Agricultural Engineering

SUGAR LOSS DUE TO MECHANICAL HARVESTING

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ABSTRACT

Loss in a sugar production system was categorized into three elements: the field stage, the harvesting stage and the milling stage. A mathematical expression to describe the sugar loss was given by introducing a concept of an expected, or standard, yield of sugar. Attention was focussed on harvest losses and deterioration. Harvest losses of 10-15% were frequent with green cane harvesting. Billet damage was also examined, and the influence of various factors in deterioration during stock piling. Deterioration was affected by damage, rainfall and the location in the stock pile.

Key words: Sugar loss, mechanical harvesting, cane loss, deterioration, billet damage.

INTRODUCTION

Cane sugar is produced through three stages: field production, manufacturing and a harvesting stage which connects the first two stages. More attention should be paid to establishing more effective total sugar production systems. Traditionally the mill yield is the main subject of our interest relating to sugar loss. In other words, the loss in the milling stage is regarded as the sugar loss itself, and a great deal of effort has been concentrated to reduce it. On the other hand, there can be much sugar loss in the other two stages, although this is often not recognized. This sugar loss has many elements, for example, the reduction of cane yield due to disease, insects, drought, lack of fertilizer and so on should be included in this sugar loss. Quality control right from planting to milling is necessary to establish a properly integrated sugar production system. Mechanical harvesting brings about a great advantage to a cane grower. Time saving and cost reduction are important merits. These effects are obtained in suitable conditions for a mechanized production system, but the mechanical harvesting becomes harmful whenever it is applied to unsuitable conditions (Ueno et al., Ueno and Izumi). Considerable cane loss can occur during cutting and transportation (Ueno et al., Dick, Ridge and Dick). Sugar loss also occurs as subsequent deterioration due to mechanical harvesting (Ueno et al.). Trash included in the cane takes away sugar in the mill processing, and this is another type of sugar loss related to mechanical harvesting. These and other losses can negate the advantages of mechanical harvesting.
Experimental Work

Cane Loss in Harvesting

Cane loss in the harvest operation was assessed for two types of Austoft 7000 units. In all about 30 trials were carried out in 1990 and 1991 to test the performance of these harvesters under various conditions. The test fields were in Minami Daito Island in Okinawa (Ueno et al*). Measurements included cane loss, extraneous matter before and after harvesting, damage of cane billets, speed and efficiency of the harvester, field conditions and crop conditions. Travelling speed was set at three levels to determine how it affected cane loss in the same field. These tests were repeated four times in the different fields in 1991.

In these tests all of the material left in plots of 9 m² of the test fields was picked up after harvesting. This material was separated into leaves and tops, uncut cane, dropped cane billets and crushed cane. Some cane billets were crushed into small pieces by the blades of the primary and secondary cleaning fans. We picked up as much of such pieces as possible and the measurements were reliable. Materials were dried at 105 °C for 24 hours and weighed. The losses and the amounts of organic matter were calculated.

Damage of cane billets due to the mechanical harvesting were also checked at the same time to investigate the influence on deterioration. The overall damage had a close relation to cane loss. About 150 kg of billets were classified into four grades of damage, i.e. sound, light, medium and heavy. The classification was reasonably consistent, although it depended on personal judgment which varied somewhat between observers.

Deterioration of Cane after Harvesting

Four types of quality test were performed. The first was to examine the influence of billet damage. Samples were selected from the canes harvested and graded into the four groups of damage. These were kept in a ventilated room for test at intervals. In a second test the samples were stored under four conditions to simulate the stock piling options. A control was kept in a refrigerator, a sample in the shade, a sample in a sunny place and a sample in a bag. In the third test about 10 tons of mechanically harvested cane were piled up in the mill yard about 1.5 m high. The canes were stock into three groups and six piles; in the first group, two piles were put in a sunny place and one of them was showered with water to simulate rainfall; in the second group two piles were prepared, which were put in the shade or in a sunny place; in the third group, two piles were prepared and put in the shade, the cane of one pile being previously processed by a detrasher. Samples were taken from the surface and the inside of piles. In the fourth test, the influence of damage and moisture was examined using manually billeted cane.
The samples were crushed in a test mill to extract about 60% of the juice. Brix, polarization, reducing sugars and pH were measured and the purity and reducing sugar ratio were calculated. These measurements were repeated at intervals during three days immediately after harvesting.

RESULTS AND DISCUSSION

Basic concept of sugar loss

Sugar loss is measured relative to a production system which would give a maximum yield of sugar if the best conditions were provided. In other words it corresponds with the potential yield of sugar. It is impossible to get the maximum yield in a natural field, therefore a concept of an "expected yield" is introduced to express what is the loss (Figure 1). This is equivalent to a standard yield under given conditions of input-energy, labor, fertilizer, chemicals and so on.

The loss is defined as the difference between the expected yield and the actual yield. If necessary a single measure of input could be devised, for example, all inputs could be reduced to energy or to cost consumed. Summarizing:

\[
\text{Loss} = \text{expected yield} - \text{actual yield}
\]

\[
\text{Total loss ratio} = \frac{\text{loss}}{\text{expected yield}}
\]

\[
\text{Total efficiency} = \frac{\text{actual yield}}{\text{expected yield}}
\]

![Figure 1. A concept of loss.](image-url)
There are many sources of the loss and it is often difficult to analyze them accurately. However, loss analysis is very important to establish an effective production system. The loss $H$ is the main subject of this study, which is composed of:

\[
\text{Loss } H = \text{loss } HF + \text{loss } HT + \text{loss } HD + \text{loss } HO
\]

loss $HF$: loss in the harvest operation
loss $HT$: loss in the transport
loss $HD$: loss by the deterioration
loss $HO$: other losses relating to the harvesting

We focus here on $HF$ and $HD$.

**Direct cane loss during harvest ($HF$)**

Table 1 shows the losses measured during the trials. The average loss was 14.4%, or 9.9 t/ha. The main loss occurred in the extractor fans. Part of the loss could be reduced by careful operation, but it is difficult to reduce the losses from the extractors. With regard to the influence of travelling speed on cane loss, it was sometimes observed in green cane harvesting that the loss appeared to decrease when the harvester moves faster. However, the relation between the loss and speed was not so clear in our test results (Figure 2). Proportionate losses increased at first and then decreased with increasing feed rate.

**TABLE 1. Results of cane losses due to mechanical harvesting.**

<table>
<thead>
<tr>
<th>Term</th>
<th>Range of data</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield of cane (t/ha)</td>
<td>30.6 - 122.0</td>
<td>75.0</td>
<td>21.1</td>
</tr>
<tr>
<td>Trash ratio (%)</td>
<td>6.1 - 19.2</td>
<td>10.5</td>
<td>3.1</td>
</tr>
<tr>
<td>Loss by extractors (t/ha)</td>
<td>2.8 - 15.2</td>
<td>7.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Loss by uncut etc. (t/ha)</td>
<td>0 - 5.5</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Loss by drop (t/ha)</td>
<td>0 - 3.0</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Total loss (t/ha)</td>
<td>4.0 - 21.7</td>
<td>9.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Loss ratio (loss/yield %)</td>
<td>6.0 - 36.3</td>
<td>14.4</td>
<td>6.7</td>
</tr>
</tbody>
</table>

**Billet damage due to mechanical harvesting**

We previously reported a study in which the percentage of sound billets was less than 30% (Ueno et al) for various types of harvesters in burnt and unburnt cane.
In our experience, billet damage in green cane was larger than that in burnt cane. Table 2 shows the results for the present study. The percentage of each degree of damage had wide variation, showing that damage depended on many factors. A rough estimation of damage was 2:4:3:1 of sound, light medium and heavy respectively. It is not easy however to find clear relations between some factors and the damage. In some cases the higher travelling speed brought about lower damage levels although the correlation was not very high.

Simple trials to seek the sources of damage were carried out. Table 3 shows the degrees of damage under different settings of extractor fans: normal, stopping the secondary fan, and stopping both fans. Sound billets somewhat increased when a fan or fans were stopped and the proportion of heavily damaged billets decreased. But the changes were not large enough to pinpoint the fans as the main source of damage.

However, sound billets increased remarkably when knife bladed of the chopper were exchanged for new ones— a well known experience for harvester users. Billets from the base or the middle of the cane were more easily damaged by the mechanical stress of chopping because of the hardness of their skins.
TABLE 2. Results of damage of billets due to mechanical harvesting.

<table>
<thead>
<tr>
<th>Term</th>
<th>Range of data</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound (%)</td>
<td>4.2 - 34.9</td>
<td>15.6</td>
<td>6.51</td>
</tr>
<tr>
<td>Light (%)</td>
<td>2.93 - 60.7</td>
<td>44.9</td>
<td>8.41</td>
</tr>
<tr>
<td>Medium (%)</td>
<td>12.7 - 39.2</td>
<td>25.5</td>
<td>5.94</td>
</tr>
<tr>
<td>Heavy (%)</td>
<td>3.9 - 26.5</td>
<td>14.1</td>
<td>5.34</td>
</tr>
</tbody>
</table>

TABLE 3. Percent damage due to the operating modes of cleaning fans.

<table>
<thead>
<tr>
<th>Fans</th>
<th>Sound</th>
<th>Light</th>
<th>Medium</th>
<th>Heavy</th>
<th>Trash ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>2.53</td>
<td>50.27</td>
<td>20.55</td>
<td>17.25</td>
<td>9.64</td>
</tr>
<tr>
<td>Secondary fan stopped</td>
<td>3.59</td>
<td>56.94</td>
<td>26.51</td>
<td>12.95</td>
<td>10.05</td>
</tr>
<tr>
<td>Both fans stopped</td>
<td>6.22</td>
<td>60.32</td>
<td>25.49</td>
<td>7.97</td>
<td>25.83</td>
</tr>
</tbody>
</table>

Deterioration of cane after harvesting

We had shown that the quality of burnt cane deteriorated faster than that of green cane (Ueno et al.) and it is known that damaged cane deteriorates faster. We examined here the influence of that damage.

1. Influence of billet damage

Figure 3 shows the quality changes with time, using reducing sugar ratios as the indicator. Experiments were carried out in winter (December) at the beginning of the harvest season, and in early spring (March). Deterioration rates in the cooler period were lower. Canes' maturity also influenced the results and is believed to be the main reason for the wide variation of reducing sugar levels. Badly damaged billets showed faster deterioration after 40 hours.

In the warmer period, deterioration was faster and more closely related to the degree of damage. The differences became obvious in the first 24 hours. However, the differences were not always consistent and more measurements are justified.
2. Influence of stocking conditions

The stocking conditions of cane in the mill yard also vary, as well as weather conditions of temperature, humidity, sunshine, rainfall and wind. The surface of a stockpile is relatively sensitive to these conditions, whereas the main factor operating inside the pile would be higher humidity.

The cane kept its quality almost constant in a refrigerator, as shown in Figure 4a. The deterioration of cane in the shade was slower than that kept in the sun or in the bag (which gave similar conditions to the inside of the stockpile). Sound billets were used in this test, selected from the unburnt cane harvesting. However, since there were relatively few sound billets from the lower part of each cane, many of these billets were from the upper part of the stalk, increasing the chance of variation in the reducing sugar ratio.
Figure 4b shows the results with burnt canes in the same test. Deterioration was particularly fast for cane kept in the bag (i.e., high humidity).

![Graphs showing reducing sugar ratio over time for green and burnt cane under different stocking conditions.]

FIGURE 4. Quality changes under four stocking conditions.

3. Influence of stock conditions

Deterioration was examined in actual stock piles in a series of trials. Unburnt canes were stocked into two piles in the first trial. Sound billets were selected and placed on the surface and into the inside of piles. One pile was showered with water to simulate rainfall. The inside sample of both showered and unshowered piles deteriorated rapidly within 20 hours. Surface-stored billets, whether showered or not, showed a small decline at first but then appeared much more stable than the billets which had been stored inside the pile.
In the second trial two stockpiles were prepared and sound billets placed on the surface. One pile was roofed and the other was in a sunny place. The samples under the roof held the values of reducing sugar ratio almost constant during three days. On the other hand the samples in the sunny place suffered some deterioration, as shown in Figure 5a. However, cloudy weather and relatively low temperature may have reduced the relative difference of the storage location.

**FIGURE 5.** Quality changes of cane on the surface of stock piles.

The third trial was similar to the second, except that the canes of one pile were processed by a detresher to remove the extraneous matter before the stock piling. Both piles were covered by a roof. The quality of both samples declined with time, but deterioration was faster for the processed billets.
Influence of damage and rainfall

We had assumed that the rainfall would accelerate quality change. However, in the trial described above the canes exposed to watering deteriorated quite slowly, except for an initial change (Figure 3). The investigation was extended as follows. Samples were prepared by manual chopping of billets, because of the difficulty of selecting sound billets from the mechanically harvested canes. Half of them were split artificially to simulate the damaged cane. Sound and split billets were divided into two samples respectively. A sound sample and a split one were watered for about two hours. These samples were put into a ventilated room. Figure 6a shows that the quality of the split and non-watered samples declined remarkably after 24 hours.

![Graph showing quality changes over time for different samples](image)

**FIGURE 6.** Quality changes relative to billet damage level and rainfall.
The results of the second trial are shown in Figure 6b. The samples were collected from the mechanically harvested cane and the same treatment carried out. Almost similar tendencies were observed as those of the first trial, however, the deterioration of the split and wetted sample was more noticeable this time.

The slower deterioration of wetted samples has been noted by other authors, but we could not recommend it since the water carried away considerable amounts of sugar.

**Overall estimation of losses**

Although these studies indicate considerable potential losses due to deterioration of billets, especially damaged billets if not processed quickly after harvesting, the results were too variable to define the exact amounts, or likely amounts, of the losses over all the conditions of a typical harvesting season. A similar conclusion was reached by Whittington-Vaughan and Hudson. Thus further detailed research is necessary before accurate measurements of the influence of mechanical harvesting on cane deterioration can be made.

**CONCLUSIONS**

We classified sugar loss into three components – the field stage, the harvesting stage and the milling stage – with respect to loss due to mechanical harvesting. The direct losses in the harvesters were relatively easy to measure and averaged about 15% (range 5-30%). Significant deterioration losses during transport and mill storage of the billeted cane were also demonstrated, but it was impossible to quantify them so precisely.

**REFERENCES**

PERDIDAS DE AZÚCAR A CONSECUENCIA DE LA COSECHA MECANIZADA

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RESUMEN
Las pérdidas en azúcar se categorizan en tres aspectos: el de campo, el de fábrica. Se da una expresión matemática que describe las pérdidas en azúcar de acuerdo con los rendimientos promedió o ponderados. Se ha hecho hincapié en las pérdidas de cosecha y el deterioro de la caña. Se observaron los daños a los trozos de caña (rolloitos), y los factores que influyan en el deterioro durante el almacenaje en montones o tongas. El deterioro a la calidad de la caña de azúcar fue producido por lo daños a los trozos, la lluvia y la localización de las tongas.

Palabras claves: Pérdidas en azúcar, cosecha mecanizada, pérdidas en caña, deterioro, daño al trozo.