
THE EFFECT OF MILL ORIENTATION ANGLE ON BAGASSE MOISTURE CONTENT

By

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Abstract

THIS PAPER DESCRIBES an experimental investigation to explore a concept designed to reduce the moisture content of bagasse. It takes advantage of gravity to separate juice from bagasse by feeding bagasse upwards into the nip of the mill while juice drains downwards under gravity. The investigation found that orienting the feed to a mill upwards does reduce bagasse moisture content and that the benefit is expected to be greater than two units of moisture. While an advantage was found in orienting the feed up to 50° above the horizontal, no extra benefit was found in increasing the angle higher (up to 60° was explored) and so a 50° orientation was identified as the preferred angle for this design concept.

Introduction

A reduction in bagasse moisture content remains an attractive objective for raw sugar factories. Since most bagasse is ultimately burned in boilers to generate steam, a reduction in bagasse moisture results in an increase in boiler efficiency and consequently a reduction in bagasse consumption for a given steam production (Mann, 2010). Surplus bagasse can be used for a range of applications (Kent, 2007). If the reduction in bagasse moisture content can be achieved at the final mill, there is an additional benefit of increased extraction. Kent and Zapatero (2007) predicted that a reduction in bagasse moisture content of two units at the final mill of a six-mill train would increase pol extraction by 0.1 units. They also predicted that a reduction in bagasse moisture content of two units for all six mills would increase extraction by 0.6 units.

This paper reports on an investigation to explore a concept for reducing bagasse moisture content. The basic premise is to take advantage of gravity as a means of separating juice from bagasse. Feeding bagasse upwards into the nip of the mill is the means by which this premise can be achieved. The concept was first demonstrated at James Cook University (Kauppila and Loughran, 2000).

Testing the premise

Introductory remarks

The basic premise was extensively investigated using the James Cook University two-roll mill (Figure 1). While Kauppila and Loughran (2000) had demonstrated the premise previously, they had done it using prepared cane as a feed material rather than bagasse, using 750 mm diameter rolls with 25 mm pitch grooving with a smooth surface, and using thin feed blankets. In the work reported here, final bagasse was used with rolls of 875 mm diameter and 38 mm pitch, arc roughened, and with much thicker feed blankets to achieve factory-like work openings.

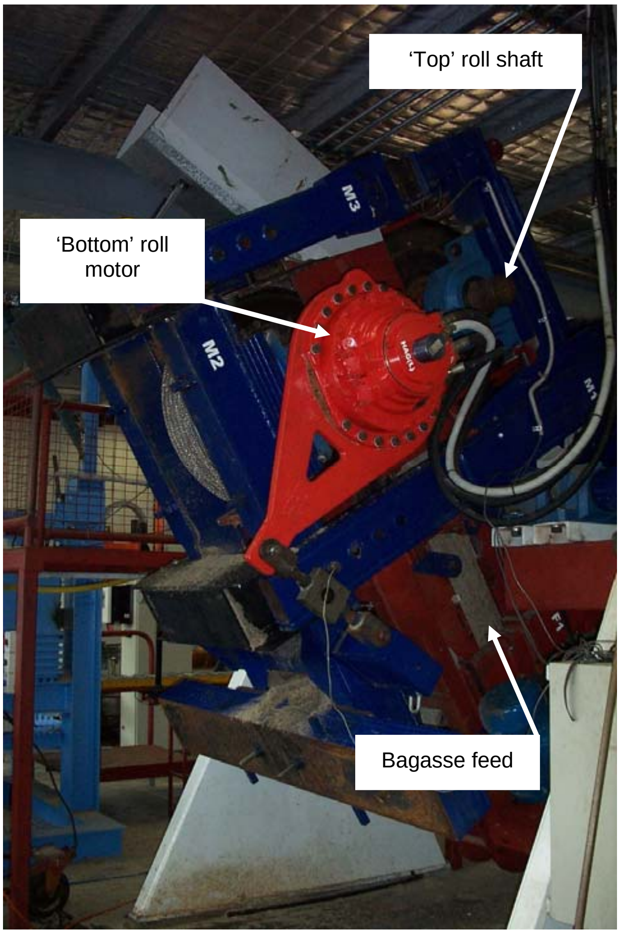

Fig. 1—The James Cook University two-roll mill feeding bagasse upwards.

The fixed mill parameters are shown in Table 1.

Table 1—Mill parameters during tests.

Mill length (mm)	225
Roll mean diameter (mm)	875
Roll groove depth (mm)	50
Roll groove angle (°)	35
Feed blanket length (mm)	1200

Experiment 1—a preliminary examination

The first experiment was designed as a $2^{6–1}$ fractional factorial experiment in a split-plot design (six factors were explored at two levels). The split-plot design was necessary because of the relative difficulty in changing work opening. The fractional design was used to reduce the number of tests in this first experiment to 32.

Table 2 shows the experimental factors and factor levels explored in the experiment. The mill orientation was the main parameter of interest and was tested to the highest value thought practical. The feed bagasse moisture content and the nip compaction were of interest as higher feed bagasse moisture content and lower nip compaction could lead to lower power consumption in the mill.While higher nip compactions were desired, the chosen values were the largest that could be reliably achieved without stalling the mill drives.

The lower bagasse moisture content of 55% was the lowest value that consistently caused juice expression at the lower nip compaction level. The higher value of 62% was typical of the moisture content expected from bagasse delivered from a pressure feeder. The work opening, roll speed and contact angle were parameters that could potentially be varied over a range of values and their effect on bagasse moisture was of interest. The chosen values were typical of values used in factories.

Table 2—Final selected experimental factors and factor levels for experiment 1.

Experimental factor	Symbol	Level 0	Level 1
Mill orientation above horizontal (°)	O	0	60
Feed bagasse moisture content (%)	M	55	62
Nip compaction (kg/m^3)	C	500	600
Work opening (mm)	W	40	55
Roll speed (mm/s)	S	150	300
Contact angle (°)	A	35	45

Of the six experimental factors listed in Table 2, three were set by the geometry of the mill (mill orientation, work opening and contact angle) and were maintained consistently throughout each test. A set point was used to achieve the desired roll speed but the actual roll speed achieved was dependent on the success of the control system in maintaining that set point. The feed moisture content was somewhat variable, being achieved by adding water to bagasse, generally before the original feed bagasse analysis was complete to identify its initial moisture content. The nip compaction was adjusted by selecting an appropriate mass of bagasse to mill, assuming the bagasse blanket was fed into the mill at a speed of $S\cos\alpha$, where S is the roll surface speed and α is the contact angle.

Nip compaction proved difficult to calculate because of difficulties in measuring fibre rate. For the adopted method to calculate nip compaction, the time to mill the feed blanket was measured from the time when the roll load measured on one side of the mill exceeded 20 kN until the time when the roll load on that side of the mill reduced down to 20 kN again. The roll speed and the feeder speed were averaged over this time interval. The fibre rate was determined from the known feed compaction of the original bagasse blanket and the average feeder speed.

Figure 2 shows that the feed bagasse moisture content and roll speed were reasonably well controlled in the experiment but that the nip compaction was not. In this figure, there are six vertical bars on each graph, representing the six experimental factors as defined in Table 2. On each bar, the experimental factor levels are shown and their positions on the vertical axis are the mean values achieved for all tests conducted at that level. For example, the top left hand graph shows that the average feed bagasse moisture content achieved when seeking 62% feed moisture content was about 63%. The top left hand graph shows that the feed moisture content was the only parameter that changed substantially when the feed moisture content changed. Similarly, the roll speed was the only factor than changed substantially when the roll speed was changed. When the nip compaction changed, however, roll speed also changed substantially.

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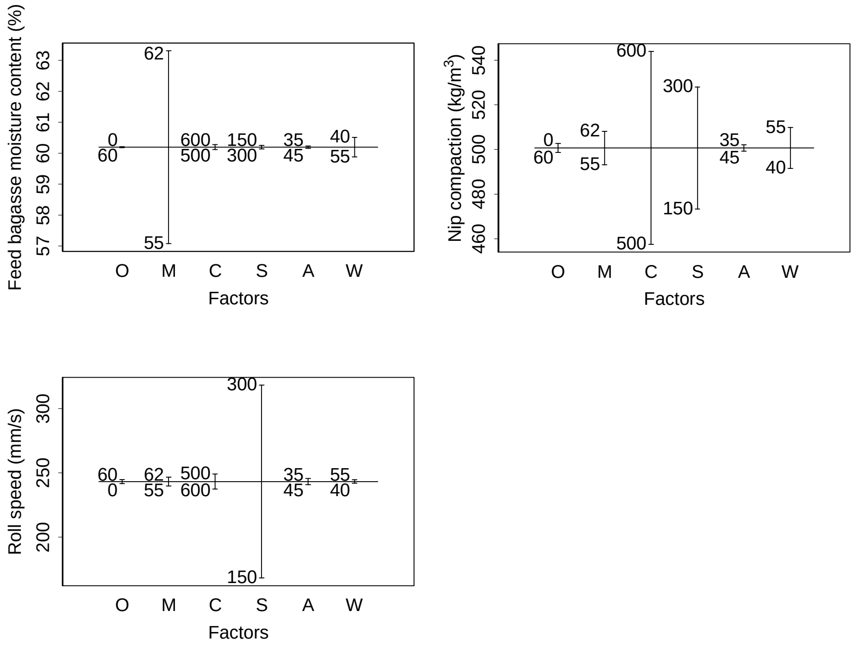

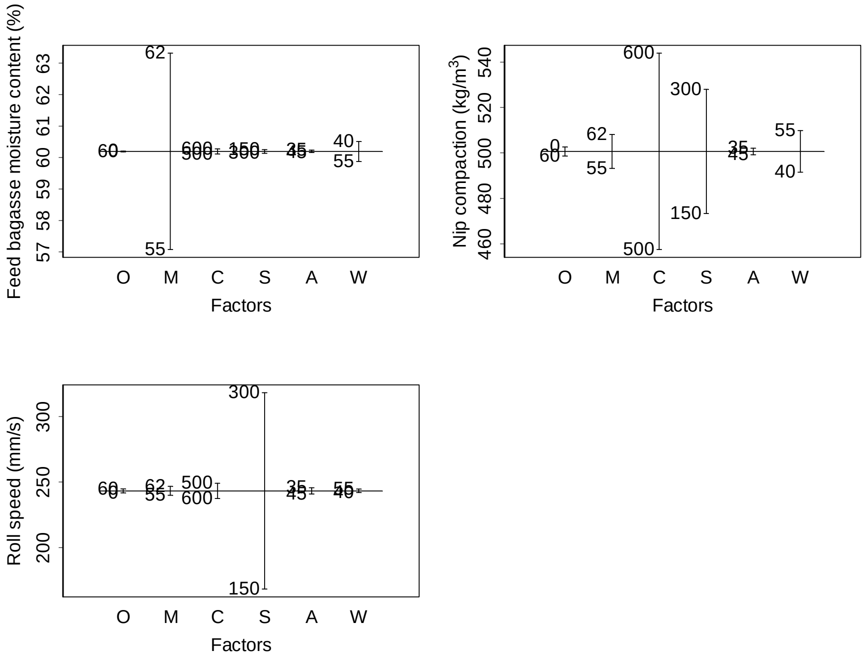

Fig. 2—Control of experimental factors in experiment 1.

The results of the first experiment are shown in Figure 3. An analysis of variance showed that:

- Bagasse moisture content was lower under low feed bagasse moisture content, low roll speed and low contact angle conditions.
- Reabsorption factor was lower under low feed bagasse moisture content, low nip compaction, low roll speed and low contact angle conditions.
- Roll load was highest under high nip compaction, low roll speed conditions.
- Mill torque was highest under high nip compaction conditions.

The results were somewhat confounded by changes in roll load and mill torque with changes in mill orientation. Attempts to use modelling to remove this roll load effect were not particularly successful.

Given the Kauppila and Loughran (2000) results, it was surprising that there was no significant effect of mill orientation on bagasse moisture content or reabsorption. One theory expressed was that the Kauppila and Loughran (2000) experiment with the coarser prepared cane did not cause the bottom of the juice grooves to be filled and so had a conduit for juice flow that this bagasse experiment did not.

Experiment 2—the effect of juice grooves

To test the hypothesis that a conduit for juice flow was the reason that the Kauppila and Loughran (2000) experiment found such a large influence of mill orientation on bagasse moisture content, juice grooves were machined into the two rolls and rings were machined to fill the juice grooves so that tests could be conducted with and without juice grooves to determine their effect.

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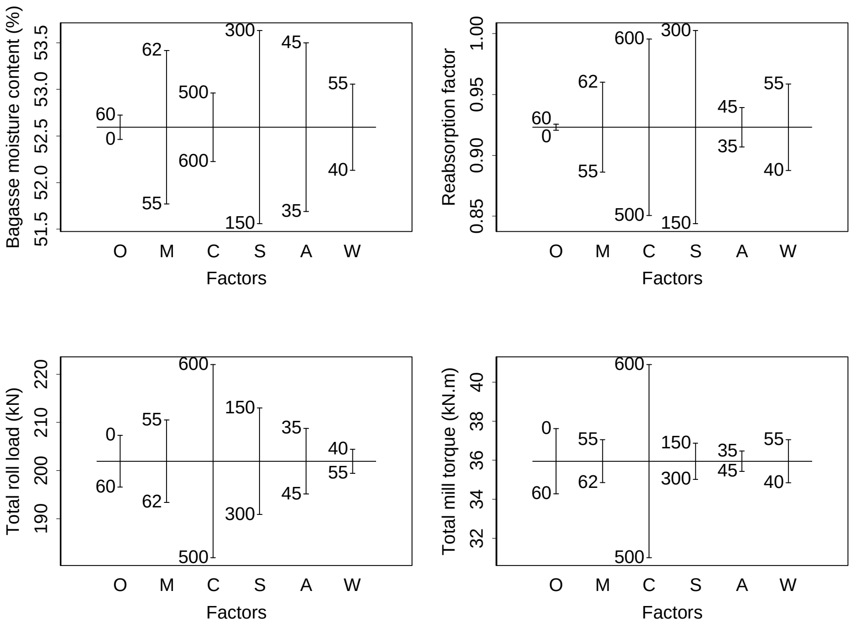

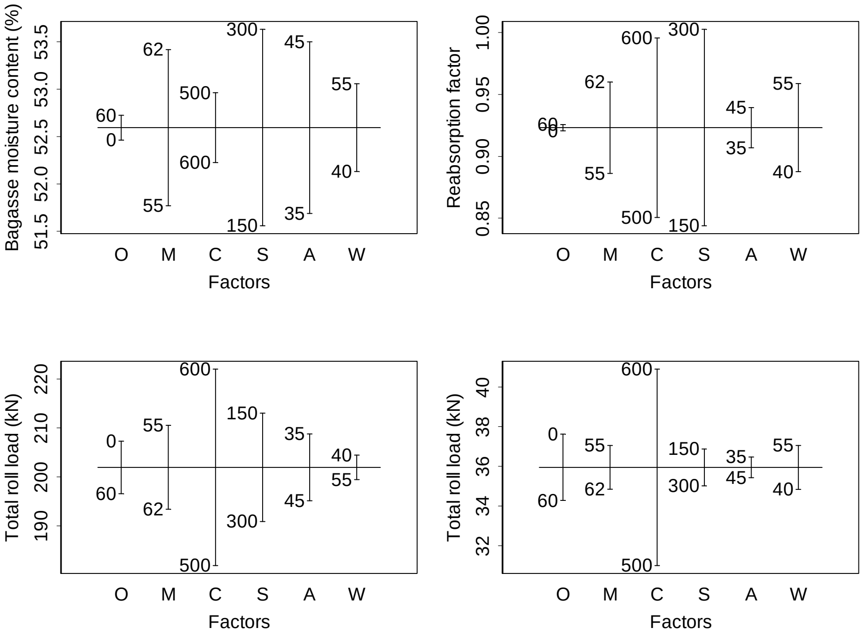

Fig. 3—Mean results for experiment 1.

Again, the experiment was designed as a 2^{6-1} fractional factorial experiment in a split-plot design (six factors were explored at two levels). In addition to the difficulty in changing work opening, the process of fitting or removing the juice groove rings was time consuming. As a result, the experiment was designed to reduce the number of changes to the work opening and juice ring configuration.

Table 3 shows the experimental factors and factor levels that were tested in the experiment. Quantifying interactions between juice grooves and mill orientation in the bagasse moisture content results was the main aim. The experiment aimed to quantify the effect of juice grooves in the top and bottom roll separately. The feed bagasse moisture content, work opening and roll speed were other parameters studied in the experiment. Two parameters studied in the first experiment, nip compaction and contact angle, were not included in this experiment in order to accommodate the juice groove factors. The nominal nip compaction selected for this experiment was 550 kg/m^3, half way between the two factor levels chosen in the first experiment. The contact angle for this experiment was set at 35°.

Table 3—Experimental factors and factor levels for experiment 2.

Experimental factors	Symbol	Level 0	Level 1
Juice grooves in top roll	GT	No	Yes
Juice grooves in bottom roll	GB	No	Yes
Work opening (mm)	W	40	55
Mill orientation (°)	O	0	60
Feed bagasse moisture content (%)	M	55	62
Roll speed (mm/s)	S	150	300

The experiment was reasonably well controlled, as shown in Figure 4. In this experiment, nip compaction varied about 30 kg/m^3 or about 6% from the desired value.

An analysis of variance found that the only factor that appeared to vary in a consistent fashion with compaction was roll speed.

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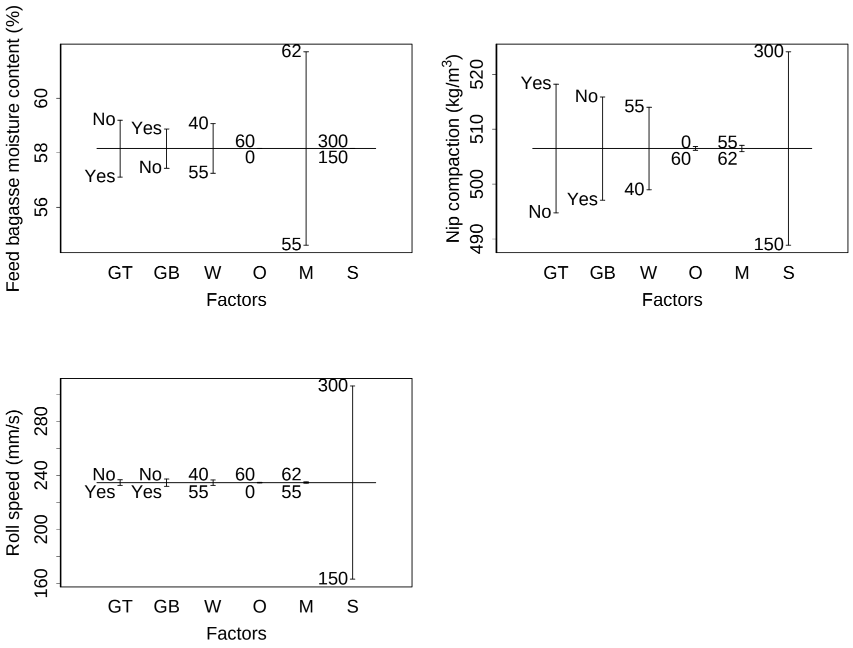

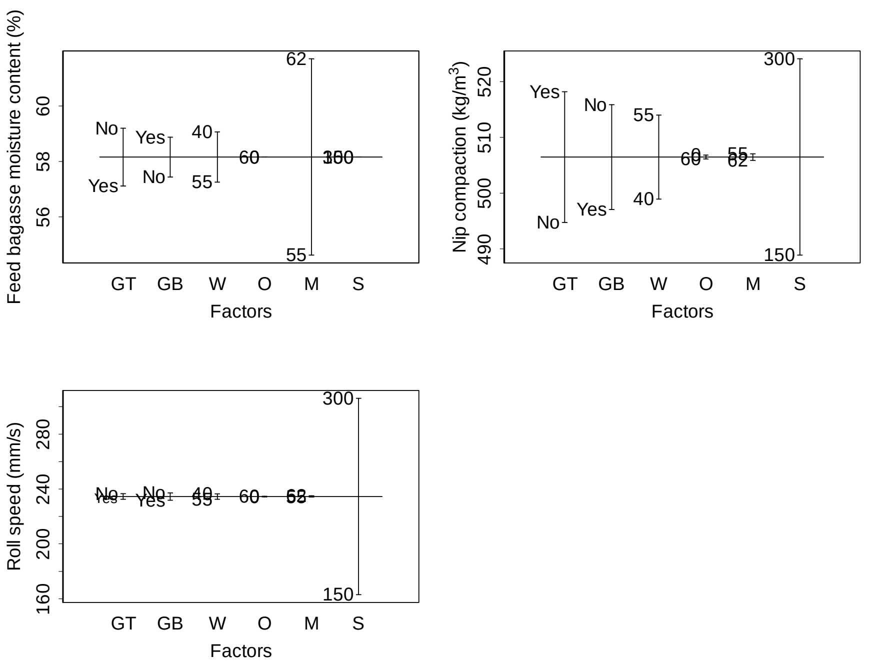

Fig. 4—Control of experimental factors in experiment 2.

The results are shown in Figure 5. Juice grooves did not significantly affect the bagasse moisture content. An analysis of variance showed that:

- Bagasse moisture content was lower under high orientation, low feed bagasse moisture content and low roll speed conditions.
- Reabsorption factor was lower under high orientation, low feed bagasse moisture content and low roll speed conditions.
- Roll load was highest under low feed bagasse moisture content and low roll speed conditions.
- Mill torque was highest under high orientation, low feed bagasse moisture content and low roll speed conditions.

Unlike the first experiment, this experiment did show that the 60° mill orientation resulted in lower bagasse moisture content than the 0° mill orientation, although the difference in bagasse moisture content was only about one unit.

The results showed no significant effect of mill orientation on roll load but a significant effect of mill orientation on mill torque was found. The variation in torque is not believed to be completely responsible for the reduction in bagasse moisture content.

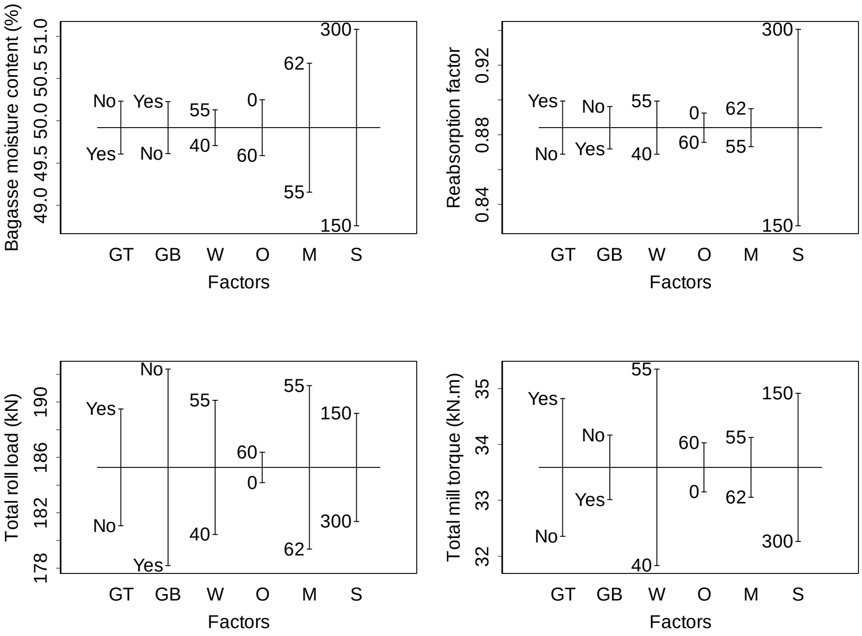

Fig. 5—Results for experiment 2.

A significant interaction between mill orientation and feed bagasse moisture content on bagasse moisture content was found. The results show that the mill orientation effect occurred mainly at the 62% feed bagasse moisture content.

It may be that the mill orientation effect is greater when there are greater quantities of juice to express.

This hypothesis is consistent with the results of Kauppila and Loughran (2000) who found a greater effect with the higher feed moisture content of the prepared cane used in their experiment.

It is also possible that the small amount of juice expressed with the 55% feed moisture content results at the nominal 550 kg/m^3 compaction may not have been enough to show any significant result.

If the mill orientation effect is greater when there are greater quantities of juice to express, it could be argued that the mill orientation effect will be greater when the nip compaction is greater.

Consequently, a greater mill orientation effect may be observed when typical delivery nip compactions of about 900 kg/m^3 are achieved.

This argument is contrary to the results of Kauppila and Loughran (2000) but the groove conduit issue may also be important. In Kauppila and Loughran’s experiment, the groove conduit size reduced when compaction increased. That is not expected to occur significantly in the presence of juice grooves.

The small amounts of juice to express may also have contributed to this experiment showing that the juice grooving had no significant effect on the bagasse moisture content.

Experiment 3—higher nip compactions

The first two experiments were conducted at close to the highest nip compactions that could be achieved on the James Cook University two-roll mill as designed. These nip compactions were well below typical delivery nip compactions for final mills.

To test the design premise at higher compactions, the roll shafts were upgraded and the hydraulic system pressures (driving the hydraulic motors on the rolls) were increased so that higher torques and hence compactions could be achieved.

The third experiment was designed as a 2^5 factorial experiment in a split-plot design (five factors were explored at two levels). The split-plot design was again necessary because of the relative difficulty in fitting and removing the juice groove rings used to explore the juice groove factors.

Table 4 shows the experimental factors and factor levels that were tested in the experiment. Quantifying the effect of nip compaction and mill orientation on the bagasse moisture content results was the main aim.

The experiment also aimed to quantify the effect of juice grooves in the top and bottom roll separately. The feed bagasse moisture content was the other parameter studied in the experiment.

The lower feed bagasse moisture content factor level was reduced from the 55% used in the first two experiments to 52% because the higher nip compactions used in this experiment were expected produce greater juice expression, allowing the feed moisture content to be reduced and still provide juice expression in the mill.

Two parameters studied in the second experiment, work opening and roll speed, were not included in this experiment.

The roll speed factor was replaced by the nip compaction factor. The work opening factor was removed to provide more degrees of freedom to test the significance of the juice grooves.

The work opening chosen for this experiment was 40 mm, the lower of the two work openings used in the first two experiments, chosen to keep the feed compaction at an acceptable level.

The roll speed chosen for this experiment was 150 mm/s, the lower of the two speeds used in the first two experiments. The contact angle for this experiment was set at 35.0°, although this contact angle was gradually increased to 37.5° to prevent overloading of the feeder drive.

Table 4—Experimental factors and factor levels for the third experiment.

Experimental factors	Symbol	Level 0	Level 1
Juice grooves in top roll	GT	No	Yes
Juice grooves in bottom roll	GB	No	Yes
Mill orientation (°)	O	0	60
Feed bagasse moisture content (%)	M	52	62
Nip compaction (kg/m^3)	C	600	900

Figure 6 shows that all experimental factors were well controlled although the achieved nip compactions were less than desired (550 kg/m^3 instead of 600 kg/m^3 and 750 kg/m^3 instead of 900 kg/m^3).

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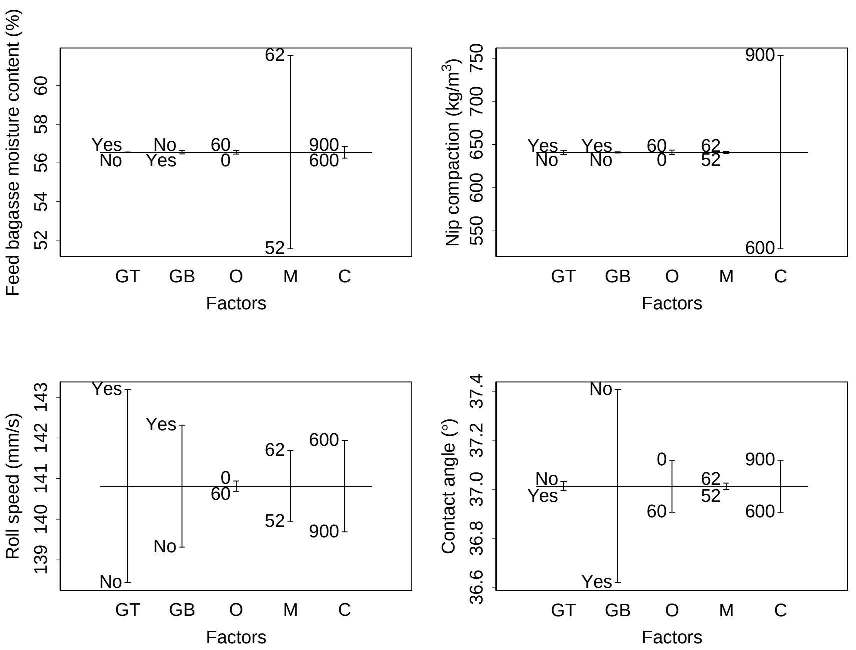

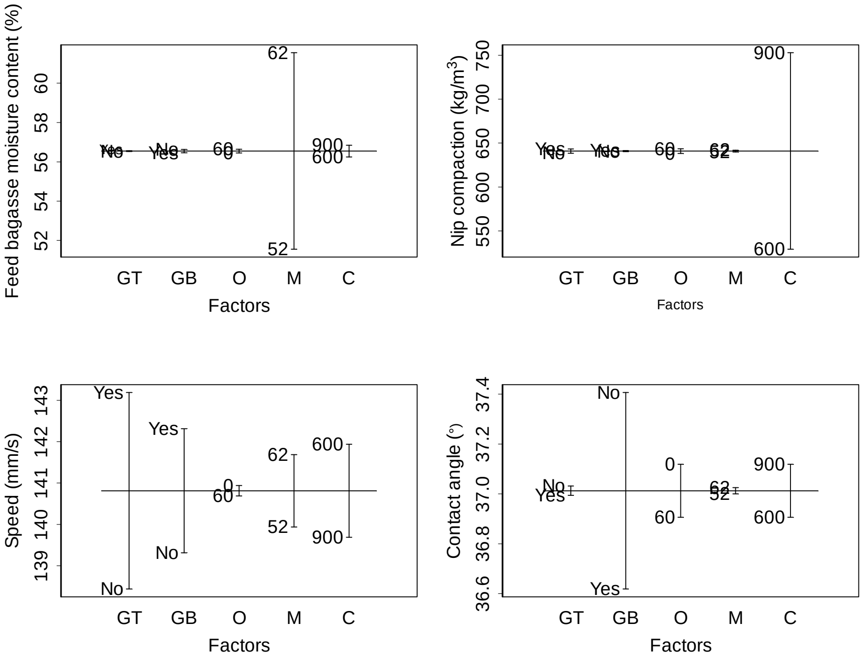

Fig. 6—Control of experimental factors in experiment 3

The results are shown in Figure 7. The bagasse moisture contents were generally lower, presumably as a result of the higher nip compactions. An analysis of variance showed that:

- Bagasse moisture content was lower under high orientation, low feed bagasse moisture content and high nip compaction conditions.
- Reabsorption factor was also lower under high orientation and low feed bagasse moisture content conditions.
- The juice grooves had no significant effect on the bagasse moisture content at the high orientation conditions.
- Roll load and mill torque were highest under low feed bagasse moisture content and high nip compaction conditions.

The results of this experiment confirm the results from the second experiment that mill orientation has a statistically significant effect on bagasse moisture content. Figure 7 shows that higher mill orientation results in lower bagasse moisture content, the desired result. The reabsorption factor was also found to be lower for the higher mill orientation results.

The analysis of variance also showed that there were significant interactions between mill orientation and juice grooves in both the top and bottom rolls and with feed bagasse moisture content and nip compaction. At the 60° orientation, the effect of the juice grooves on bagasse moisture was very small and it was the 0° orientation results that showed the juice groove effect.

The effect of mill orientation was greater at the higher feed bagasse moisture content and at the higher nip compaction. The roll load was higher for the 52% feed bagasse moisture content tests than for the 62% feed bagasse moisture content tests which at least partly explains why the delivery bagasse moisture content was lower for the 52% feed bagasse moisture content tests.

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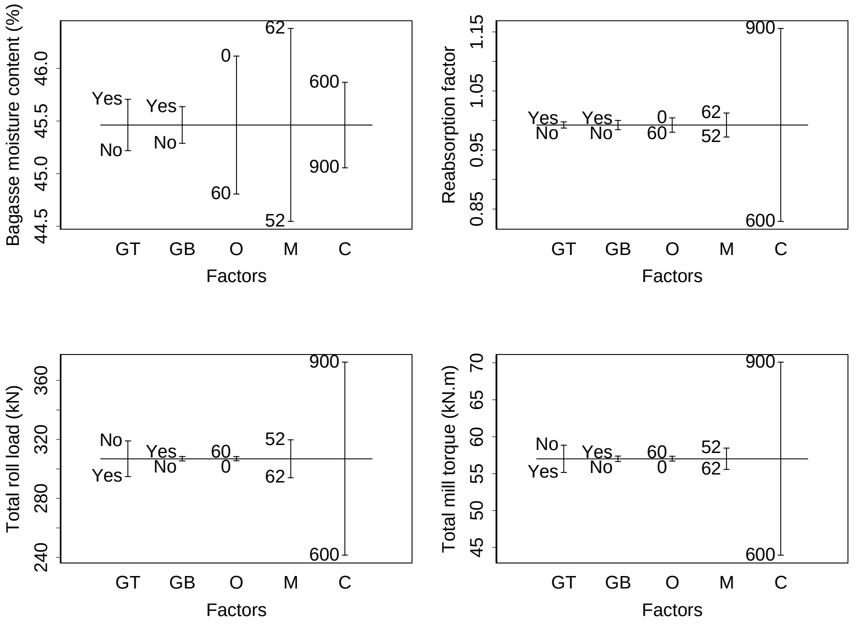


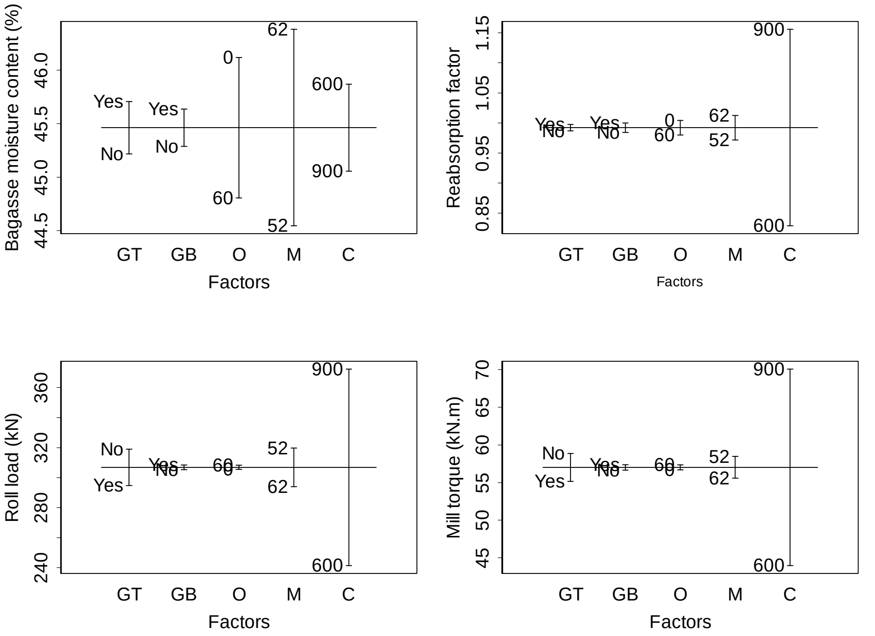


Fig. 7—Results for experiment 3.

The greater effect with higher nip compaction is an encouraging result. Considering that the desired nip compactions were not reached, it is likely that an even greater mill orientation effect could be obtained at higher nip compactions.

The average bagasse moisture achieved in this experiment for the 60° mill orientation, 900 kg/m^3 tests was about 44%. For these tests the average nip compaction was calculated to be about 750 kg/m^3. If the target 900 kg/m^3 nip compaction had been achieved, it is expected that a lower bagasse moisture content would have been achieved.

During this test series, one test did achieve a bagasse moisture content of 42.5%. This test did occur at the 60° mill orientation and had the highest calculated nip compaction at 816 kg/m^3.

Experiment 4—optimising mill orientation angle

Having established that mill orientation angle has an impact on bagasse moisture content, the question remains what mill orientation angle is best.

An experiment was designed as a blocked 4×2 factorial experiment. In all, four blocks of tests were conducted, giving a total of 32 tests. Table 5 shows the experimental factors and factor levels that were tested in the experiment.

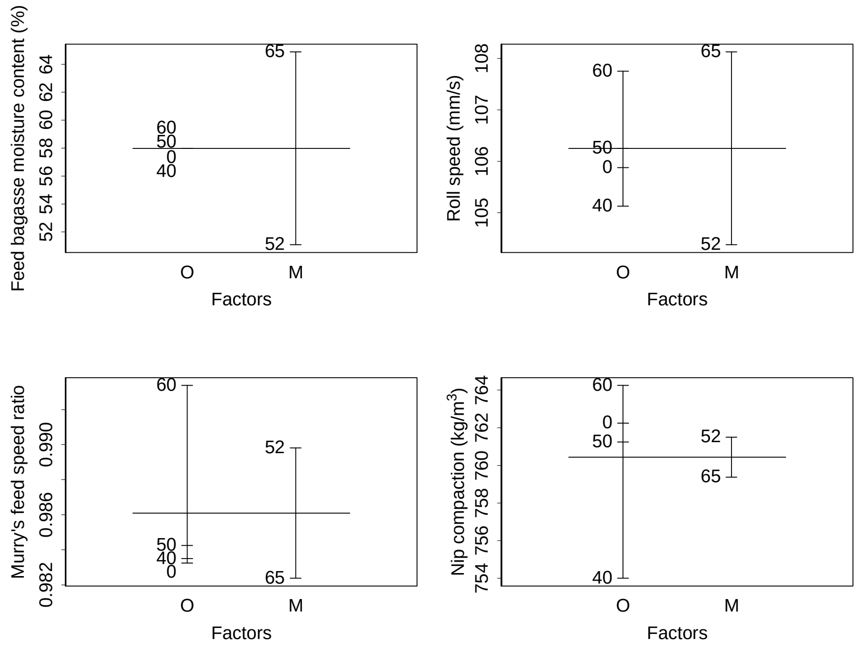
The tests were conducted without juice grooves, and with a work opening of 40 mm, a contact angle of 38° and a nominal roll speed of 100 mm/s.

While a nip compaction of 900 kg/m^3 was desired, the target nip compaction was dropped to 775 kg/m^3 due to limitations in the hydraulic drives for the mill.

Table 5—Experimental factors and factor levels for experiment 4.

Experimental factors	Symbol	Level 0	Level 1	Level 2	Level 3
Mill orientation (°)	O	0	40	50	60
Feed bagasse moisture content (%)	M	52	65		

Figure 8 shows that feed bagasse moisture content, nip compaction and roll speed were all well controlled during the experiment. A forth parameter, *Murry's feed speed ratio*, defined by Kent (2004) as the ratio of feed speed to *S*cos*α*, where *S* is the roll surface speed and *α* is the contact angle, is also presented and shows that the mill was also fed quite consistently.



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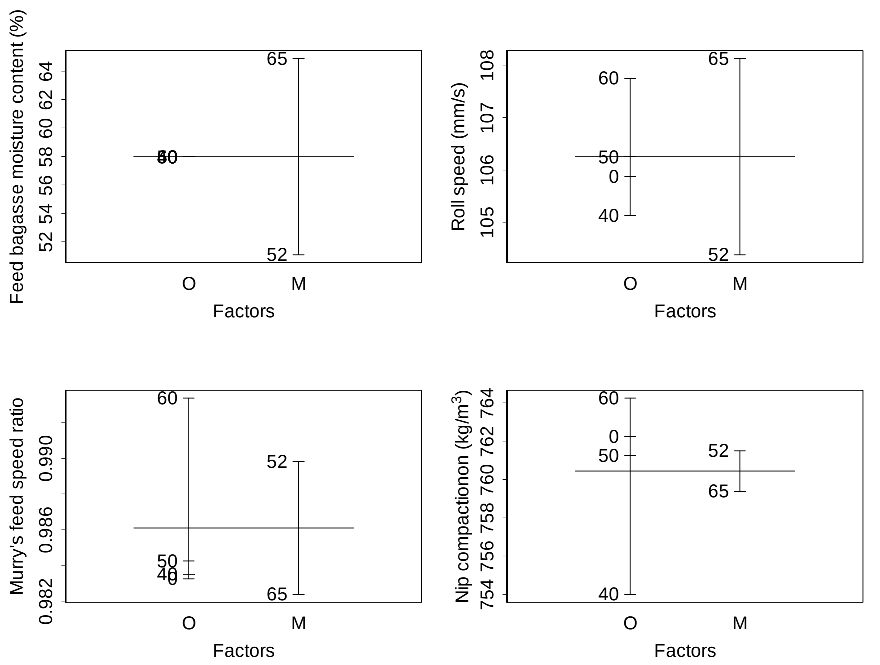

Fig.8—Control of experimental factors in experiment 4

Figure 9 shows the mean levels for delivery bagasse moisture content, reabsorption factor, total roll load and total mill torque. An analysis of variance showed that the variation of delivery bagasse moisture content (and reabsorption factor) with feed bagasse moisture content was statistically significant.

The interaction between mill orientation and feed bagasse moisture content was also statistically significant. The effect of feed bagasse moisture content on roll load and the effect of mill orientation on mill torque were also statistically significant but the effect of these two effects on the delivery bagasse moisture content results was small.

The roll load varied by 6% between the 52% and 65% feed bagasse moisture content levels. The mill torque varied by 3% between the 60° and 40° mill orientation levels.

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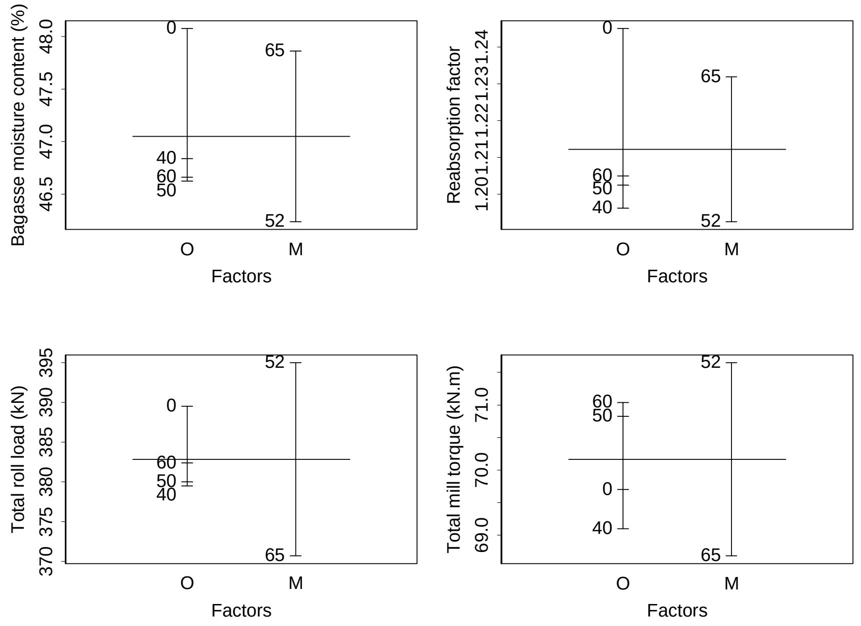

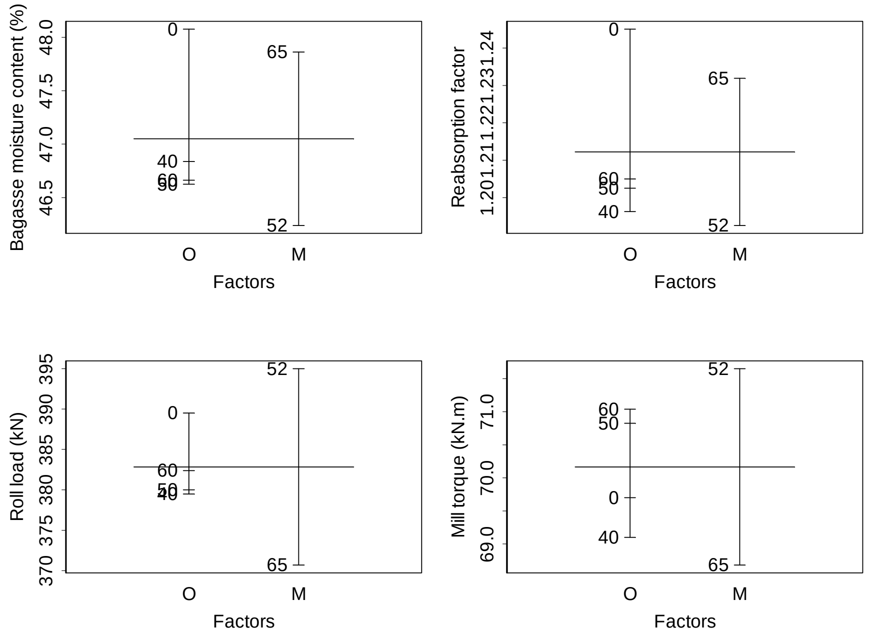

Fig. 9—Results for experiment 4.

The delivery bagasse moisture content was significantly higher at 0° orientation than at any of the other orientations and didn't vary much as the orientation was changed from 40° to 50° to 60°. The lowest results were achieved with an orientation of 50°, indicating there is no obvious value in increasing the orientation above this value.

Conclusions

The basic premise that lower bagasse moisture content can be achieved if the bagasse is fed upwards into a mill has been confirmed through experimentation on a laboratory size two-roll mill. A typical reduction in bagasse moisture content of about two units has been achieved at a nip compaction of 760 kg/m^3.

Limitations in the two-roll mill prevented nip compaction from being increased to typical final mill delivery nip compactions of about 900 kg/m^3. Nonetheless, experimental evidence was found that the reduction in bagasse moisture content at high mill orientations increases with increasing nip compaction. As a result, a greater reduction in bagasse moisture content is expected at higher nip compactions.

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