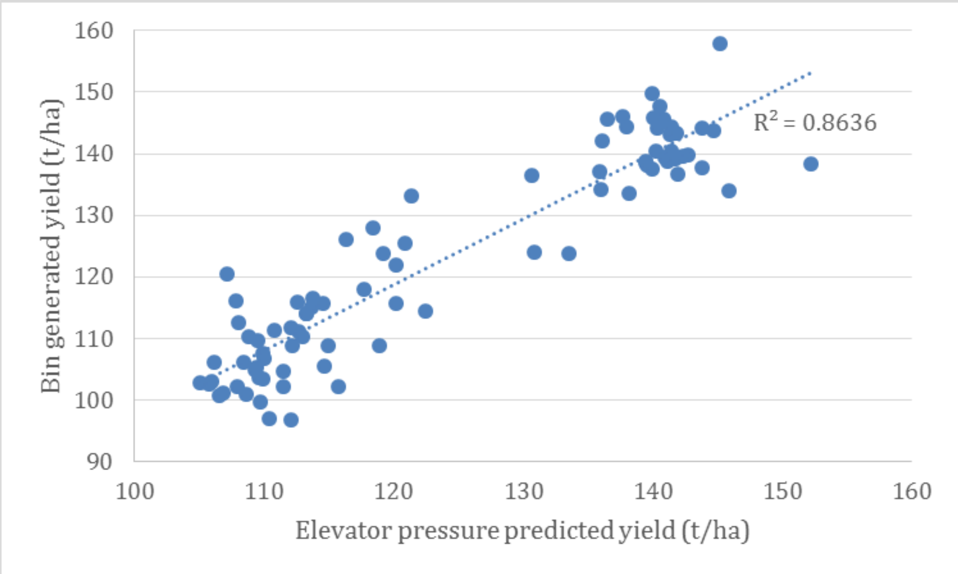


Figure 16. Comparison of the actual yield (calculated from bin totals) verses elevator pressure predicted yield from the yield monitor

De-noising/de-trending of yield monitor data

Yield monitor data often presents different results depending on the sensors used and the way the harvester was operated. This was particularly evident when analysing the data from the SRA project 2014/045 "Boosting NUE in sugarcane through temporal and spatial management" block. The plots formed part of a larger field (the southeast corner of the block show in Figure 17). As the plots were only 10 m long and cut into a weighbin, there was a large number of stops and starts in the field, caused by the trial. When applying the yield monitoring protocol to this data, a significant amount of data was filtered out due to the combination of ground and elevator speed not being in range and also filtering 3 seconds on either side of a stoppage. The resultant of the filtering process was only 3-4 valid yield points per 10 m row. When this data was generated into a yield map, there was little variation across the trial and there was no similarities with the weigh bin derived yield map (the centre of Figure 17).

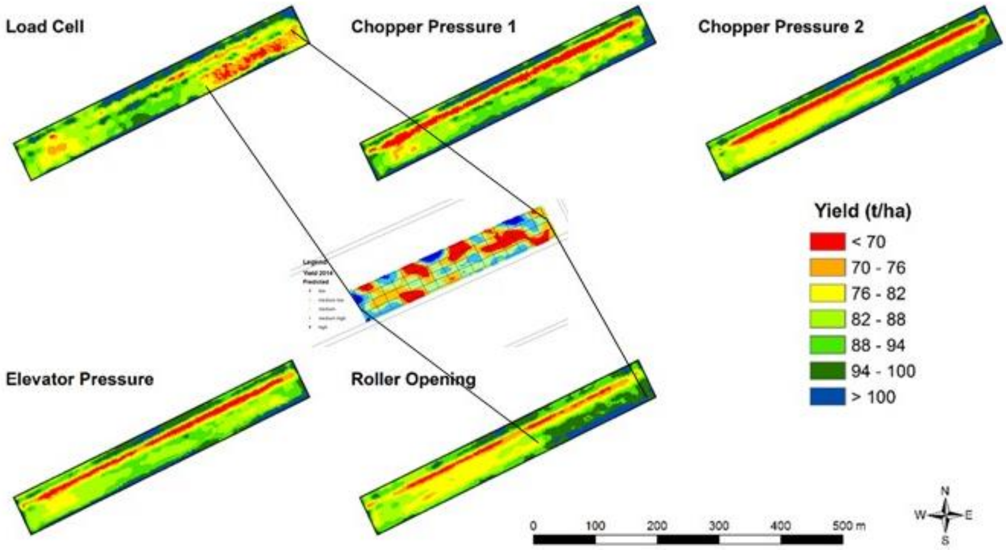


Figure 17 The yield maps for the block containing the NUE trial, using the tools/protocols

In an effort to improve the results, a novel approach was taken identify the role of signal noise on the quality of the maps generated by the different sensors. Additional data mining (conducted in MATLAB) steps were undertaken by Dr Tai Nguyen-Ky from the Computational Engineering and Science Research Centre at USQ. This process uses a wavelet-based de-noising algorithm to detect the low and high frequencies of raw signals (Nguyen-Ky 2010), which has then been applied to this selected dataset. The concept behind this approach is that raw signals are corrupted by spikes and low-frequency noise. By decomposing the data to detect both the low and high frequency signal to filter the data, the underlying trends (the low frequency component) could be accessed.

To analyse signals of a non-stationary nature, the time and/or frequency analysis can be applied. For frequency analysis, a signal can be expressed as the sum of a series of sines and cosines in Fourier theory. However, a Fourier analysis has only frequency resolution and no time resolution. In contrast to the Fourier transform, a wavelet analysis is able to acquire a correlation between the time and frequency domains of a signal with the basic functions called wavelets, mother wavelets, or analysing wavelets.

A wavelet transform can be used to analyse time series that contain nonstationary power at many different frequencies (Daubechies 1990). The wavelet transform decomposes a given signal into a number of wavelet segments. Each of these wavelet segments contains a time series which represents the activity of the signals in a particular frequency band with sampling frequency. For each wavelet segment, the wavelet coefficients are calculated by a time-scale function relating the wavelet correlations. The concept based on this approach is that signal can be accurately approximated using the following elements: a small number of approximation coefficients (A) and some of the detail coefficients (D).

Using the discrete wavelet transform (DWT) method, the input signals are filtered separately by a low-pass filter and a high-pass filter. The original signal (x) can be reconstructed to signal (x') from the approximation and detail coefficients by a synthesis filter bank. The detail coefficients contain the main component of noise and the true signal wavelet transforms. The wavelet-threshold de-noising method filters each coefficient from the detail sub-bands with a threshold function.

The idea of thresholding, then, is to set to zero all coefficients that are less than a particular threshold. To obtain the hard-threshold, detail coefficient (D) with an absolute value below the threshold T is replaced by the value of zero. A wavelet coefficient with an absolute value above the threshold is kept. Noise decreases as the threshold value increases and vice versa. Noise may persist in the signal if a small threshold value is chosen. Therefore, it is important to select an optimum threshold value (Nguyen-Ky, 2010, 2011, 2012).

Since the wavelet transform is a bandpass filter with a known wavelet function, it is possible to reconstruct the original time series using the inverse filter. The original signal (x) can be reconstructed from approximation and detail coefficients by synthesis filter bank to reconstructed signal. These filters reconstruct the data while cancelling any aliasing errors that occur.

The signals are decomposed, thresholded and reconstructed. The technique is a significant step forward in handling noisy data because the de-noising is carried out without smoothing out the sharp structures. The result is cleaned-up signal that still shows important details.

In order to test this approach, the yield monitor data collected from the NUE trial at Bundaberg from 2014 was used. This block was targeted as the spatial variation was known (driven by different fertiliser regimes) and the conventional yield monitoring approach had limitations.

Figure 18(a) shows the raw signal from chopper pressure sensor 1 which has more fluctuation. Figure 18(b) shows the de-noising signal of chopper pressure and Figure 18(c) shows the fluctuation signal of the chopper pressure. The obtained result is good for the signals from chopper pressure sensors in Figure (b). The de-noising is very efficient at the beginning to nearly the end of the signal. Figures 18(d, e, f) show the spectrograms of frequency. The short-time Fourier transform (STFT) is a Fourier-related transform used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time. In a similar fashion, the other sensor data from chopper pressure sensor 2, elevator pressure and roller opening sensors are analysed and presented in Figures 19, 20 and 21, respectively.

A spectrogram is built from a sequence of spectra by stacking them together in time, and by compressing the amplitude axis into a 'contour map' drawn in a colour scale. The graph has time along the horizontal axis, frequency along the vertical axis, and the amplitude of the signal at any given time and frequency is shown as a colour level in contour bar. The colours of the spectrogram encode frequency power levels. Red colours indicate frequency content with higher power; and blue colours indicate frequency content with very low power.

After removing the fluctuation from the raw signal, the de-noising signals are used in the next step to plot the yields as shown in Figure 25. The four de-noising signals corresponding to elevator pressure (EP), chopper pressure (CP1, CP2) and roller opening (RO) sensors are shown below.

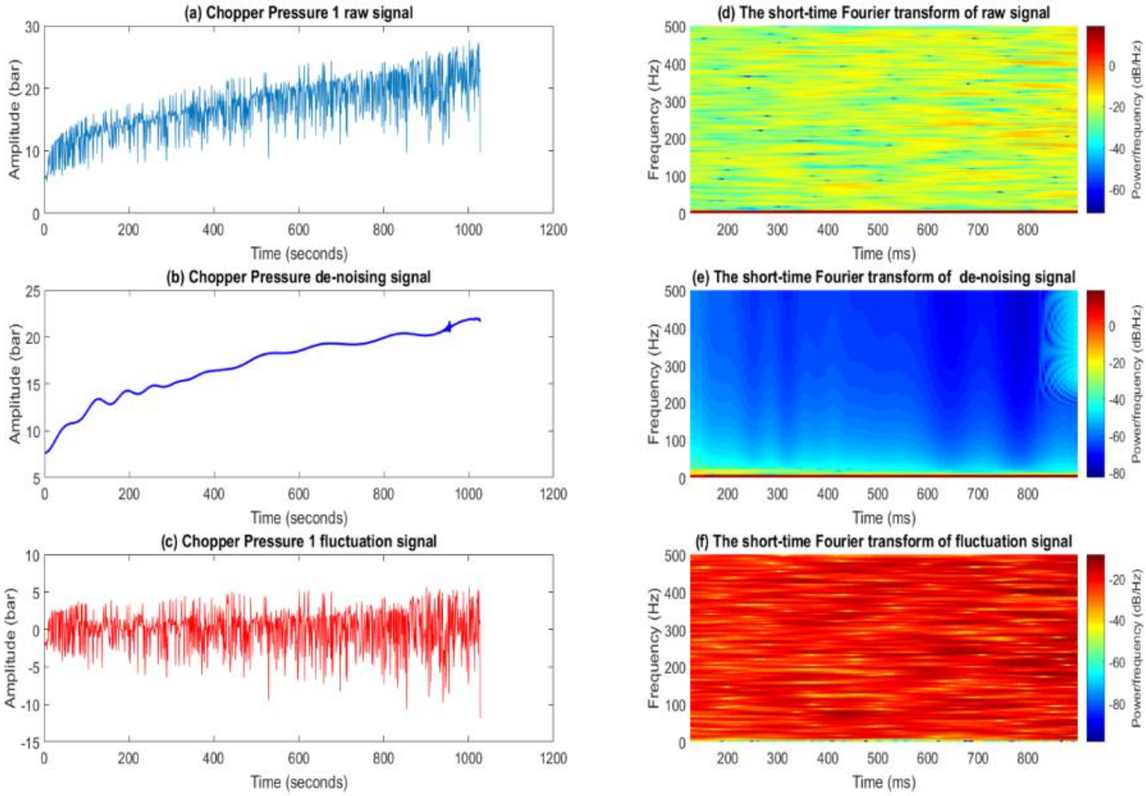


Figure 18. Chopper Pressure 1 (CP1) signal is de-noised using a wavelet method

(a) CP1 raw signal
(b) De-noising CP1 signal
(c) CP1 fluctuation signal
(d) The short-time Fourier transform of raw signal
(e) The short-time Fourier transform of de-noising signal
(f) The short-time Fourier transform of fluctuation signal

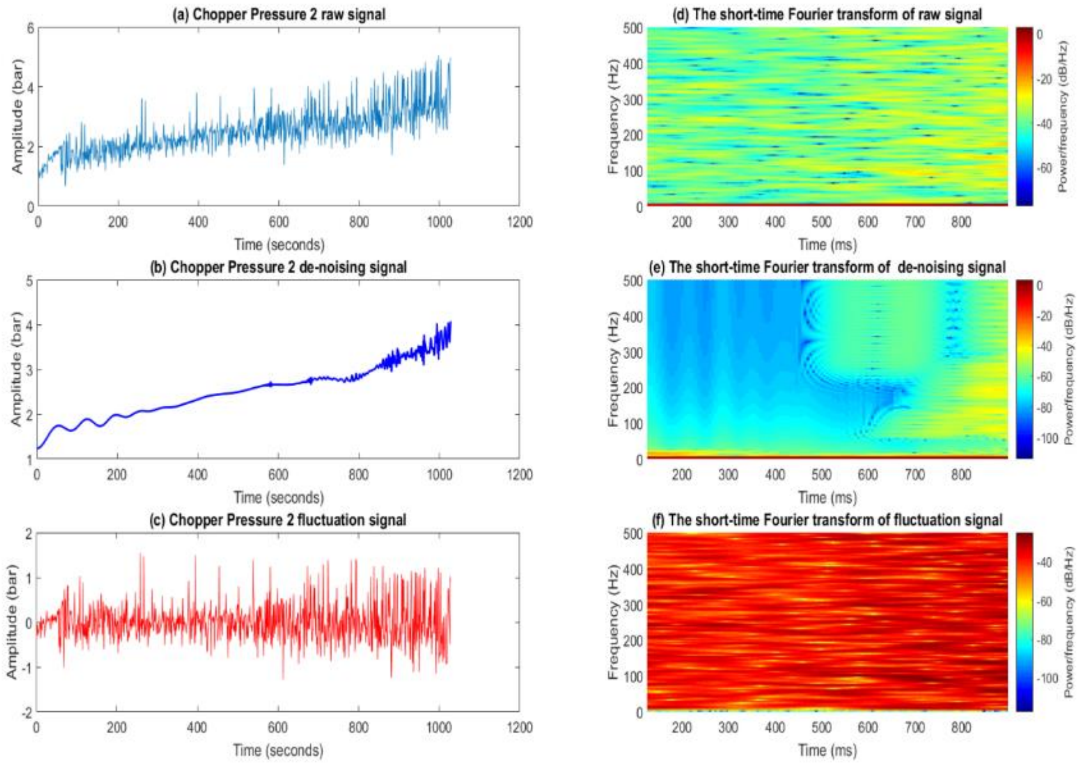


Figure 19. Chopper Pressure 2 (CP2) signal is de-noised using a wavelet method

(a) CP2 raw signal
(b) De-noising CP2 signal
(c) CP2 fluctuation signal
(d) The short-time Fourier transform of raw signal
(e) The short-time Fourier transform of de-noising signal
(f) The short-time Fourier transform of fluctuation signal

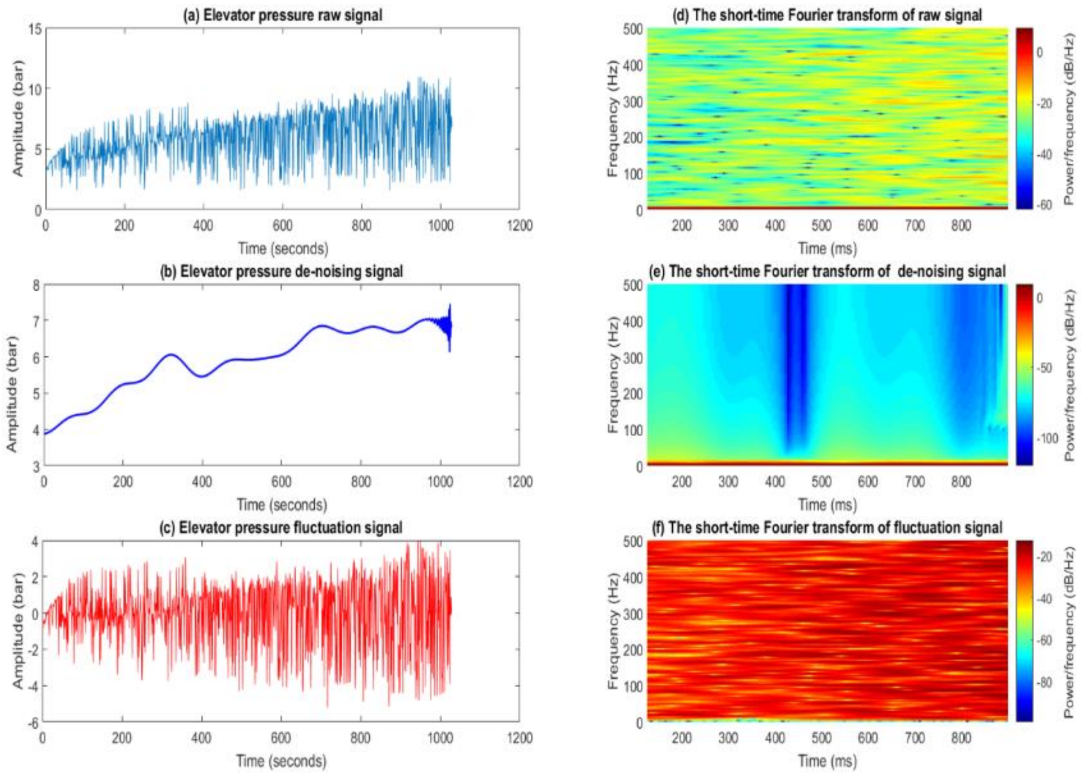


Figure 20. Elevator Pressure (EP) signal is de-noised using a wavelet method

(a) EP raw signal
(b) De-noising EP signal
(c) EP fluctuation signal
(d) The short-time Fourier transform of raw signal
(e) The short-time Fourier transform of de-noising signal
(f) The short-time Fourier transform of fluctuation signal

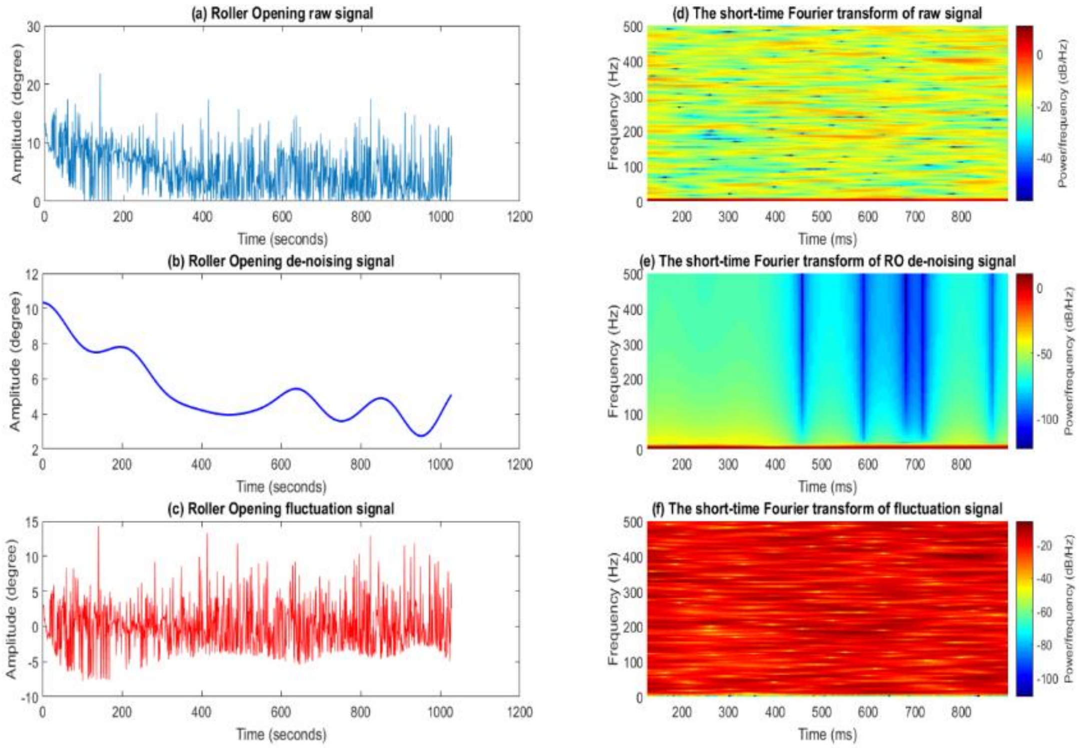


Figure 21. Roller Opening (RO) signal is de-noised using a wavelet method

(a) RO raw signal
(b) De-noising RO signal
(c) RO fluctuation signal
(d) The short-time Fourier transform of raw signal
(e) The short-time Fourier transform of de-noising signal
(f) The short-time Fourier transform of fluctuation signal

To test this approach, the data collected from the NUE block (SRA project 2014/045) was revisited. The trial layout is shown in Figure 22 and 23 with weight truck values for the plots shown in Figure 24. Having this reference data available, the resulting yield maps were expected to show a strong correlation.

N	kg/ha	K	kg/ha
0	0	***0***	0
1	75	***1***	60
2	150	***2***	120
3	225	***3***	180

Figure 22. Fertilizer rates

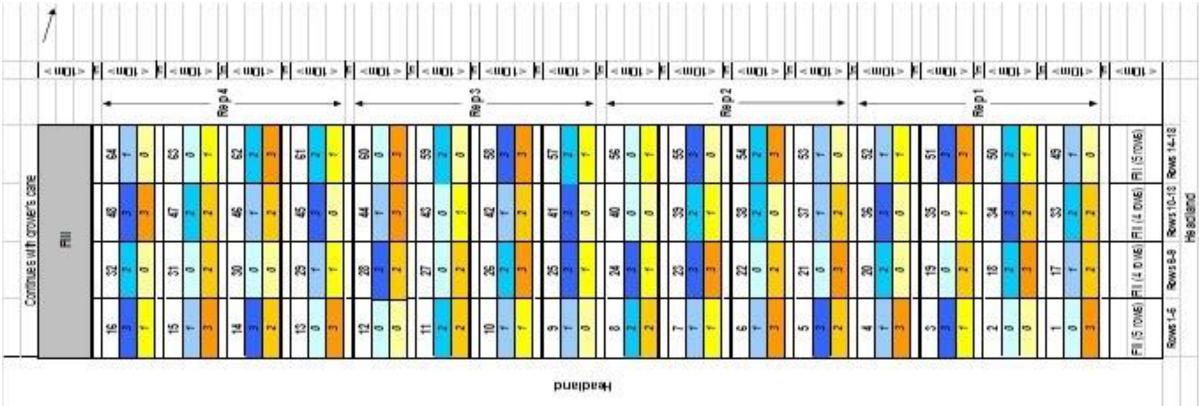


Figure 23. NUE trial map showing the fertilizer rates applied.

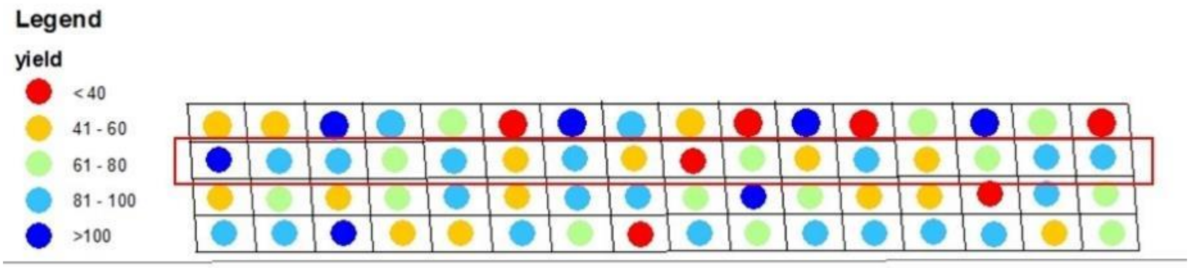


Figure 24. The NUE trial plot yields obtained from a weight tipper

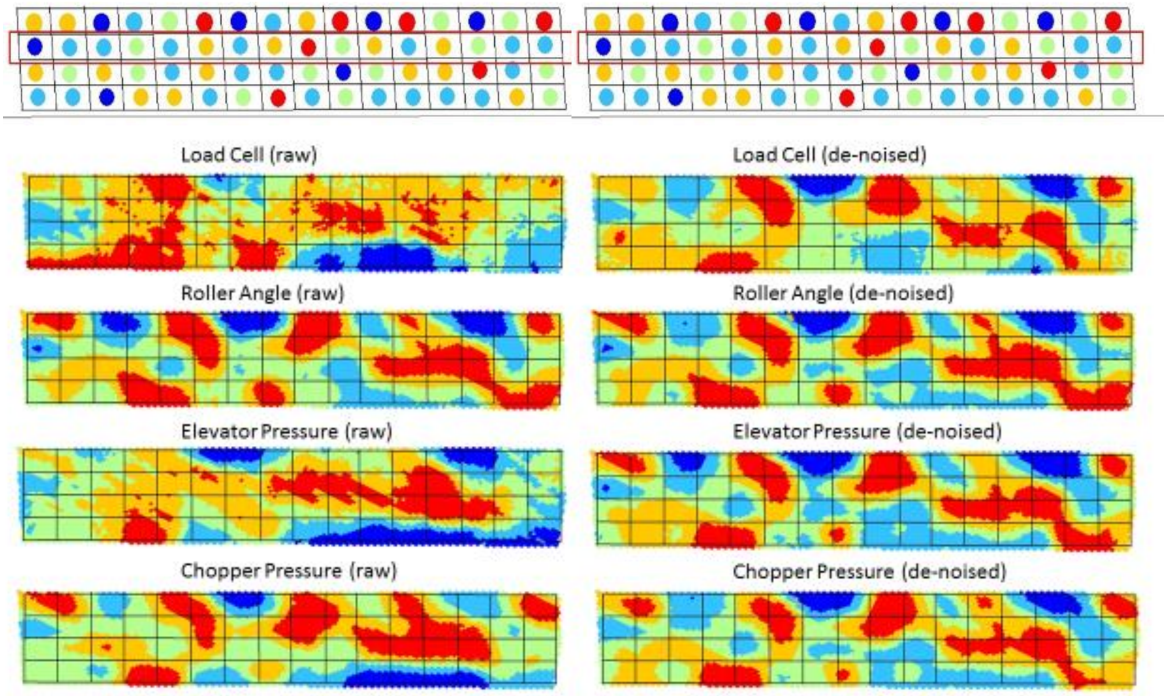


Figure 25. All four sensors' yield maps raw (left) and de-noised (right). De-noised maps are remarkably similar and correlate with the weight truck's yield estimation (top).

On the left side of Figure 25, the yield maps have been generated using raw signal values following the standard data manipulation protocol (Bramley and Jensen, 2013). On the right side, the de-noised yield maps are shown. From the raw maps, the roller angle sensor shows a quite accurate description of the expected variability in the field. Chopper Pressure sensor does a reasonable job as well, except for the lower right corner (Figure 26) where higher than expected values are shown. This is also seen in the elevator pressure sensor (Figure 27), which does an overall poorer job. This anomalously high values happen during the beginning of the day (harvest starts from the south-eastern corner).

The higher sensor values at the beginning of the day has been seen before and it is attributed to the colder hydraulic fluid. The pressure readings tend to stabilize after the fluid reaches a stable working temperature. Using the de-noising process it is possible to remove these artifacts.

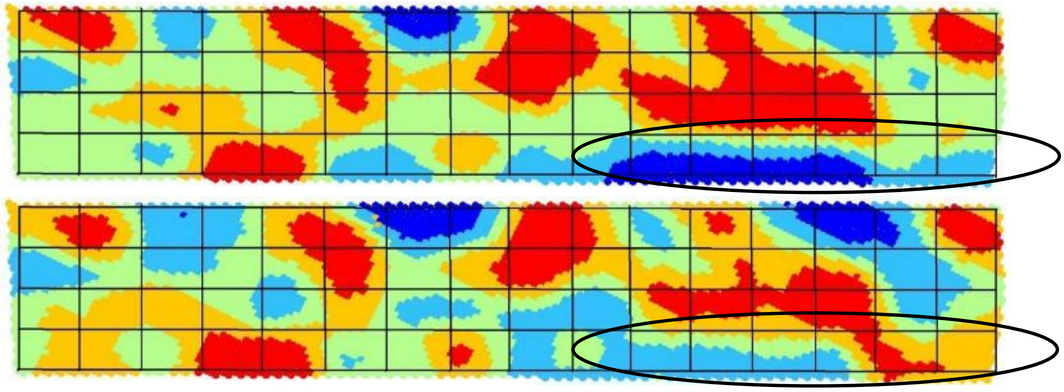


Figure 26. Chopper Pressure raw (top) and de-noised (bottom) comparison. Raw signal data tends to be higher at the beginning of the day (circled). De-noising fixes the issue.

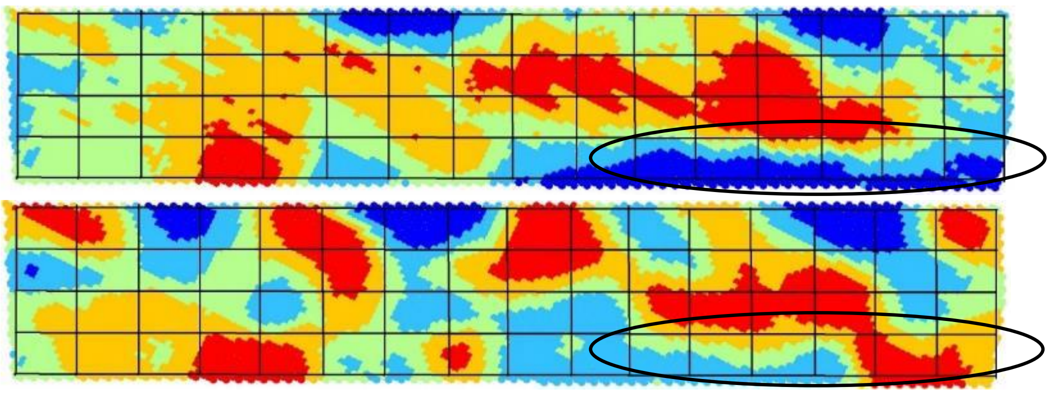


Figure 27. Similar to Figure 5, Elevator Pressure sensor tends to be higher at the beginning of the day (circled). De-noising fixes the issue again.

This de-noising method has not yet been tested on commercial scale cane farming due to the lack of reference signal with which to train the algorithm. Reference signals are key in the development and training of this algorithm, but they are also very scarce and difficult to obtain. However, the promising results shown in this trial would be extremely valuable to pursue further. It could provide very accurate yield monitoring for trial situations (at first), where the standard data processing protocol is less suitable due to the smaller scale and sharp variability

Further work is required to improve the algorithm for a de-noising method. The reference data such as fertilizer application, crop yield and/or satellite images are also required for a supervisor training of an adaptive threshold in a de-noising method. This requires for refinement algorithm to ensure the robustness when the de-noising method to be applied on the new field.

In this project, the four sensor data were studied independent for mapping the crop yield. They could also be further integrated to be used for monitoring and prediction in a crop production model. This model could be used for optimising and management the harvesting.

This de-noising method can run real time and only depend on the raw sensor signals. There is potential for this de-noising method to be developed for different size of the fields on different climate conditions. This de-noising method could then be used in a prediction crop yield model using machine learning and artificial intelligence model in future work.

E. Possible harvesting scenarios

In order to assess the reliability of the data collected, we looked at various scenarios to identify trends in the data, or 'signatures'. In the initial project proposal, it was envisaged that specific signatures could be identified for agronomic, environmental and mechanical influences. These ranged from coarse difference resultant from varietal changes, green vs burnt and lodging to more subtle changes such as weed pressure, water logging and topping. It was hoped that these changes would present as different yield sensor trends. This aspiration was difficult to achieve as these instances were hard to find in commercial operations and their impact on the sensors were masked by other influencing factors during the harvest.

A Bundaberg dataset provided some evidence that weed presence may be detected as it resulted in lower values for the sensors on elevator compared to on main body of harvester. However the same 'signature' can be achieved by increasing primary extractor fan speed resulting in reduced sensor values from the elevator. Changing pour rates can have a similar impact, as at lower pour rates, the cleaning undertaken by the primary extractor is more efficient than at higher pour rates. Factor over this, the inherent yield variation across the field (contributing to height chances, differential lodging, biophysical makeup…) and changing machine operating parameters, these signatures are hidden in the greater harvesting 'noise'.

The coarser differences provided greater ability, but where not however conclusive. The range of harvesting conditions considered were:

- burnt/green harvest,
- lodged/erect cane and
- one/various varieties within a harvest event.

The data used was collected at the Burdekin site during the 2014 season. This site was selected due to the variety of harvest conditions and the availability of grower notes detailing the characteristics of the blocks. Every harvest event considered filled between 52 and 96 bins. Signatures looked at in every sensor were:

- standard deviation of predicted yield,
- sensor free running values,
- sensor high/low values, sensor range of values and
- sensor histogram distribution curve.

Burdekin 2014 – Block 8-1 (23-10-2014). Green harvest, lodged cane, one variety

This block was expected to show poor sensor quality due to the lodged presentation of the cane to the harvester and the additional plant material being fed as a green harvest. Roller opening sensor (volumetric measure) was expected to be particularly susceptible to these conditions. The variety planted was Q208.

As expected, the standard deviation of the predicted yield of the roller opening sensor was the highest of all sensors, indicating lower reliability when compared to the other sensors, which shared a similar standard deviation. When looking at the sensor's histograms, the volumetric sensors show a bimodal or non-normal distribution, skewed towards the lowest values. This is most likely due to the extra plant material (volume) being processed affecting the reliability of the sensor readings. Pressure sensors show a more normal distribution.

Table 6. Summary statistics for green cut lodged cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	171.00	171.81	172.02	173.55	173.51
MAX	344.78	282.62	246.66	275.40	266.80
MIN	45.48	75.58	105.77	105.39	110.53
SD	57.99	37.04	25.03	34.01	31.22

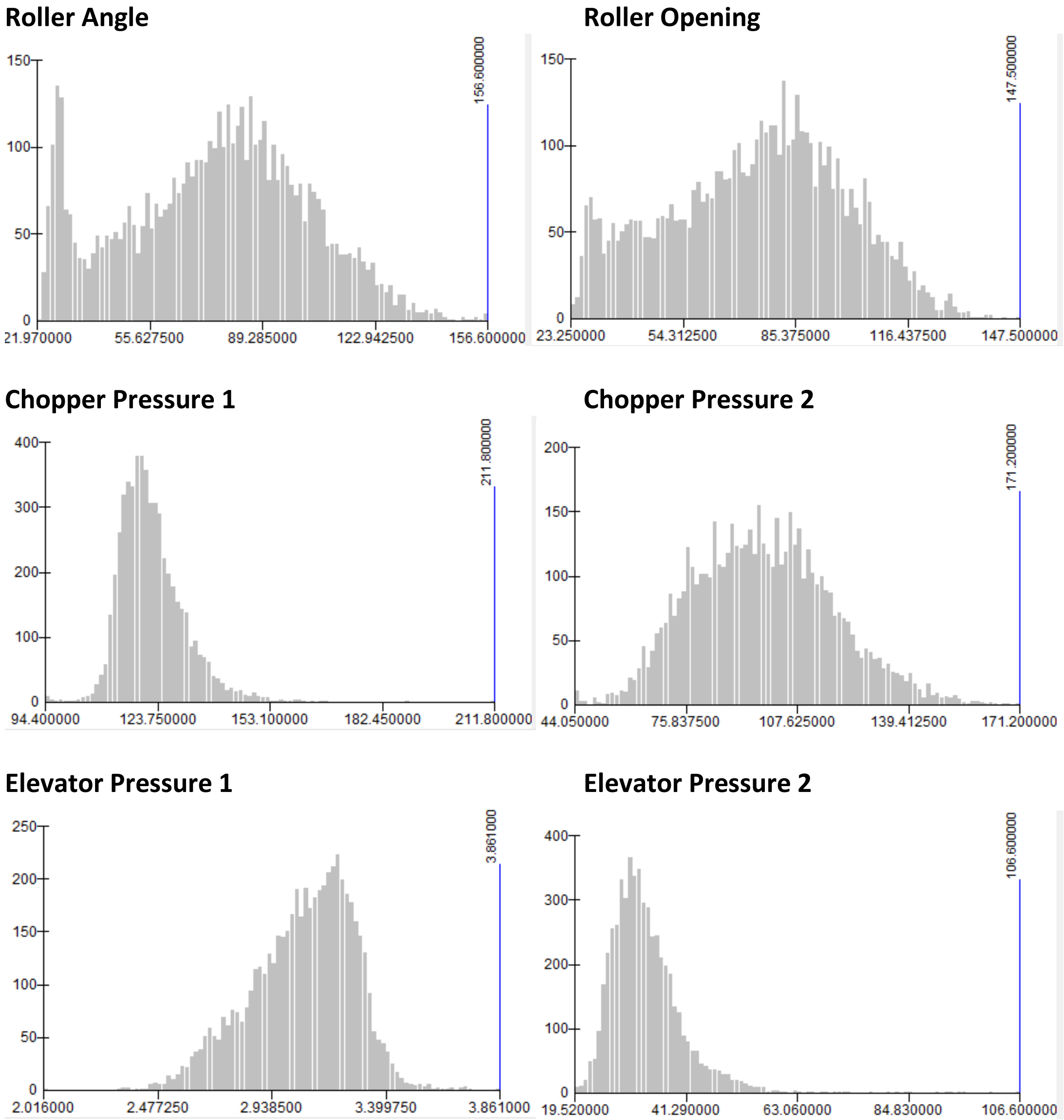


Figure 28. The sensor response for green cut lodged cane

Burdekin 2014 – Block 10 (24-10-2014). Burnt, lodged, one variety

Block 10 was harvested in one harvest event and the cane was burnt, but lodged. The expectation on this block was that the sensors would show cleaner readings compared to the previous block, especially for the roller opening, despite the lodgement.

Table 7. Summary statistics for burnt lodged cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	167.16	167.85	169.45	169.34	169.17
MAX	258.39	259.18	246.47	229.36	227.21
MIN	75.68	77.50	98.18	110.27	111.25
SD	30.55	30.44	25.84	20.05	19.36

The predicted yield values are more consistent among the different sensors. Elevator Pressure shows the lowest standard deviation. This could be explained as the billets going up the elevator are likely to be quite clean and offer a more homogeneous reading to the sensor.

Roller Angle and Roller Opening show a well distributed curve, most probably due to the cleaner cane being fed. The lodgement of the cane doesn't seem to affect the sensor readings.

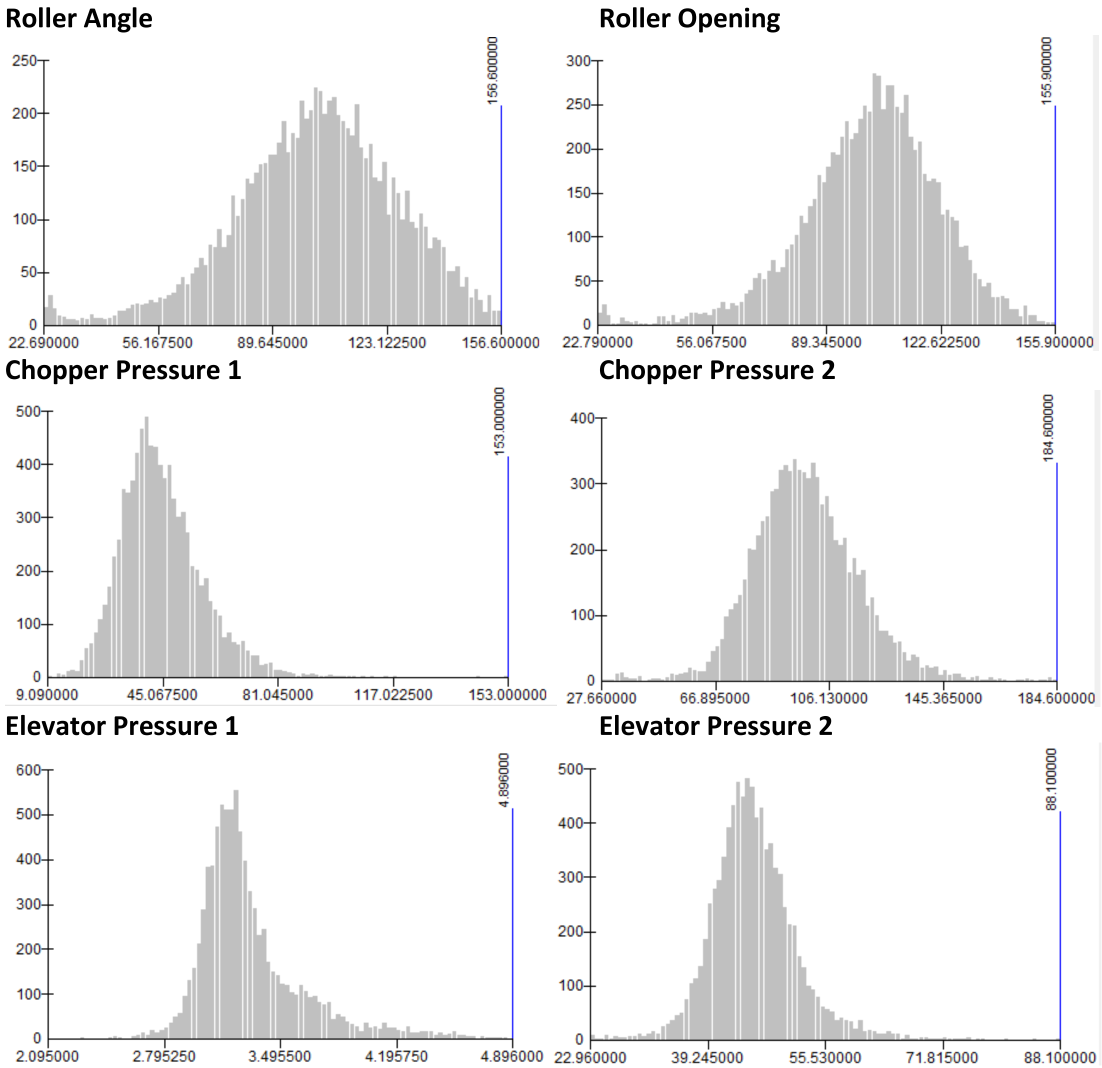


Figure 29. The sensor response for burnt lodged cane

Burdekin 2014 – Block 11 – Event 1 (25-10-2014). Burnt, lodged, one variety

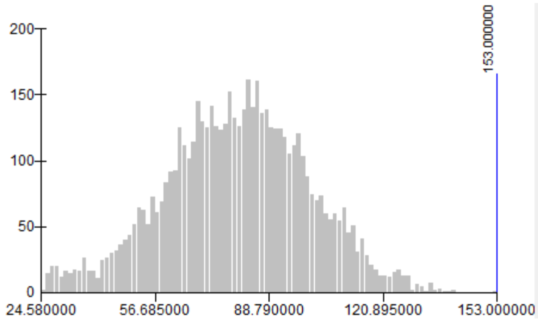
Block 11 was harvested in two harvest event and the cane was burnt, but lodged. The expectation on this block was that the sensors would show similar readings compared to the previous block, as conditions are similar.

Table 8. Summary statistics for burnt lodged cane

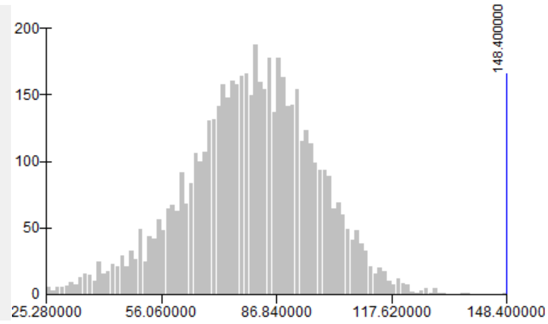
YIELD	RO	CP2	CP avg	EP2	EP avg
Average	158.85	159.33	161.99	159.68	160.18
MAX	254.12	225.19	219.53	204.72	202.74
MIN	63.12	94.03	118.19	115.07	120.04
SD	31.86	22.04	19.27	15.03	14.19

Roller opening sensors show again a higher standard deviation and the elevator pressure sensor the lowest standard deviation during this event. These values are still significantly lower than the green harvest of Block 8. The histograms also show a normal distribution of the values, similar to the previous block.

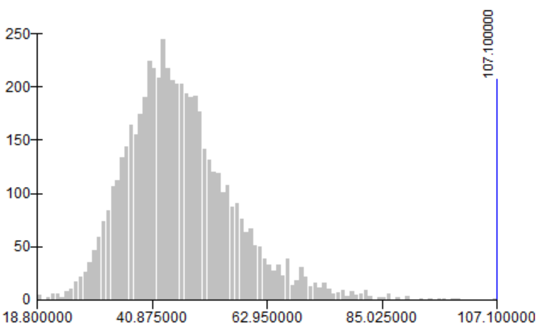
Roller Angle



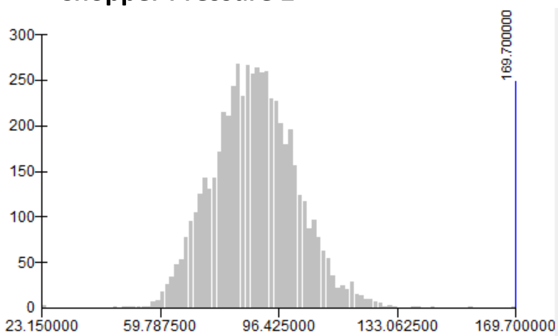
Roller Opening



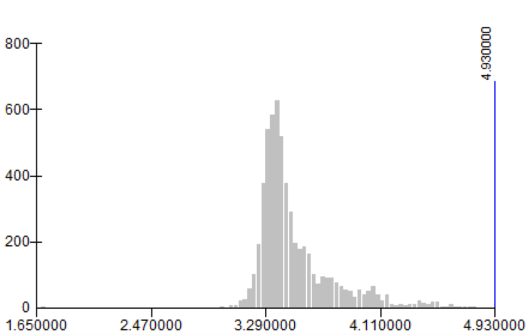
Chopper Pressure 1



Chopper Pressure 2



Elevator Pressure 1



Elevator Pressure 2

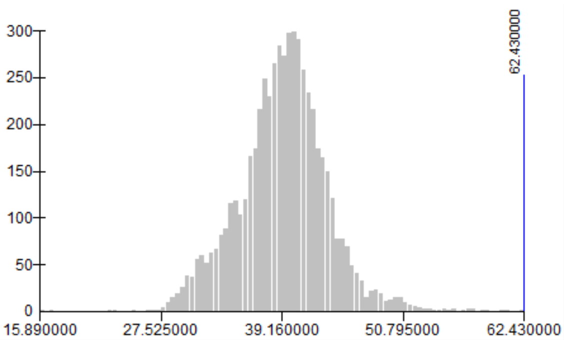


Figure 30. The sensor response for burnt lodged cane

Burdekin 2014 – Block 11 – Event 2 (26-10-2014). Burnt, lodged, one variety

The second harvest event from Block 11 was expected to show similar results than the first event as they share the same conditions.

Table 9. Summary statistics for burnt lodged cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	157.59	156.77	153.66	150.55	150.83
MAX	249.09	225.87	202.22	196.93	194.38
MIN	67.03	92.46	111.61	105.90	110.47
SD	30.77	23.03	16.27	15.56	14.55

Indeed, the results are almost identical as it would be expected. The histograms also show a normal distribution for all sensors, very similar to the previous harvest event the day before. Again, lodgement does not seem to affect the sensors in any noticeable way.

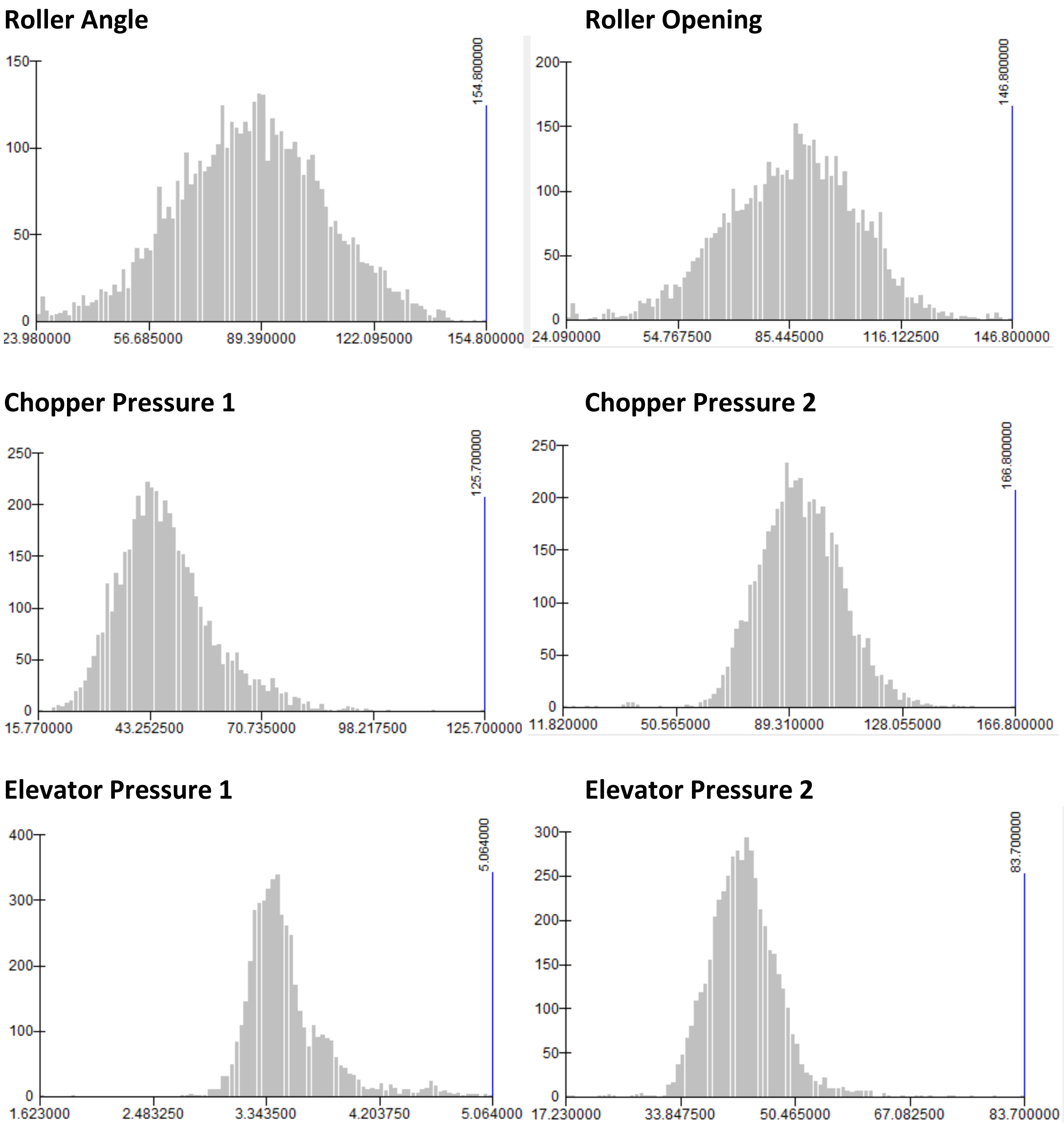


Figure 31. The sensor response for burnt lodged cane

Burdekin 2014 – Block 13 – Event 1 (16-11-2014). Green, not lodged, one variety

Block 13 was harvested as two harvest events, similar to the previous block 11. This block was harvested green, there was no lodgement and the variety was Q208.

Table 10. Summary statistics for green cut erect cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	99.56	100.05	99.96	99.51	99.53
MAX	183.44	147.28	136.98	137.87	136.37
MIN	35.31	52.63	62.78	61.68	63.40
SD	27.96	15.83	12.40	12.89	12.32

Compared to block 8, block 13 has the same characteristics except for the lodgement of the cane. The yield prediction of all sensors showed a much lower standard deviation than in block 8, possibly due to a better cane presentation to the harvester. However, the histograms of the volumetric sensors (roller angle and opening) show once again a non-normal distribution which is likely caused by the green harvest. In addition, these values seem to be stacked against the sensor's lowest value, indicating that the maps derived from that data are unlikely to be reliable.

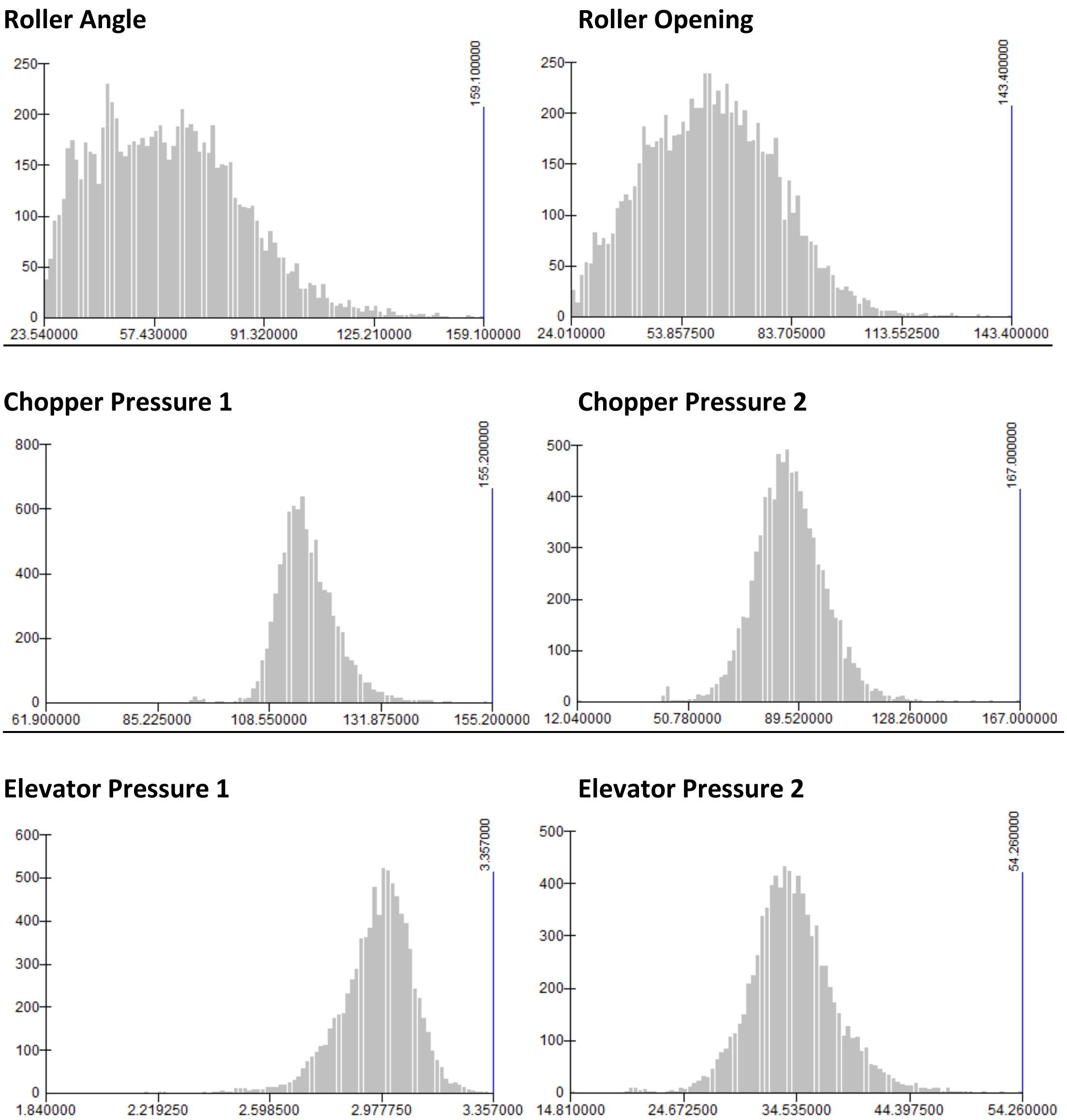


Figure 32. The sensor response for green cut erect cane

Burdekin 2014 – Block 13 – Event 2 (17-11-2014). Green, not lodged, one variety

The second event for Block 13 was expected to show comparable results as conditions were similar.

Table 11. Summary statistics for green cut erect cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	95.44	96.73	97.41	95.65	95.95
MAX	192.82	163.39	162.87	147.47	147.72
MIN	30.20	43.85	52.17	50.89	53.02
SD	32.54	22.24	21.86	17.28	17.27

Predicted yield values were very similar to the first harvest event. However, the non-normal distribution seen for the roller angle and roller opening is even starker than during the first harvest event. Chopper Pressure 2 sensor shows a normal distribution as it does the Elevator Pressure 2 sensor. Elevator Pressure 1 shows a non-normal distribution.

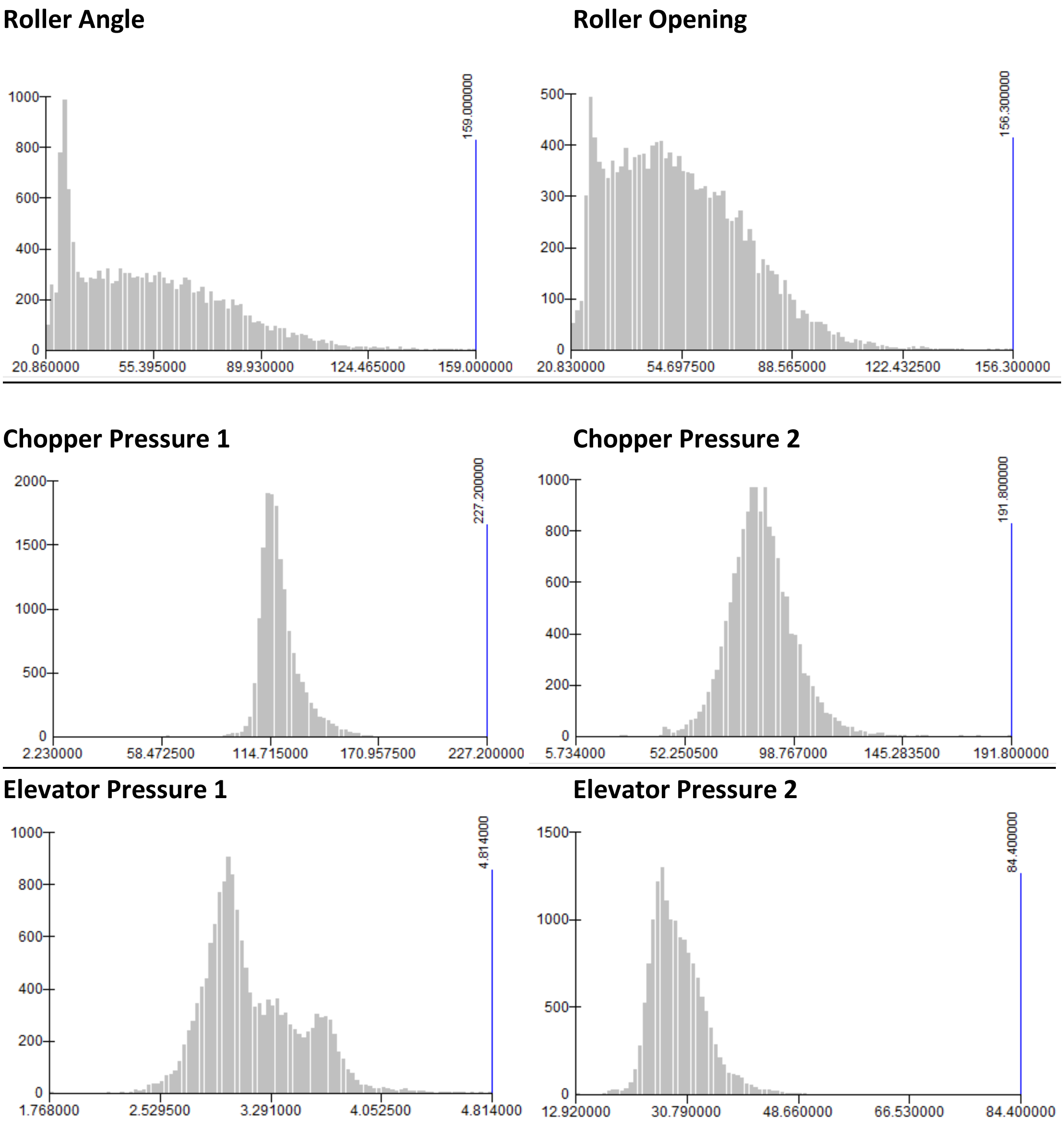


Figure 33. The sensor response for green cut erect cane

Burdekin 2014 – Block 14 – Event 1 (24-10-2014). Green, not lodged, one variety.

Block 14 was harvested during three harvest events. The whole block was harvested green and the cane was not lodged. This first event had a single variety KQ228.

Table 12. Summary statistics for green cut erect cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	197.09	199.18	199.15	198.33	198.61
MAX	415.81	324.51	295.00	297.58	293.47
MIN	61.84	91.01	108.90	103.07	109.23
SD	73.62	41.98	32.22	33.27	31.96

The predicted yield values show the Roller Opening has more extreme values (maximum and minimum) than other sensors with a similar average. Because of this, the standard deviation is also much higher than other sensors. In addition, the histogram shows that the roller opening and roller angle sensors have non-normal distributions, skewed towards the sensor minimum value. This would indicate that the volumetric sensors will be more unreliable than the other sensors, which show a normal distribution.

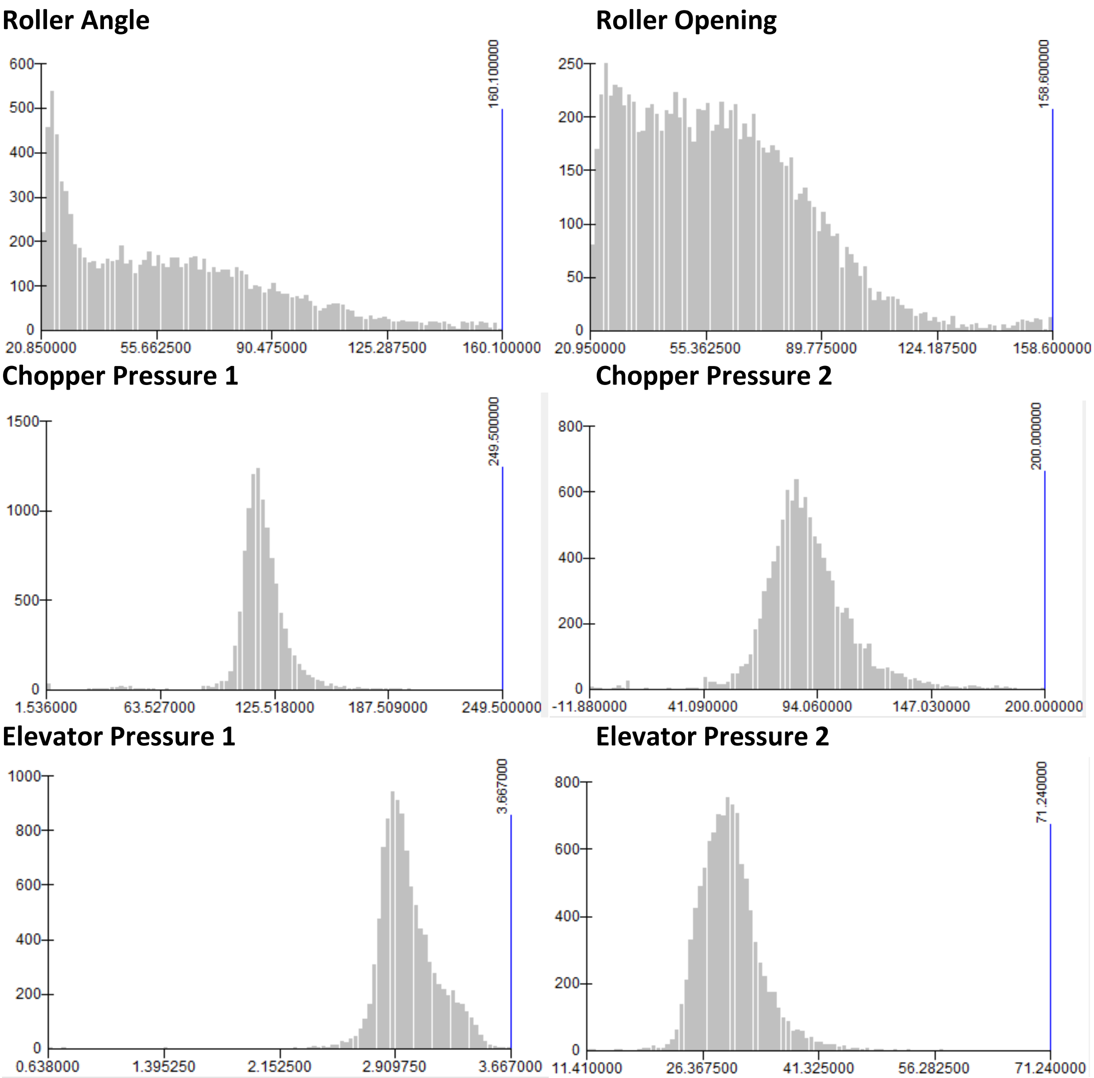


Figure 34. The sensor response for green cut erect cane

Burdekin 2014 – Block 14 – Event 2 (25-10-2014). Green, not lodged, one variety.

The second harvest event for Block 14 is very similar to the first harvest event. Roller opening values show a greater standard deviation compared to other sensors and their non-normal distribution indicates poor confidence is the data.

Table 13. Summary statistics for green cut erect cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	167.03	170.43	170.47	170.23	170.02
MAX	354.63	269.69	253.83	247.56	246.07
MIN	41.61	75.08	91.38	92.87	93.99
SD	62.65	33.13	27.82	25.82	25.47

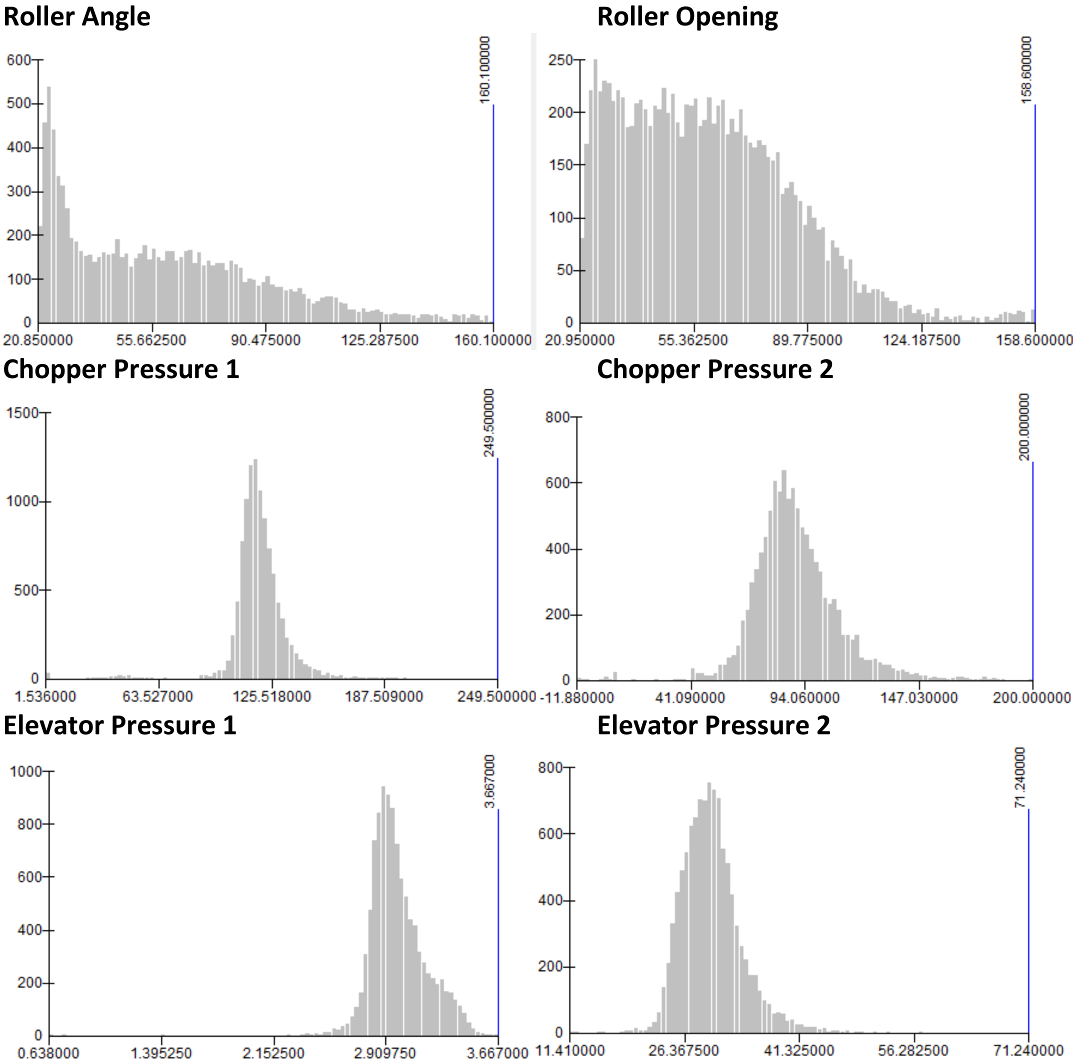


Figure 35. The sensor response for green cut erect cane

Burdekin 2014 – Block 14 – Event 3 (26-10-2014)

The third harvest event shows very similar results to the first and second harvest events for this block. Again, the roller opening shows symptoms of unreliability when compared to other sensors, especially when looking at the sensor's histograms.

Table 14. Summary statistics for green cut erect cane

YIELD	RO	CP2	CP avg	EP2	EP avg
Average	165.33	166.68	166.84	166.95	167.01
MAX	333.09	251.49	246.03	245.93	246.37
MIN	60.15	98.57	105.45	98.36	99.46
SD	57.18	28.60	26.41	27.26	26.93

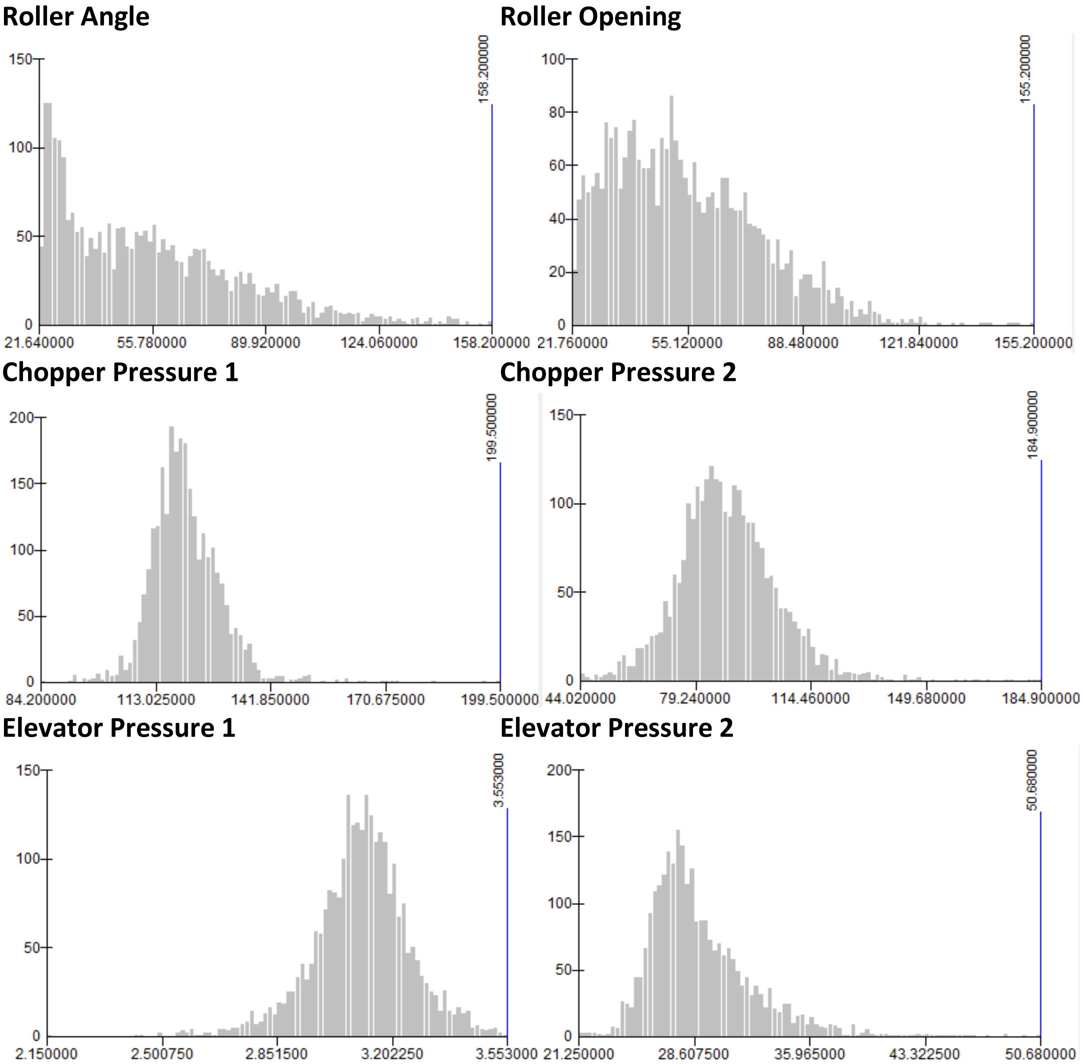


Figure 36. The sensor response for green cut erect cane

Conclusions:

- Sensors' standard deviations are higher in green harvest than burned cane blocks. This by itself doesn't necessarily have to affect the reliability of the data.
- Elevator Pressure sensors consistently show lower standard deviation than other sensors. This is probably due to being the last sensor through the system and the material being fed at this point being more homogenised.
- Roller opening sensors consistently show the highest standard deviation of all sensors, particularly when harvesting green. The greater amount of plant material could be affecting the reliability of the sensors.
- According to the grower, lodged/ not lodged fields were characterised by the heading of the harvester: lodged fields were harvested always in the same direction and erect fields were harvested both ways. Given the presence of both scenarios in the Burdekin farm, it is likely that single direction harvesting indicates heavily lodged blocks while when the harvester direction goes both ways the cane is not necessarily well presented to the harvester, but erect enough to harvest from both directions.
- Volumetric measurements (roller angle and roller opening) show symptoms of unreliability when the harvest is green. With burnt cane, the sensors show a normal distribution.
- Pressure sensors (chopper pressure and elevator pressure) overall show normal distributions. It is difficult to identify any signature in their distribution that would indicate unreliability issues.
- Other factors, or an interaction of them, could affect the sensors' readings and show a non-normal distribution. In these cases, that data is not recommended to be used for yield mapping. Only the data from sensors that show a normal distribution should be used.

Figure 37. The yield standard deviation and free running values across the range of scenarios tested

F. 10 harvest events to be analysed each year

A selection of the harvest events analysed during the life of 2014/028 have been extracted from the Milestone Reports and displayed here to meet this requirement.

Figure 38 shows the yield maps generated for blocks 20A-C (Bundaberg 2014) using data collected using a Load Cell yield sensor. Since all of these blocks were third ratoon K228, each has been classified using the same legend, although it is evident both from the maps (Figure 38) that the mean yield in each of the sub-blocks varies somewhat. It is worth emphasising here that each of the harvest events have been mapped separately – which is one reason for apparent discontinuities in the legend categories across sub-block boundaries.

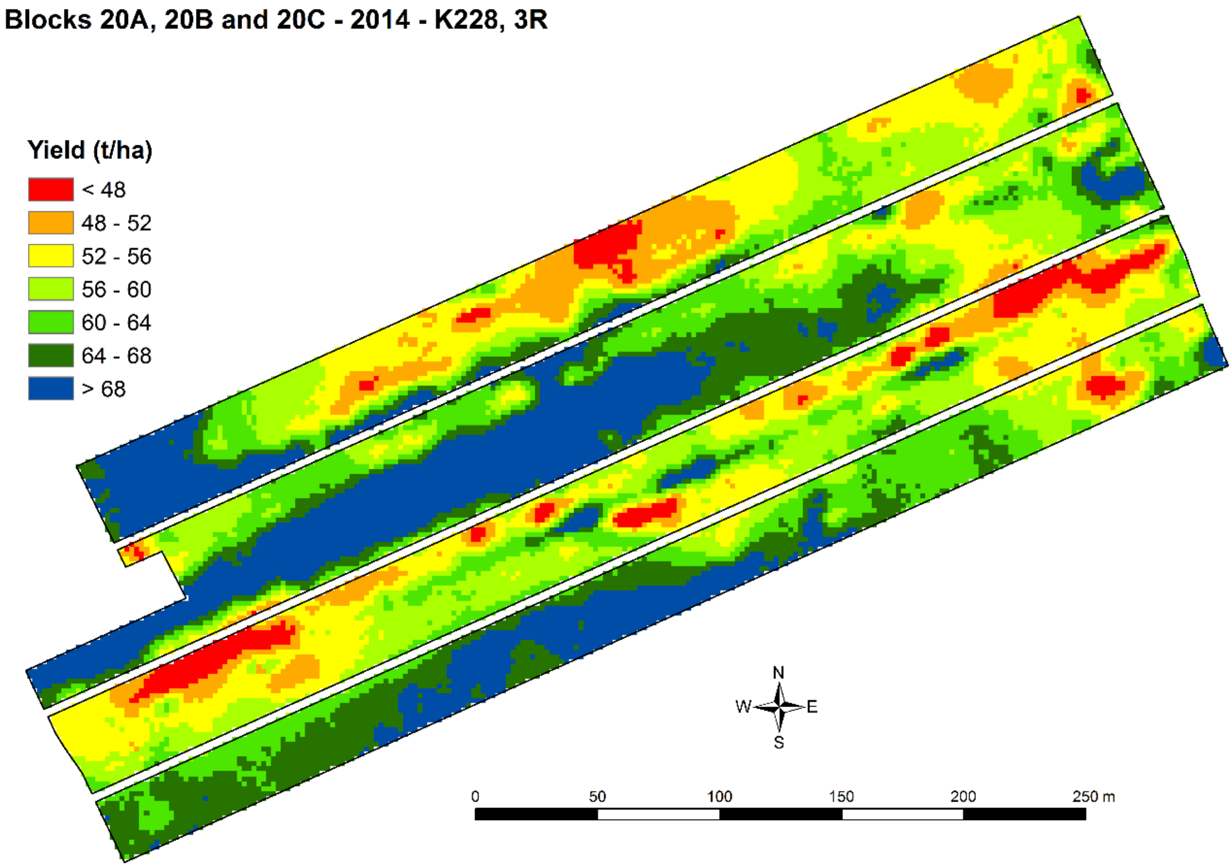


Figure 38. Yield maps for blocks 20A-C, 2014. Since each sub-block was of the same crop age and variety, and harvest of each occurred on the same day, the same legend has been applied to each

Arguably, since the sub-blocks in Figure 38 are all of the same variety and crop age, they would have been better mapped together as a single map. However, in the absence of an electronic consignment system, and/or a more sophisticated means of block/crop class discrimination than reliance on standard Mill data output, the degree to which our mapping process can be automated is confined to the sub-block and harvest event.

Figure 39 gives a similar presentation for blocks 5A, 26B,C and 27A,B using the roller opening yield sensor. However, because of differences in mean block yield, a number of different legends have been used. Block 5A is plant cane Q138 so it is unsurprising that its mean yield (65.1 t/ha) should be different to the other blocks which were planted to K228. 26B is first ratoon K228 (mean yield of 69.1 t/ha); 27A is also first ratoon K228 yet its mean yield is considerably higher (115.7 t/ha). In contrast, blocks 26C and 27B have similar means (95.0 and 95.4 t/ha respectively) even though 26C is first ratoon and 27B is second ratoon (both K228). Whilst the maps for the 3 sub-blocks comprising 26B highlight the potential merit of being able to interpolate maps across sub-block boundaries where appropriate (see above discussion of Figure 38), the presentation in Figure 39 is clearly confusing; the utility of the yield maps for any individual block or group of blocks is constrained by the apparent need to view them independently of neighbouring blocks. This is counter-intuitive given that patterns of yield variation tend to be driven by variation in the land (soil, topography) underlying the block as CSE022 and countless other studies in a range of crops have demonstrated.

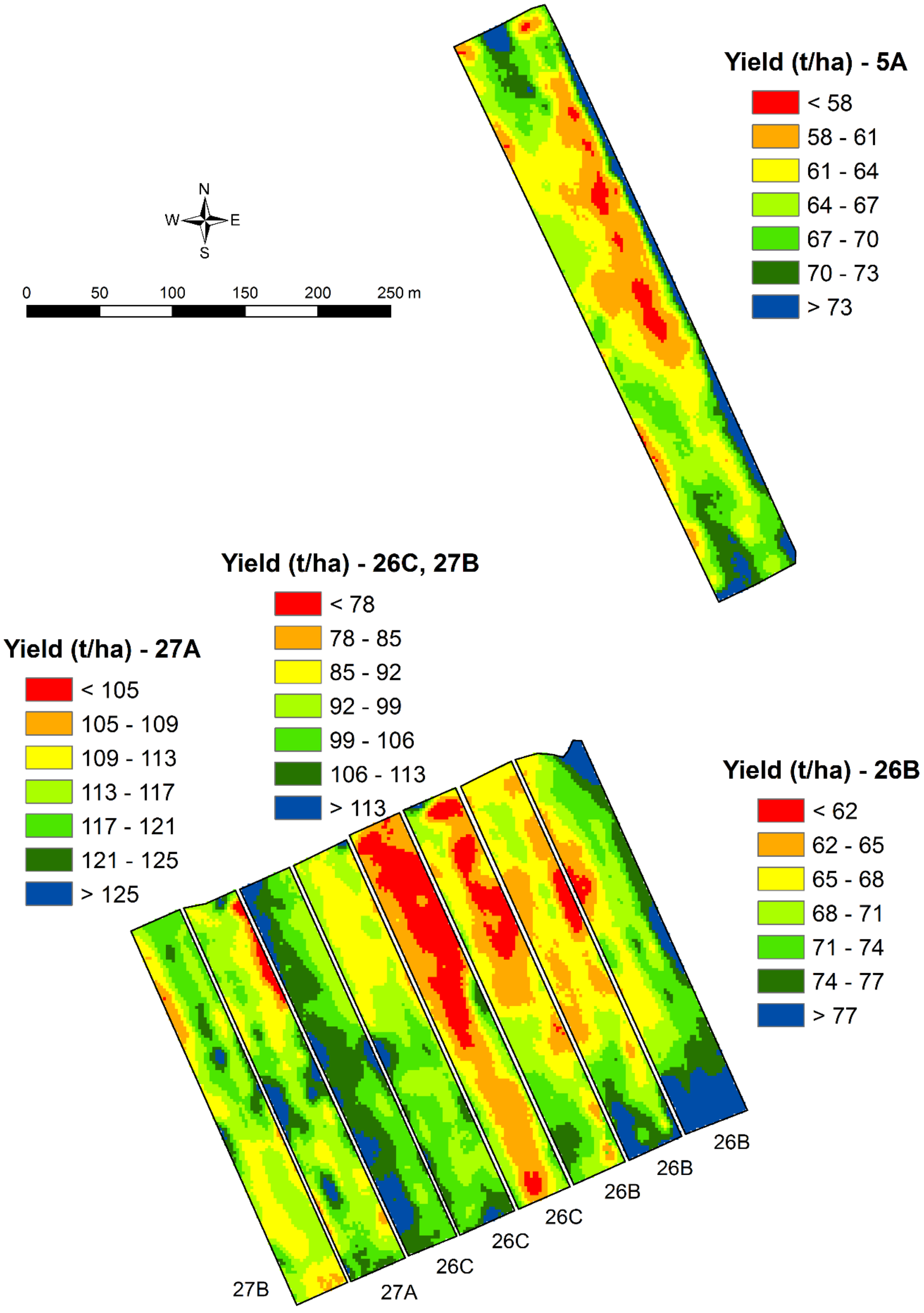


Figure 39. Yield maps derived from the roller opening sensor in blocks 5A, 26B and C and 27A and B. Note the different legends which apply to different blocks.-

Experience suggests that most farmers who adopt PA are interested in the identification of zones for differential treatment, rather than pursuing continuous variable rate application. In light of this, the actual yield values underpinning a yield map, whilst important to the consideration of issues such as identification of potential yield, are somewhat unimportant to the identification of patterns of variation. With this in mind, the issues highlighted by Figure 39 were canvassed, to some extent in the SRA project CSE022, by adjusting data on a sub-block or harvester event basis to a common mean value. This adjustment has been implemented in Figure 40 for blocks 26 and 27 in an attempt to remove the confusion apparent in Figure 3; the maps for all blocks have been adjusted to a mean yield of 95.0 t/ha, the mean yield in block 26C. Whilst the result of this adjustment (Figure 40) allows for a less confusing presentation by comparison with the unadjusted maps (Figure 39), it is evident that in this section of the Hubert farm, other aspects of management in individual sub-blocks might have a greater bearing on yield variation in this mapped area than inherent variation in the underlying land; the contrast between the western-most and eastern-most sub-blocks of 26C and the rest of the area highlight this. Nonetheless, in further development of the map automation tool, we will be considering how to refine the processing and for what minimum area of interest, so that the results are those which will deliver greatest utility to the end-user.

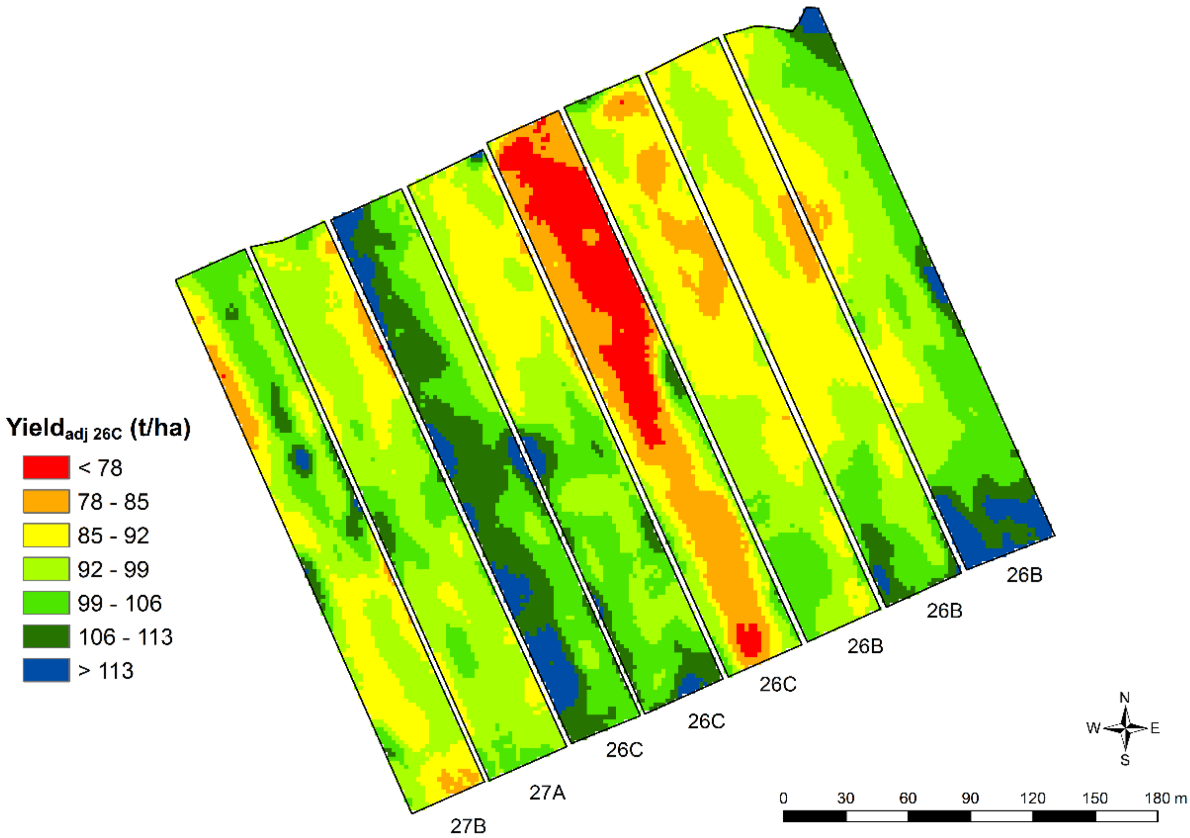


Figure 40. Yield maps derived from the roller opening sensor in blocks 26B and C and 27A and B when the mean yield in each block is adjusted to 95.0 t/ha, the mean yield for 26C. Each sub-block is planted to K228 and is first ratoon except for 27B which is second ratoon.

G. Correlation with the mill tonnages

To assess the correlation of field data to mill tonnages, an investigation was conducted to track the cane from the field to the mill. This test was conducted at Childers in November 2016 as part of yield monitor evaluations. The location in the field from whence the cane was cut by the harvester into the haulout, was noted, as was the subsequent transfer into rail bins at the siding. The fill sequence of the rail bins, along with the progression of bins to the mill was similarly noted. As this investigation was conducted on cane that was being supplied to the Isis Mill, electronic consignment (see Figure 41 below) was also undertaken with the telemetry data also being interrogated. A total of 358 bins were tracked over 4 days of harvesting. The field notes perfectly aligned with the electronically consigned data on all bar 2 occasions. On the first occasion, 2 bins were cut late at night but only consigned the next day. The second instance was a problem of sequencing with 5 bins getting out of order. They were however consigned to the correct block, but may have got out of sequence due to the locomotive picking up and transporting bins.

An investigation similar to that conducted in Bundaberg in 2015 was also conducted at this site. Over the 15 days of harvesting, 187 different rakes of bins were consigned totaling 2247 bins. This equated to more than 14,800 t of cane being cut with an average bin weight of 6.61 t. This consisted of 62 separate harvest events cut from 22 different blocks.

The protocol developed during CSE022 and applied during this projectr states that the yield prediction is to be performed on a per-harvest-event-basis. A per harvest-event (HE) basis means the cane cut from a designated block or sub-block per day. A per HE trigger can be a change of day, change of variety (within block) or a change of block. In order to investigate the frequency of anomalies that trigger a change of harvest events and thus the flow on consequences of influencing consignment, a summary of events for the 2016 Childers data is detailed below;

- A total of 7 blocks were cut in their entirety on a single day, with each, as such, being a single harvest event.
- Additionally, 4 blocks were cut over two separate days constituting 2 harvest events per block. As with the single HE, these blocks were generally small in size and where cut when convenient.
- The block that consisted of >2 HE were larger in size requiring more time to cut. 6 blocks that were observed require >150 bins and were harvested over multiple HE, with 2 blocks required >300 bins and were harvested over 6 HE. Where large blocks were encountered, it was observed that the haul distance, number of haulouts and number of bin on the line all played a factor in the sequencing of the blocks that were cut, in order to minimize operating time and maximize bin fill capacity.

The Childers operations used a combination of straight tip bins (one haulout bin tip per rail bin – see Figure 42 –Grieve bin) and an elevator fill bin (see Figure 43 - McLean bin). Figures 44and 45 show the bin combination in the field. As the capacity of the McLean bin was slightly less than that required to fill 2 rail bins, topping up was required during subsequent unloads to maximise bin capacity and prevent bin de-railing due to light bins. This topping up makes tracking the cane from field to mill impossible. Hence the field to mill tracking could only be performed when the pair of ‘Grieve’ bins where operating in tandem.

Figure 41. Haulout operator entering electronic data for consignment of the cane to the Isis mill

The simplest form of electronic consignment (using a tablet to replace the consignment book) will not overcome the problem of cut cane being assigned to an incorrect field. At best it might overcome transcription errors, either on farm or at the mill. If however, the IPad/tablet/smart phone that is used for consignment used the internal GPS or GPS information from the harvester to automatically record the location of where the cane was cut, then there can be no mistake in assigning the cane to the wrong field. A potential for future work might be to link the bin filling spatial details with the harvester yield monitor data (by the use of RFID or similar) to get an increase level of accuracy in the cutting data.

Another option that was initially considered was the use of portable weigh scales at the siding. The above information shows that when the harvest progress is carefully monitored, both the manual and electronic methods can be accurate. The use of scales would greatly restrict productivity in a commercial operation, and it is during the cutting of commercial cane that was the primary interest of this project. Scales were not further investigated.

Figure 42. The single tip 'Grieve' bin

Figure 43 The 'McLean' bin that allows for topping up of bins

Figure 44 the 'Grieve' bin

Figure 45 the 'McLean' Bin

H. Electronic consignment

In order to investigate how the sugar mills view electronic consignment, the project team developed and refined interview questions following advice from industry representative, researchers and extension staff. The questions asked in the interviews are attached as Appendix 1. The objectives of this investigation was to document the directions of mills towards electronically consigning cane and the ability to spatially interrogate data. Meetings were conducted with 3 mills areas in southern Queensland. The results from the electronic consignment questionnaire are summarised and included as Table 15.

Table 15. Summary statistics for green cut erect cane

Crop estimates	**Mill area 1**	**Mill area 2**	**Mill area 3**
1. How are block estimates achieved?	Visual estimate of crop.	• Growers do an initial estimate – late April • Mill does an analysis of previous history looks for similarity, weather etc. – Late January – Feb – March – April • Information obtained from Satellite Spot Imagery (Andrew Robson).	Visual estimate of crop.
2. Are the estimates completed by Cane Inspector, grower or other	Grower 70-80%, Cane Inspector 20-30%	Grower with some input from Cane Inspector	Grower, Cane Inspector if required
3. How many times visited?	During harvest season Cane Inspectors revise estimate.	Just the once	Mid-season re-estimate for production planning.
4. Is satellite imagery used?	Yes	Yes	No
• As the sole estimation tool or	No	No	NA
• In addition to visual crop estimates conducted by _______?	Grower/Cane Inspector	Grower/Cane Inspector	NA
• Using what algorithms?	Andrew Robson	Andrew Robson	NA
• …and how much ground-truthing? (Using what methods)?	A few blocks ground-truthed	12 sites visited	NA
5. Are any crop notes taken, e.g. lodging, poor growth?	No, some 'feel' for lodging for expected Extraneous Matter.	No	No
6. How accurate are the estimates compared to harvest yield?	Estimate revised as harvest progresses	Within 5% + or -	Av 3-5% for individual blocks, can be up to 15%
• Is this based on data rather than opinion?	Yes		Yes
7. How does your mill make use of these estimates?	Determine season length, bin allocation, equity	• Maintenance planning, budgets • Crushing program, start date for season	Production planning and harvest allotments

		• Manning for 'Slack Season' etc.	
8. Is row width recorded?		Yes	No, plan to do so in the future
Block information			
9. Are blocks reviewed yearly for variety and crop class?	Yes, variety and crop class	Yes, computerised roll-over, grower input	Yes, Information from grower form and pre-season estimates
10. What changes, ratoon only?	Plough out, plant and ratoon	• Area • Fallow to Plant Crop • Ratoon to Fallow Crop (peanuts, soy, horticulture)	If no information received fallow to plant; plant to ratoon etc.
11. How often are block boundaries mapped?	Plant cane, unless change identified, sometimes use imagery	Only when indicated that a change has occurred, grower input	On request or from an identified error. Harvester GPS track or imagery used to identify problems.
12. Are shapefiles available?	Yes, with authority from grower	Yes, with permission	Yes, with permission
13. When a block is replanted to a new variety / mix of varieties, how is this recorded, by whom, and how are the new sub-block boundaries recorded or surveyed?	Recorded by grower. Will split blocks for mapping and consignment (a, b, c etc.) for the life of the crop, as per planting.	• Grower notifies of changes • GPS coordinates taken by Cane Inspector, mapped into farm map	Recorded by grower Sub-blocks mapped if requested by grower and is a consignable harvest unit.
Consignment process			
14. Is the consignment process paper based (book with carbon copy) or electronic? Explain method.	Paper based, books with carbon copy for rail bins. 'Cheque butts' for multi-lift bins	Electronic	Paper based 'lotto' ticket book, no carbon copy
15. How does this information get to the mill?	Via road or rail, with consignment.	Mobile phone network	Via truck driver to be scanned at weigh bridge
16. Do you plan to introduce electronic consignment if not already doing so?	Investigating electronic consignment.		Yes, but not in the immediate future.
17. What value do you think would accrue from electronic consignment or some other accurate method?	Operator-less weighbridge, know when bins are full, accurate tracking if bins, real-time feedback to contractor. Need harvester tracking as well.	• Almost live information, allows for full utilisation cane bins and transport systems. • Reduces waiting time for bins and harvesting down time. • NIR information relayed back to harvest contractor and grower as soon as it becomes available i.e. minutes after processing at No. 1 mill. • Knowledge of where the cane came from, almost to the row. • Better scheduling for road and rail pickups.	The ability to better manage transport logistics. Reducing cut to crush times.

		• No cane arrives at mill tippler without consignment information. • Reduced cut to crush delays. • Grower has consignment information within a few hours of harvest. • Locomotive crews are not filling in consignment information. • No paper tickets, no stamping books, no lost tickets, no wet or illegible tickets. • Field Officer not waiting hours trying to retrieve ticket books to verify information.	
18. Please detail how this will/does happen – i.e. the methodology.	NA		Agtrix have done some investigations on methodology.
19. Will the grower/contractor replace their consignment book with an IPad?	NA	Mill owns the tablets.	Probably
20. Will there be any smarts in it? i.e. the GPS records where and when within field boundary and assigned position?	Yes, will need smarts	Relative to farm.	Most likely
21. How are block names recorded? (dropdown menu or manual)	Numeric	Dropdown	Numeric
22. How are split blocks recorded?	Numeric and alpha	Numeric and alpha	Numeric and alpha
23. With regard to cane that has been cut for plant, is the block total adjusted accordingly? • What happens next year? i.e. is the block still 'split' or are the splits combined?	NA NA	Yes Combined	Yes, if information supplied Combined back
24. Is your mill interested in precision agriculture?	Yes	Practicing	Yes
25. How well is the need for accurate yield monitor calibration understood?	Can see advantages e.g. Vanderfield yield monitor on JD harvester	Understood	Farm side of business is pushing for this
26. Have you canvassed the idea of weighing cane at the siding rather than the mill, whether for consignment of yield	No	• No, have explored elevator weighing. • Load cells on some equipment gave an indication of weight.	No

monitor calibration purposes, perhaps using a portable weighbridge?			
At the mill			
27. How is the cane delivered to the mill? • Cane rail? • Road transport?	Yes Yes	Yes* No* * All cane arrives at the tippler by rail, however 600,000 tonnes has a road component.	No Yes
28. With regard to rakes of bins delivered to mill: • What is the preferred rake size? • What is the actual range of rakes size delivered? (i.e. min to max)	65 rail bins 6-250 rail bins	70 x 6.5 tonne (pay weight) bins No restrictions on rake size. For CCS a minimum of 3 x 6.5 tonne.	24 or 39 tonnes Concessional freight arrangements in place.
29. Are the bins uniform in capacity or is there a mix of bin in use?	Rail bin and road multi-lift bin	Yes, all cane bins 6.5 tonne pay weight.	Yes, semi or B double
30. What is the nominal capacity for the bins used?	Rail bin 6 tonne Multi-lift bin 21 tonne	6.5 tonne	24 or 39 tonnes
31. What is the average empty bin weight?	Rail bin 1.34 t Multi-lift bins tarred in and out of mill	1.3 tonne	NA
32. Are 'full' bins weighed individually and reported to grower?	Yes	Yes All weighed at tippler - gross and tare.	Yes
33. What is the CCS sampling frequency?	12 rail bins Each multi-lift bin	Payment (CCS calculation is a minimum of 3 x 6.5 tonnes). NIR uses all 6.5 bins tested, wash occurs on first and last bin.	Each load – semi or B double
34. How is the CCS sample obtained?	• NIR • Laboratory analysis	NIR	NIR
35. Is 'daily cut information' sent to grower? • How is this information sent? • When? Daily? Once per week? etc.	Yes Email Daily Cane Pay advice - weekly	Yes, near to live Email, online	Yes Email or fax Daily Weekly summary
Quality assurance			
36. How do we know that cane is assigned to the correct block?	Rely on contractor to consign cane correctly	Harvester tracking, electronic consignment (but still relies on human input).	GPS data logger on most of fleet
37. Is there a check between estimate and what actually cut?	Yes	Yes	Yes
38. What amount of re-adjustment is done?	100%, only a small number of large adjustments.	• Automatic update of estimate when block is harvested.	Weekly cut to estimate review, adjustment for trend

		• Prompts for change based on information obtained from each harvest round. • Manually if you desire.	
39. How are part blocks consigned? i.e. half bin from one block, topped up from next?	Mixed	Manual input	Can be split between blocks
40. What are the consequences of part filled bins?	Risk of problems when hauling bins to mill.	• Derailment • Under-utilisation of resources, road transport is expensive, maximisation of fleet capacity is critical.	Freight cost
41. This is important from a yield monitor calibration perspective. How important is it too you	Accuracy in the consignment is important to the mill.	As above	Accuracy required for productivity data and planning

The review of cane consignment questionaire highlights the fact that cane consignment differs slightly from mill to mill and within milling companies. They all receive harvested cane supplied from grower's fields via a transport system and processed into raw sugar. While this sounds pretty straight forward, there are differences in the way sugar mills manage the logistics of cane supply, transport and processing.

Crop estimates are largely undertaken by growers, with some input by Cane Inspectors as required. Satellite imagery is used in conjunction to field estimation of crop size at two of the three areas reviewed. These crop estimates are reviewed as the harvest progresses and adjustments are made to harvest allocations if necessary.

One of the mill areas has introduced electronic consignment, utilising 'tablets' to record harvest data and to transmit this to the mill via the mobile phone network. This mill believes that there are considerable advantages in this consignment method over the previous paper based consignment method.

All mills have expressed interest in precision agriculture (PA), with some aspects of PA being implemented in all mill areas. Weighing of cane other than when received at the factory has little appeal, although, some alternatives have been investigated.

Two mills recently added electronic tools that assist in improving consignment accuracy. These tools (GPS tracking of harvesters and electronic cane consignment) allow cane supply officers to manage transport logistics and optimise transport systems in real time. This same system is being used in NSW mills to optimise road transport.

As alluded to in section G of this report, it will not be until the cane cut can be electronically tracked from the position in the field to the mill (as was done manually and reported in section D of this report) that we can have complete confidence in assigning cane to the field from whence it was cut, provided that the electronic field boundaries (shapefiles) are up-to-date and the naming protocols are consistent, between the mill and the farm (also discussed in Section K of this report).

I. *Free sharing of data*

Data has been made available to the following entities:

Provisions of data to farmers

Fully processed yield monitor data has been provided to collaborating farmers (Hubert, Pozzebon and Russo) for the several seasons of data, collected during the life of this project. In some regions, these same field have been used by other researchers and data has been made available to them. Access to this data will allow growers and researchers to consider variable treatment zones for their blocks of interest.

Provisions of data to manufactures

Yield monitor data from the Bundaberg harvester has been freely shared with Agtrix as part of the low cost yield monitoring investigation that was conducted. More details of this investigation is provided in Section J of this report.

Yield monitor data from the Childers harvester has been freely shared with John Deere as part of the evaluation of the yet-to-be-released yield monitoring equipment that they are developing. As this was a commercial-in-confidence investigation only limited details can be discussed. More details of this investigation is provided in Section J of this report.

Provisions of data for NUE project

This project has strong linkages to SRA project 2014/045 "Boosting NUE in sugarcane through temporal and spatial management". As the Bundaberg trial site at the Hubert's is part of the PA block from CSE022, it is cut by their harvester which has yield monitoring equipment mounted. Data has been collected from block 15a and 15b for the 2014 and 2016 season. Data was also collected from the Macknade trial site in 2015 (see Figure 46). The data collected has been analysed and detailed in milestone reports for the 2014/045 project.

Due to the intense nature of the biophysical data collected, particularly at the Bundaberg site, the NUE project has also provided this project with known calibration data that will be reported on in the de-noising/de-trending component of Section D in this report, and also in student's works on sugar loss and compaction, detailed in Appendix 2 & 3.

Figure 46 yield monitoring of NUE trials - Macknade 2015

J. Low cost yield monitor

Over the course of this project, the Austoft 7000 harvester cutting cane in the Bundaberg region was also monitored using a commercial GPS tracking unit from Agtrix. This unit was capable of accepting analogue input data from a sensor. This, or earlier models of this tracking units have been widely used in the Australian sugar industry over the last 13 years to provide a cost-effective method to monitor the progress of the harvest for the milling sector. More recently, they are also being used to monitor harvester performance against key performance indicators such as ground speed, fan speed and the operation of secondary fans.

The objective of this component of the trial was to gauge if these low-cost GPS tracking units could be used to collect, store and send the sensor data being used to interpret yield variability, as they were already fitted to almost half the Australian harvesting fleet.

The main limitations of these GPS tracking units for this purpose was:

(a) the low data sampling frequency (at least 5 seconds between samples, sometimes more), and

(b) the sensor data recorded was the accumulated value for the preceding period of time (approximately 1 sec) that was sensed at the time, and there was no on-board processing of data to be able to calculate the mean value over the entire time period since the preceding recording (early trials noted that the highly fluctuating nature of the sensor signal was a major contributing factor to inaccurate results).

Two simple signal dampener component were fitted to input terminals of the logger in an attempt to dampen the amplitude of signal variations.

The data from the Agtrix loggers showed that these GPS tracking units performed well for their intended purpose – to monitor the areas that had been harvested, and the speed of harvesting (Figure 47). Anecdotal evidence is that maps of harvester speed have been used by growers as a gross indicator to identify low yield patches within fields since these GPS tracking units were first used (2003). However, while harvester track maps may indicate gross differences between fields or even within fields to a grower who knows the fields well, too many other factors affect harvester speed to use this approach reliably.

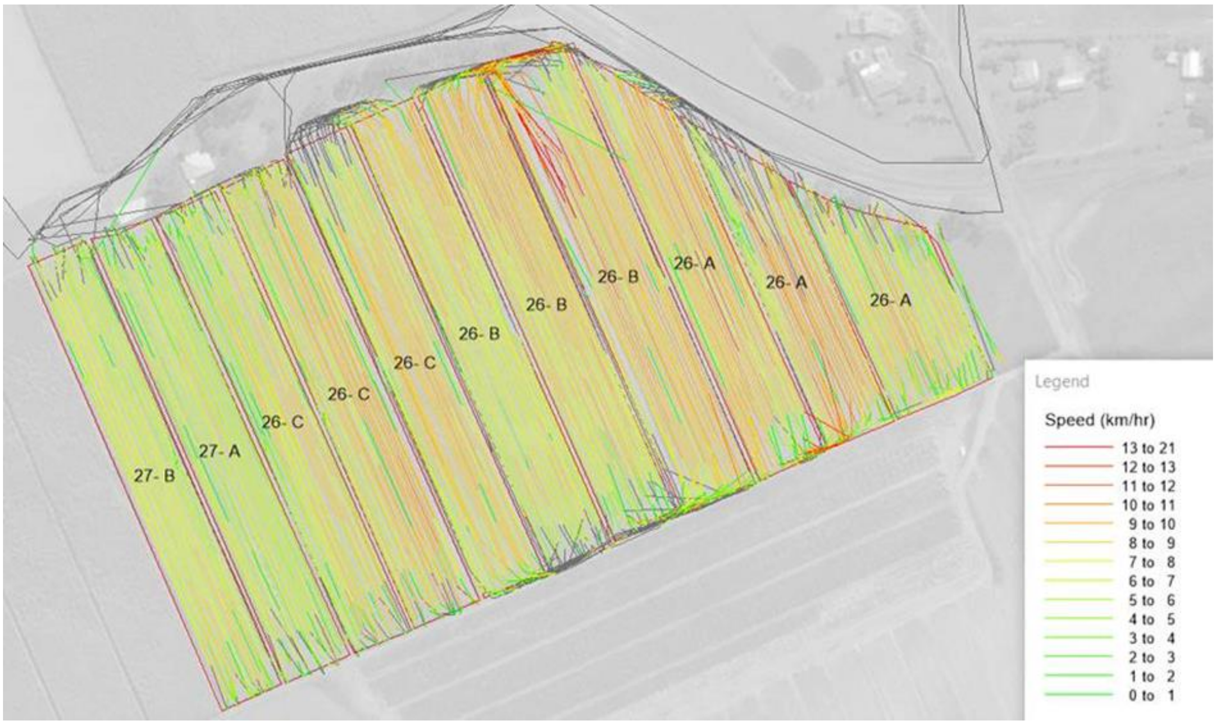


Figure 47 Harvester tracking using the Agtrix loggers that are used to monitor harvest progress for almost half of the Australian harvesting fleet, showing the variation of speed between blocks.

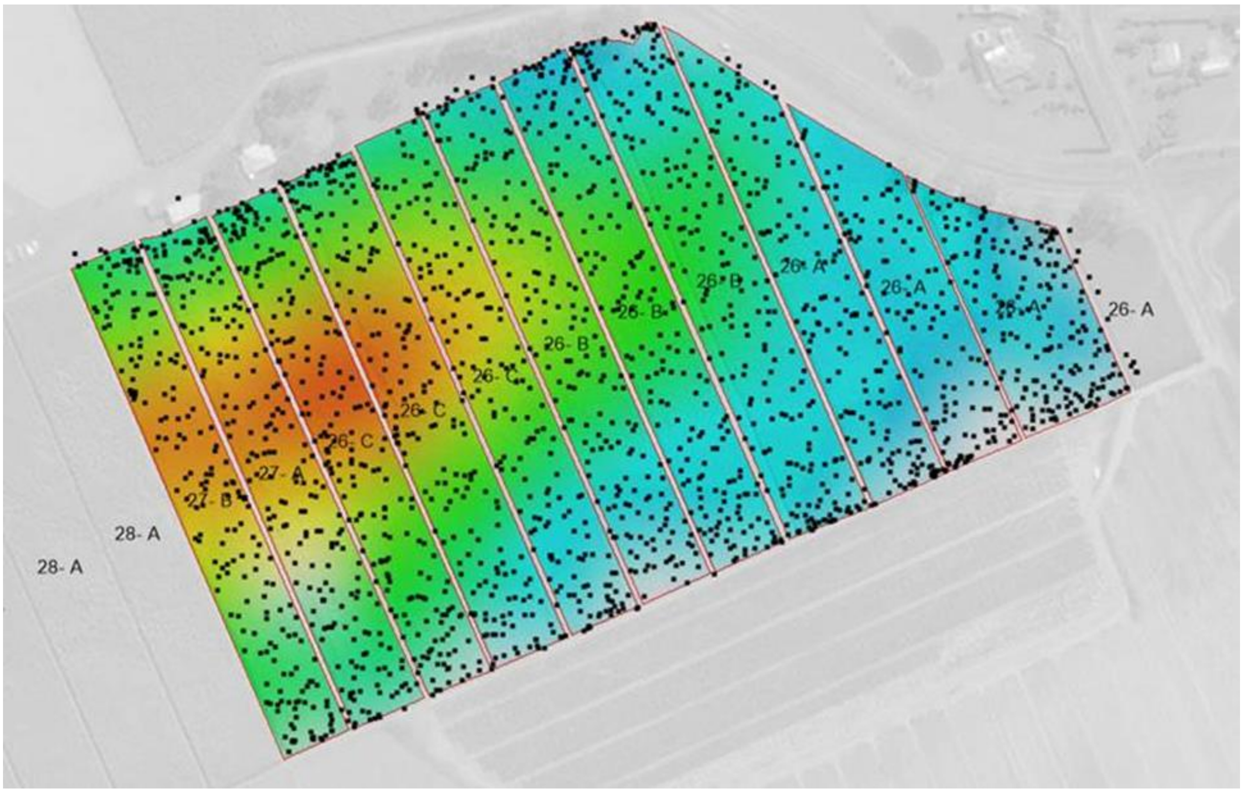


Figure 48 Yield surface derived from sensor data recorded from Agtrix GPS tracker, including locations of data points recorded, using Agtrix software.

The harvester trace is shown in Figure 48 (black dots) along with a coarse yield prediction provided by Agtrix. When the sensor data was analysed to give a yield index surface using a modified version of the yield monitor protocol (filtering protocol had to be modified for the coarser data intensity), the results (Figure 49) were found to be inconsistent with the data from the USQ's yield monitor (Figures 51 and 52). It was noted that the yield index surface did not utilise harvester speed. Incorporating harvester speed (Figure 50) provided a result that more closely resembled the elevator and chopper pressure yield maps. There was general consistency between the maps in identifying the higher and lower yielding areas across the blocks.

The difference between the results most likely indicate that a greater number of data points are required to be collected than are currently needed for harvest activity monitoring, and/ or the signal interpretation needs to be more sophisticated than the simple dampener that was used in this trial. Further distortions in the data could have resulted in the in-built bias in the configuration of these loggers to collect more points at the end of the rows.

While the currently available mass-produced tracking devices were not found to be immediately fit for the purpose of yield monitoring, advances in the computing power of these devices is resulting in more capable loggers coming onto the market at competitive prices. This may enable the sort of data collection rates and signal processing that is commensurate with the loggers used in this trial.

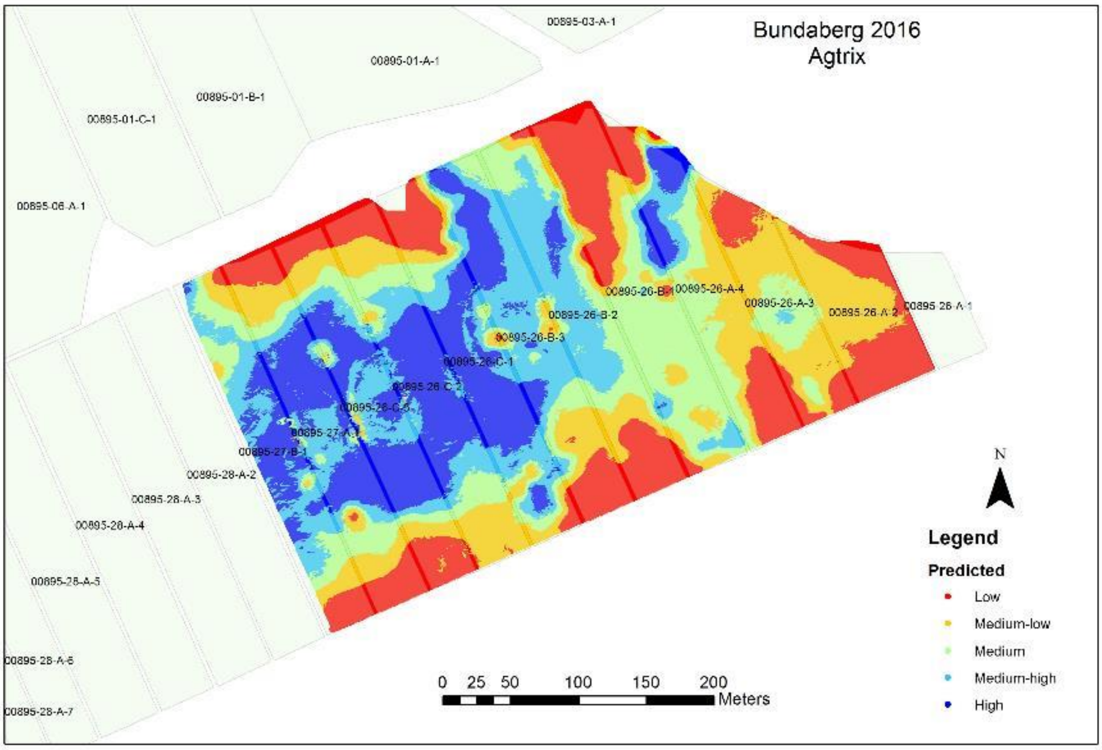


Figure 49 AgTrix sensor values for blocks at Bundaberg 2016

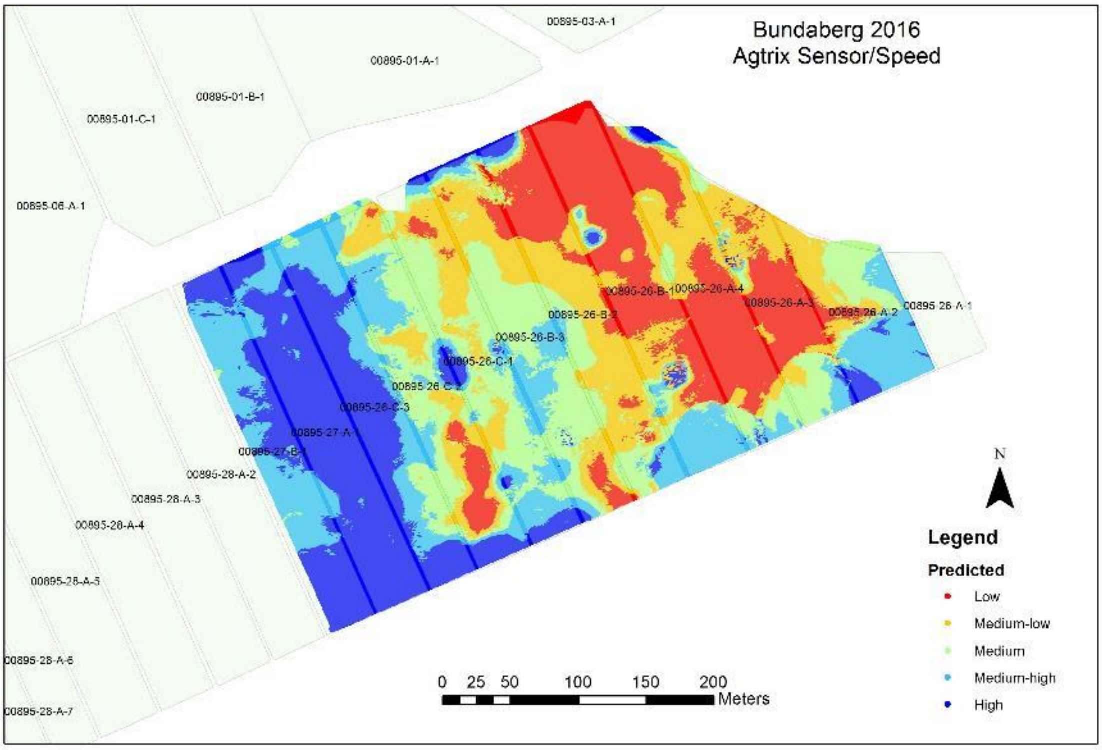


Figure 50 Speed correction of the yield surface using the Agtrix data

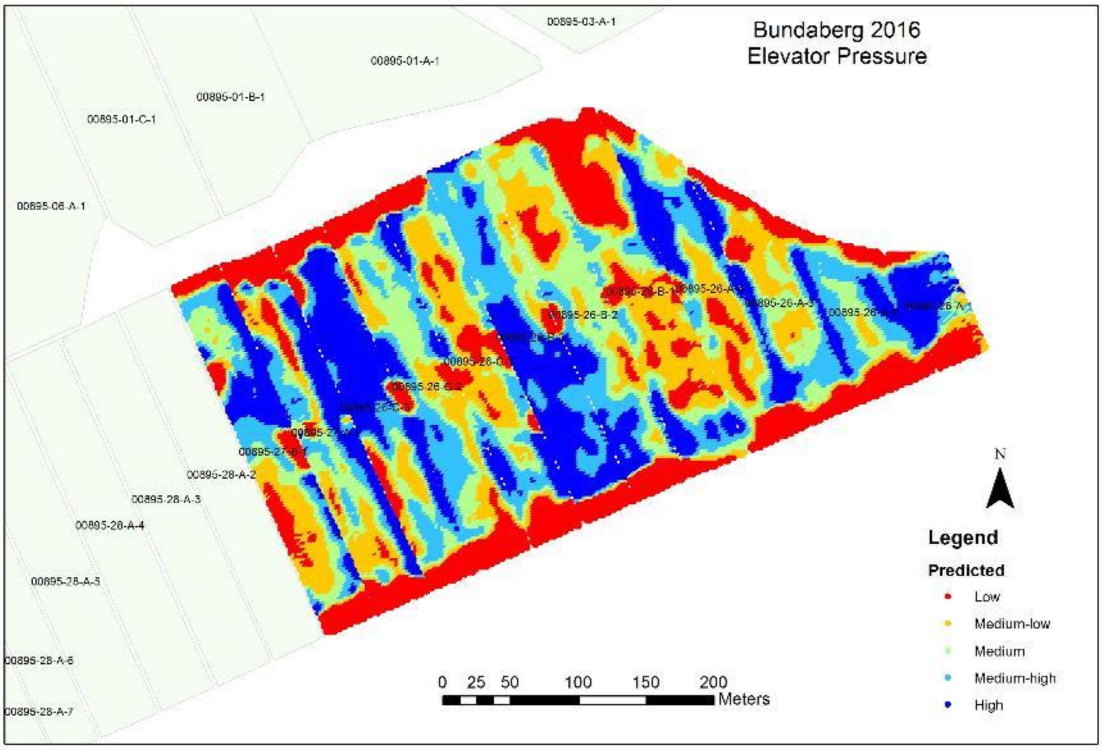


Figure 51 Elevator pressure map using the yield protocol and tool

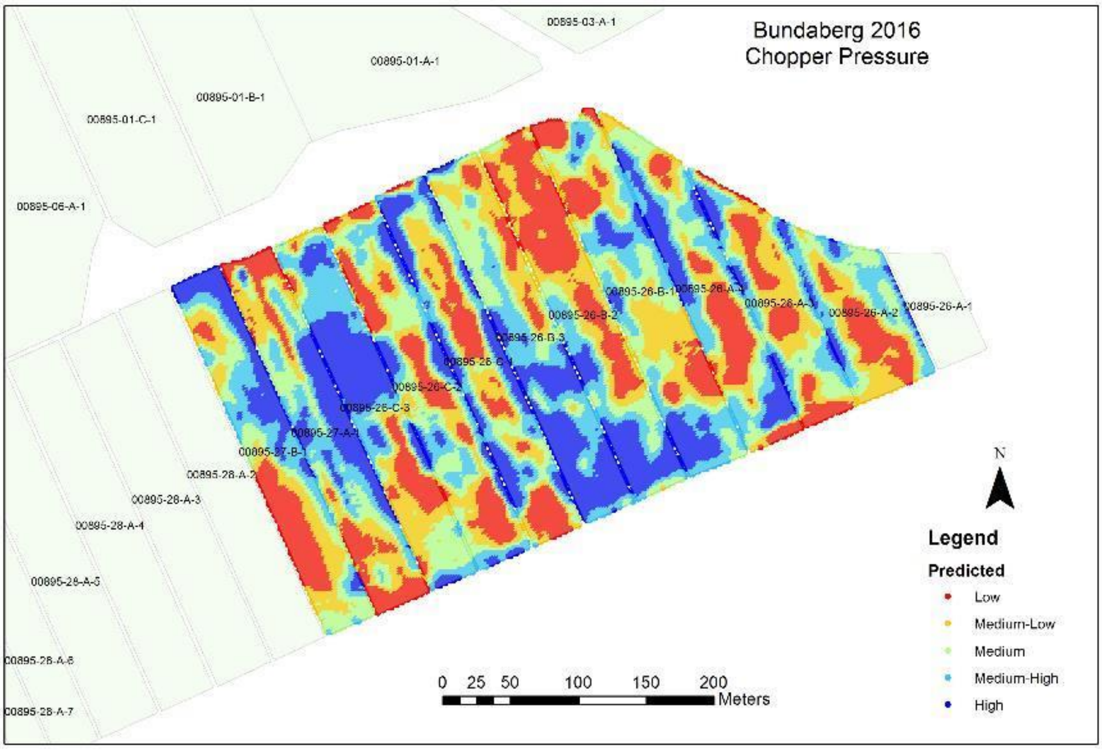


Figure 52 Chopper pressure map using the yield protocol and tool

K. Accurate consignment data

In addition to the yield monitor data files containing sensor data, two additional key datasets are essential for automated generation of calibrated (adjusted) yield maps utilising consignment data. These required datasets are

- A spatial data layer containing boundaries of cane blocks, as well as the names of the individual blocks
- Consignment data detailing, for each day the tonnes harvested, and if possible the area harvested.

In both cases, these data are typically sourced from the mill, although some growers are likely to retain their own block boundary data. Importantly, these two datasets must be linked by a common naming of blocks and/or sub-blocks to ensure correct linking of the spatial boundary data to the tonnages and dates associated with the consignment records. Even small variations in the formatting or names used for blocks can result in automated processing failing to link yield monitor data with delivered tonnages. As all mills have different formats, this step requires standardisation of data to confirm with the input template.

L. Produce a program/app/package

A Python script has been developed, utilising freely available Python packages and Python libraries including geoprocessing tools previously developed by CSIRO. The CSIRO geoprocessing tools are themselves dependent on a number of open source Python libraries installed through the Anaconda Python distribution. These libraries include:

- **GDAL/OGR**: Geospatial Data Abstraction Library (http://www.gdal.org/); GDAL for reading and writing geospatial raster data such as gridded yield maps, and OGR for reading and writing geospatial vector data such as GPS points and block boundaries. GDAL is utilised by many open source and commercial GIS software packages including QGIS and ArcGIS.
- **fiona**: Simplifies the reading and writing of OGR spatial data files using Python (https://pypi.python.org/pypi/Fiona/)
- **shapely**: For manipulation and analysis of geometric objects in the Cartesian plane, such as calculating polygon areas, overlap etc. (https://pypi.python.org/pypi/Shapely).
- **pandas**: High-performance, easy-to-use data structures and data analysis tools for tabular data (http://pandas.pydata.org/).

Appendix 4 outlines the installation of Anaconda and additional packages.

Batch processing and status tracking

The sugar yield data processing script is a ‘batch’ tool. That is, the tool automates the processing from raw yield monitor data ‘packets’ to yield map, and no user input is required, provided consignment and mill information is in the correct format. The script is designed in such a manner that it can be re-run repeatedly and will check the input folders for new data files on each run. It will then only process new files and/or reprocess sub-blocks for which new data has been found. Previously processed yield data files will not be re-processed unless affected by new data files. This approach would enable the tool to be run on a scheduled basis – for example, daily, as part of an automated system for capture and generation of sugarcane yield maps.

Each sub-block will only be mapped when an adequate proportion of the block (90%) has been covered by yield monitor data which frequently will not all be harvested on the same day. If data are received from any additional harvest operations in a sub-block, whether previously mapped or not, that block will be reprocessed. To manage the irregular availability of data for each sub-block, several status tracking files are used to record and tracks the processing of each file through different steps, and enable the processing script to rerun and continue where it left off (without processing files that have been previously completed). These tracking files can be viewed to check for errors, and to investigate the processing of individual yield data files, and are described in Appendix 5.

Site and harvester-specific customisation

To handle different sensor and data inputs associated with harvesters and the farms on which they operate, a number of lookup tables are coded into the script, or read from CSV text files. These include:

- A lookup table to link harvester (location) to a shapefile of caneblock polygons, and the specific attribute field in the shapefile in which the block name is recorded. For example:

```
'BUNDY':   {'2014': {'shapefile': 'HubertFarm2015_GDA.shp',
                     'blockNameAttrib': 'C_LINKCODE'},
            '2015': {'shapefile': 'HubertFarm2015_GDA.shp',
                     'blockNameAttrib': 'C_LINKCODE'},
            '2016': {'shapefile': 'HubertFarm2016_GDA.shp',
                    'blockNameAttrib': 'C_LINKCODE'} },
```

- A lookup table to outline the name of the data columns associated with the specific sensors present on each harvester which require mapping, and whether these are treated as single ('S'), averaged ('A) or differenced ('D') values.

```
'BURDKIN':  [ ['S','CELL','cell_avg_Avg'],
               ['S','RANG','Roller_angle_Avg'],
                              ['S','RO1','RO1_avg_Avg'],
                              ['S','CP1','CP1_avg_Avg'],
                              ['S','CP2','CP2_avg_Avg'],
                              ['S','EP','EP1_avg_Avg'],
                              ['S','EP2','EP2_avg_Avg'],
                              ['A','CP-AVG','CP1_avg_Avg','CP2_avg_Avg'],
                              ['A','EP-AVG','EP1_avg_Avg','EP2_avg_Avg'],
                              ['D','EP-DIFF','EP1_avg_Avg','EP2_avg_Avg'] ]
                      }
```

- Consignment data entered into input CSV file of the format

Table 16. Consignment data entered into form to be accessed by script

Harvester	Farm_ID	Block_ID	Cut_date	Tonnes	Hectares
Bundy	895	00895-14-A	3/11/2014	120.1	2.9
Bundy	895	00895-15-A	3/11/2014	174.6	2.7
Bundy	895	00895-18-A	17/12/2014	169.6	5.13
Bundy	895	00895-25-A	10/10/2014	288.7	3.33
Bundy	895	00895-25-B	10/10/2014	250.6	3.51
Bundy	895	00895-28-A	17/12/2014	260.5	3.29
Bundy	895	00895-10-A	2/11/2014	139.9	2.38

Potential refinements to script

Suggestions for future improvements to the script include:

- Special handling of sensors has been implemented in the Python tool to accommodate sensors not operating over certain times. For example, the elevator speed filtering (described in the protocol section above) could not be applied to harvester data at certain times when the sensor was faulty and not recording meaningful values. This is accommodated within the Python code. For robust ongoing use of the tool, a more flexible solution would need to be implemented to deal with individual sensor failure over selected time periods. Additionally, in an operational setting where the code is run on a daily basis, alerts (e.g. such as via email) could easily be triggered when sensor faults are detected by the code, enabling rectification to be carried out in a timely manner.
- The average point density per sub-block is calculated and output as supplementary information to assist in yield map interpretation (see description above). An additional data quality filter could be applied to exclude sub-blocks from the mapping process if a minimum threshold (as advised by USQ) of data points per hectare is not met. Additionally, a more robust check to ensure adequate sensor data coverage across a sub-block could be implemented by re-calculating the area covered by yield data for each sensor after data cleaning/filtering. The 90% coverage rule (outlined previously) would then be applied for each sensor (currently this check is only implemented at the sub-block level prior to data cleaning).

M. Extension of tool to industry

The tool has been developed to operate with the specific file formats and data types associated with the NCEA experimental yield monitors. The use of look-up tables and CSV input files allow the script to be customised with some flexibility, such as handling different harvesters and sensors. However, tailoring the tool to interact with different yield data types, delivery formats, farms/locations and existing software systems would require further specific customisation.

The batch processing format of the tool could form a component of an operational yield mapping process once it was integrated with an existing system for capture of sugar yield monitor data. Consequently there may be opportunities to undertake a software development and delivery project to integrate and implement the processing script in an industry context.

Enquiries about accessing the tool and Python script code can be made to David.Gobbett@csiro.au.

Particulars of the tool have been discussed with John Deere, Vanderfields (for use with their Greentronics yield monitors via PCT), HCPSL and with Agtrix. As yet, none of these parties have taken up the offer, but as relationships continue to grow, the possibility of the steps/tools/scripts being utilized by industry will be greater.

N. Extension of PA procedures and practices to industry

The following extension activities have either been undertaken by team members, or are planned:

-
- SPAA PA in Cane workshop, Home Hill 2 June 2016
- SPAA 19th PA symposium , Toowoomba, 12-13th September 2016
- on review panel for agriculture section for ISSCT – 6 papers reviewed
- ISSCT chair of 2 sessions (December 2016 – Thailand)
- presentation of yield monitor work at ISSCT (December 2016 – Thailand, Figure 49), paper attached as Appendix 6
- presentation of students sugar loss work at ISSCT (December 2016 – Thailand), paper attached as Appendix 7
- sugar field tour in Thailand (December 2016 – Thailand, Figure 50)
- request to publish work in International Sugar Journal
- newly elected to ISSCT committee
- invited to attend the Wet Tropics Major Integrated Project (MIP) Workshop in Tully on the 3rd March 2017 and will attend the follow-up meeting in April
- Providing PA/yield monitoring expertise to 2014/045 'NUE project' meeting in Mackay 9-10 March 2017
- SPAA PA Expo for the Queensland Dry Tropics, Townsville, 14th March 2017
- plans underway for ASSCT to be held in Toowoomba in 2018 (organising committee).
- formulating linkages with doctoral student, Mr. Kittisak Phetpan from King Mongkut's Institute of Technology Ladkrabang, Thailand. Research area in yield monitoring and sugar loss sensing
- MOU being formulated with Kasetsart University, Thailand to advance sugar research.

Student involvement has also assisted with the extension activities. Details of their sugar specific research along with the audience are noted below:

- Sombat Khawprateep, PhD student
    - presentation of sugar loss work at ASSCT 2015
    - presentation of sugar loss work at ISSCT 2016
    - request to publish work in International Sugar Journal

- David West, B.Eng student
  - presentation of impacts of compaction on sugar loss at Student's Presentations Conference, USQ 2016

Figure 53 Troy presenting at ISSCT (Note Bernard Schroeder chairing Agriculture session in background)

Figure 54 Troy on field visit in Thailand

O. *Additional Activities*

- Review of Australian sugar cane yield monitoring options, prepared for WT MIP and NUE activities – refer to Appendix 8
- Photographs from the JD collaboration – refer to Appendix 9
- Documentation and installation instructions for the Greentronics/Vanderfields yield monitor and several processed maps.– refer to Appendix 10
- Student Projects
    a. David West – B.Eng Research Project Title “Tracking Machinery to Investigate the Effect of Compaction during Sugar Cane Harvesting” (refer to Appendix 3)
    b. Sombat Khawprateep – PhD title “Optimising sugarcane production best management practise from a harvesting and sugar loss perspective” (refer to Appendix 2).
    c. Kittisak Phetpan – Thailand. Conducted meeting with Dr Vasu Udompetaikul and a new doctoral student, Mr. Kittisak Phetpan (student on the right, Figure 51) whilst in Thailand. Troy Jensen will be part of the supervisory team. The student’s topic is proposed to be “Pre-harvested yield assessment and real-time yield monitoring in sugarcane using NIRS and acoustic techniques.” The student has received a Royal Golden Jubilee Scholarship which provides funds visit Australia and conduct research and also for the supervisor to travel to the host institution-King Mongkut's Institute of Technology Ladkrabang, Thailand.

Figure 55 Building linkages with King Mongkut's Institute of Technology Ladkrabang

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Section 4: Outputs and Outcomes

Outputs

The primary output of this project was the development of a suite of procedures to automate the data handling processes associated with the generation of yield maps from sugar yield monitor sensor data. These procedures have been encapsulated into a software tool. Using the tool to treat all data in the same way also provides consistent results, independent of the sensor used, across a range of operating conditions, provided that obviously erroneous data (due to sensor malfunctions) is excluded prior to being processed by the tool. The time take to analyse and process yield monitor data is also greatly reduced by using the tool.

The correlation of individual bin weights predicted by the yield sensors with the mill bin records compared favourably. The elevator sensor (R^2=0.864) had a slightly higher correlation coefficient than the chopper sensor (R^2=0.769). The only caveat on the accuracy statement is that the amount of cane cut must be correctly assigned to the block from whence it was cut, be that via manual or electronic methods, so that a true harvest event can be mapped. In the block-mill assessment that was undertaken with electronic consignment, there were no discrepancies encountered other than at change of blocks proving competent operators can do a good job. However, if the goal is accurate consignment across the entire industry, electronic consignment is not necessarily the golden bullet here as there is still possibilities of transcription errors. Until there is full automation in the transfer of data (GPS position) from the harvester to align with the bin to go the mill (potentially via a haulout), transcription error will still occur.

An additional output of this project has been advice to commercial providers (John Deere, Vanderfields, AgTrix and HCPSL) on how to correctly handle sugar cane yield monitor data. Officers have also provided others sugar projects (WTMIP, NUE and GPS planter project) with yield monitoring/mapping and PA advice and guidance.

Outcomes

Precision Agriculture (PA) offers the opportunity of enhancing the efficiency of farm management compared to the conventional uniform approach, through the targeting of inputs and/or selective harvesting of outputs. One of the pivotal data layer in the PA approach is the measure of production, with yield monitors and remotely sensed imagery being the two main methods. This project has focused on developing tools and testing these under a range of conditions. The benefits that the tool provides include reducing the data processing time from a day per block to approximately 10 minutes, providing consistency in the data handling steps and providing accurate and reliable data on which to build management decisions.

Due to the increased understanding and automation step performed by the tool, the sugar industry can have confidence in the ability of the yield monitor to represent production differences across the field. With this increased confidence, a grower's profitability can be enhanced either by addressing the limiting constraints and raising the level of production, or by reducing the level of inputs to match the lower production potential.

Section 5: Intellectual Property (IP) and Confidentiality

There has been no registrable IP developed by research activities. Potential IP may reside in the scripts/tool for the analysis of data from various yield monitoring concepts. It was, however, always the intention of the project to make the scripts/tools available to industry, as was detailed in the original project application.

Section 6: Industry Communication and Adoption of Outputs

The project has produced a number of communication outputs which are detailed in the 'list of publications'. Three papers on this list are a result of continued investigation by the current research team following on from CCS sensing work conducted during CSE022. The result of these communications has been an increase in the understanding of PA in the sugar industry, but most specifically about the accuracy and reliability of yield monitors, and their limitations.

Presentations have been made at numerous forums, both within Australia and overseas, and are detailed in Section N - Extension.

Discussions are ongoing with commercial yield monitoring companies (John Deere, Vanderfields and Agtrix) regarding the implementation of the tools developed during this project.

Presentations have been made at numerous forums, both within Australia and overseas, and are detailed in the 'conferences and workshops' section.

Opportunities to further disseminate and promote project outputs include;

- Was invited to attend the Wet Tropics Major Integrated Project (MIP) Workshop in Tully on the 3rd March 2017 and will attend the follow-up meeting in April
- Will continue to provide PA/yield monitoring expertise to 2014/045 'NUE project' and potential continuing project.
- Publication of research results in ASSCT 2018, to be held in Mackay.

Section 7: Environmental Impact

With greater confidence in the capability of yield monitoring equipment, comes increased confidence in the ability to put the right thing in the right place at the right time, the primary premise of precision agriculture. With increasing pressure to be accountable for their operations, particularly from an environmental perspective, PA gives sugar cane farmers the tools to achieve these goals. Yield monitoring/mapping is one of the fundamental layers that will allow PA to achieve this.

Section 8: Recommendations and Future Industry Needs

From the research that has been conducted during this project, areas of opportunity to either overcome existing impediments, or to extend current capacity / knowledge have been identified. These include;

Electronic Consignment

At the start of this project, it was hoped that electronic consignment would overcome issues with cane being allocated to incorrect fields. The current state-of-play of electronic consignment uses a tablet device as a digital replacement for the paper based system. The technology does overcome transcriptions errors (due to dropdown menus and prepopulated fields) and lost / wet / misplaced / illegible handwritten ticket. The mobile phone network also make transmission of the information from the device to the mill automatic allowing the mill to act/respond in near real-time. It does not however have the smarts to ensure that the cane is consigned to the appropriate field.

Some mills use harvester tracking GPSs to help with mill logistics and scheduling of bins. Although not currently available, linking this capability to the consignment information could provide increased benefits although the sampling frequency (as detailed in Section J) is currently greater that 5-10 seconds. This coarse sampling frequency would make it difficult to determine haulout changes (unless some other clever algorithm was developed). It is only when sampling is more frequent (1 sec data as detailed in Section D) that certainty in haulout changeovers can be determined, however considerable effort would still be need to marry the consignment and tracking datasets as the timestamp would be the common denominator. As also detailed in Section D, this requires consistent bin fill order and matching haulout/rail bin sizes, both of which could be hard to coordinate / implement in a commercial cutting situation.

The only way to overcome the issues raised above would be to link the bin filling rake details with the spatial harvester yield monitor data to get an increase level of accuracy in the cutting data. In the Burdekin, this would be more straightforward as the bins could be identified whilst filling and this data appended to the yield monitor file. In other regions that utilise haulouts, this would require some form of data handover from the harvester to the haulout to the bin, possibly by the use of RFID or similar. This is a potential future research area.

Machine Settings / Yield Monitoring

Machine performance settings due to operator preferences can have a significant impact on the cleaning performance of the harvester. This is particularly important from a yield monitoring perspective (especially if the yield sensors are on the elevator) and if setting are significantly changed/adjusted during a single harvest event.

Components of future research should investigate whether these machine changes constitute a different harvest event and how this might be automatically detected. The other approach is too advocate for constant pour rate harvesting to ensure the yield sensors have the best chance of capturing variability. This is particularly important when the yield monitor data is to be used as a basis for agronomic decision making.

Sugar Loss / CCS Sensing.

Following on from the machine setting discussion above, one such event was detailed in Section D. In this event, harvester pour rate was reduced by decreasing the ground speed resulting in a cleaner sample going into the bins (determined by John Deere yield monitor – not reported here).

The consequence of this cleaner sample was that more trash (and billets) was being discarded by the extractors, resulting in greater sugar loss. This statement is based on work by Sombat Khawprateep (PhD study) that is aligned with this and the NUE project. There is also renewed interest in CCS sensing (previous PhD study by Nazmi Mat Nawi investigated the use of NIR spectroscopy to detect CCS in the field) by a student from Thailand (detailed in Section O).

With the sensing and data recording capabilities provided by yield monitoring equipment (both research and commercial), the functionality of CANBUS on new harvesters and the interest in CCS sensing, there is a confluence of potentials to fully understand the movement of materials (both billets and trash) through the chopper harvester and the implications on sugar recovery.

The potential for future research in this area would require the involvement of harvester manufactures, interested farmers and researchers from the yield monitoring and HBMP teams to target this issue.

John Deere and Vanderfields (Greentronics) yield monitors

With the recent and pending release of two new sugar cane yield monitors, it is important to investigate how the proprietary software is handling the data and whether it meets the sugarcane yield monitoring harvest protocol. Discussion are underway with these respective companies, but additional research in this area may be a potential industry need.

The use of PA tools allows for the above listed opportunities/limitations to be further investigated.

Section 9: Publications

Bramley RGV, Jensen TA, Webster AJ, Robson AJ (2017) Precision Agriculture and sugarcane production – A case study from the Burdekin region of Australia. Chapter 15 in Rott PC (Ed) Achieving sustainable cultivation of sugarcane. Burleigh Dodds Science Publishing, Cambridge, England. In press.

Garmendia, A. G., & Jensen, T. A. (2015). An innovative framework to implement precision technologies. *International Sugar Journal* (August 2015), 2-7.

Ishkandar, C. D. M., Nawi, N. M., Chen, G., Jensen, T., & Mehdizadeh, S. A. (2016). *Comparison of chemometrics methods for classification of sugarcane brix using visible and shortwave near-infrared technology.* Paper presented at the International Conference on Agricultural and Food Engineering (Cafei2016), Kuala Lumpur, Malaysia.

Jensen, T. A., Gobbett, D., Bramley, R. B., & Garmendia, A. G. (2016). *A methodology to assess the accuracy and reliability of yield monitor data*. Paper presented at the XXIX ISSCT 2016 CONGRESS, Chiang Mai, Thailand.

Khawprateep, S., Jensen, T. A., Schroeder, B. L., & Eberhard, F. (2016). *The extent of cane loss during harvesting due to different pour rates*. Paper presented at the XXIX ISSCT 2016 CONGRESS, Chiang Mai, Thailand.

Lazim, S. S. R. M., Nawi, N. M., Chen, G., Jensen, T., & Rasli, A. M. M. (2016). Influence of different pre-processing methods in predicting sugarcane quality from near-infrared (NIR) spectral data. *International Food Research Journal, 23*, S231-S236.

Nawi, N. M., Jensen, T., & Chen, G. (2015). Application of spectroscopic method to predict sugar content of sugarcane internodes. *Journal of Tropical Agriculture and Food Science, 41*, 211-220.

The two papers from the 2016 ISSCT have been requested for publication in the International Sugar Journal.