A Comparison of Potential Mass Flow Rate Sensors for Sugar Cane Harvesters

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Abstract

Four methods for measuring mass flow rate through cane harvesters have been compared, by installing them on a harvester and investigating their performance in a series of parallel experiments.

The methods measured elevator power, chopper power, feed roller separation and the weight of cane on a hinged flap. The harvester was operated at a range of ground speeds to establish a range of mass flow rates.

The results from each method are compared, and other data and evidence are used to draw some conclusions concerning the method which will be the most effective.

Introduction

Yield mapping systems have received considerable attention in the development of precision agriculture and this is rightly so as the yield mapping operation is seen as the first step for adoption of the precision agriculture concept. This process provide essential information on the variability of crop production and therefore provides the backbone to site specific activities. Extensive work has been carried out in yield mapping of grain crops and more limited work in other crops such as potatoes, sugar beet and forage harvesters. This work at the University of Southern Queensland (Australia) is the first that has been carried out in sugar cane.

The components of a yield mapping system are; a yield measurement technique, Differential Global Positioning System (DGPS) hardware and data acquisition/logging hardware. The yield measurement technique consists of a mass flow rate sensor and a harvester ground speed sensor. The mass flow rate sensor measures the crop flow through the harvester and is unique for different crop materials. Sugar cane and forage crops are similar as they are both harvested for their bulk biomass and then chopped into lengths. However the harvesters for these two crops are vastly different and hence the possibilities for mass flow rate sensing are different.

Sugar cane is planted in 1.5 m rows and produces stalks 2 to 4m in length and 25 to 50mm in diameter, similar in appearance to bamboo. It is normally harvested annually, either “green” or after being burnt to remove leaf material, with all cane in Australia being mechanically harvested. The chopper-harvester, which was designed and built in Queensland, removes the top, cuts the cane stalk at ground level and chops it into billets 200 to 300mm long. Extraneous matter mainly tops, leaves and trash, is extracted pneumatically and the chopped cane loaded into a bin drawn alongside the harvester. The harvested cane is delivered to the mill where the cane is crushed and manufactured into raw sugar. The average Australian cane yield is approximately 80t/ha (Reid, 1990), however yields up to 300 t/ha are possible. Below is a picture of a cane harvester describing the different mechanical components.

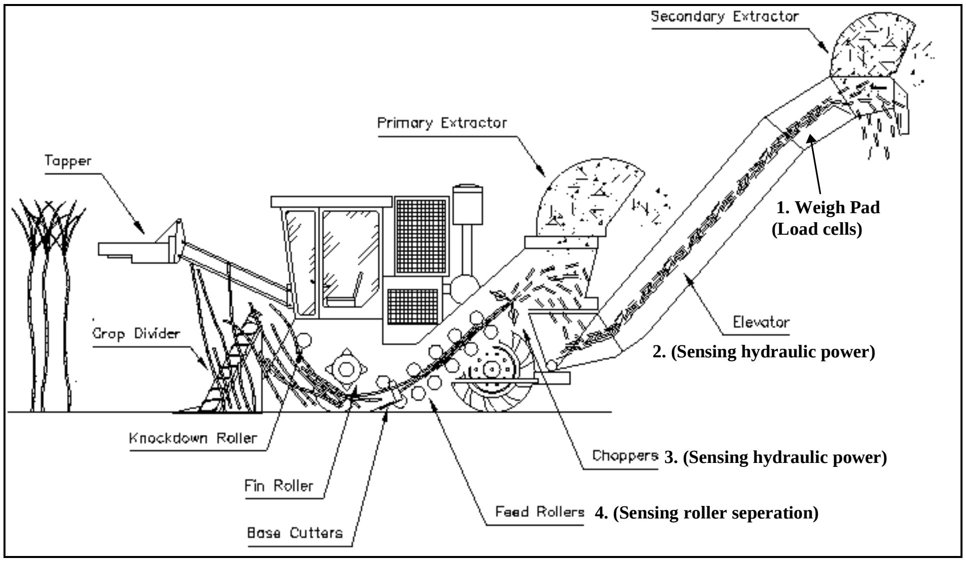

Figure 1. A sugar cane chopper-harvester with main components and mass flow rate sensing points labelled.

We have considered four different techniques to measure mass flow rate in a sugar cane harvester. These four techniques were tested simultaneously and the results are presented in this paper.

Materials and Method

A chopper-harvester was set up with the four sensing techniques and a data acquisition system. These sensing techniques were the chopper power, elevator power, feed roller separation and weigh pad. Figure 1 shows the position of these sensors throughout the machine.

The power measurements were made using pressure transducers positioned in the hydraulic hose line before the motors, with magnetic sensors for motor speed of the hydraulic motors. It was assumed that there was negligible leakage in the motors and that therefore the angular speed is proportional to the oil flow rate. The hydraulic power was calculated from:

$$Power(kW) = \frac{\Pr essure(kPa)}{Angular\_Speed(rev/s).\,Motor\_Capacity(m^3/rev)}$$

The chopper system consists of two hydraulic motors driving the chopping cylinders which have blades running along their lengths. These blades chop the cane stalks into billets and pass them back to the elevator. The chopper power measurement is therefore the power required cut standard lengths of cane and eject them back to the elevator. As the mass flow rate increases so do the power requirements. However there are many factors which can affect this measurement including blade sharpness, crop maturity and hardness, and these trials gave evidence of these effects. It should be noted that this sensing technique unavoidably measured the power required to drive the feed rollers. It is assumed that this power will be negligible compared to the chopper power.

The elevator has two hydraulic motors driving chained flights which drag the billeted cane over the fixed elevator floor and drop it into the bin travelling along side the harvester. The sensors measure the power required to lift the cane three metres and also overcome the frictional resistance of the cane on the floor. This is a more direct measurement of mass flow rate than the chopper but there are still interfering factors such as elevator friction and chain wear.

The feed roller arrangement consist of a series of cylinders with teeth which feed the mat of cane stalks through the machine to the choppers as shown in Figure 1. While the bottom rollers are fixed in position, the top rollers are mounted on swing arms which allow them to “float” over the mat of cane. Therefore the separation between the bottom rollers and the top rollers is a measure of depth of cane flowing through the machine. Assuming that the velocity of the cane through this area is constant and that the width of the mat remains at maximum then the roller separation is a measure of cane volume passing through the machine. Although this is not a direct measure of mass flow rate, it provides a simple and robust sensing point which can give valuable information on mass flow rate. This separation was measured by an angle sensor on the swing arm.

The weigh pad consisted of a plate mounted in the elevator floor, hinged at one end and supported with two load cells on the other end (Figure 2). An accelerometer was included to measure the dynamics of this system, with the potential to improve the mass flow rate measurements.

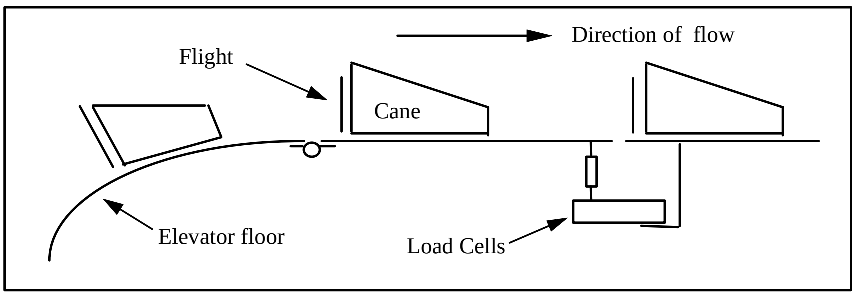

Figure 2. Elevator weigh pad set up.

The 8 channels of data were logged on a laptop computer at a rate of 100 Hz per channel.

The field tests were carried out the Burdekin Agricultural College in North Queensland. This testing consisted of harvesting a row of cane, approximately 100m long, into a truck with a weighing facility. Overall forty test runs were carried out giving an adequate data set to compare the measurement techniques. Results were obtained for both burnt cane and green cane and in conditions of widely varying yields.

Results

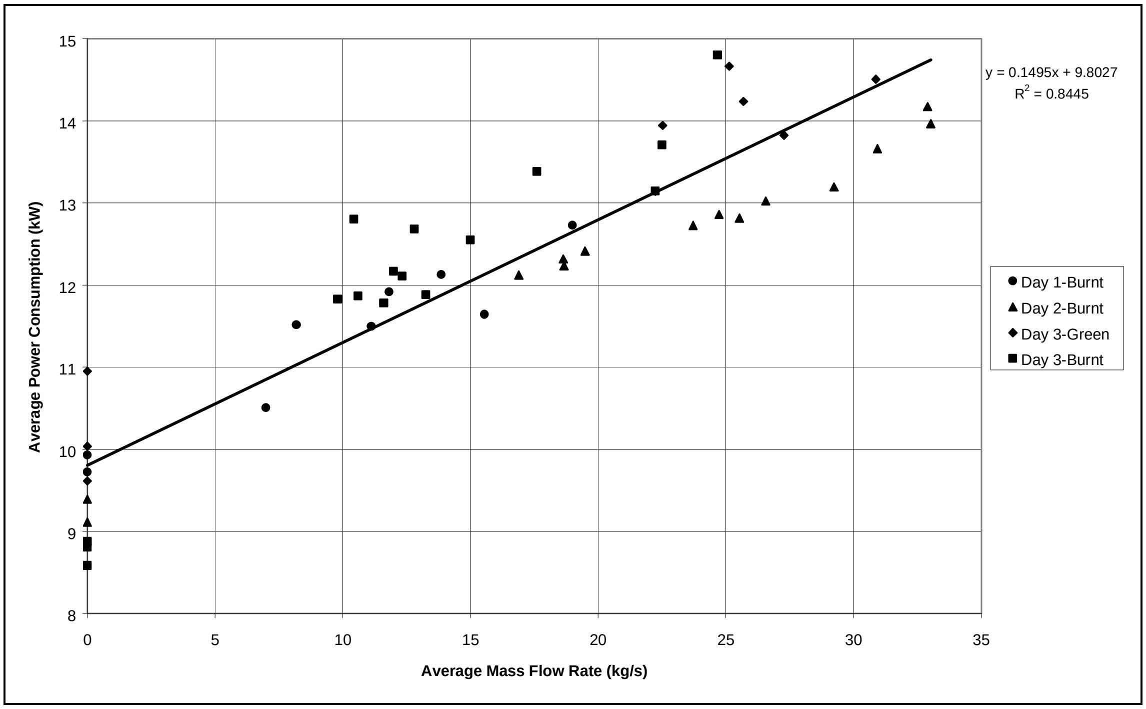

Figure 3. Results of Chopper Power Measurements

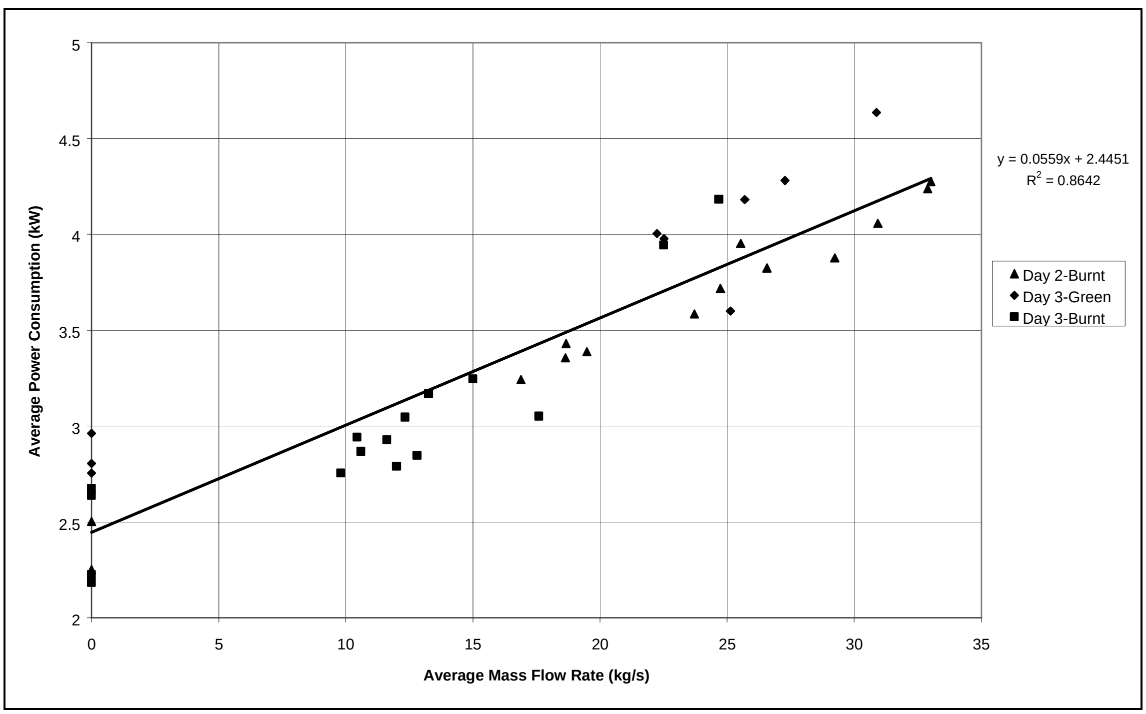

Figure 4. Results of Elevator Power measurements.

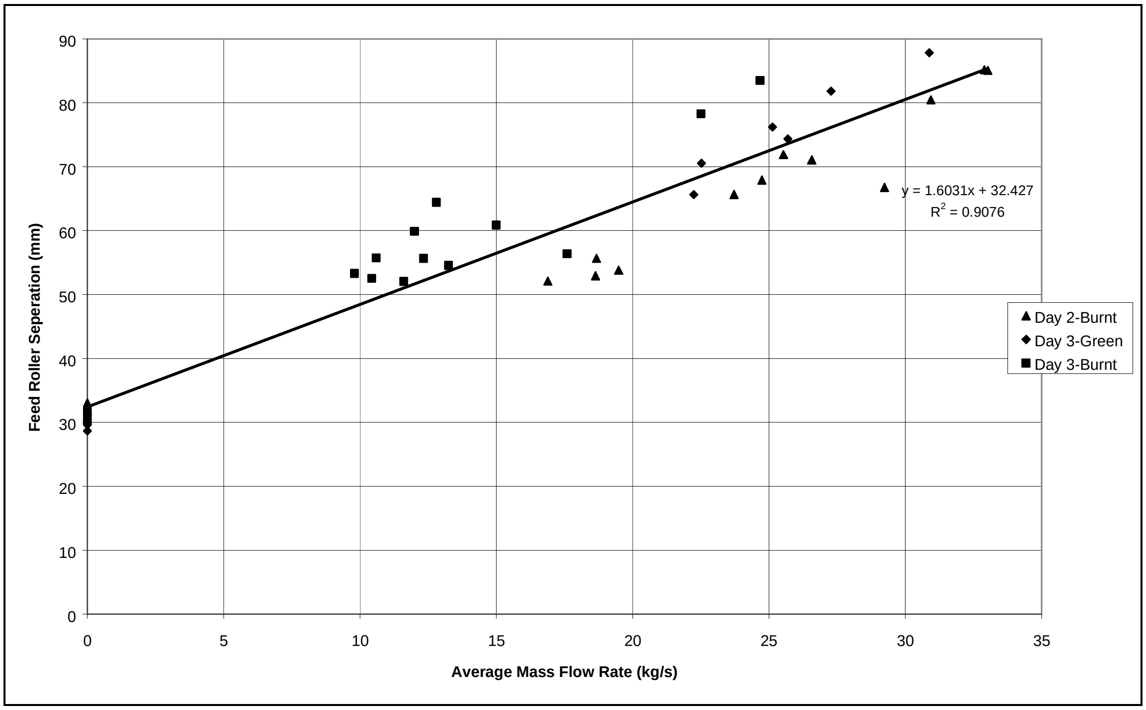

Figure 5. Results of Feed Roller Separation Measurements

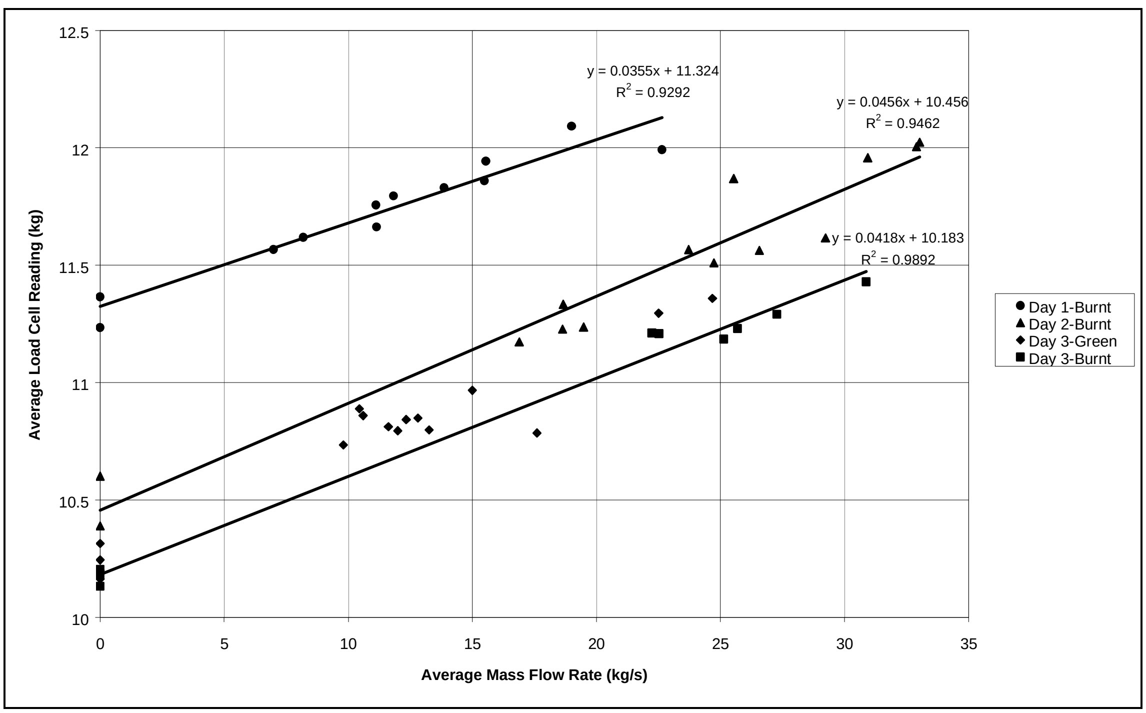

Figure 6. Results of Weigh Pad measurements.

Table 1. Summary of Results

Technique	Calibration Line Intercept	Slope	R^2	Std Error (kg/s)
Chopper Power	9.80 kW	0.149 kW/(kg/s)	0.84	4.18
Elevator Power	2.44 kW	0.056 kW/(kg/s)	0.86	4.08
Feed Roller Separation	32.4 mm	1.60mm/(kg/s)	0.91	3.36
Weigh Pad*	10.45 kg	0.046 kg/(kg/s)	0.95	3.33

*Weigh pad results are taken from Day 2 as an general indicator of the results.

The results for each technique are shown in Figures 3 to 6. The y axis is the average reading of the respective measurements technique taken over the harvesting time. The x axis is the average mass flow rate of cane, calculated by dividing harvested mass by the time to harvest. These calibration results of these figures are summarised in Table 1. The results for the elevator power and the feed roller separation do not contain measurements for Day 1, due to problems encountered with the elevator speed sensor and feed roller sensor. Although a smaller data set is available for these sensors, valid information was still derived. Each day of results for the weigh pad has been treated separately because of the obvious differences between them. This will be discussed further in the next section.

Discussion

Chopper power

In Figure 3 the chopper power results at zero mass flow are highly variable. At approximately 10kW, this is quite high compared to the maximum power of 15 kW. This free running power is required to overcome friction in the drive mechanism and inefficiencies in the hydraulic system, and its variation is significant compared to the full range of the data and can therefore introduce significant errors. This problem could be avoided by re-taring at every opportunity (every few minutes), but also requires closer operator attention.

The Day 2 results appear to follow a calibration line of their own with a narrow scatter. This could be due to the differences in conditions experienced between these days such as such as varietal changes or burnt versus green harvesting. The most significant difference is probable due to green versus burnt cane harvesting and it is debatable if the yield measurement should be affected by this change in condition. This point is discussed further in the feed roller discussion.

Overall this sensor gave a coefficient of determination (R^2) of 0.84 which is less than desirable but still provided a valuable indicator of mass flow rate. A standard error of 4.18 kg/s for this sensor is the highest of all those measured.

Elevator Power

Figure 4 shows again a substantial variation in the free running power measurements which can vary over short times with no apparent reason. The elevator is constructed from a multitude of rotating and sliding elements, so the contribution of friction to its operating power will be large and variable.

The other data points in Figure 4 also have considerable spread while the Day 2 results again have their own distinct trend with a much smaller scatter. A reason for Day 3 exhibiting a greater scatter maybe the longer duration of testing for that day, which allowed the friction and therefore the free running power requirement more time to change.

An R^2 of 0.86 and a standard error of 4.08 kg/s is better than for the chopper but worse than the other two techniques, but these are based on a smaller data set.

Feed roller separation

The feed rollers rest against a stop when there is no cane passing through the harvester, so the zero mass flow rate is well defined (Figure 5).

The other points on the graph show significant scatter and a distinct difference between Day 2 and 3. This is due to the fact that the results from Day 3 were obtained on both burnt and green cane. Sugar cane harvested green has up to 30% additional extraneous material than a burnt crop (Ridge and Dick, 1988). This results in the feed roller separating more to allow this material to pass through. This extraneous matter is removed by the extractor fans before the cane is dumped into the weigh truck. Therefore the weigh truck measures less material than that which passed through the feed roller giving a lower average mass flow rate. This is why some of the data points on Day 3 are higher than Day 2. This same reasoning can be applied to the variation in the chopper results.

It is debateable if this is a problem. It results in a more accurate measure of biomass yield and also is not affected by cane loss in the cleaning process. However it would produce yield maps which are different for green and burnt cane and this would not be desirable for agronomic analysis purposes.

The R^2 of 0.91 and a standard error of 3.36kg/s is a substantial improvement on the power measurements for such a simple technique. The method is volumetric but it benefits from its simplicity. When used to sense mass flow rate, factors affecting its accuracy such as cane density variation and feed rate variations need to be examined .

Weigh pad

Although the results in Figure 6 do appear more widely scattered than the data for other techniques, this preliminary assessment has provided positive results. The main points of concern relate to the changing intercept value and more importantly the changing slope of the calibration line.

The three days of testing gave three distinctly calibration lines. The obvious explanation for this finding are adjustments which were carried out at the beginning of each day’s testing. The loads on the two load cells were adjusted to equalise each load cell readings, using turn buckles. This adjustment could have changed the characteristics of the weigh pad operation, affecting the free running results and adjusting the gradient from day to day. Another source of error could be pieces of cane or dirt that may have wedged themselves in the gap between the pad and floor section.

A drawback of this particular weigh pad design the very slight gradients that were obtained from the weigh pad calibration lines and this was due to the large static mass of the sensing pad.

Results from Day 3 shows that different harvesting techniques (ie. green or burnt) do not effect the weigh pad calibration. Most of the trash found in green cane should be removed by the primary extraction fan before it reaches the weigh pad, therefore having no influence on the load cell readings.

Overall the results from the weigh pad are mixed but provide a positive step to continue the research into this technique and improve the results by an improved weigh pad design, being lighter, larger and immune from calibration variations.

Conclusion

Four different techniques for measuring mass flow rate through a sugar cane harvester have been investigated and compared. The elevator power measurement is limited in that is suffers from variations in the free running power due to a number of uncontrollable factors including friction, mud built up and chain wear. The chopper power measurement suffers to a lesser extent from the same problem of variation in free running power. Other factors such as crop properties don't affect results as much as first thought. Some of the differences between weigh truck weights and chopper measurement can be explained by the removal of material by the extracting system. This material is processed by the chopper but not measured in the weight truck. This could be useful for measuring biomass yield however problems results when changing from green to burnt cane. The feed roller separation is the simplest technique and warrants further investigation to determine the affect of changing conditions such as cane density. The elevator weigh pad shows promise with more work needed to solve the problems of varying calibration intercept and slope by way of an improved weigh pad design.

Plans have been made to measure the chopper power, feed roller separation and weigh pad techniques over the whole 1997 harvesting season. The performance of the respective techniques will be monitored to determine the most suitable technique for yield sensing sugar cane.

References

Reid, R.L.(ed), (1990). The Manual of Australian Agriculture, 5th ed. Macarthur Press, Australia

Ridge, D.R. and Dick R.G., (1988). Current research on green cane harvesting and dirt rejection by harvesters. Proc. Aust. Soc. Sugar Cane Tech. 8:19-24