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QUEENSLAND, AUSTRALIA

FINAL REPORT – SRDC PROJECT MCB001
LIFTING THE VIABILITY OF THE MOSSMAN SUGAR INDUSTRY BY IMPROVING THE CANE SUPPLY

by

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SD03004

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SUMMARY

The project was initiated to investigate techniques to improve the long-term viability of the Mossman sugar-producing area through better harvesting techniques. The overall aim was to dovetail with previous SRDC-funded research by Mossman Mill that had suggested that a cane supply much lower in extraneous matter could potentially eliminate the need for expansion of mill capacity, negating a capital expenditure of at least $9 million dollars. The major brief of this project was to help implement these techniques, whilst ensuring that they did not cause any additional sucrose loss in the field.

Due to varying crop conditions throughout the lifecycle of the project, it was impossible to gauge whether there had been any net decrease in the level of extraneous matter in the cane supply. Nonetheless, the project did provide some significant quantifiable benefits to the Mossman sugar-producing region, not the least of which was the further development and widespread adoption of a process called 'Feed-Train Optimisation' which has been shown to reduce sucrose loss and improve billet quality during mechanical harvesting.

This project also undertook some novel research into the linkages between billet length and productivity, which indicated a previously unknown linkage between billet length and declining CCS in far north Queensland. The results suggest that a decrease in billet length of just 20 mm can decrease the CCS of green cane by approximately half a unit, and increase extractor losses by 5-10%. These results are considered to be extremely relevant to the current trend of CCS decline in far north Queensland.

Trials investigating the effects of billet length upon productivity highlighted another previously unrecorded phenomenon, that average billet length changes with fan speed, and that there is an interaction between this change and the nominal billet length setting of the harvester. This may have implications upon the interpretation of previous research and the future design of machinery.

Technological outputs of this research included a computer model of the feed-train and chopper system of modern mechanical harvesters, and the development of a computer system designed to give harvester operators a more intuitive guide to their performance relative to their peers. These are being used commercially.

1.0 BACKGROUND

Declining CCS is threatening the viability of many of the northern sugar mills. CCS for coastal cane in the Mossman area in 1998 was approximately 10.9 units. This is substantially lower than the 5-year average and the lowest in the mill's history. An increase of CCS in the district by 2 units would increase the net revenue to the district by $4.6 million annually at a sugar price of $300/t.

Recent research by BSES with some assistance from Mulgrave Mill has shown that extraneous matter and suckers in the cane supply can reduce CCS by at least 2 units. These causal factors can be overcome by implementation of better farming and harvesting practices. BSS189 (Whiteing 2002) has demonstrated that strategies are available to reduce extraneous matter in the cane supply, and such strategies need to be urgently implemented across the north to counteract the decline in CCS.

Mossman Mill is currently crushing at capacity. Tonnage of the cane is increasing with the Tableland cane, and potential expansion into the Lakeland Downs area. Increasing the milling capacity is reported to cost $350,000 per tonne of cane per hour (where increased boiler capacity is not required) and at the current sugar price such capital expansion is difficult to justify. Trials at Mossman in 1998 demonstrated that a clean cane supply can increase crushing rates by 30 t/h. Such an improvement in the cane supply would negate a capital expenditure of $9 million for the district. Where an increase in boiler capacity needs to accompany the expansion of milling capacity, costs of expansion are considerably higher. Mossman Mill would need to take this step to substantially increase crushing rate.

BSS189 has shown that increasing harvester extractor speed to improve the quality of the cane supply increases cane loss significantly. Such losses would discount any of the benefits mentioned above. However, the strategies developed in BSS189 to minimise cane loss and reduce extraneous matter can provide a benefit across all sectors of the industry's value chain.

This project was designed to implement such strategies into the Mossman area through a participatory extension program. Harvesting best practices were identified by the Mossman working group as a high priority in their integrated work program.

2.0 OBJECTIVES

The original aim of the project was to improve the quality of the cane entering Mossman Mill, without increasing cane loss as a result. This was to be achieved by:
1. Undertaking an awareness and education program with the local growing, harvesting and milling sectors of the industry.
2. Demonstrating best practice in the area.
3. Developing tools that enable benchmarking for quality in both the farming and harvesting sectors.

An intensive program of trials and extension work was conducted between 1999 and 2002. The project was intended to identify and implement strategies that would lead to better CCS and lower extraneous matter in the cane supply, thereby allowing Mossman Mill to increase its crushing rate without the need for major capital expansion. A major consideration was that any such changes should not increase cane loss in the field.

The trial and extension program encountered significant barriers to the adoption of best-practice harvesting techniques. The most significant of these barriers was that the mill wished to improve its transport efficiency by strongly compelling harvester operators to match a minimum bin weight threshold of 8.8 tonnes. This was having the inadvertent effect of encouraging harvester operators to adopt practices that were not necessarily complementary to the stated aim of adoption of best practice harvesting.

As a result of these local issues, trials were conducted to establish the effect of billet length upon sugar loss during harvesting. These trials indicated that a small reduction in billet length could lead to a statistically significant decrease in sugar yield of up to 10%. A computer model was adapted to show the link between billet length and bin weight. This model showed that it was unlikely that the minimum bin weight could be achieved under all conceivable conditions without reducing billet length.

This finding led to pressure to find a compromise that would allow reasonable bin weights, and yet minimise the deleterious affects of shorter billet lengths. Subsequently, advice was sought from the engineering section of BSES, and a computer model was designed that allowed rapid deployment of a process called 'feedtrain optimisation', which promised reduced chopper losses and better billet quality and uniformity. Over 80% of the Mossman harvesting fleet subsequently underwent some degree of modification. These modifications proved successful.

This project showed that it was possible to tailor existing research to fit the individual requirements of diverse milling areas, and provide benefits for all sectors of the industry. It also showed that payment systems could be a major impediment to the adoption of best practice harvesting techniques.

This project was originally intended to be largely an extension exercise. However, additional trial work was required to help address local issues.

The awareness and education campaign was originally intended to occur through a group participatory approach, with representatives from all three major sectors (growers, millers, harvesters) to meet regularly and discuss the progress of the project. This was seen as necessary to maintain the unity of the three groups, and improve the chances of effecting any long-term paradigm shift.

The original idea of having a separate group for these discussions proved unwieldy and unsuccessful, so it was considered appropriate to hold discussions with the Mossman Agricultural Services (MAS) board instead. This board already met on a monthly basis, and had representatives from the milling, harvesting and growing sectors.

Another weakness was that the project was unable to achieve the 'before' and 'after' snapshots of the industry (benchmarking) that were originally intended to be a central measure of the success or otherwise of this project. Hindsight shows that the scope of this task was too large for one person, and provision should be made in future similar projects for casual labour.

The second and third objectives were substantially exceeded – this project showed leadership in developing, showcasing and implementing some important modifications and innovations either developed previously or in parallel with it. It also investigated and implemented on a trial basis a feedback system to give harvesters more timely and useful data about their relative performance. This system shows promise for further development.

3.0 METHODOLOGY

The following is a general description of the techniques used and benchmarking tools developed for assessing quality and yield components during the project. Not all of these techniques were developed specifically for this project. However, many have been refined during the project.

3.1 Extraneous matter (EM) analysis

3.1.1 Definitions

Extraneous matter is defined as any material other than clean billets that occurs within the homogenous mixture of harvested biomass that is processed at the mill. The components of an extraneous matter analysis are defined as:

***Clean cane**:* pieces (termed 'billets') of cane without any adhering trash.

Trash: leaf material, dry or green. During the process of EM evaluation, any leaf material adhering to the billets must be removed and included in the analysis of trash levels.

Tops: the growing point of the cane plant; generally begins from the last node of the plant. Where a billet from a harvester is assessed and it contains millable cane as well as tops, the two components should be broken apart and assessed separately.

Suckers: a somewhat subjective measure. Suckers are immature cane plants, and generally occur within a mature sugarcane crop as next year's crop begins to grow. In their advanced stage, suckers are characterised by their whitish colour and large diameter; when immature, suckers resemble tops.

Stool: any piece of harvested cane that has roots and dirt as the majority of its weight; the lower subterranean section of the cane plant.

***Foreign material*:** material that is not of interest in the analysis of harvested components and that if included would significantly alter the results of an extraneous matter analysis. Examples are a basecutter blade, wheel nut or plant material of non-cane origin.

Dirt: loose material left over after all other components of the analysis have been removed.

4.0 JUSTIFICATION

A major limiting factor for many of Australia's smaller sugar mills is *crushing rate*, defined as processing capacity (tonnes of biomass per hour) of a mill. Unpublished research from the Mossman district has provided some indication that the provision of a clean cane supply could increase the mill's crushing rate by up to 30 t/h.

During the planning stages of this project, considerable importance was attached to developing relatively accurate ways of measuring extraneous matter levels during benchmarking and trial work. It was hoped that these data could be used to produce an NIR calibration for EM by the end of the project. However, this has not eventuated, due to the technical difficulty of calibrating NIR to differentiate an extremely heterogenous characteristic such as EM.

4.1.1 Technique

The experimenter climbs into a full cane transport unit (bin), and selects a location on top of the bin (without conscious bias) from which to sample cane. Approximately 15 kg of cane is then removed from the bin using a 'raking action', so as not to artificially separate trash from the sample. The sample is then placed into appropriately labelled plastic garbage bags. The contents of each bag are then separated into its components (categories as in 3.1.1), and individual components are weighed.

Considerable importance is attached to collecting a representative sample. However, the limitations of this technique are known to be important. For example, trash levels among samples taken from an individual transport unit can be quite considerable. As a result, the likelihood of a type II statistical error (failing to detect a significant difference between treatments when one actually exists) is quite high. Many samples must be taken from each experimental unit to enable accurate estimation of between-sample variation.

In practice, I found that the likelihood of identifying such differences was negligible unless at least five samples were taken from each experimental unit within each replicate of each trial. That each sample takes at least 30 minutes to process, and the lack of provision for casual labour in this project presented an important barrier to the collection of statistically valid data pertaining to the effect of harvester settings upon cleaning. The provision of casual labour should be considered of great importance in future similar projects.

As a compromise, NIR individual fibre levels were often used to provide an indication of EM levels in replicated trials. It was considered that in such a trial (same block, same variety) there should be a certain baseline fibre level in millable stalk, and that any significant difference in fibre levels between treatments should be at least partly attributable to differences in EM. A notable exception would be if any given treatment affected the moisture content of a billet due to increased juice losses.

For final analysis, the weights of suckers, dirt, tops, stool and foreign matter were not included. These components are usually fairly homogenously mixed through a bin. However, on a small scale (15-kg samples), the relatively large weight of these components can add a significant extra layer of experimental error. Exceptions are obvious, for instance if the treatment of experimental interest was likely to affect the quantity of one of these measures it would be included in the analysis. EM in these trials was thus calculated by the equation:
EM = weight(trash)/weight(billets + trash).

Differences were assessed statistically using the analysis of variance (ANOVA). I found that variation between samples was often large, so most trials incorporated multiple subsamples from each experimental unit. This improved the precision of the ANOVA.

4.2 Billet quality and length measurement

4.2.1 Definitions

The ISSCT billet-quality assessment criteria were used in this project. This technique was developed to assess planting billets and has been used widely by Robotham and Chappell (2002). However, it is also suitable for billets destined for the mill, and I adapted the sampling and processing system that Robotham and Chappell developed for use in this project.

De Beer *et al*. (1985) based billet quality on the criteria:
- Billet size distribution;
- Mean billet length;
- Percentage of sound, damaged and mutilated billets;
- Percentage of sound billets of good length.

Of the four criteria, only billet size distribution and percentage sound, damaged and mutilated billets were reported. The percentage of billets of good length is dependent on definitions of a good billet length, which can vary between mill areas.

Billets were sorted into the length categories of 10-mm increments, eg 200-210 mm, 210-230 mm, etc. Each billet-length category was further assessed to determine billet quality based upon the ISSCT guidelines. A summary of billet quality criteria (De Beer *et al*. 1985) is listed below:

Sound billets: Those sections of stalk longer than 100 mm with no splits (other than growth cracks) longer than 80 mm through one end. Small rind cracks, less than 40 mm long are not regarded as splits. No section of rind more than 400 mm^2 removed exposing the pith; no squashed ends with frequent rind cracks.

Damaged billets: Those with splits larger than 40 mm in the rind and totalling more than 80 mm per billet or with sections of rind between 400 and 2000 mm^2 removed, exposing the pith. No squashed ends with frequent rind cracks. All billets less than 100 mm in length.

Mutilated billets: Those that have been broken, squashed and damaged, so that there are numerous rind cracks and a portion of the cane is reduced to a pulpy condition. Billets with more than 2000 mm^2 of rind removed are also classified as mutilated.

Billets were ranked as sound, damaged and mutilated and the mass of each category recorded. A percentage by mass of the total sample mass was calculated.

4.2.2 Justification

Whilst it would seem reasonable to assume that the extent of damage inflicted upon the cane product during harvesting is of real interest to those cutting billets for planting purposes, it is becoming more apparent that there are certain synergies linking billet quality and per-hectare recoverable sugar yields.

There are two major apparent causes of depletion of sugar levels in mechanically harvested sugar cane: that from microbial degradation (mostly evidenced as dextran production); and a relatively new idea (largely realised during this project), that juice lost during the cutting process causes a net decline in CCS, as first expressed juice (FEJ) is of higher pol than that of juice in the billet taken as a whole. A damaged billet is likely to be one that has experienced above average juice loss during harvesting, and thus billet quality is considered to be an important indicator of the likely extent of non extractor-fan losses during harvesting.

There is also evidence suggesting that being lighter, those billets that are shorter than average or significantly damaged may be more prone to loss through the extractor fans.

This technique is subjective in nature and extremely labour intensive. However, I consider that it offers some excellent insights into the coarseness or otherwise of the machine-crop interface.

4.2.3 Technique

Billets were manually sorted into the three categories and each component weighed. Individual billets were then measured to the nearest centimetre, and lengths were recorded on a tally sheet. The lengths were then entered into a spreadsheet that calculated the average length and standard deviation of lengths for each of the three billet-quality categories. Differences were then assessed statistically using the ANOVA technique.

4.3 Direct cane-loss measurement – the 'Blue Tarp' technique

4.3.1 Justification

This technique was developed and refined as an extension tool in the early 1980s. It involves placing a tarpaulin (of any colour!) adjacent to the cane row to be harvested, so that material thrown from the primary extractor fan can be collected and sorted. The sugarcane fragments are then removed and weighed to give an estimate of extractor-fan losses. An interesting observation is that the 'blue tarp' technique evolved from being simply a qualitative extension tool to becoming a surrogate quantitative measure of cane loss.

The tarp technique, however, has a number of limitations. The first is that after being ejected from the fans, billets are often pulverised to such an extent that they are not readily discerned from other non-billet material. Secondly, this pulverisation is exponentially related to fan speed and the relationship is dependent upon varietal characteristics of the cane being ejected. A third limitation is that the technique is specific to primary extractor loss, and ignores other sources of loss in the harvesting process.

Brotherton (2002) concluded that a major limitation to the tarp technique is not its precision, which can be checked easily, but rather the inability to calculate the accuracy or closure error for each trial unless a material balance is conducted.

Near to the start of this project, I became disheartened at the variability inherent to the tarp technique and chose to pursue measurement of comparative cane loss using a technique largely developed during this project. This is called the CCS loss measurement technique. This technique will be discussed in more detail in section 3.4.

4.3.2 Technique

A tarpaulin measuring approximately 5 m by 5 m is pegged to the ground in the harvested row adjacent to the line of travel of the harvester. As the harvester passes the tarpaulin, the operator is asked to align the extractor hood so that extracted material is directed onto the tarpaulin. Extracted material is then manually sorted and ejected billets and billet fragments are removed and weighed. An appropriate correction factor is applied giving an estimate of cane loss on a per hectare basis. Practice has shown that the most uniform results are obtained when more than five samples are taken per experimental unit, which makes this technique extremely labour intensive.

4.4 The CCS (or pol) loss measurement technique

4.4.1 Justification

The newly developed CCS (or pol) method for estimating cane loss during harvesting has been used extensively during this project. It is a derived figure, calculated from mill and field measurements. Thus, some argue that it includes more sources of error than the tarp technique, including sampling error at the mill for parameters such as pol, brix and bin weight, and field measurements such as length. Whilst this may be true, the advent of NIR analysis means that mill parameters such as pol and brix are now calculated from tens of thousands of samples per rake. Hence, estimates are now far more accurate than traditional laboratory techniques.

The tarp technique is by its very nature completely insensitive to sources of loss other than the primary extractor fan (broadly feed-train loss, chopper loss, secondary extractor loss, and sugar loss through degradation). I argue that the tarp technique was also prone to a number of sources of largely uncontrollable error, including differences in technique and precision between researchers, the velocity and direction of the prevailing wind, varietal characteristics and inter-row differences in the presentation of the cane to the machine.

My contention is that the CCS (or pol) method when properly executed gives a far more accurate estimate of ‘whole-of-system’ losses than the tarp technique; it also has the major benefit that it is less labour intensive than earlier techniques. However, one major drawback of the CCS method is that the inherently large minimum sample size for mill analysis (generally at least 30 t), coupled with extremely high variation across the crop necessitates large numbers of replications. The CCS (or pol) method requires large and uniform crops of a single crop class and variety to be successful.

4.4.2 Technique

Potential trial sites were carefully chosen prior to harvest to maximise the chances of a successful outcome, with uniformity of the crop being the major consideration. Of secondary consideration was even row length, as it made determination of per hectare yields less time consuming.

These trials frequently used a randomised complete-block design, which combined the benefits of randomisation and blocking. This design is also a fully balanced design, which allows the use of classical analysis of variance (ANOVA) to indicate significant differences where they occur, and estimate the magnitude of these differences. An example of a typical trial design is given in Table 1.

Table 1 Example of typical trial design used in this project; replicates are across the field

Replicate ('Block')	Treatment			
1	Long billet 1000 rpm	Short billet 1250 rpm	Short billet 1000 rpm	Long billet 1250 rpm
2	Long billet 1250 rpm	Short billet 1000 rpm	Long billet 1000 rpm	Short billet 1250 rpm
3	Short billet 1250 rpm	Short billet 1000 rpm	Long billet 1000 rpm	Long billet 1250 rpm
4	Short billet 1000 rpm	Long billet 1000 rpm	Short billet 1250 rpm	Long billet 1250 rpm

At the start of each trial, the operator was given a briefing explaining the purpose of the trial, and was provided with a sheet giving the order and protocol for each experimental unit (treatment). During the trial, regular radio contact was maintained with the mill and the harvester operator. EM samples (where taken) were removed from each bin as it arrived at the siding and placed into marked bags for later analysis.

Published (South Johnstone Cane and Sugar Committee 1980; Fuelling 1981; Crook *et al.* 1999) and unpublished (Brotherton 2002) data suggest that yield variation between adjacent rows can be significant, especially where dual-row cultivation is practised. It is, therefore, preferable if each treatment replicate consists of a discrete number of rows of cane. In practice, this was usually an impossible consideration, as every attempt was made to limit the inconvenience caused to harvesters and haul-out operators. Furthermore, some mills were reluctant to haul partially full bins, as there is a perception that they increase the risk of derailment.

As a compromise, each experimental unit usually consisted of a discrete number of bins, rather than a set number of rows. At the culmination of each experimental unit (treatment replicate), a marker was placed into the ground directly behind the harvester, and the total row distance covered per experimental unit was later measured using a wheel. These data were used to calculate gross biomass per hectare.

Following the field stage of the trial, EM sampling was conducted and mill data collected. The mill data were combined with field data, and used to generate yield estimates such as the tonnes of CCS, and tonnes of pol per hectare for each experimental unit. These data were entered into a database, and subsequent statistical analysis was used to detect differences between treatments.

The use of a minimal-cane-loss 'no-fans' or 'low-fans' control in these trials was preferable. However, it was often omitted due to the difficulty of processing such material at the mill. As such, most trials described in this report only indicate relative differences between treatments, and not an estimate of overall loss for each treatment.

Trials were conducted at realistic commercial pour rates, and great care was taken to minimise the effect of unintended sources of variability on the outcome of each trial.

4.5 Small-mill trial

4.5.1 Technique

The trial was a factorial trial, with four cut-to-crush delays (0, 6, 12 and 18 h), two billet lengths (nominally 'long' and 'short'), and four replicates of each combination. Juice from each delay*billet length*replicate combination was divided into two subsamples. Pol and brix were determined from each sample by the BSES juice laboratory (Burdekin Station).

These samples were collected from a harvester in the field. The ambient maximum temperature on the day of the trial was 32°C, and the trial commenced at 0600 hours. The variety harvested was Q165.

The operator was asked to stop and empty the entire contents of his elevator and feed-train into a waiting haul-out. The operator was then asked to set the machine at its shortest billet length setting and maintain the extractor fan at a moderate speed (1000 rpm). A 10-m length of row was then harvested and elevated into the tray of one of the two waiting utilities.

This entire process was repeated twice, giving two 10-m samples of row elevated into each utility (for quasi replication). Each utility collected samples of a single billet length. These samples were taken back to the BSES station immediately, and the contents of each utility were mixed thoroughly. Sixteen 20-kg billet samples were then randomly removed from each utility, placed into opaque plastic garbage bags and labelled. There were 32 20-kg samples.

Four samples from each billet length group were immediately crushed using the small mill and analysed. Because of the small sample size, tops, suckers and stool material were excluded to prevent undue dilution. The remaining 24 bags were sealed and placed outside in full sun to stimulate accelerated degradation. These bags were then randomly selected, eight at a time, crushed and analysed at 6, 12 and 18 h. At 18 h, the juice samples were becoming extremely difficult to filter and smelt alcoholic.

5.0 RESULTS

The results of the trials conducted during this project are detailed below. These had a very specific focus upon quantifying the effects of billet length and fan speed on recoverable sugar yields, and examined the possibility of a link between the two factors.

The trials were typically conducted using a randomised complete block design, with at least three replicates and at least three EM subsamples per experimental unit. Where possible, trials were conducted using a factorial design, which has the advantage of 'hidden replication' for statistical analysis, and increase the productive use of manpower by allowing measurement of the effect of more than one factor per trial. Where a trial was factorial in nature, factors were as in Table 1. All trials summarised below were factorial in design, except the Tully trial, which did not include the effect of primary extractor fan speed.

It is important to note that there were physical differences (chopper type, feed-train set-up, etc) between machines. This means that the factors of interest (especially billet length), were not necessarily homogenous between trials.

Of eight trials conducted, four showed statistically significant trends between treatments (one of these was a small-mill trial). Detailed results and statistical analyses for all trials are available from the author, and full analyses of the four trials of interest are given in Appendix 1. A summary of results for the three field trials of interest is provided in Table 2. Why are results from only three of the eight field trials conducted given here? Basically the other five trials failed either due to missed samples at the mill or poor paddock selection. The perceived reasons for these failures are given in Appendix 1, along with details on each trial including crop class, location, variety and machine type.

5.1 Biomass yield per hectare

Biomass yield is commonly referred to as tonnes of cane per hectare (or TCPH). However, this nomenclature is somewhat misleading, as the measure includes trash and other extraneous matter.

In all three trials, increasing billet length increased the biomass per hectare yield. These increases were significant in all trials, except the Tully trial, and ranged in magnitude (as percent of trial mean) from 2.25 to 5.5% additional tonnes of biomass per hectare. As these increases did not have corresponding increases in percentage trash or fibre levels, I assume that they were due to a net decrease in associated cane and juice loss for the long-billet treatments.

Table 2 Summary of results of three trials investigating the effect of billet length and fan speed on mill quality parameters.

Measure	Trial	Grand Mean	Estimated Effects Billet Length Short to Long	Estimated Effects Fan Speed Slow to Fast	Estimated Effects % Increase or (Decrease)# Short to Long	Estimated Effects % Increase or (Decrease)# Slow to Fast
Biomass Yield (t/ha)	**Singh**	102	+ 2.26 ***	- 2.74 ***	2.22 ***	(2.69) ***
	Sciacca	57.2	+ 2.22 *	- 6.23 ***	4.07 *	(10.89) ***
	Tully	83.1	+4.66 ns	N/A	5.61 ns	N/A
NIR % Fibre	**Singh**	14.01	+0.37 ***	- 0.28 **	2.64 ***	(2.00) **
	Sciacca	14.22	+0.44 ***	- 0.14 ***	3.09 ***	(0.98) ***
	Tully	12.85	+0.25 *	N/A	1.95 *	N/A
CCS	**Singh**	14	+0.217 **	+0.25 ***	1.57 **	1.79 ***
	Sciacca	15	+0.32 *	-0.117	2.13 *	(0.78)
	Tully	13.4	-0.2 ns	N/A	(1.49) ns	N/A
Purity (%)	**Singh**	86.85	+0.23 **	N/A	0.26 **	N/A
	Sciacca	90.68	+0.8 *	-0.167% ns	0.88 *	(0.18) ns
	Tully	89.88	-0.23 ns	N/A	(0.26) ns	N/A
t CCS/ha	**Singh**	14.2	+0.532 ***	-0.131 *	3.72 ***	(0.92) *
	Sciacca	8.57	+0.511 ***	-1.02 ***	5.96 ***	(11.90) ***
	Tully	11.13	+0.48 ns	N/A	4.31 ns	N/A
% Trash by Weight	**Singh**	1.99	-0.1 ns	-0.79 ***	(5.03) ns	(39.70) ***
	Sciacca	2.39	+0.5 ns	-1.48 ***	0.23 ns	(0.62) ***
	Tully	5.07	+1.13 **	N/A	22.29 ***	N/A
NIR % Ash	**Singh**	0.61	+0.21 **	-0.03 ns	34.43 **	(4.92) ns
	Sciacca	1.53	+0.2 *	-0.05 ns	13.07 *	(3.27) ns
	Tully	1.24	+0.23 ns	N/A	18.55 ns	4.03
Bin Weight (t)	**Singh**	11.54	-0.51 ***	+0.422 ***	(4.42) ***	3.66 ***
	Sciacca	9.3	-0.96 ***	+ 0.41 ***	(10.32) ***	4.41 ***
	Tully	9.84	-1.52 ***	N/A	(15.45) ***	N/A
Millability Coefficient	**Singh**	1	-0.01 ns	+0.04 ***	(1.00) ns	4.00 ***
	Sciacca	1.05	-0.01 ns	+0.003 ns	(0.95) ns	0.29 ns
	Tully	1.05	-0.04 *	N/A	(3.81) *	0.00

* = sig @ pr(F) 15%, ** = pr(F) 10%, *** = pr(F) 5%
\# = As percentage of trial mean

Highly significant decreases in biomass yield per hectare were observed as primary extractor fan speed increased. The estimated magnitude of this decrease in biomass yield ranged from 2.7% to 10.89% and can not be explained by decreases in trash or fibre levels. It is therefore likely that these results represent increased loss of millable cane through the primary extractor fan. This supports the results of Whiteing *et al.* (2001).

In both factorial trials, there was a significant interaction (<5%) between billet length and fan speed (Figure 1). This interaction was interpreted as an indication that shorter billet lengths were more prone to loss through the primary extractor.

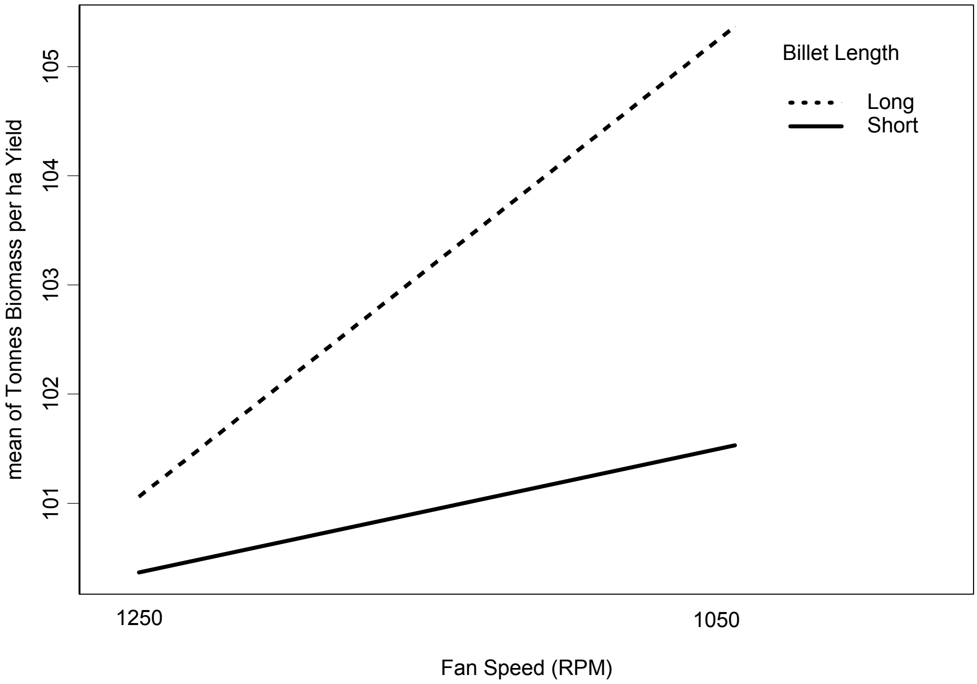


Figure 1 **Effect of billet length and fan speed on biomass per hectare yield (data from Singh trial)**

5.2 NIR fibre levels

The advent of NIR has been especially advantageous for field researchers, as it allows timely and accurate analysis of fibre levels for individual rakes. Fibre levels are broadly comprised of contributions from the cane stalk itself, dirt and leaf material. They are interpreted here as a rough estimate of treatment effects upon EM levels (including dirt) within each trial.

Increasing billet length caused a significant, but small, increase in fibre levels in all trials, with estimates of magnitude ranging from 0.25 to 0.47 units. Much of this increase can be explained by corresponding increases in percent NIR ash; about 50% of the increase in each case. The remaining component was between 0.02% and 0.24% by weight for each treatment. I interpret this as an indication that increasing billet length leads to an extremely small decrease in trash removal by the primary extractor fan.

Fan speed had a similar effect, with the higher fan speed resulting in a small (0.14 to 0.28 fibre units), but significant decrease in fibre levels compared to the slower speed.

There was no significant interaction between the two parameters in either trial. I interpret this to mean that any additional trash removed by the action of cutting a short billet is just as efficiently removed at both fan speeds.

5.3 Mill CCS

All CCS results were calculated using NIR individual fibre values.

These results suggest the possibility that there can be a significant positive correlation between billet length and mill CCS percent biomass under some conditions. This trend was not present in the Tully trial.

The estimate of measured increase in CCS due to increasing billet length ranged from 0.21 to 0.32 units increase.

The effect of changing fan speeds was less clear-cut, with one trial indicating a significant increase of 0.25 units of CCS with increased fan speed, and the other trial indicating a non-significant decrease of 0.12 units.

No significant interactions were recorded, indicating that the differences between billet length were relatively unaffected by fan speed.

5.4 Purity

Purity results were compiled using laboratory data, not NIR.

Purity analysis showed that fan speed had no significant effect upon purity of juice. However, increasing billet length caused a significant increase in purity in two of the three trials. The magnitude of this increase was not great, estimated at between 0.23 and 0.8 of a unit.

5.5 Tonnes CCS per hectare

Tonnes CCS per hectare has become a measure of increasing importance since the beginning of this project. It is theorised that this measure gives a good indication of overall relative losses in a given harvesting trial. This measure is obtained through the formula: CCS/100*Biomass Yield.

The combination of increased CCS and increased biomass per hectare led to an overall significant increase of between 0.48 and 0.53 tonnes of CCS per hectare as billet length increased. As a percentage of trial means, this equates to a recoverable per hectare sugar yield increase of between 4.31 and 5.96%; this result was statistically highly significant (<0.01%) in two of the three trials. This result is of substantial importance, and demands further research.

Overall, recoverable sugar yields per hectare showed a significant decrease as fan speed increased from 1050 to 1250 rpm, with this decrease estimated at between 0.13 and 1.02 tonnes of sugar per hectare. As a percentage of trial means, this equates to a drop in recoverable sugar yield of between 0.92 and 11.9%. It is interesting to note here that the smaller magnitude drop occurred in standing irrigated cane, whereas the larger drop occurred in a slightly lodged sprawled crop of cane. This may indicate that the evenness of feed and crop conditions can have a significant effect upon cane loss.

There was a significant interaction between terms. The magnitude of loss between billet lengths was greater at the lower fan speed, broadly indicating that at higher fan speeds billet length has a smaller real effect upon the magnitude of cane loss. However, the relationship was slightly different between trials. In Sciacca's trial, there was no significant difference in tonnes CCS yield per hectare attributable to billet length at the higher fan speed (Figure 2), whereas there were obvious differences at both fan speeds in Singh's trial (Figure 3).

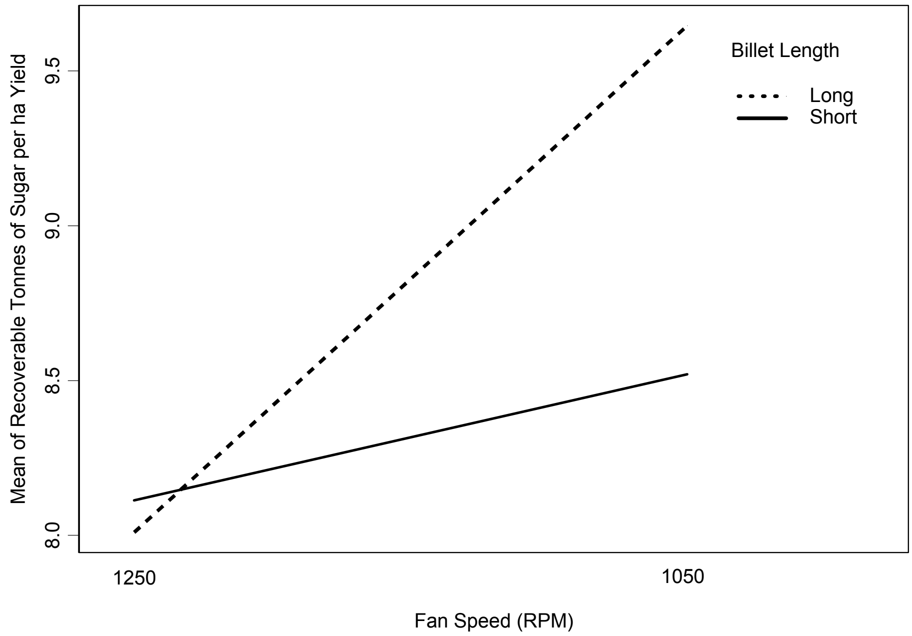


Figure 2 **Effect of billet length and fan speed on tonnes of CCS per hectare (Sciacca trial)**

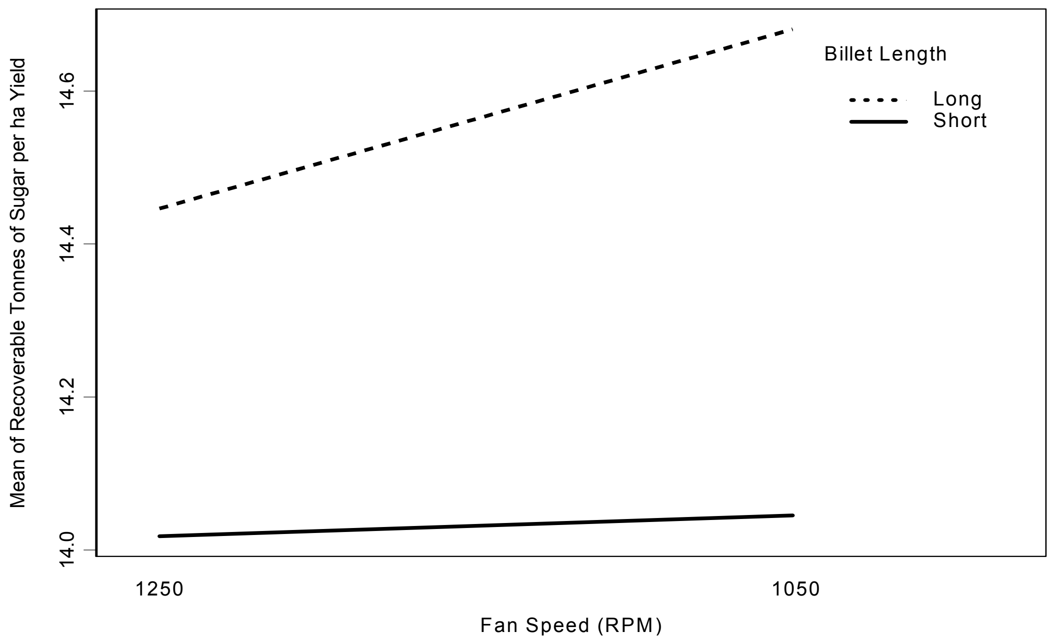


Figure 3 **Effect of billet length and fan speed on tonnes of CCS per hectare (Singh's Trial)**

5.6 NIR percent ash

NIR percent ash is generally used in North Queensland as an indication of dirt levels. Whilst this is fair in general terms, it must be remembered that ash also includes the non-combustible mineral component of the plant material itself, much of which is contained in leaf material (S. Staunton, pers com). This must be remembered when interpreting the data.

There was a significant positive correlation between billet length and ash levels. The percentage ash increase relative to the trial mean in all trials significantly exceeded the corresponding proportional increase in fibre levels, a point that I interpreted as an indication that there was a real dirt increase with longer billets. This increase was small in magnitude, ranging from 0.20 to 0.23% by weight of additional dirt in long-billet treatments (Figure 4). However, as a percentage of the trial mean, this was a relatively large increase, ranging from 13% to 34.5%.

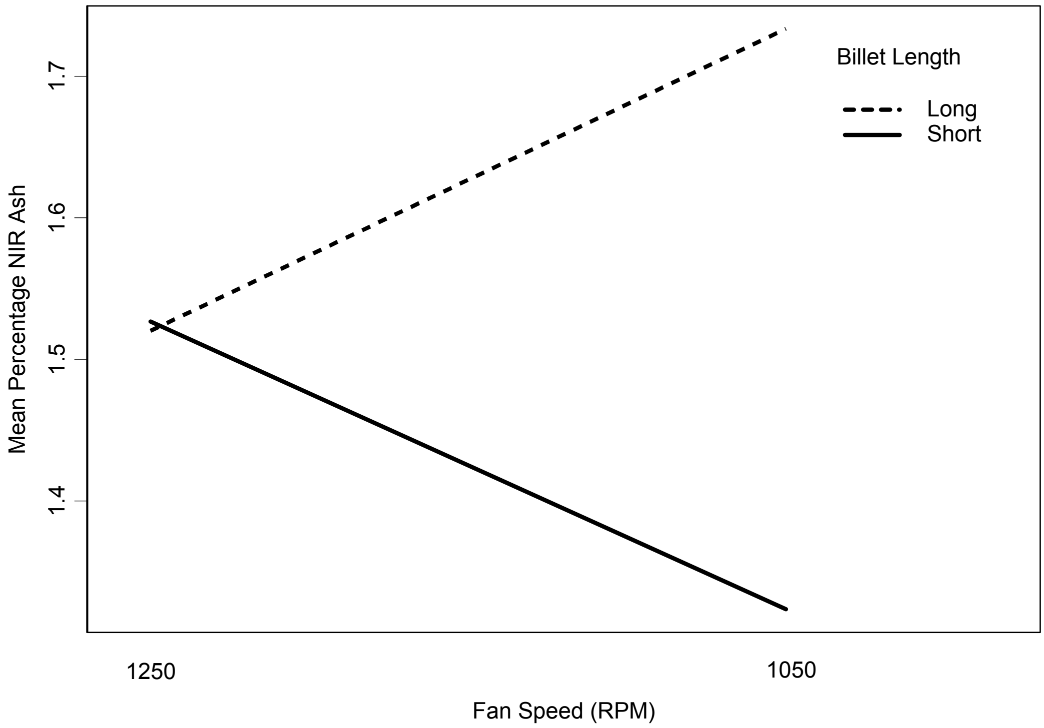


Figure 4 Effect of billet length and fan speed on ash levels (Sciacca trial)

I consider that there are two possible explanations for this phenomenon: that the additional chops per stick and related agitation with short-billet treatments leads to more efficient removal of entrained dirt by the extractor fan; or that more dirt falls from the feed-train itself when cutting short billets for the same reason.

If the first was the case, I would expect that there would be an interaction between the effects of billet length and fan speed upon dirt extraction. This was not the case, although the Sciacca trial showed a nonsignificant interaction (pr(F)=18%), which could be considered to be supporting evidence for this contention. This effect is considered worthy of further investigation considering the often-stated adverse economic implications of excessive dirt in the cane supply upon the Australian sugar industry.

5.7 Bin weight

Bin weight is becoming an increasingly topical issue for the Australian sugar industry, with millers and haul-out contractors seeking to improve the efficiency of their operations by hauling more cane per trip using existing infrastructure. This has meant that there is considerable pressure within the industry to reduce billet length.

Bin weight was inversely proportional to observed billet length, and this effect was significant with all trials (Table 3). This decrease was estimated at between 0.52 (Singh) and 1.52 tonnes per bin (Tully). These figures, when converted to percentage of the trial mean, were 4.4-15.45% additional weight per bin with shorter billets. Actual billet lengths for each trial are given below.

Table 3 Effect of billet length on bin weight

Trial	Variety, class	Billet length (mm)		% Weight increase
		Short	Long	
Singh	Q120, 1R	130	170	4.42
Sciacca	Q120, 2R	175	204	10.32
Tully	Q174, 2R	162	202	15.45

Fan speed also had a significant effect upon bin weight, and this effect was additive to the billet-length effect. The magnitude of the effect was approximately 0.41-0.42 additional tonnes per bin for both trials (Singh and Sciacca), which, expressed as a percentage of the trial mean value, equates to a 3.7-4.4% increase with increasing fan speed. The fan speed effect is of particular interest, as the implication is that increasing fan speed by 200 rpm increases the bulk density of material in the bin – less dense billets are more effectively removed by the extractor fans.

Whilst all trials with fan speed as a factor indicated a significant increase of trash levels of up to 61%, this only equates to a 0.8-1.5% by weight increase. It would seem unlikely that an increase in trash levels of such a small magnitude would be responsible for such a large decrease in bin weight. This raises the suspicion that the primary extractor fan may selectively remove billets having lower density due to damage or small diameter.

Fan speed and billet length effects were additive in nature (Figure 5). It is important to note that all trials not summarised here showed similar statistically significant effects.

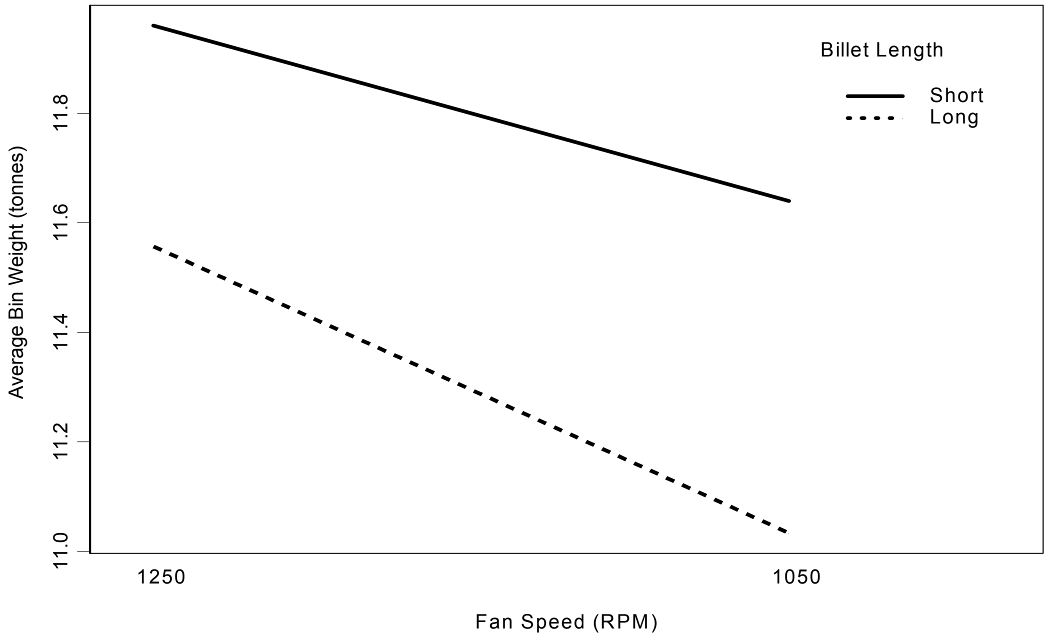


Figure 5 Effects of fan speed and billet length on bin weight

5.8 Percent trash by weight

The measurement of trash is particularly prone to bias due to samples being removed from the top of the bin only, and to the extent and nature of trash variation within the bin being an unknown entity. It is considered reasonable to assume, however, that the results here, having been derived from replicated trials, should actually represent the magnitude of relative differences between treatments.

Significant trash differences between billet lengths were rarely found in these trials, although the non-significant trends generally indicated trash levels to be proportionate to billet length. These increases, as *percentage of trial mean trash percent biomass weight* lay between 0.25 (Sciacca) and 19.57% (Tully), with the latter relative difference strongly statistically significant.

Fan speed was of statistically significant importance to trash levels in all trials, with the effect of increasing fan speed from 1000 rpm to 1250 rpm estimated at 40-61% less trash percent biomass weight. All effects here were additive in nature.

5.9 Effect of billet length upon billet quality

It was difficult to detect statistically significant results when assessing billet quality. I consider that this is due to the additional layer of experimental error imposed by the qualitative nature of the measurement, and that there was often more than one person assessing billet quality in any given trial.

All trials did, however, show that billet quality followed an upward trend as billet length increased. This is well illustrated by the box plot (Figure 6) (pr(F)=18%). This is considered a function of the additional forces that occur during chopping of short billets, as described by Hockings *et al* (2000).

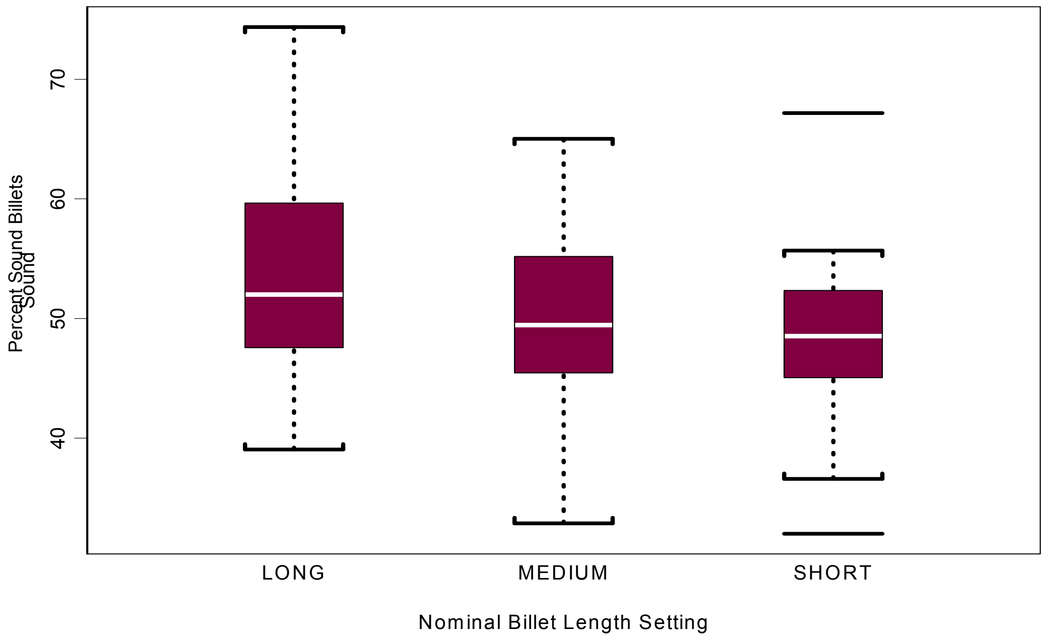


Figure 6 Boxplot showing the typical relationship between billet length and billet quality (data from Singh's trial)

5.10 Small-mill trials

The significant relationship between billet length, CCS and purity noted in the field trials became a contentious issue in Mossman and within BSES, as this interaction had not been identified before. There was general consensus that the effect, given the relatively short cut-to-crush delay, was likely not to be real. It was thought that this effect was most likely a result of a quirky combination between chance and large variation across the field.

As a result, the following small-mill trial was conducted. ANOVA results for this trial are included in Appendix 1.

Increasing billet length caused a significant net increase in the polarity of juice. This relationship was not dependent upon cut-to-crush delay, and occurred even when the samples were crushed immediately following cutting. This was surprising, as we assumed that the relationship seen in earlier trials was largely due to short billets having more open surfaces for bacterial colonisation and polysaccharide production. This contention was challenged by the trial, and a new hypothesis developed: that the higher pol in long billets might be due to a higher percentage by weight loss of high pol first expressed juice (FEJ) in short billets.

Polarity also decreased significantly in proportion to cut to crush delay, with a spike at the 6-hour point. I consider that this pol spike was a direct result of water evaporation from the cane during the first 6 hours after cutting (Figure 7); Figure 8 gives confidence intervals for these findings.

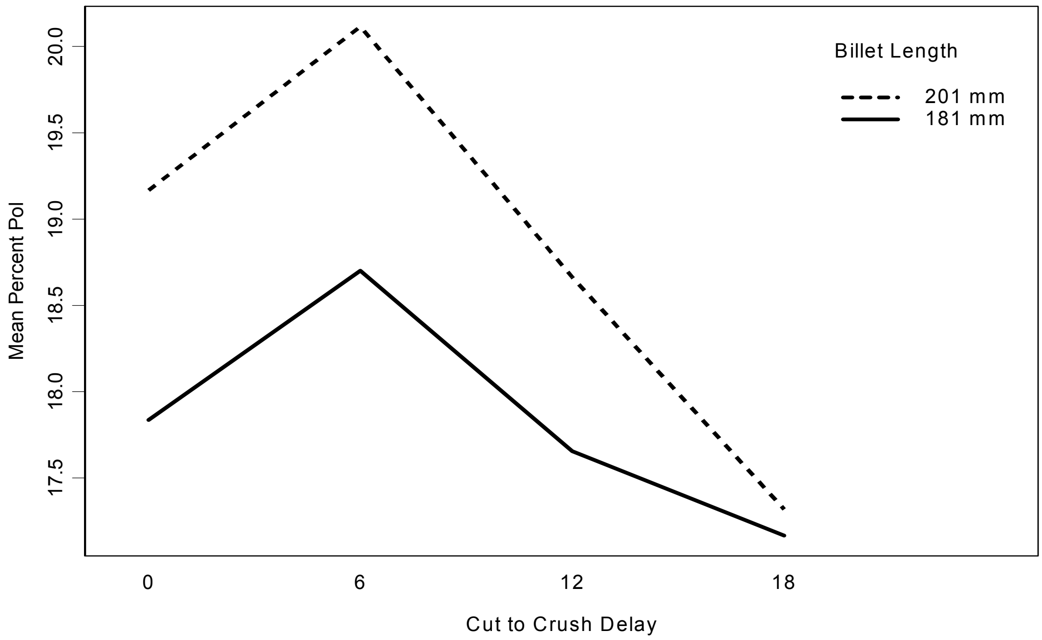


Figure 7 Pol trends in small-mill trial

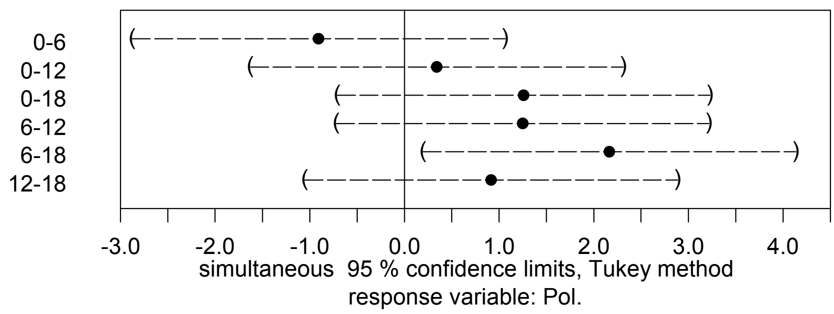


Figure 8 Multiple-comparison plot showing effect of cut-to-crush delay on polarity

The divergence in pol levels at the later stages of the trial was associated with decreasing filterability of the mixed juice. This was interpreted as an indication of increasing dextran concentration. Treatment effects for both billet length and delay were additive.

Brix levels were directly and significantly proportionate to billet lengths, and trended downwards as cut-to-crush increased. The trend of the brix response was broadly similar to that for pol. However, the response shown for cut-to-crush delay was not statistically significant. All factor effects for brix were additive (Figure 9).

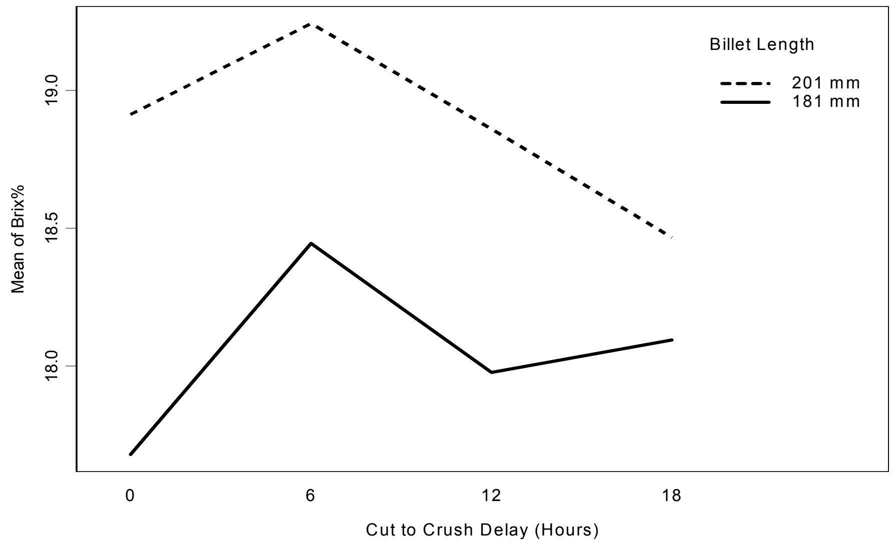


Figure 9 Brix trends (billet length versus delay) in the small mill trial

The effects of billet length and cut to crush delay upon brix and Pol combined to form significant effects upon CCS. Increasing the billet length from 181 mm to 201 mm led to an overall average statistically significant estimated CCS increase of 0.805 units or 5.92% as a percent of the trial mean. CCS declined significantly from the 6-hour delay to the 18-hour delay by 2.41 units or 17.74%. Treatment effects were additive in nature (Figure 10). Summary statistics for the small trial are given in Table 4.

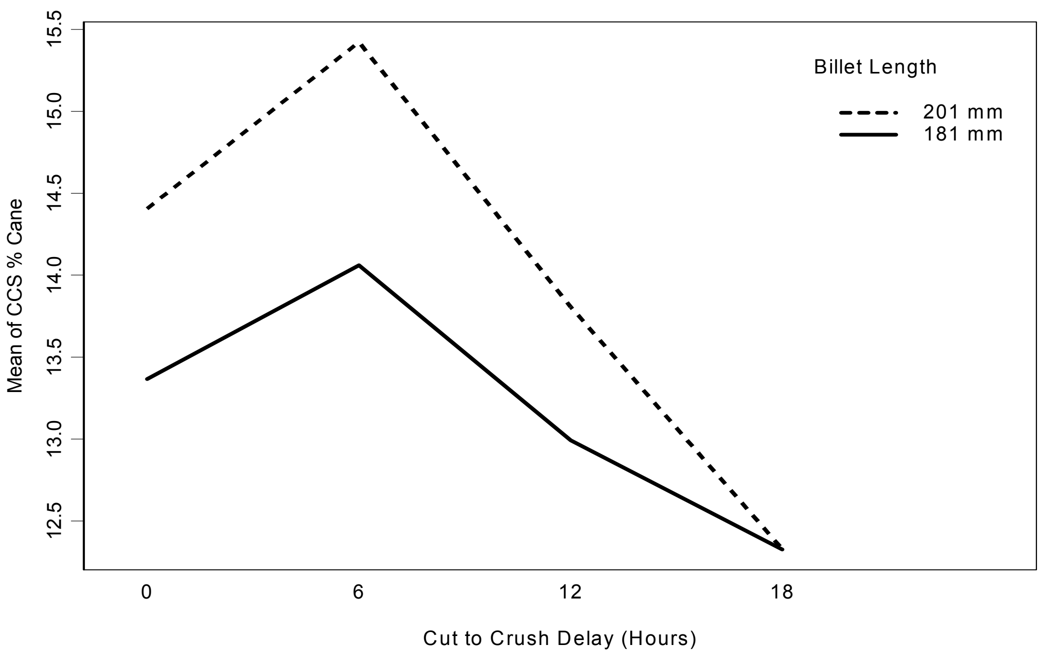


Figure 10 Commercial Cane Sugar versus cut-to-crush delay and billet length

Table 4 Summary statistics for the small-mill trial

Measure	Grand Mean	Estimated Effects Increase or (Decrease)#		Estimated Effects % Increase or (Decrease)#	
		Short to Long	6-18 hours	Short to Long	6-18 hours
Pol	18.32%	0.976 ***	-2.17 ***	5.33% ***	(11.84)% ***
Brix in Cane	18.46%	.821 ***	-.56 ns	4.45% ***	(3.03)% ***
CCS	13.59%	.805 **	-2.41 ***	5.92% **	(17.74)% ***

* = sig @ pr(F) 15%, ** = pr(F) 10%, *** = pr(F) 5%
\# = As percentage of trial mean

5.11 Fan speed and billet length interaction trials

Some small replicated trials were conducted to determine the effect of fan speed upon average billet length in the bin after some unusual results were obtained during a factorial fan speed trial in the Burdekin (Figures 10-12).

The data obtained in these trials are considered to be of at least academic interest, and possibly of great importance to future harvester research. The trend was initially noticed during routine statistical evaluation of data collected in a field trial that was otherwise unusable due to a mill failure. This trial had incorporated quite extensive EM sampling and billet-length assessment, and these results had shown what was considered to be an irregularity in the data, ie that billet length at any given billet setting varied with fan speed, and that this interaction between billet length setting and fan speed was not additive in nature. That is, the overall trend of the effect seemed to be different depending upon the billet length selected.

Figure 11 shows this irregularity. At the long-billet-length setting, average billet length decreased as fan speed increased above 1000 rpm. At the short-billet-length setting, the opposite trend was observed. Two additional trials were conducted, and both showed similar results (Figures 12-13).

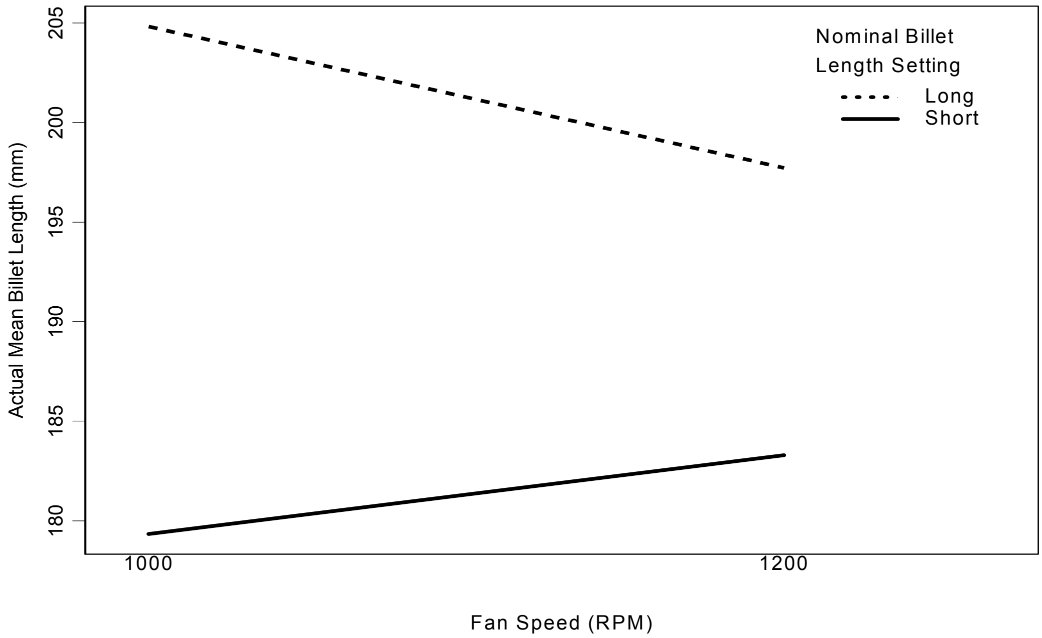


Figure 11 Interaction between billet length setting, primary extractor rpm and actual billet length (Stockham trial 1)

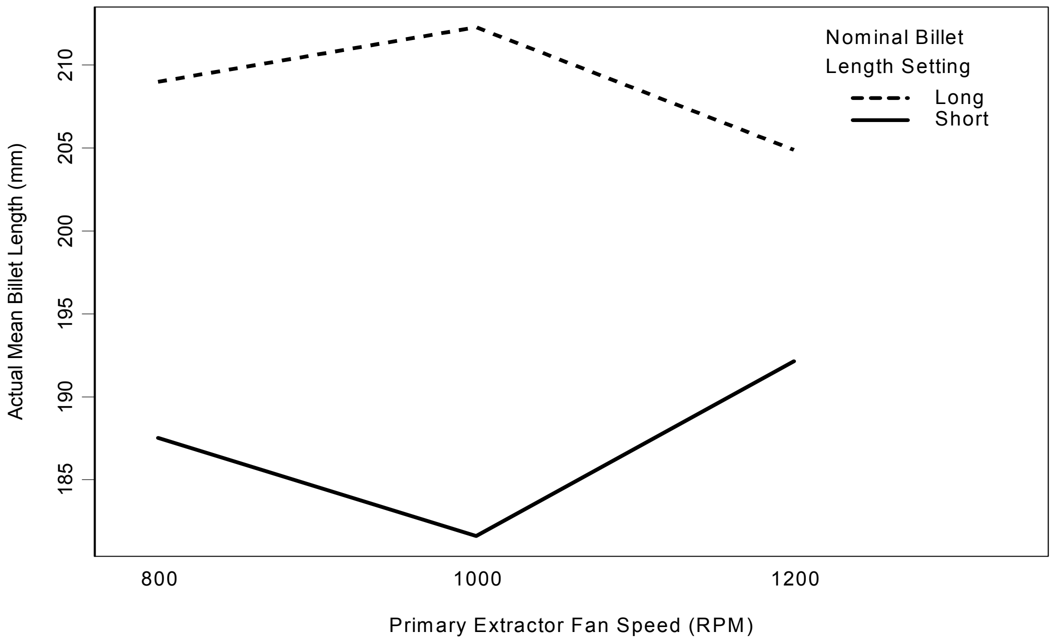


Figure 12 Billet length setting*rpm interaction on billet length (Rover trial)

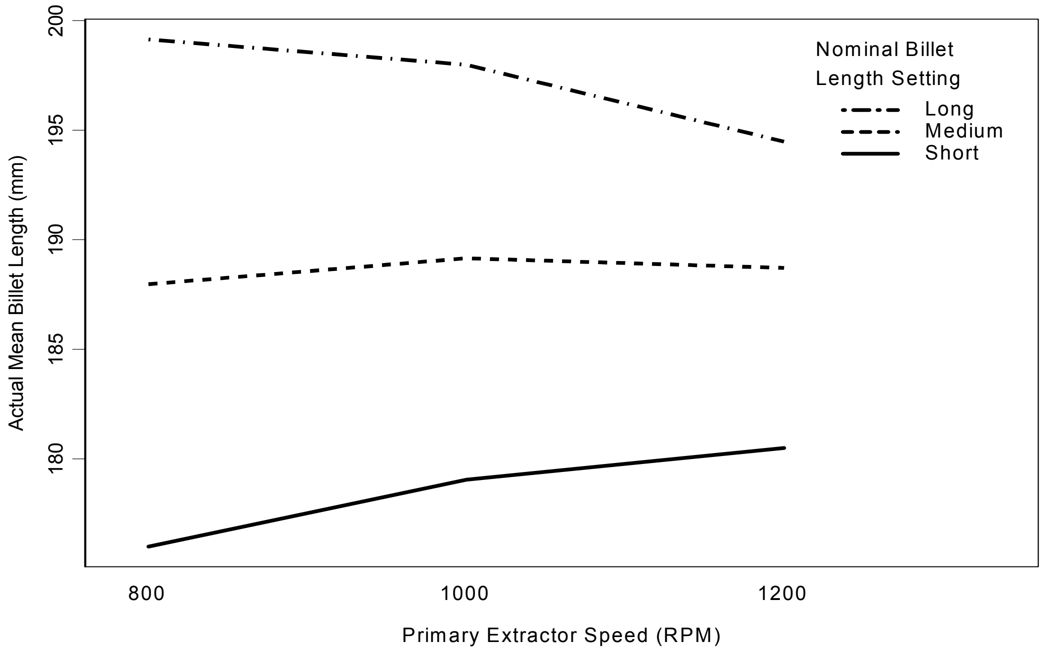
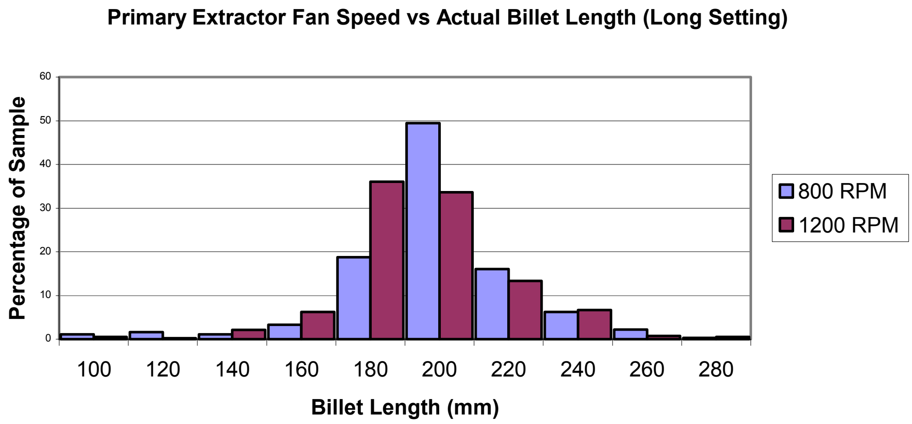


Figure 13 Billet length setting*rpm interaction on billet length (Stockham trial 2)

Initially, it was somewhat difficult to understand what these results represented, as billet length is controlled by a different hydraulic circuit to that of the primary extractor fan. There was no obvious mechanism by which changing the fan speed could physically alter the billet length produced.

The only logical conclusion is that these trends represent a degree of selective removal of billets above and below a certain critical value, with that critical value perhaps changing non-linearly with increasing fan speed. This is most evidenced by the divergent characteristics of the graphs above as fan speed increases above 1000 rpm.

If this hypothesis is supported by future trials, it will have *significant implications upon the interpretation of previous harvester trials*, and the future design of the harvester. Most harvester cane-loss trials in Australia and abroad have been performed with the unconscious precept that any billet-length fan-speed interaction would be additive in nature. Figure 14 shows the breakdown of billet lengths under each setting.



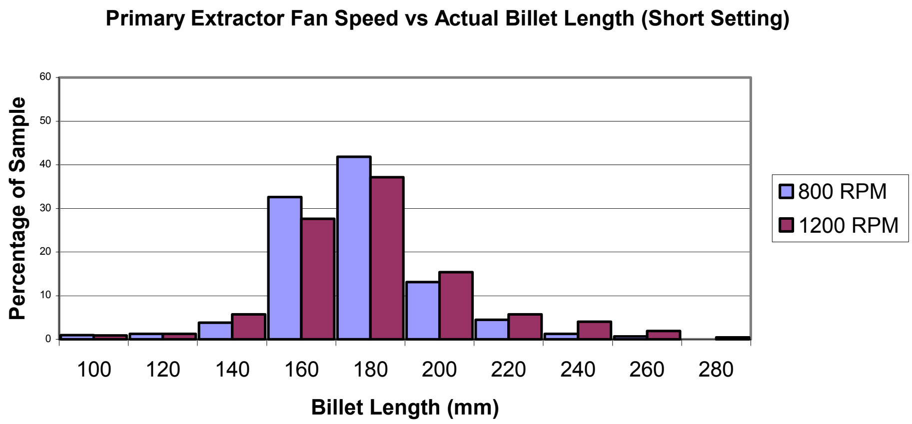


Figure 14 Billet length frequency histograms for nominal long billets (top) and short billets (bottom) at two primary extractor fan velocities

6.0 DISCUSSION OF RESULTS

6.1 Background to the billet-length results

Although no long-term information on average billet length for mill areas has been collected, anecdotal evidence suggests that average billet length has been declining over the last 20 years. In the late 1970s and early 1980s, the most commonly installed chopping system in mechanical harvesters was either a swinging knife, or a 12-inch rotary chopper with two blades per drum. Both these systems tend to cut a 300-325 mm billet when set up properly. As time passed, people began to realise that they could improve bin weights and cleaning somewhat, by shortening the billet. Figure 15, gives an indication of the attitude to the importance of billet length in 1973.

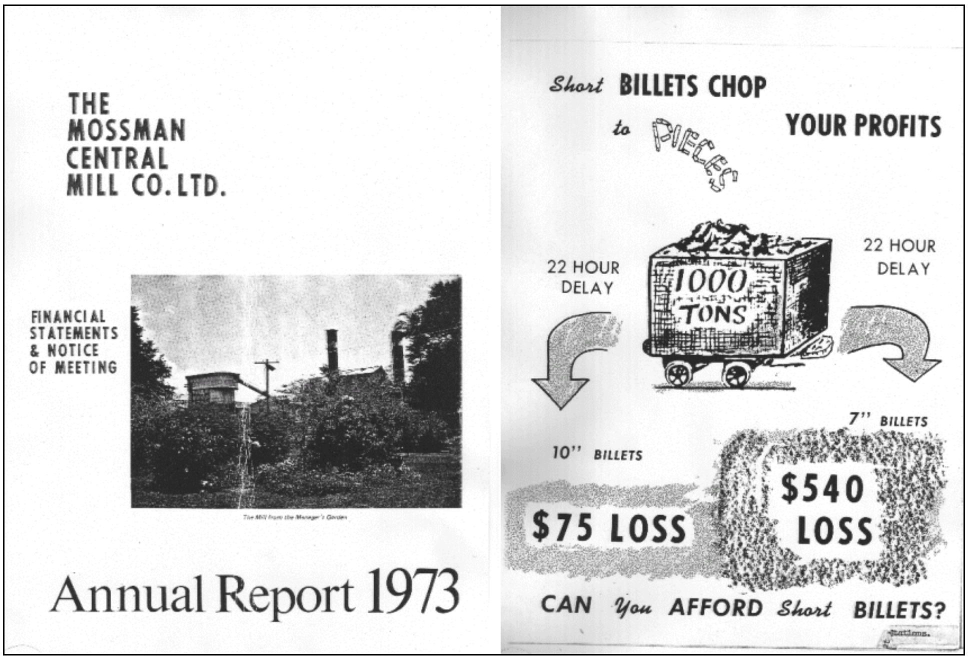


Figure 15 Extract from Mossman Cooperative Mill Annual Report, 1973

Figure 15 shows that the views at the time were largely against such shortening of billets. However, with time, and the widespread introduction of green-cane trash-blanketing, millers and growers softened their hard-line attitude on billet length. It was considered that the majority of the loss referred to was due to dextran activity, which was considered to be a less problematic issue when cutting green cane. Furthermore, mills had become more efficient, with most beginning to crush 7 days per week, which helped to reduce cut-to-crush delay.

By the late 1980s to early 1990s, most machines had either slowed down the feed train or accelerated the choppers in an attempt to improve bin weights. In hindsight considering the data of Hockings *et al.* (2000), this would have led to a significant increase in juice loss and damage in billeted cane, by increasing the speed of the choppers relative to the feed of cane to supply them.

Field observations suggest that, by about 1988, harvester manufacturers had begun to make changes to the harvesters in deference to the demand for a shorter billet. By 1992, harvesters were fitted with three-blade choppers as standard, and tended to produce billets 180-240 mm long, depending upon the way the machine had been set up.

1996 saw the introduction of the 15-inch chopper drum, which was touted as a way to allow more room for cane to pass between the drums and thus reduce losses. In practice, the opposite may have occurred. By increasing the diameter of the chopper drums, the manufacturers had increased their tip speed, which increased the mismatch between the speed of the choppers and feed-train further. Furthermore, many growers ordered machines with three blades per drum, probably without realising that due to the larger diameter of the chopper drums, a three-blade 15-inch chopper would produce a billet of 280-300 mm instead of the 180-230 mm billet they had become used to.

As a result, the manufacturers introduced a 'billet-length' selector valve that allowed the operator to shorten the billet length from the cabin of the harvester by slowing down the speed at which cane was fed to the choppers. This allowed machines to produce a 180-230 mm billet. However, anecdotal evidence suggests that many saw the lack of uniformity of billet quality and length from these 1996 machines as a problem. As a result, many operators from 1996 onwards opted for four-blade 15-inch chopper. These are now the standard chopper and, depending upon machine set up, are capable of producing billets of 100-200 mm in length.

Hence, in the last 20 years, billets produced by mechanical harvesters have approximately halved in length. Mills have not been too concerned about this trend, as the belief seems to have been that with the passing of burning and reduced cut-to-crush delays, billet length related sugar loss was no longer a serious issue. Some mills would have also seen the increasing bin weights achieved by shorter billets as beneficial to the efficiency of their transport operation. The advice given in Figure 15 now seems ironic, as the average billet length in the Mossman region is now close to 180 mm.

6.2 Discussion of results

The results of trials conducted during this project point to a different conclusion, ie that the causal link between billet length and harvesting related sugar loss remains. The components of these losses appear to include additional relative physical cane loss, and an immediate reduction in CCS as billet length reduces. To my knowledge, neither of these sources had been specifically identified prior to this project.

A weakness of these data is that they do not provide any indication of whether this effect is predominantly due to actual physical length, or differences in the roller to chopper ratio as described in Hockings *et al.* (2000). I suspect that both factors probably contribute about equally.

The evidence to date suggests that the majority of this CCS depletion *is not* linked to additional polysaccharide formation in short billets, although this undoubtedly still occurs. It appears that the CCS reduction occurs at the time of harvest, with the most likely cause being loss of high pol juice during chopping. This contention is supported by the results of the small-mill trial, and also that all trials occurred in green cane with a minimal cut to crush delay of 8 hours or less.

Increasing billet length was shown to cause a reduction in the percentage of damaged billets in the cane sample, most probably due to the additional force applied by the choppers when cutting short billets. Hockings *et al.* (2000) showed that when cutting such billets, the force applied to the cane bundle can approach 120 kN, which is roughly equivalent to the drawbar pull of an 120 HP tractor. Considering that this force occurs roughly 12 times per second, it is no surprise that additional damage is inflicted.

This action was also shown by Hockings *et al.* to cause chopper-related juice loss of up to 12% by weight of cane, with the loss being inversely proportional to the billet length produced. Other work by Norris *et al.* (1998) and Berding *et al.* (2002) has suggested that much of this juice is then transferred to the trash, from where it is either removed by the primary extractor fan or sent to the mill. Perhaps surprisingly, the research has suggested that this transferred sugar can then be recovered by the mill, although it is especially prone to bacterial degradation during the intervening delay.

I believe that this mechanism accounts for the majority of the ‘missing sugar’, evidenced by the difference in pol between billet lengths, as the juice removed is first expressed juice and hence high in pol. The fact that the increased CCS in long billets occurred even in the presence of a 2-3% (0.25-0.5 unit) fibre increase I consider to be complementary to this argument.

The information gathered regarding the previously unknown relationship between billet length and pol should be taken seriously during policy formation by millers and research organisations such as BSES. For the last 20 years, the industry has unconsciously or otherwise been moving towards a much shorter billet length. The results of trials during this project would indicate that this move could well be part of the reason for the declining CCS trend in far north Queensland.

This contention becomes especially strong when one examines the data of Lawes (2000) (Figure 16), which shows a sharp decline in mill CCS over the last 20 years. Over the same time period, the CCS of field wholestick samples remained constant. Lawes relates this discrepancy to increasing levels of extraneous matter. However, that hypothesis remains untested and largely unsupported due to a lack of information on mill EM levels. His contention could easily be tested if corresponding data on pol was obtained. If these data showed that mill pol had also declined, it would serve as substantial vindication of my belief that the phenomenon is mostly due to a consistent decline in billet length during the same period.

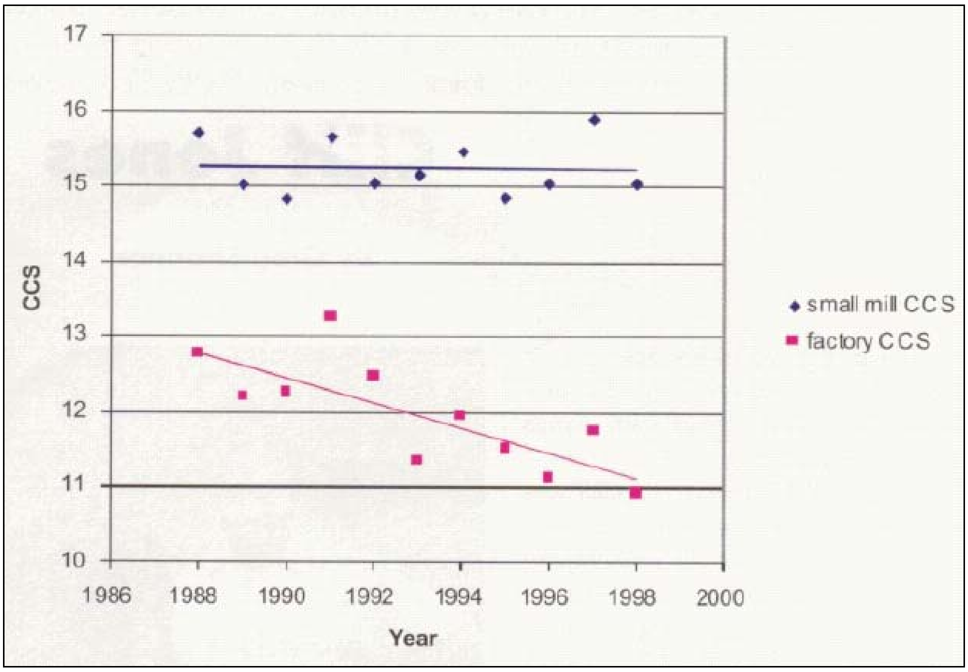


Figure 16 **Relationship between small-mill whole-stick samples and actual mill CCS over the last 15 years (Lawes 2000)**

The CCS difference alone, however, does not explain the entire difference in per hectare sugar yield. The data showed a large recovered biomass yield increase from short to long billets that was not explained by the small increase in trash levels seen with the longer billet treatments. I conclude that shorter billets are, therefore, more effectively removed by the primary extractor fan. Further supporting evidence is provided by the apparent difference in billet length distribution between fan speeds.

The proportional relationship between NIR ash and billet length is of interest, as the magnitude of the increase is not completely explained by the corresponding small fibre increase. The difference in ash, therefore, is probably due to additional removal of entrained soil in the short-billet treatments. This might occur within the feed train itself due to the additional aggression inflicted upon the cane bundle during the chopping of short billets, or at the choppers themselves for the same reason. The fact that the fan speed and billet length apparently combine to form a statistically significant interaction upon ash levels would suggest that the majority of this dirt removal occurs at the choppers.

Billet length had a significant effect upon bin weight, with an increase of around 10% achieved by reducing the billet length, but at the overall expense of recovered yield. This is discussed further in the next section of this report.

7.0 OUCOMES

I consider that the outcomes of this project have the potential to directly or indirectly contribute to significant change within all sectors of the Australian sugar industry. The extent of this change will be limited by how seriously the results are taken, which will concurrently depend upon how each individual section of the industry perceives how the changes would benefit, or be of detriment to their position. The likely impact of the two main outcomes of this project (widespread extension and implementation of feed-train optimisation and billet length research) are summarised below.

7.1 Billet-length research

It seems apparent that there are definite recoverable sugar yield benefits to be gained by cutting a longer billet (Table 5).

Table 5 Relative returns per hectare for various fan speeds * billet length combinations (data from Sciacca trial)

Treatment	**1250 / SHORT**	**1050 / SHORT**	**1250 / LONG**	**1050 / LONG**
Lab CCS and Fibre				
Pol	19.43	19.63	19.90	20.27
Brix	21.83	21.77	21.87	22.23
Fibre %	13.99	14.00	14.30	14.56
CCS	**14.55**	**14.82**	**15.05**	**15.29**
Cane Payment and CCS				
Sugar price $/tonne	$ 300.00	$ 300.00	$ 300.00	$ 300.00
Harvesting	$ 6.00	$ 6.00	$ 6.00	$ 6.00
Grower Levies	$ 0.38	$ 0.38	$ 0.38	$ 0.38
Mill Levies	$ 0.19	$ 0.19	$ 0.19	$ 0.19
Lab CCS	14.6	14.8	15.0	15.3
Mill daily ave CCS				
Mill Season CCS				
Relative CCS	14.6	14.8	15.0	15.3
Tonnes/ha	**54.48**	**57.61**	**53.61**	**62.89**
Grower Fibre	14.0	14.0	14.3	14.6
Grower CCS	14.6	14.8	15.0	15.3
Industry Return	**$ 2,203**	**$ 2,372**	**$ 2,240**	**$ 2,669**
Growers Return $/ha	**$ 1,290**	**$ 1,405**	**$ 1,341**	**$ 1,614**
Mill return $/ha	**$ 587**	**$ 621**	**$ 577**	**$ 677**
Harvester $/ha	**$ 327**	**$ 346**	**$ 322**	**$ 377**

	1250 / SHORT	**1050 / SHORT**	**1250 / LONG**	**1050 / LONG**
Growers Return $/ha	$1,289.56	$1,405.48	$1,340.59	$1,613.79
Mill return $/ha	$586.83	$620.61	$577.50	$677.43
Harvester $/ha	$326.86	$345.68	$321.67	$377.33

The overall figures in Table 5 are enticing. However, it is the grower that is the main beneficiary of these changes, as he receives the benefit of increased CCS. The benefits to millers and harvester operators are comparatively small, and based almost entirely on the benefit of additional physical recovered cane yield per hectare.

The side effect of increasing billet length is that bin weights decrease (Figure 17), which increases the marginal per tonne cost of transport for the milling and haulage sectors of the industry. With both of these sectors (and especially the harvest and haul out sector) under extreme financial pressure, the observed reaction to this research has naturally been reluctance to act, and is often evidenced as incredulity.

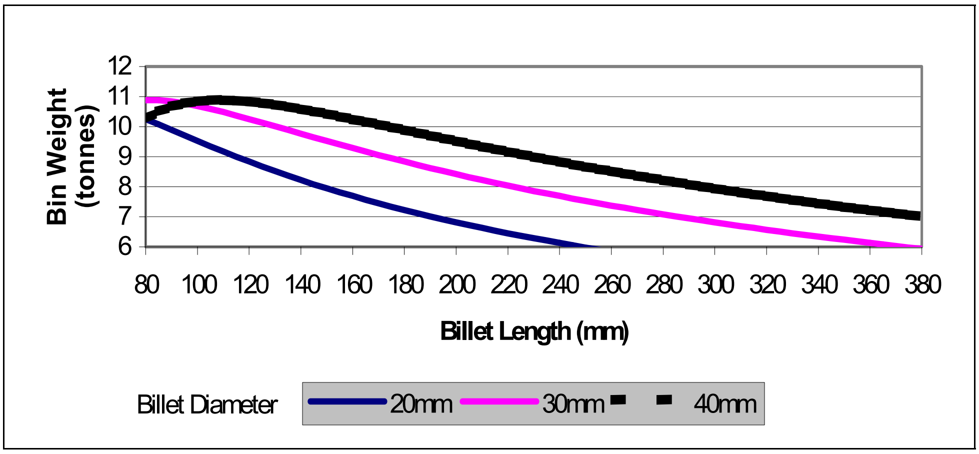


Figure 17 Estimated effects of billet length and diameter on average bin weights for Mossman high-sided bins (adapted from a model by Parkhouse and Kelly 1995)

The reality is probably that all sectors would be more profitable overall if these changes were implemented, regardless of the bin weight effect. Vitale and Domanti (1997) attempted to collate all available data pertaining to the effect of billet length on factors such as bin weight, extraneous matter levels and cane loss. Using these relationships, they developed a model to predict the cost of different billet lengths to the industry. The conclusion of the model was that the 'optimum billet length' using typical data was around 190 mm.

The model was an excellent attempt at helping the sugar industry make educated decisions regarding billet length. However, with the benefit of hindsight it had a number of fatal flaws. The model assumed:

- that extraneous matter levels were significantly affected by billet length (a tenuous assumption from the results of my study);
- that extraneous matter was totally devoid of sugar, and as such has a purely deleterious effect upon mill efficiency - since cast into doubt by Davis and Norris (2001) and more recently by Berding *et al.* (2002);
- that billet length had no effect upon physical cane loss from the extractor (not supported by my results);
- that juice losses in the choppers were substantially less than determined by subsequent research by Hockings *et al.* (2000).

The model also failed to include billet diameter as a significant factor affecting bin weight. This was a serious omission in the light of data from Parkhouse and Kelly (1995), which indicates that billet diameter may have an extremely large effect upon bin weight. Vitale and Domanti also stated that sensitivity analysis of the model showed that cane loss during harvesting and the cost of EM to be the two most influential variables impacting on the outcome of the model. Since the assumptions used within the model for both these factors have now been questioned, it is reasonable to assume that the true 'optimum billet length' for the industry would be substantially longer than 190 mm.

In conclusion, my data suggest that, if the relative losses recorded were consistent across the entire industry, moving to a longer billet setting could lead to a conservative 5% increase of whole of industry net returns. This equates to about $50 million per year for the Queensland industry.

More fundamental work needs to be completed before this assumption can be fully validated. Recommendations for such work are detailed below.

7.2 The feed-train optimisation process

The research outcomes of Hockings *et al.* (2000) have now been known throughout the industry since 1998. Even so, the uptake of the new technology was slow until my project provided field data to support its findings. These field data have shown that, in most cases, the chopper test rig underestimated the true magnitude of physical cane and juice loss differences between an optimised and non-optimised machine. The graph below (Figure 18) plots field test losses against actual relative field losses, calculated using data obtained during this project.

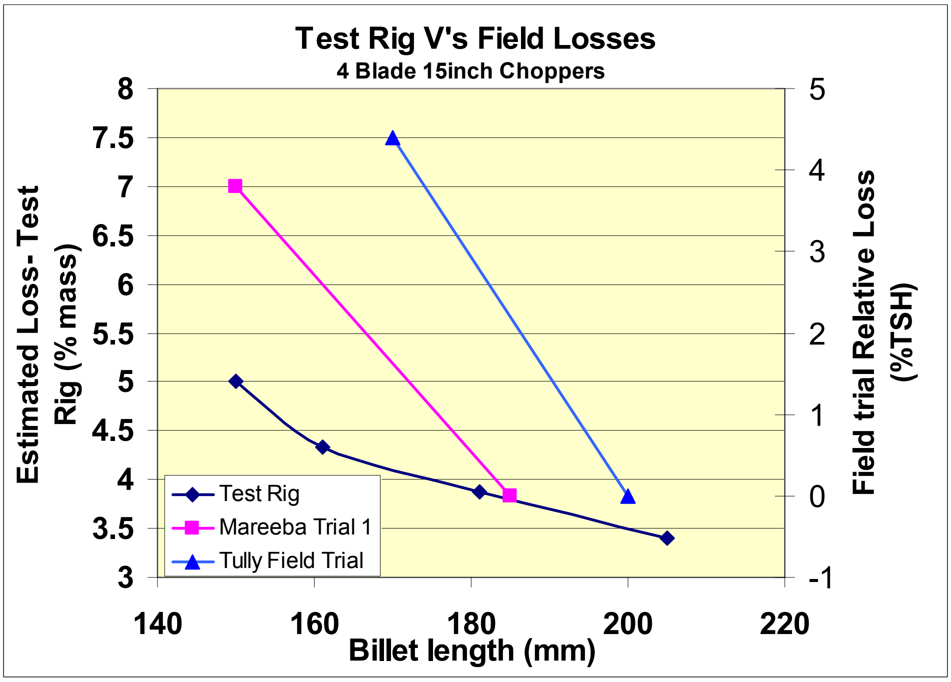


Figure 18 Actual field physical losses versus test rig losses (combining data from Hockings *et al.* (2000) and this project)

Since field validation of the test rig results during the 2001 season, recommendations have been formulated and provided for approximately 8% of the Queensland mechanical harvesting fleet. Actual recoverable sugar yield improvements attributable to machine optimisation based upon data from this project are estimated to be 4-7%. If this figure was even as low as 1%, the overall net additional sugar production would be worth around $10 million dollars to the Queensland industry each year.

Optimisation also causes an improvement in billet quality, which has important downstream positive financial consequences for billet-planted crops. Anecdotal evidence suggests that the strike and density of billet-planted crops was significantly improved after optimisation of the feed-train components of a billet-harvesting machine.

There are a number of possible reasons for this improvement. The most obvious is that there are fewer entry points for pathogens, such as pineapple disease. Field observations, however, suggest a less immediately obvious reason.

The metering system in billet planters relies upon a ‘mass flow’ system whereby billets are randomly pulled from a large sample by an elevator and placed into the ground. This system is notoriously random and uneven. However, at present, there are no effective alternatives for planting billeted cane. Whilst this system should theoretically be completely random, field observations suggest that the planters tend to selectively meter the shorter billets in a sample first. These shorter billets often have greater levels of damage, and depending upon the length, may have only one eye. Both of these factors can encourage infestation of planted billets by pathogenic organisms, which have adverse implications on subsequent crop establishment.

One of the less obvious benefits of feed-train optimisation for billet planting contractors is that it allows the machine to produce billets that are of an extremely uniform length (Figure 19). The metering of these even billets (giving a more even crop) is generally superior to the more variable billets from an unmodified harvester.

Figure 19 Billets produced by an optimised harvester

8.0 OUTPUTS

The feed-train optimisation process has been further developed, and is now a commercial service run by the BSES. This service provides advice to growers and harvester operators regarding optimisation of their machinery, and aims to add value to the process by finding the absolute least-cost method of conducting the modifications.

Judging from current demand, I expect that this technology will have been adopted by 50% of existing harvester operators by 2004. One major manufacturer has also indicated that they intend to implement the recommendations of this research during production of all new machines.

8.1 The feed-train optimisation model

Early in the project, I was made aware of a technique developed in Bundaberg by Hockings *et al.* (2000) known as 'feed-train optimisation'. This technique had been shown to substantially reduce the magnitude of juice losses during the chopping process of mechanical cane harvesting, and substantially improve the quality and uniformity of harvested billets. Owing to the apparent effect of billet length and quality upon economic returns discovered during this project, I considered 'Feed-Train Optimisation' as a process that had significant potential to lift economic returns in the Mossman area.

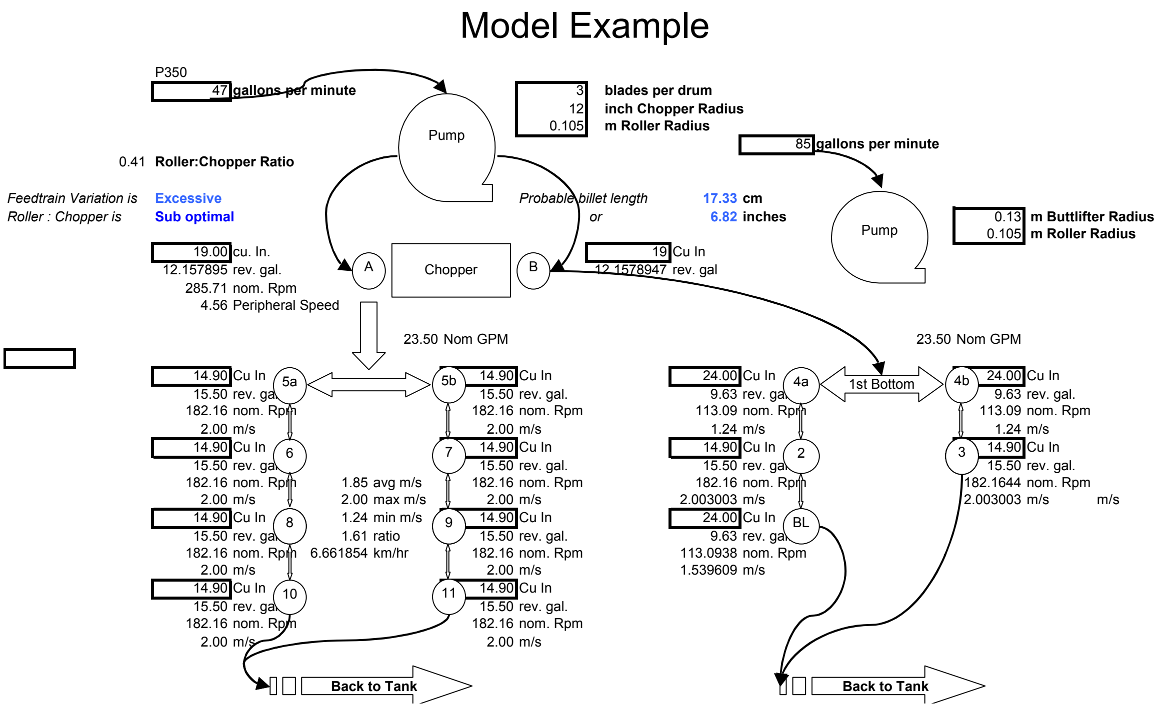


Figure 20 A screen shot from the feed-train optimisation model

After some initial benchmarking of the local Mossman harvesting fleet, it became quickly apparent that the feed-train and choppers in machines were set-up in a diverse number of ways, and that there was never going to be a single solution that would suit every machine. The process of working out the most economically sound way of implementing an 'optimised feed-train' for each machine was proving to be extremely time consuming and prone to a range of errors. As a result, I developed a computer model. The intention of the model was to help facilitate more rapid, accurate and cost effective extension of the technique. The model was written using Microsoft Excel, and is relatively straightforward in construction (Figure 20).

Two machines were 'optimised' using this model prior to the 2000 crushing season, and underwent testing during the season. The effect of feed-train optimisation upon billet quality, feeding and cleaning was noticeable. In the following year, the majority of harvesters in the Mossman mill district underwent some form of feed-train modifications. Since 2000, the model has been used to assist over 120 operators to find the most cost-effective way of modifying their machines, with many more considering undergoing the modifications during the coming season.

8.2 The harvester feedback model

A computer model (Figure 21) was designed during the later stages of this project in an attempt to improve the timeliness and effectiveness of feedback mechanisms to the harvester operator. The model was quite complex in nature. It had to combine the processing power of four separate computer programs (Excel, Mill Database, Microsoft Access and S-Plus) into one functional user interface.

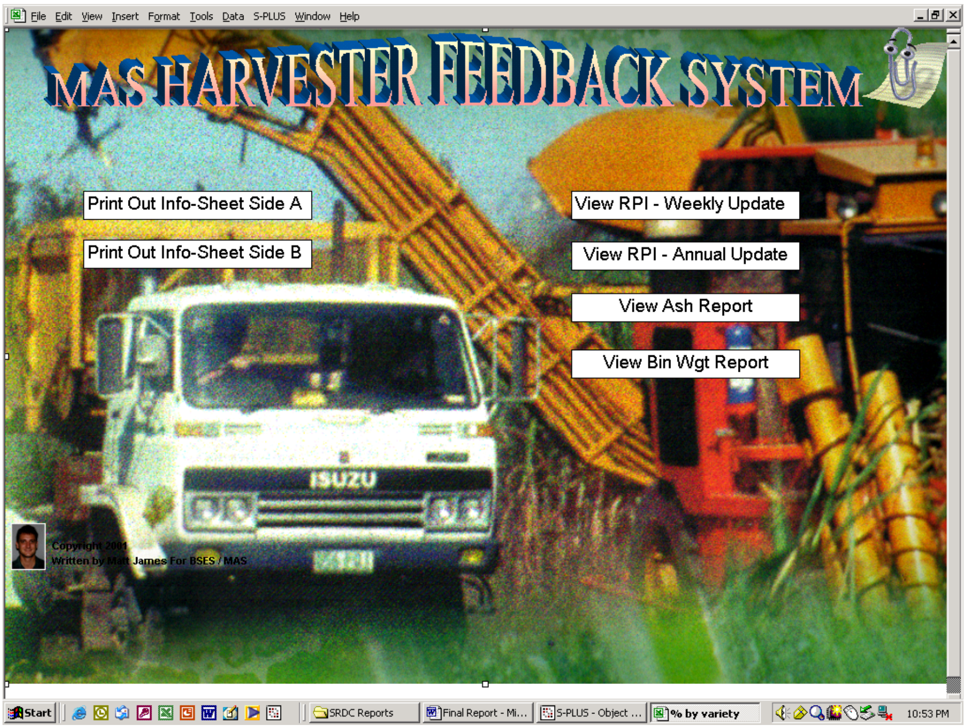


Figure 21 Screen shot showing the Graphical User Interface (GUI) of the feedback model

8.2.1 How the model works

The model first retrieves live rake data from the mill's server via a direct network connection. These data come in two separate tables, the first containing all mill data up to the beginning of each week, and the second containing rake data from the current week. These two sources are first imported into Microsoft Excel, and a large Visual Basic program called a macro then converts the data to a form suitable for further manipulation by another program, Microsoft Access (see Figure 22 for an example of this code).

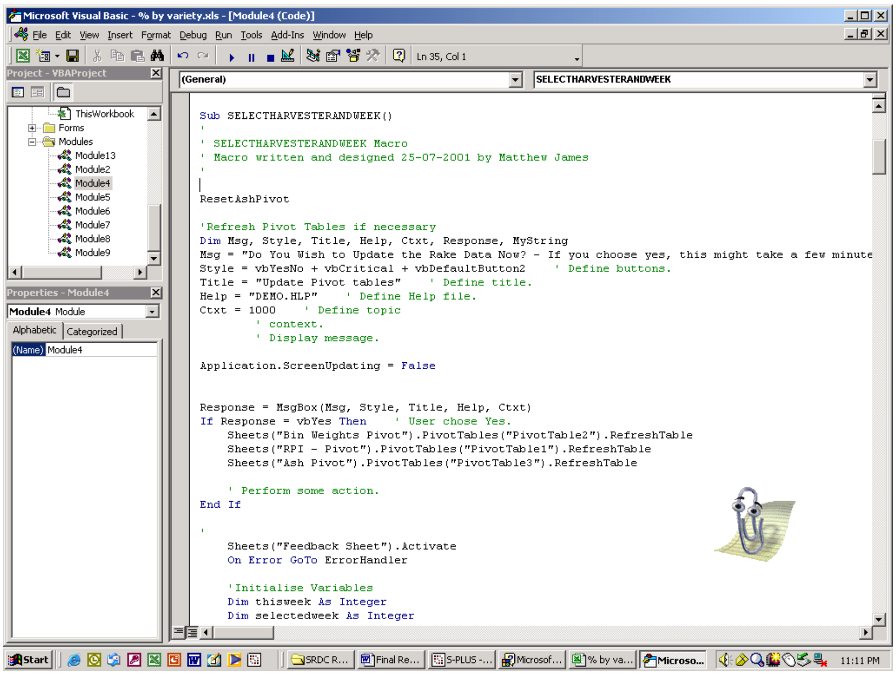


Figure 22 An example of Visual Basic code used by the model

Microsoft Excel then sends the two tables across to Microsoft Access, which appends the two tables together into one fully functional rake data database. Access then examines the data and, in the likely scenario where more than one rake has been delivered from any given block on a single day, the rakes are combined and a weighted average produced. A number of calculations are then conducted, based upon some initial research done prior to development of the model.

Rake data were analysed using Principal Components Analysis (PCA). This process allowed the determination of the quantifiable fixed differences in rake data (such as harvester driver, crop variety, crop class, soil type, harvester brand, geographical location, drop-off point and type of harvesting machine for example) and which contributed the most to rake data variation. Why? I hoped to be able to produce a model that could remove some of the sources of variability in rake data not attributable to the harvester operator. In effect, I was trying to create a level playing field. From this analysis we identified week of harvest, crop class, geographical location and crop variety as being the three components contributing the most to variability in fibre, ash, purity and CCS levels. Drop-off point was identified as the major contributing factor to variations in bin weight.

The next logical step in the model was to summarise the data by week of harvest, crop class, geographical location, crop variety and drop off point. Standard deviations and means were calculated for each combination of these five factors. These data were then combined with the raw rake data, and sent back to Excel, which then used the standard deviations from each group to 'standardise' the rake data, that is, to express the rake data as a function of standard deviations from the mean of each principal component (This technique is broadly similar to that employed in the OP system for tertiary admission to Queensland universities, and I acknowledge the statisticians from the Queensland Tertiary Admissions Centre (QTAC) for their information and assistance).

For example, if a harvester operator was harvesting in an area particularly prone to high ash levels, this part of the model attempts to take that fact into account, and modify his ash levels so they better represent his relative performance compared to other operators in the area (Figure 23). The standardised values are expressed in standard deviations from the principal component mean, and are generally between –3 (excessively low compared to others in the area) and +3 (excessively high compared to others in the area). This value is called the 'RPI', an abbreviation for 'relative performance indicator'.

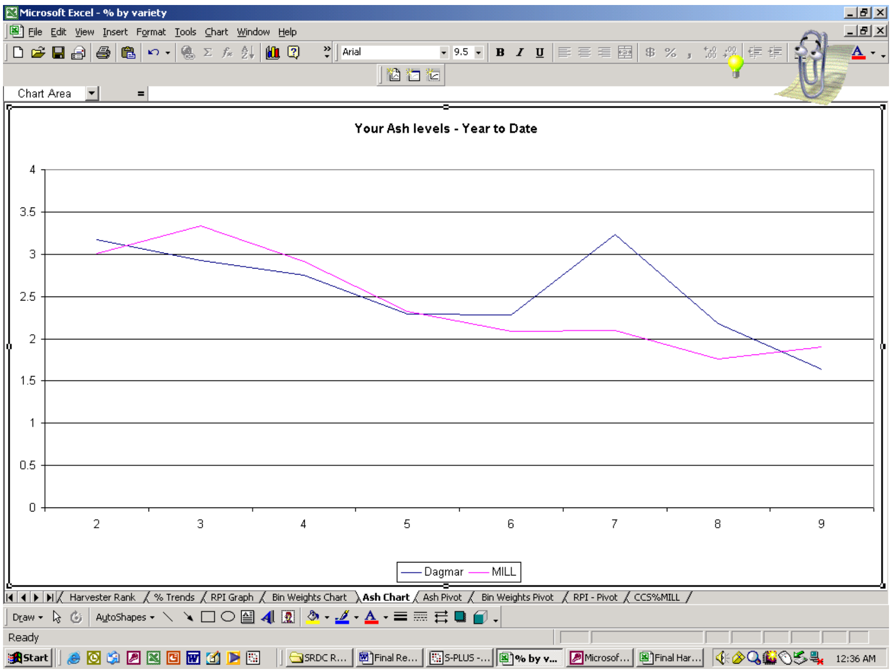


Figure 23 **Example output from the model showing weekly NIR ASH averages for a harvesting group versus the Mill Average**

The normalised data are then sent back to MS Access, which conducts other calculations and produces weighted averages of the data by block, week and harvester. The user can adjust the model so that it attributes different weights to each of the five identified principal components of variation when calculating the final RPI (Figure 24). These data are then sent back to Microsoft Excel.

A graphical user interface (GUI) in Excel then allows the user to view a breakdown of results for each harvester by week, farm and block. It also provides the user with a year-to-date graphical summary of relative performance of each harvesting group compared to mill average bin weight and ash levels.

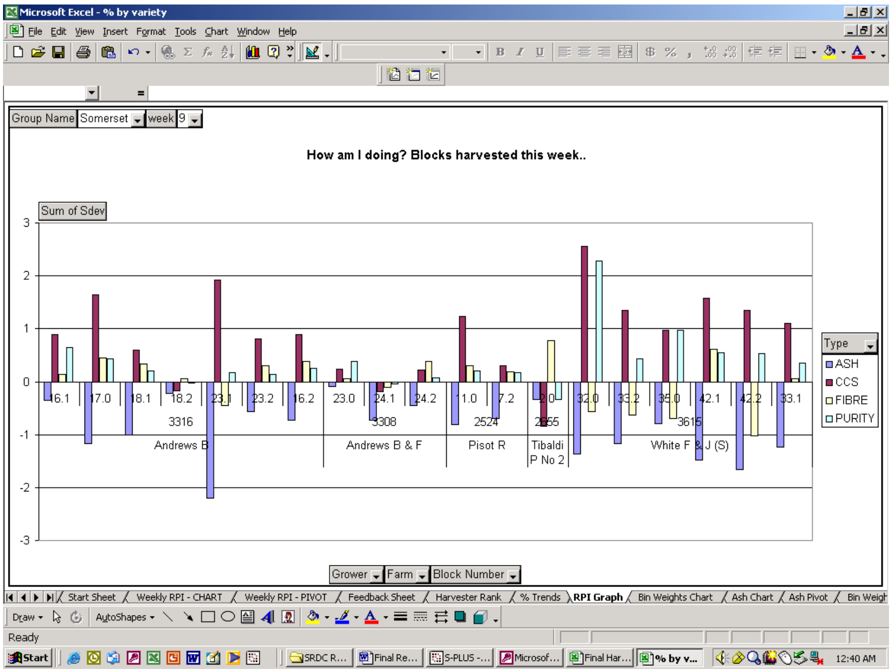


Figure 24 Example weekly RPI summary for a Mossman harvesting contractor

The model GUI is relatively seamless, notwithstanding the complexity of the model, and it is extremely easy to operate. It also has a facility to print out results, which automatically cycles through all contractors and produces a two-page weekly update for each operator.

8.2.2 What are the potential benefits of this model?

NIR has provided an enormous amount of new information, and many mills are experimenting with using it to provide a cane quality incentive scheme to growers and harvester operators. In the rush to take advantage of these new data, the approaches used so far could be considered to be fairly ad-hoc, and not necessarily in the best interest of the industry.

An example of note would be the approach used by one northern mill, which rewards harvester operators for low-fibre percent cane. This risks undermining an enormous amount of R&D work in the area emphasising the importance of maintaining low levels of cane loss by inadvertently providing a positive price signal to reward high primary extractor fan speed. Such an approach is also unfair to harvester operators harvesting high-fibre varieties.

The more measured approach of my model may help to alleviate such inadvertent effects of these cane-quality schemes. The model should also help to provide a ‘level playing field’ between harvesters, with each harvester competing against colleagues harvesting in similar conditions, rather than against the mill average. One of the significant positives of the model is that it potentially achieves this outcome without infringing the privacy of other industry participants.

Given the nature of the output of this model, it could potentially be quite easily interfaced with a GIS (Geographical Information System) such as ArcView to allow interpretation of the output to be more intuitive.

8.2.3 Why hasn’t the model been implemented?

Some preliminary ground proofing of the model was conducted during the 2001 crushing season in Mossman. The response from harvesters was positive overall. However, I refrained from further testing until the fundamental tenets of the model could be discussed in depth with statisticians, millers and industry representatives. Whilst I believe that this model has some extremely strong points, I am quite reticent to accidentally impose a model that follows the GIGO (Garbage In, Garbage Out) principle upon an industry already struggling with a multitude of complex issues. This possibility should be entirely ruled out prior to full-scale implementation.

Further development of this model is firmly in the court of SRDC, as it will require additional funding by the industry, and some co-operation between various industry bodies that would be best facilitated by a neutral body such as SRDC.

8.3 Alternative technique for determining cane loss

This project was instrumental in encouraging discussions regarding the validity of the old ‘Blue Tarp’ testing technique. As a result of these initial discussions, a number of industry representatives met to conduct an in depth review of the current techniques available for measuring sucrose loss in the field, and a review paper has been submitted to SRDC. The broad findings of this review paper have been that the ‘Blue Tarp’ technique is severely flawed, and that the technique used in this project has merit.

9.0 RECOMMENDATIONS FOR FURTHER RESEARCH

This project has identified a number of important gaps in our knowledge of how mechanical harvesting affects returns to the industry. All have significant implications both for policy formation by the industry, and some may have implications for the design of machines. To a certain extent this project has created more questions than it has answered, and further research is required.

9.1 Key recommendations

I recommend that the following areas require future research:

1. Are the observed differences in CCS between billet lengths entirely attributable to physical length, or is additional damage the major factor? If these are both significant causes of CCS differences, what proportion of the CCS loss is explained by each?

   This will allow better conclusions to be drawn about the veracity of the contention that declining billet length explains much of the recent CCS decline.
2. Further work on the relative length distribution of billets at various fan speeds. A better understanding of these mechanisms will enhance our understanding of cane-loss processes, and could conceivably have a massive effect upon the interpretation of all previous cane-loss trials. It may also give new insights that would allow better design of trash-removal systems.
3. Further investigation into why lengthening the billet appears to increase dirt levels.
4. Further validation of these data, and incorporation into the model of Vitale and Domanti (1997).
5. Parkhouse and Kelly (1995) formulated a model to estimate the effect of the length and thickness of randomly packed fibres of a given density upon packing density, and hence weight for a given volume. This model was adapted to sugar cane (Figure 16), and it suggests that a billet diameter increase of 10 mm causes an equivalent increase in bin weight as an 80 mm decrease in billet length (from 225 mm to 145 mm). I suggest that further investigation of this phenomenon is warranted considering the possible economic implications to the industry. An alternative to this approach would, of course, be to fund research into ways to harvest thinner stalks without causing additional cane loss.
6. The usefulness of the harvester feedback model produced during this project should be independently assessed, and funding allocated for further development as a priority.

9.2 Additional key recommendation

The body of knowledge developed by this and other projects researching the effects of mechanical harvesting practices upon sugar yield is considerable. The majority of research has shown that a large proportion of cane loss is due to operator error or misguided preconceptions regarding what constitutes 'clean cane' and 'best harvesting practice'. Over the last 20 years an enormous amount of money has been spent in an attempt to extend the results of harvesting research to harvester operators, and some of this money has been well spent.

The over-riding limitation upon widespread adoption of best-management harvesting practice is its complexity, and the diverse number of choices presented to harvester operators. Harvester operators need to be freed of this complexity to be able to concentrate upon the task at hand.

One solution to the problem is to introduce more automation into existing harvesters. There are an increasingly diverse number of tools called 'electronic embedded systems' that could use existing research to either assist harvester operators in their decision making process, or fully automate certain machine performance parameters. At present, the sugar industry is lagging far behind other industries in its adoption of this technology. Embedded systems are not expensive, and are widespread in a large range of other agricultural machinery. SRDC should strongly consider funding embedded systems research as a future strong priority. The benefit to cost ratio of such research could be substantial.

10.0 PUBLICATIONS ARISING FROM THE PROJECT

None.

11.0 ACKNOWLEDGEMENTS

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The many others whom I have omitted, your help is appreciated.

12.0 REFERENCES

Berding, N., Johnson, S.E. and Hurney A.P. (2002). What happens from field to mill? Crop-fraction and CCS considerations. *Proc. Aust. Soc. Sugar Cane Technol.* 24:47-55.

Brotherton, G.A. (2002). Literature review - loss measurement in sugar cane harvesting. Unpublished SRDC Review.

Crook, T.D., Pope, G.M., Staunton, S.P. and Norris, C.P. (1999). A survey of field CCS vs mill CCS. *Proc. Aust. Soc. Sugar Cane Technol.* 21:33-37.

Davis, R.J. and Norris, C.P. (2001). Final report – SRDC project BS244S. Impact of chopper harvesting on the translation of field CCS to factory realised CCS. BSES Publication SD01007.

De Beer, A.G., Baxter, S.W.D., Ridge, D.R., Abreucil, J. and Clayton, J.E. (1985). Report by the Agricultural Engineering Section Committee, International Society of Sugar Cane Technologists, South African Sugar Association Experiment Station, Mount Edgecombe.

Fuelling, T.G. (1981). Harvest extractor tests – 1980 season. BSES Progress Report on Project 308.80.134.

Hockings, P.R., Norris, C.P. and Davis R.J. (2000). Chopper systems in cane harvesters: B: Results of a test program. *Proc. Aust. Soc. Sugar Cane Technol.* 22:250-255.

Lawes, R. (2000). Small mill study helps identify reasons for low CCS. *Australian Sugarcane* Aug-Sep:32-33.

Norris, C.P., Davis, R.J. and Poulsen, L.S. (1998). An investigation into the feeding of lodged green cane by harvesters. *Proc. Aust. Soc. Sugar Cane Technol.* 20:224-231.

Parkhouse, J.G. and Kelly, A. (1995). The random packing of fibres in three dimensions. *Proc. R. Soc. Lond. A* 451:737-746.

Robotham, BG and Chappell, W.J. (2002). High quality planting billets – whole-stalk planter billets compared to billets from modified and unmodified harvesters. *Proc. Aust. Soc. Sugar Cane Technol.* 24:199-206.

South Johnstone Cane and Sugar Quality Improvement Committee. (1980). The sampling of cane for extraneous matter content. *Proc. Aust. Soc. Sugar. Cane Technol.* 2:21-26.

Vitale, M.M. and Domanti, S.A. (1997). An investigation into the optimal length of sugar cane billets. *Proc. Aust. Soc. Sugar Cane Technol.* 19:170-178

Whiteing, C. (2002). Final report – SRDC project BSS189. Facilitation of best practice to reduce extraneous matter and cane loss. BSES Publication SD02009.

Whiteing, C., Norris, C.P. and Paton, D.C. (2001). Extraneous matter versus cane loss: Finding a balance in chopper harvested green cane. *Proc. Int. Soc. Sugar Cane Technol.* 24(2): 276-282.

APPENDIX 1 – TRIAL SITE DETAILS

Singh trial This trial was conducted on Farm 4028 (owned by Rajinder Singh) and was cut by a 1999 model Austoft harvester with a four-blade 15-inch differential chopping system. On the date of harvest (27 July 2000) conditions were dry, and the variety cut was Q120, plant cane. Soil type was a sandy loam. The trial design was a 2*2 factorial, with three replicates. Treatments were two billet lengths (nominally long and short) and two fan speeds (1050 and 1250 rpm).

Tully trial This trial was conducted on Tony Reichardt's home farm, approximately 10 km due south of Tully mill. Conditions were fine, and the variety cut was Q117, first ratoon growing on a dark alluvial loam. The trial was cut on 19 August 2000. The harvester used was a 1998 Cameco, with a four-blade 15-inch differential chopping system. The trial was a two-treatment design, with one primary extractor speeds (900 rpm) and two billet lengths (nominally long and short, 164 mm and 201 mm). There were four replicates.

Sciacca trial This trial was conducted on a farm managed by Joe Sciacca in the Mossman district. The farm number was 1636, block 11.0. The variety cut was plant Q120, and the conditions were slightly overcast with some showers occurring on the morning of the trial. The cane was cut on the 25 September 2000. The harvester used was a 1998 Austoft, fitted with a three-blade 12-inch differential chopping system, and standard fans on the primary and secondary extractor. The trial design was a 2*2 factorial, with three replicates. Treatments were two billet lengths (nominally long and short) and two fan speeds (1050 and 1250 rpm).

Andrews' trial This was a three-replicate 3*2 factorial trial conducted in first-ratoon Q152 on block 1.B of farm 3308, owned by Mr Bruce Andrews of Mossman. The treatments were three primary extractor fan speeds (900, 1050 and 1250 rpm) and two billet lengths (nominally short and long). The harvester used was the same harvester as that used in the Sciacca trial. This trial failed due to a large number of missed samples at the mill, and a large section of severe rat damage in the middle of the paddock.

Biomass per hectare yield

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.947837
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
       BL  1  15.37314 15.37314 17.11179 0.0061015
       FS  1  22.46819 22.46819 25.00925 0.0024501
      Rep  2   1.18453  0.59226  0.65925 0.5510476
    BL:FS  1   7.41516  7.41516  8.25378 0.0283180
Residuals  6   5.39037  0.89840

Tables of means
Grand mean
      102.08
```

```
 BL
      L      S
 103.21 100.95

 FS
      F      S
 100.71 103.45

 Rep
      1      2      3
 102.11 102.45 101.68

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 101.06 105.37
S 100.37 101.53
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 2.159259
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
       BL  1   14.8415  14.8415  3.18323 0.1246565
       FS  1  116.3032 116.3032 24.94492 0.0024658
      Rep  2  168.5090  84.2545 18.07105 0.0028861
    BL:FS  1   28.6511  28.6511  6.14514 0.0478741
Residuals  6   27.9744   4.6624

Tables of means
Grand mean

 57.158

 BL
      L      S
 58.270 56.045

 FS
      F      S
 54.044 60.271

 Rep
      1      2      3
 61.823 57.003 52.647

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 53.611 62.928
S 54.477 57.613

Standard errors for differences of means
            BL     FS    Rep BL:FS
        1.2466 1.2466 1.5268 1.763
replic. 6.0000 6.0000 4.0000 3.000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 5.251325
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
    treat  1   43.4021 43.40210 1.573885 0.2984883
      rep  3  254.0585 84.68616 3.070963 0.1907099
Residuals  3   82.7293 27.57642
```

```
Tables of means
Grand mean

 83.082

 treat
   LONG  SHORT
 85.411 80.752

 rep
      1      2      3      4
 87.844 86.512 84.417 73.553

Standard errors for differences of means
         treat    rep
        3.7132 5.2513
replic. 4.0000 2.0000
```

Fibre

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.2378055
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       BL  1 0.4136653 0.4136653 7.314850 0.0353591
       FS  1 0.2385720 0.2385720 4.218672 0.0857728
      Rep  2 0.3472807 0.1736403 3.070484 0.1206962
    BL:FS  1 0.0522720 0.0522720 0.924327 0.3734691
Residuals  6 0.3393087 0.0565514

Tables of means
Grand mean

 14.007

 BL
      L      S
 14.193 13.822

 FS
      F      S
 13.866 14.148

 Rep
      1      2      3
 14.248 13.875 13.900

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 13.986 14.400
S 13.747 13.897

Standard errors for differences of means
            BL     FS     Rep   BL:FS
        0.1373 0.1373 0.16815 0.19417
replic. 6.0000 6.0000 4.00000 3.00000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.1166548
Estimated effects are balanced
```

```
          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       BL  1 0.5720333 0.5720333 42.03552 0.0006399
       FS  1 0.0560333 0.0560333  4.11758 0.0887644
      Rep  2 0.3981500 0.1990750 14.62890 0.0049282
    BL:FS  1 0.0456333 0.0456333  3.35334 0.1167918
Residuals  6 0.0816500 0.0136083

Tables of means
Grand mean

 14.215

 BL
      L      S
 14.433 13.997

 FS
      F      S
 14.147 14.283

 Rep
      1      2      3
 14.473 14.093 14.080

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 14.303 14.563
S 13.990 14.003

Standard errors for differences of means
              BL       FS      Rep    BL:FS
        0.067351 0.067351 0.082487 0.095248
replic. 6.000000 6.000000 4.000000 3.000000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.1683251
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
    treat  1     0.125 0.1250000 4.411765 0.1265146
      rep  3     0.550 0.1833333 6.470588 0.0797183
Residuals  3     0.085 0.0283333

Tables of means
Grand mean

 12.85

 treat
   LONG  SHORT
 12.975 12.725

 rep
     1     2     3     4
 13.05 13.15 12.70 12.50

Standard errors for differences of means
          treat     rep
        0.11902 0.16833
replic. 4.00000 2.00000
```

CCS

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.1598611
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       BL  1 0.1408333 0.1408333  5.51087 0.0572519
       FS  1 0.1875000 0.1875000  7.33696 0.0351676
      Rep  2 0.8866667 0.4433333 17.34783 0.0032049
    BL:FS  1 0.0408333 0.0408333  1.59783 0.2530979
Residuals  6 0.1533333 0.0255556

Tables of means
Grand mean

 14.008

 BL
      L      S
 14.117 13.900

 FS
      F      S
 14.133 13.883

 Rep
      1      2      3
 13.725 13.925 14.375

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 14.300 13.933
S 13.967 13.833

Standard errors for differences of means
              BL       FS     Rep   BL:FS
        0.092296 0.092296 0.11304 0.13053
replic. 6.000000 6.000000 4.00000 3.00000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.3122499
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       BL  1  0.300833 0.3008333 3.085470 0.1295118
       FS  1  0.040833 0.0408333 0.418803 0.5414868
      Rep  2  1.761667 0.8808333 9.034188 0.0154922
    BL:FS  1  0.140833 0.1408333 1.444444 0.2747007
Residuals  6  0.585000 0.0975000

Tables of means
Grand mean

 15.008

 BL
      L      S
 15.167 14.850

 FS
      F      S
 14.950 15.067
```

```
 Rep
      1      2      3 
 14.500 15.425 15.100

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S 
L 15.000 15.333
S 14.900 14.800

Standard errors for differences of means
             BL      FS     Rep   BL:FS
        0.18028 0.18028 0.22079 0.25495
replic. 6.00000 6.00000 4.00000 3.00000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.1534601 
Estimated effects are balanced

          Df Sum of Sq Mean Sq  F Value     Pr(F) 
    treat  1   0.07605 0.07605 3.229299 0.1701863
      rep  3   0.38430 0.12810 5.439490 0.0989065
Residuals  3   0.07065 0.02355                   

Tables of means
Grand mean
                                    
 13.415 

 treat 
   LONG  SHORT 
 13.317 13.512

 rep 
      1      2      3      4 
 13.145 13.295 13.490 13.730

Standard errors for differences of means
          treat     rep
        0.10851 0.15346
replic. 4.00000 2.00000
```

Purity

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.2034426 
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F) 
       BL  1  0.163333 0.163333  3.94631 0.0941676
       FS  1  0.030000 0.030000  0.72483 0.4272299
      Rep  2  2.085000 1.042500 25.18792 0.0012055
    BL:FS  1  0.003333 0.003333  0.08054 0.7861096
Residuals  6  0.248333 0.041389                   

Tables of means
Grand mean
                                    
 86.85 

 BL 
      L      S 
 86.967 86.733
```

```
 FS
    F    S
 86.9 86.8

 Rep
      1      2      3
 86.275 87.025 87.250

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 87.000 86.933
S 86.800 86.667

Standard errors for differences of means
             BL      FS     Rep   BL:FS
        0.11746 0.11746 0.14386 0.16611
replic. 6.00000 6.00000 4.00000 3.00000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.7617597
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
       BL  1  1.920000 1.920000 3.308760 0.1187848
       FS  1  0.083333 0.083333 0.143609 0.7177669
      Rep  2  2.411667 1.205833 2.078028 0.2061952
    BL:FS  1  0.120000 0.120000 0.206798 0.6652786
Residuals  6  3.481667 0.580278

Tables of means
Grand mean

 90.683

 BL
      L      S
 91.083 90.283

 FS
      F      S
 90.600 90.767

 Rep
      1      2      3
 90.050 90.975 91.025

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 90.900 91.267
S 90.300 90.267

Standard errors for differences of means
            BL     FS     Rep   BL:FS
        0.4398 0.4398 0.53865 0.62197
replic. 6.0000 6.0000 4.00000 3.00000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.5645795
Estimated effects are balanced
```

```
          Df Sum of Sq Mean Sq  F Value     Pr(F)
    treat  1   0.10125 0.10125 0.317647 0.6124065
      rep  3   3.61365 1.20455 3.778980 0.1518805
Residuals  3   0.95625 0.31875

Tables of means
Grand mean

 89.878

 treat
   LONG  SHORT
 89.765 89.990

 rep
      1      2      3      4
 88.930 90.250 89.615 90.715

Standard errors for differences of means
          treat     rep
        0.39922 0.56458
replic. 4.00000 2.00000
```

CCS per hectare yield

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.1279336
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       FS  1 0.0512903 0.0512903  3.13376 0.1270812
       BL  1 0.8486937 0.8486937 51.85390 0.0003630
      Rep  2 0.7178843 0.3589421 21.93082 0.0017424
    FS:BL  1 0.0321283 0.0321283  1.96299 0.2107378
Residuals  6 0.0982021 0.0163670

Tables of means
Grand mean

 14.298

 FS
      F      S
 14.232 14.363

 BL
      L      S
 14.564 14.032

 Rep
      1      2      3
 14.016 14.265 14.612

 FS:BL
Dim 1 : FS
Dim 2 : BL
       L      S
F 14.446 14.018
S 14.681 14.045

Standard errors for differences of means
               FS       BL      Rep   FS:BL
        0.073863 0.073863 0.090463 0.10446
replic. 6.000000 6.000000 4.000000 3.00000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.2697262
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value      Pr(F)
       BL  1  0.784397 0.784397 10.78176 0.01674796
       FS  1  3.129813 3.129813 43.02018 0.00060145
      Rep  2  2.405788 1.202894 16.53412 0.00362228
    BL:FS  1  1.133288 1.133288 15.57737 0.00756521
Residuals  6  0.436513 0.072752

Tables of means
Grand mean

 8.5721

 BL
      L      S
 8.8277 8.3164

 FS
      F      S
 8.0613 9.0828

 Rep
      1      2      3
 8.9700 8.7996 7.9465

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 8.0097 9.6457
S 8.1130 8.5198

Standard errors for differences of means
             BL      FS     Rep   BL:FS
        0.15573 0.15573 0.19073 0.22023
replic. 6.00000 6.00000 4.00000 3.00000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.7079779
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
    treat  1  0.454334 0.4543342 0.906434 0.4113005
      rep  3  2.911145 0.9703817 1.935990 0.3005385
Residuals  3  1.503698 0.5012327

Tables of means
Grand mean

 11.131

 treat
   LONG  SHORT
 11.369 10.893

 rep
      1      2      3      4
 11.548 11.497 11.388 10.091

Standard errors for differences of means
          treat     rep
        0.50062 0.70798
replic. 4.00000 2.00000
```

Trash percent sample

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.7739807
Estimated effects may be unbalanced

Type III Sum of Squares
              Df Sum of Sq  Mean Sq  F Value     Pr(F)
           FS  1   8.86663 8.866630 14.80125 0.0004311
           BL  1   0.11773 0.117729  0.19653 0.6599883
          REP  2   2.74852 1.374262  2.29408 0.1143067
        FS:BL  1   0.13178 0.131777  0.21998 0.6416679
sub %in% REP 15  13.10318 0.873545  1.45823 0.1696269
    Residuals 39  23.36280 0.599046

Tables of means
Grand mean

 1.9924

 FS
         F      S
     1.591  2.394
rep 30.000 30.000

 BL
         L      S
     1.949  2.036
rep 30.000 30.000

 REP
         1      2      3
     2.395  1.968  1.816
rep 12.000 24.000 24.000

 FS:BL
Dim 1 : FS
Dim 2 : BL
         L      S
  F  1.520  1.698
rep 18.000 12.000
  S  2.392  2.395
rep 12.000 18.000

 sub %in% REP
Dim 1 : REP
Dim 2 : sub
         1      2      3      4      5      6
  1 2.3268 3.2233 2.2298 3.0277 2.7331 0.8294
rep 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000
  2 2.0289 2.1571 1.9320 2.2105 2.1478 1.3307
rep 4.0000 4.0000 4.0000 4.0000 4.0000 4.0000
  3 1.0860 1.9879 1.6691 1.8586 1.9314 2.3606
rep 4.0000 4.0000 4.0000 4.0000 4.0000 4.0000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 1.276858
2 out of 60 effects not estimable
Estimated effects may be unbalanced

                               Df Sum of Sq  Mean Sq  F Value     Pr(F)
                            bl  1   4.67461  4.67461 2.867216 0.1212690
                            fs  2  24.56855 12.28427 7.534675 0.0100991
                           rep  2   8.57214  4.28607 2.628902 0.1209316
bagrep %in% ((bl * fs) * rep) 52  27.96864  0.53786 0.329901 0.9957082
                     Residuals 10  16.30365  1.63037
```

```
Tables of means
Grand mean

 2.3916

 bl
        LB     SB
     2.670  2.144
rep 32.000 36.000

 fs
        FF     MF     SF
     1.600  3.060  2.565
rep 23.000 21.000 24.000

 rep
         A      B      C
     2.825  2.354  1.973
rep 24.000 21.000 23.000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.01235318
Estimated effects are balanced

                 Df   Sum of Sq     Mean Sq  F Value     Pr(F)
           treat  1 0.000976011 0.000976011  6.39584 0.0187526
             rep  3 0.007496451 0.002498817 16.37484 0.0000065
bag.rep %in% rep 20 0.003885670 0.000194283  1.27315 0.2867013
       Residuals 23 0.003509823 0.000152601

Tables of means
Grand mean

 0.046373

 treat
     LONG    SHORT
 0.050883 0.041864

 rep
        1        2        3        4
 0.063019 0.053867 0.034051 0.034557

 bag.rep %in% rep
Dim 1 : rep
Dim 2 : bag.rep
         1        2        3        4        5        6
1 0.059854 0.054785 0.075938 0.062330 0.064639 0.060567
2 0.062579 0.055093 0.055233 0.038051 0.069991 0.042256
3 0.032579 0.032172 0.043521 0.039635 0.028497 0.027901
4 0.019906 0.025225 0.056109 0.034479 0.036163 0.035458

Standard errors for differences of means
             treat        rep bag.rep %in% rep
         0.0035661  0.0050432         0.012353
replic. 24.0000000 12.0000000         2.000000
```

Ash

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.1585851
Estimated effects are balanced
```

```
          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       BL  1 0.1318803 0.1318803 5.243913 0.0619475
       FS  1 0.0027603 0.0027603 0.109758 0.7516847
      Rep  2 0.3174407 0.1587203 6.311143 0.0334468
    BL:FS  1 0.0001470 0.0001470 0.005845 0.9415440
Residuals  6 0.1508953 0.0251492

Tables of means
Grand mean

 0.61317

 BL
       L       S
 0.71800 0.50833

 FS
       F       S
 0.59800 0.62833

 Rep
      1      2      3
 0.8375 0.5450 0.4570

 BL:FS
Dim 1 : BL
Dim 2 : FS
        F       S
L 0.69933 0.73667
S 0.49667 0.52000

Standard errors for differences of means
              BL       FS     Rep   BL:FS
        0.091559 0.091559 0.11214 0.12948
replic. 6.000000 6.000000 4.00000 3.00000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.2398205
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
       BL  1 0.1220083 0.1220083 2.121372 0.1955126
       FS  1 0.0000750 0.0000750 0.001304 0.9723650
      Rep  2 0.6483167 0.3241583 5.636175 0.0419179
    BL:FS  1 0.1302083 0.1302083 2.263946 0.1831187
Residuals  6 0.3450833 0.0575139

Tables of means
Grand mean

 1.5258

 BL
      L      S
 1.6267 1.4250

 FS
      F      S
 1.5233 1.5283

 Rep
      1      2      3
 1.8325 1.4750 1.2700

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 1.5200 1.7333
S 1.5267 1.3233
```

```
Standard errors for differences of means
             BL      FS     Rep   BL:FS
        0.13846 0.13846 0.16958 0.19581
replic. 6.00000 6.00000 4.00000 3.00000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.307544
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value     Pr(F)
    treat  1   0.10125 0.1012500 1.070485 0.3769244
      rep  3   0.21375 0.0712500 0.753304 0.5892782
Residuals  3   0.28375 0.0945833

Tables of means
Grand mean

 1.2375

 treat
  LONG SHORT
 1.350 1.125

 rep
    1    2    3    4
 1.40 1.10 1.40 1.05

Standard errors for differences of means
          treat     rep
        0.21747 0.30754
replic. 4.00000 2.00000
```

Average bin weight

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.1866295
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
       BL  1  0.765075 0.765075 21.96563 0.0033722
       FS  1  0.533408 0.533408 15.31438 0.0078619
      Rep  2  2.064950 1.032475 29.64279 0.0007763
    BL:FS  1  0.031008 0.031008  0.89026 0.3818310
Residuals  6  0.208983 0.034831

Tables of means
Grand mean

 11.548

 BL
      L      S
 11.295 11.800

 FS
      F      S
 11.758 11.337

 Rep
      1      2      3
 10.980 11.702 11.960
```

```
 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 11.557 11.033
S 11.960 11.640

Standard errors for differences of means
              BL      FS     Rep   BL:FS
        0.10775 0.10775 0.13197 0.15238
replic. 6.00000 6.00000 4.00000 3.00000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.2587201
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
       BL  1  2.764800 2.764800 41.30506 0.0006705
       FS  1  0.496133 0.496133  7.41204 0.0345277
      Rep  2  0.286650 0.143325  2.14122 0.1986849
    BL:FS  1  0.010800 0.010800  0.16135 0.7018349
Residuals  6  0.401617 0.066936

Tables of means
Grand mean

 9.3

 BL
    L    S
 8.82 9.78

 FS
      F      S
 9.5033 9.0967

 Rep
      1      2      3
 9.0900 9.4575 9.3525

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 9.0533 8.5867
S 9.9533 9.6067

Standard errors for differences of means
              BL      FS     Rep   BL:FS
        0.14937 0.14937 0.18294 0.21124
replic. 6.00000 6.00000 4.00000 3.00000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.1857418
Estimated effects are balanced

          Df Sum of Sq Mean Sq  F Value     Pr(F)
    treat  1    4.6208  4.6208 133.9362 0.0013854
      rep  3    0.4113  0.1371   3.9739 0.1434480
Residuals  3    0.1035  0.0345

Tables of means
Grand mean

 9.84
```

```
 treat
  LONG SHORT
  9.08 10.60

 rep
      1      2      3      4
  9.565  9.670 10.030 10.095

Standard errors for differences of means
          treat     rep
        0.13134 0.18574
replic. 4.00000 2.00000
```

Millability coefficient

Singh

```
*** Analysis of Variance Model ***

Residual standard error: 0.01299812
Estimated effects are balanced

          Df   Sum of Sq     Mean Sq  F Value     Pr(F)
       BL  1 0.000309291 0.000309291  1.83065 0.2248058
       FS  1 0.004220320 0.004220320 24.97955 0.0024573
      Rep  2 0.009950476 0.004975238 29.44781 0.0007903
    BL:FS  1 0.000860008 0.000860008  5.09028 0.0648891
Residuals  6 0.001013706 0.000168951

Tables of means
Grand mean

 1.0007

 BL
      L      S
 0.9957 1.0058

 FS
      F      S
 1.0195 0.9820

 Rep
      1      2      3
 0.9641 1.0037 1.0344

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 1.0229 0.9685
S 1.0161 0.9955

Standard errors for differences of means
               BL        FS       Rep    BL:FS
        0.0075045 0.0075045 0.0091911 0.010613
replic. 6.0000000 6.0000000 4.0000000 3.000000
```

Sciacca

```
*** Analysis of Variance Model ***

Residual standard error: 0.02427998
Estimated effects are balanced

          Df  Sum of Sq     Mean Sq  F Value     Pr(F)
       BL  1 0.00028110 0.000281100  0.47683 0.5156711
       FS  1 0.00001789 0.000017892  0.03035 0.8674280
      Rep  2 0.01861626 0.009308128 15.78940 0.0040703
    BL:FS  1 0.00009961 0.000099605  0.16896 0.6953148
Residuals  6 0.00353710 0.000589517
```

```
Tables of means
Grand mean

 1.0564

 BL
      L      S
 1.0516 1.0613

 FS
      F      S
 1.0576 1.0552

 Rep
      1      2      3
 1.0022 1.0946 1.0725

 BL:FS
Dim 1 : BL
Dim 2 : FS
       F      S
L 1.0499 1.0532
S 1.0654 1.0572

Standard errors for differences of means
              BL       FS      Rep    BL:FS
        0.014018 0.014018 0.017169 0.019825
replic. 6.000000 6.000000 4.000000 3.000000
```

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.02476329
Estimated effects are balanced

          Df  Sum of Sq     Mean Sq  F Value     Pr(F)
    treat  1 0.00250550 0.002505503 4.085812 0.1364796
      rep  3 0.01143909 0.003813031 6.218044 0.0838089
Residuals  3 0.00183966 0.000613220

Tables of means
Grand mean

 1.045

 treat
   LONG  SHORT
 1.0273 1.0627

 rep
      1      2      3      4
 1.0073 1.0117 1.0622 1.0988

Standard errors for differences of means
          treat      rep
        0.01751 0.024763
replic. 4.00000 2.000000
```

Brix

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.07242813
Estimated effects are balanced

          Df Sum of Sq    Mean Sq  F Value      Pr(F)
    treat  1 0.0435125 0.04351250  8.29468 0.06352652
      rep  3 0.1781375 0.05937917 11.31930 0.03829134
Residuals  3 0.0157375 0.00524583
```

```
Tables of means
Grand mean

 19.524

 treat
   LONG  SHORT
 19.450 19.597

 rep
      1      2      3      4
 19.510 19.290 19.690 19.605

Standard errors for differences of means
           treat      rep
        0.051214 0.072428
replic. 4.000000 2.000000
```

Pol per hectare yield

Tully

```
*** Analysis of Variance Model ***

Residual standard error: 0.1071603
Estimated effects are balanced

          Df Sum of Sq    Mean Sq  F Value     Pr(F)
    treat  1   0.06125 0.06125000 5.333817 0.1040781
      rep  3   0.24765 0.08255000 7.188679 0.0697333
Residuals  3   0.03445 0.01148333

Tables of means
Grand mean

 17.547

 treat
   LONG  SHORT
 17.460 17.635

 rep
      1      2      3      4
 17.350 17.410 17.645 17.785

Standard errors for differences of means
           treat     rep
        0.075774 0.10716
replic. 4.000000 2.00000
```

Stockham small mill results

Pol

```
*** Analysis of Variance Model ***

Short Output:
Call:
   aov(formula = Pol. ~ ((Length * Delay)/Rep)/SubSample - Length:Delay, data =
        Stocky.Small.Mill, na.action = na.exclude)

Terms:
                  Length    Delay Rep %in% (Length * Delay)
 Sum of Squares 15.23624 38.43814                  40.62062
Deg. of Freedom        1        3                        24

                SubSample %in% ((Length * Delay)/Rep) Residuals
 Sum of Squares                               0.07527   3.99302
Deg. of Freedom                                    32         3

Residual standard error: 1.153692
```

```
Estimated effects are balanced

                                      Df Sum of Sq  Mean Sq  F Value
                               Length  1  15.23624 15.23624 11.44717
                                Delay  3  38.43814 12.81271  9.62634
            Rep %in% (Length * Delay) 24  40.62062  1.69253  1.27161
SubSample %in% ((Length * Delay)/Rep) 32   0.07527  0.00235  0.00177
                            Residuals  3   3.99302  1.33101

                                          Pr(F)
                               Length 0.0429845
                                Delay 0.0476009
            Rep %in% (Length * Delay) 0.4867216
SubSample %in% ((Length * Delay)/Rep) 1.0000000
                            Residuals

Tables of means
Grand mean

 18.328

 Length
      L      S
 18.816 17.840

 Delay
      0      6     12     18
 18.501 19.408 18.159 17.243

Standard errors for differences of means
          Length    Delay Rep %in% (Length * Delay)
         0.28842  0.40789                    1.1537
replic. 32.00000 16.00000                    2.0000

        SubSample %in% ((Length * Delay)/Rep)
                                       1.6316
replic.                                1.0000


90 % non-simultaneous confidence intervals for specified
linear combinations, by the Fisher LSD method

critical point: 2.3534
response variable: Pol.

intervals excluding 0 are flagged by '****'

    Estimate Std.Error Lower Bound Upper Bound
Long-Short    0.976     0.288       0.297        1.65 ****


      Estimate Std.Error Lower Bound Upper Bound
  0-6   -0.907     0.408      -2.410       0.593
 0-12    0.342     0.408      -1.160       1.840
 0-18    1.260     0.408      -0.241       2.760
 6-12    1.250     0.408      -0.251       2.750
 6-18    2.170     0.408       0.665       3.660 ****
12-18    0.916     0.408      -0.583       2.420
```

Brix in cane

```
*** Analysis of Variance Model ***

Short Output:
Call:
   aov(formula = BIC ~ ((Length * Delay)/Rep)/SubSample - Length:Delay, data =
        Stocky.Small.Mill, na.action = na.exclude)

Terms:
                  Length    Delay Rep %in% (Length * Delay)
 Sum of Squares 10.77891  3.32564                  13.17569
Deg. of Freedom        1        3                        24
```

```
                SubSample %in% ((Length * Delay)/Rep) Residuals
 Sum of Squares                               0.34319   1.50133
Deg. of Freedom                                    32         3

Residual standard error: 0.7074208
Estimated effects are balanced

                                      Df Sum of Sq  Mean Sq  F Value
                               Length  1  10.77891 10.77891 21.53869
                                Delay  3   3.32564  1.10855  2.21513
            Rep %in% (Length * Delay) 24  13.17569  0.54899  1.09700
SubSample %in% ((Length * Delay)/Rep) 32   0.34319  0.01072  0.02143
                            Residuals  3   1.50133  0.50044

                                          Pr(F)
                               Length 0.0188551
                                Delay 0.2652527
            Rep %in% (Length * Delay) 0.5498928
SubSample %in% ((Length * Delay)/Rep) 1.0000000
                            Residuals

Tables of means
Grand mean

 18.46

 Length
      L      S
 18.870 18.049

 Delay
      0      6     12     18
 18.296 18.843 18.418 18.280



Standard errors for differences of means
          Length    Delay Rep %in% (Length * Delay)
         0.17686  0.25011                   0.70742
replic. 32.00000 16.00000                   2.00000

        SubSample %in% ((Length * Delay)/Rep)
                                       1.0004
replic.                                1.0000


95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method

critical point: 4.826
response variable: BIC

intervals excluding 0 are flagged by '****'

      Estimate Std.Error Lower Bound Upper Bound
  0-6  -0.5470      0.25      -1.750        0.66
 0-12  -0.1220      0.25      -1.330        1.08
 0-18   0.0159      0.25      -1.190        1.22
 6-12   0.4250      0.25      -0.782        1.63
 6-18   0.5630      0.25      -0.644        1.77
12-18   0.1380      0.25      -1.070        1.35

L-S      0.821     0.177       0.258        1.38 ****
```

CCS % cane

```
*** Analysis of Variance Model ***

Short Output:
Call:
   aov(formula = CCS1 ~ ((Length * Delay)/Rep)/SubSample - Length:Delay, data =
        Stocky.Small.Mill, na.action = na.exclude)
```

```
Terms:
                  Length    Delay Rep %in% (Length * Delay)
 Sum of Squares 10.35632 48.70375                  39.07843
Deg. of Freedom        1        3                        24

                SubSample %in% ((Length * Delay)/Rep) Residuals
 Sum of Squares                               0.17551   4.03601
Deg. of Freedom                                    32         3

Residual standard error: 1.159886
Estimated effects are balanced

                                      Df Sum of Sq  Mean Sq  F Value
                               Length  1  10.35632 10.35632  7.69795
                                Delay  3  48.70375 16.23458 12.06731
            Rep %in% (Length * Delay) 24  39.07843  1.62827  1.21031
SubSample %in% ((Length * Delay)/Rep) 32   0.17551  0.00548  0.00408
                            Residuals  3   4.03601  1.34534

                                          Pr(F)
                               Length 0.0693067
                                Delay 0.0351026
            Rep %in% (Length * Delay) 0.5076300
SubSample %in% ((Length * Delay)/Rep) 1.0000000
                            Residuals

Tables of means
Grand mean

 13.588

 Length
      L      S
 13.990 13.186

 Delay
      0      6     12     18
 13.886 14.741 13.399 12.327


Standard errors for differences of means
          Length    Delay Rep %in% (Length * Delay)
         0.28997  0.41008                    1.1599
replic. 32.00000 16.00000                    2.0000

        SubSample %in% ((Length * Delay)/Rep)
                                       1.6403
replic.                                1.0000


90 % non-simultaneous confidence intervals for specified
linear combinations, by the Fisher LSD method

critical point: 2.3534
response variable: CCS1

intervals excluding 0 are flagged by '****'

    Estimate Std.Error Lower Bound Upper Bound
L-S    0.805      0.29       0.122        1.49 ****


  0-6   -0.855      0.41      -2.830        1.12
 0-12    0.487      0.41      -1.490        2.47
 0-18    1.560      0.41      -0.420        3.54
 6-12    1.340      0.41      -0.637        3.32
 6-18    2.410      0.41       0.435        4.39 ****
12-18    1.070      0.41      -0.907        3.05
```