CANE STOOL MATHEMATICAL MODEL FOR THE EVALUATION OF A TOPPER

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ABSTRACT

A sugarcane field mathematical model for predicting the results of a topper is discussed. On the basis of this model, the advantages of using the topper were established. The range of application in terms of the uniformity of the sugarcane field and cane losses was determined through a nomogram worked out during the research. The minimum allowed uniformity was 0.60 with losses up to 5%.

A nomogram was recommended in order to predict the results of the topper unit and to set the work norms of the operator.

INTRODUCTION

During the last two decades, beginning with results obtained in Australia and in other sugar producing countries, sugarcane mechanization has gained momentum. Particularly in Cuba, various combines have been introduced, such as the KTP, the Libertadora Class, the Massey-Fergusson and various prototypes have been appraised (Iglesias4).

Special attention has been paid to cane-top cutting elements (green stalk and green leaves) by Brito2, as well as to the effects of various harvesting systems on raw material quality (Lage5, Betancourt4).

However, the lack of a theoretical basis to correlate cane uniformity and the height of the topper in order to predict the quality of the raw material obtained and the losses produced by the system, has been a limiting factor in establishing the advantages and the limits of practical application.

In order to know the action of a topper unit, it is necessary to characterize the field in terms of uniformity and to design a cane stool model that would allow prediction of the effects of the topper unit such as the composition and losses of the processed sugarcane at various cutting heights of the machine. Thus, it would be possible to set the work norms of the combine both in quantity and...
quality, to establish the limits of application of the topper and the characteristics that sugarcane varieties must have for mechanized harvesting. The symbols used are as follows:

- $h$: length of clean cane stalks
- $r$: length of green stalks
- $\Theta$: angle of inclination of each cane
- $h_c$: cutting height of the topper
- $C_1$: clean cane
- $T_v$: green stalks
- $H_v$: green leaves
- $H_s$: dry leaves
- $n$: numbers of stalks in each stool
- $u$: stool uniformity
- $p$: sugarcane losses
- $c$: subindex indicating cut cane
- $nc$: subindex indicating uncut cane
- $r$: subindex indicating relative to initial value
- $M_{e}$: foreign matter
- $l$: quality index equal to $C_1 m_e$

**THEORETICAL BASIS**

Uniformity is the most important feature of a sugarcane field as far as mechanized harvesting is concerned. In the above-mentioned literature, this concept is often used in association with that of "straightness", which has a certain relationship, but is not identified. On the other hand, the concept of uniformity often refers to sugarcane of the same height, not accounting for the influence of slant.

Brito introduced the concept of "height variation coefficient", taking into consideration only the stalks that are within the reach of the topper unit. He defined "straightness" as the relationship scope of the sugarcanes that are covered by the topper. Thus, a field is characterized by two factors, notwithstanding the fact that Brito finds an interdependence between them.

However, the topper covers a band that can range up to 1.6 meters. This magnitude is comparable to the distance between rows and in operation the action of the topper covers the total area of high top density to be harvested.

In order to develop the stool model, it is considered that uniformity is based on the dispersion of the projections of each sugarcane on the Y axis, in relation to the mean value of the projections, as the sole expression characterizing a field.

\[
    u = 1 - \frac{\sqrt{\sum (h_1 \cos \Theta - h \cos \Theta)^2}}{n-1} \frac{1}{h \cos \Theta}
\]

(1)
The following describes the basis of the system of equations describing the stool. It is assumed that both the sugarcane and the green stalks have the same diameter throughout its length for all sugarcanes.

**Calculation for clean cane (C).**

Evidently:

\[ h \geq C_{nc} = h_0 \sec \Theta \]  
(2)

If

\[ C_{c} = h - h_0 \sec \Theta \geq 0 \]  
(3)

and

\[ h_0 > h_0 \cos \Theta, \quad C_{nc} = h y C_{c} = 0 \]

\[ P = \frac{h - h_0 \sec \Theta}{h} \]

The value 7.0 g/ml cm was experimentally determined for the ratio of weight to length of both green and burned canes.

**Green stalk (Tv)**

Due to positive phototropism the position of the green stalk is oriented along the perpendicular field plane.

and

\[ T_{vc} = h \cos \Theta + r - h_0 \]  
(5)

\[ T_{vnc} = h_0 - h \cos \Theta \]  
(6)

If

\[ h_0 \leq h \cos \Theta, \quad T_{vnc} = 0 = y T_{vc} = r \]

\[ h_0 > h \cos \Theta + r; \quad T_{vnc} = y T_{vc} = 0 \]

The experimental values of green cane stalk length are shown in Table 1.

In this paper \( r \) is taken to be constant:

\[ r = 0.50 \text{ m} \]

A ratio of weight to length of 5.0 g/ml cm was experimentally determined for both green and burned cane.
TABLE 1. Green stalk length for different varieties and stools

<table>
<thead>
<tr>
<th>Variety</th>
<th>Stool</th>
<th>r (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ja 60–5</td>
<td>Spring left on the field</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Ratoon</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>First ratoon</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0.50</td>
</tr>
<tr>
<td>My 55–14</td>
<td>Spring left on the field</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Ratoon</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>First ratoon</td>
<td>0.54</td>
</tr>
<tr>
<td>B 43–82</td>
<td>Ratoon</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0.56</td>
</tr>
<tr>
<td>C 87–51</td>
<td>Ratoon</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>First ratoon</td>
<td>0.57</td>
</tr>
<tr>
<td>CP 52–43</td>
<td>Ratoon</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>First ratoon</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.46</td>
</tr>
</tbody>
</table>

\[ F = 0.51 \pm 0.04 \]

**Green leaves (Hv)**

In practice, there is a direct relation between the quantities of Hv and Tv, thus it is assumed that:

\[ Hv = K \cdot Tv \quad \text{where, } K = \text{Proportionality factor} \tag{7} \]

The values of leaf and green stalk content reported in the literature as well as those experimentally obtained are shown in Table 2.

**Dry leaves or cane trash (Hs)**

A relation between dry leaf weight and stalk length is to be expected both in green and burned sugarcane, despite the fact that in the latter case the absolute value of dry leaf weight will be small.

Thus:

\[ Hs = K \cdot C_l \quad K = \text{Proportionality factor} \tag{8} \]
TABLE 2. Values of leaf and green stalk content at the sugarcane tops

<table>
<thead>
<tr>
<th>Variety</th>
<th>Stool</th>
<th>According to Lodos and Casanova</th>
<th>According to Brito 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tv%</td>
<td>Hv%</td>
</tr>
<tr>
<td>Ja 60-6</td>
<td>PO</td>
<td>58</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Ratoon</td>
<td>58</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>First Ratoon</td>
<td>56</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>B 4362</td>
<td>Ratoon</td>
<td>61</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>53</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>59</td>
<td>44</td>
</tr>
<tr>
<td>C 8751</td>
<td>Ratoon</td>
<td>57</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>First Ratoon</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Experimental values ranged from 0.68 to 1.34 gm trash/cm cane for green cane and from 0.05 to 0.10 for burned cane.

In this paper, $K = 1$ that is,

$$Hv = Tv$$

In this paper $K = 1.00$ for green cane and $K = 0.10$ for burned cane.

"Stool" system of stalk

From the expressions (1) to (8), the equations defining the stool are obtained and shown in Table 3.

RESULTS AND DISCUSSION

Experimental determinations of the various parameters describing the vegetative structure of the sugarcane plants and uniformity of various sugarcane fields were determined experimentally.

A program for the CID-201 B computer, capable of obtaining the composi-
Model of individual cane

Real cane

FIGURE 1. Actual cane and its model according to the equation system.

TABLE 3. Expressions for calculating the components of a cane stool

<table>
<thead>
<tr>
<th>Vegetative</th>
<th>Component</th>
<th>Cut (c)</th>
<th>Uncut (nc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma h_i$</td>
<td>Cl</td>
<td>$\Sigma (h_i - h_o \sec \theta_i)$</td>
<td>$\Sigma h_o \sec \theta_i$</td>
</tr>
<tr>
<td>nr</td>
<td>$Tv = Hv$</td>
<td>$\Sigma (h_i \cos \theta_i + r - h_o)$</td>
<td>$\Sigma (h_o - h_i \cos \theta_i)$</td>
</tr>
<tr>
<td>$K \Sigma h_i$</td>
<td>Hs</td>
<td>$K \Sigma C_{lc}$</td>
<td>$K \Sigma C_{lc \text{nc}}$</td>
</tr>
</tbody>
</table>

There are certain distribution of cane that result in two stools having the same uniformity with different heights. This made the analysis difficult. Therefore, in all cases the equations of the model were worked out with heights, $h_r$ related to mean height both of canes and green stalks.
The relationships between cane losses and cane height for different height uniformities are shown in Fig 2.

The family of lines for uniformity indicates that for $U$ values lower than 0.6, cutting heights became very high implying a slight increase in the quality index of the sugarcane.

**FIGURE 2.** Cane losses according to relative cutting height, for different height uniformities

**FIGURE 3.** Relative increase in quality index $I_r$ according to relative cutting height
The expression obtained for the family of straight lines under the study was:

\[ h_r = \frac{h_0}{h} = (2.105 - 1.126 U) + (0.0956 U - 0.1114) P \]

for \( U > 0.6 \) \hspace{1cm} (9)

From this expression, the dependence of \( h_r \) on \( U \) for different losses may be established.

The relation between the quality index and cutting height was also obtained. In this case, too, the index obtained was referred to the initial index in order to eliminate differences between stools. Fig. 3 shows the relative increase in quality index \( I_r \) according to relative cutting height \( h_r \).

The results were processed according to a potential program, obtaining.

**Green Cane**

\[ h_r = 2.322 - 1.717 I_r + 0.780 I_r^2 - 0.122 I_r^3 \] \hspace{1cm} (10)

**Burned cane**

\[ h_r = 1.510 - 0.361 I_r + 0.088 I_r^2 - 0.007 I_r^3 \] \hspace{1cm} (10)

With a correlation coefficient of 0.97 is in the range under consideration.

These expressions were independent of \( U \).

It is obvious that a grower, when investing in the addition of a topper to a combine, wishes to improve the quality of his sugar cane with the least possible loss. That is to say, he wants that the increase in cane quality and the mill profits to surpass the loss. By combining the expressions 9 and 10 Fig. 4 was obtained, in which it can be seen that in a field of \( U = 0.6 \) the use of topper does not satisfactorily increase cane quality since losses are up to 5%. The quality of the cane may decrease if smaller losses are forced.

Lodos\(^5\) reached the conclusion that the expression correlating the efficiency of a cleaning system with the recovery, taking into account the increase in sugar loss in bagasse due to an increase in foreign matter, was:

\[ K = \frac{FB}{100 P-FB} \] \hspace{1cm} (11)

<table>
<thead>
<tr>
<th>Values</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>f fiber in Me</td>
<td>25</td>
</tr>
<tr>
<td>F fiber in cane</td>
<td>14</td>
</tr>
<tr>
<td>B loss in bagasse</td>
<td>6</td>
</tr>
<tr>
<td>P sugar content in cane</td>
<td>14</td>
</tr>
</tbody>
</table>
On the other hand, the relation established by Buchanan allowed us to assume that loss in molasses resulting from the presence of non-sugars in the canetop were at least as great as the loss in bagasse.

By evaluating expression 11, we concluded that it was necessary to eliminate approximately four times the amount of foreign matter compared to the amount of cane in order to compensate for sucrose loss in bagasse and in molasses.

This did not take into consideration the additional effects of foreign matter on equipment wear, capacity loss, increase of mud, and clarification difficulties which may be very significant.

Fig. 4 represents the nomogram that relates cutting height to field uniformity, and allows us to forecast losses in sugar cane and the quality increase obtained by the action of the topper.

The shaded area comprises the range where the use of the topper is justified. This area is covered by the following values 0.90 < $h_m < 1.25$ y $U > 0.75$.

It must be pointed out that the operator of the combine can improve the results given by the topping unit which supposes a constant height. In fact, the operator raises or lowers the topper according to his appraisal of each stool and to
his skill. The effect of the topper will be greater in proportion to the fraction of stools which have a $U$ greater than 0.75.

Brito working with an individual topper in a row of stools determined $U$ and $P$ experimentally. The data provided by him allows us to calculate $I_r$. Table 4 shows the results of the $I_r$'s predicted with the model discussed in this paper.

**TABLE 4.** Experimental values of $U$, $P$ and $I_r$ according to Brito and Abreu

<table>
<thead>
<tr>
<th>No.</th>
<th>$U$</th>
<th>$P$</th>
<th>$I_r$</th>
<th>$I_r$ Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.97</td>
<td>1.5</td>
<td>6,1</td>
<td>$&gt;6$</td>
</tr>
<tr>
<td>2</td>
<td>0.90</td>
<td>2.2</td>
<td>2,7</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>0.89</td>
<td>2.1</td>
<td>3.6</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>0.89</td>
<td>0.3</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>0.85</td>
<td>1.7</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>0.81</td>
<td>0.4</td>
<td>0.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The analysis of these results shows that the operator is generally skillful. His skill is manifested in the improvement of the quality of the cane in 15-20% for the same loss. Brito attributes the above to the fact that the operator concentrates his full attention on cutting the top, which was the only thing he did with the machine.

From this analysis it is inferred that maybe the shaded area could be widened up to uniformities of 0.6-0.7 with favorable distributions and depending on the skill of the operator. The scheme worked out allow not only for the determination of the general possibilities for using the topper but also for the prediction of the results to be expected in each concrete case. It could even be used as a device for controlling the work of the operator of the combine and eventually establish wage scales based on quantity as well as quality, that is to say, low loss index and high $ClMe$ index.

**CONCLUSIONS**

1. A system of equations modelling a sugar cane stool was established to foresee the effects of a topper, cutting at fixed heights.

2. It was determined that fields with a uniformity of 0.75 constitute the limit of application of the topper unit, and that by using it the quality index in green cane could be tripled and this could be increased sixfold in burned cane, with losses lower than 3%.

3. A nomogram was designed which allows one to predict the results obtained
by using a topper in concrete cases and to norm the work of the combine operator.

REFERENCES


UN MODELO MATEMATICO DE UN CAMPO DE CAÑA DE AZUCAR PARA PREDECIR LOS RESULTADOS DE UN CUCHILLO DESCOGOLLADOR.

Jorge Lodos y Eduardo Casanova

RESUMEN

Se discute un modelo matemático de un campo de caña de azúcar para predecir los resultados de uno cuchillo descogollador.

Las ventajas del uso del descogollador son establecidas a base de este modelo. El promedio de uso, en términos de uniformidad del campo y las perdidas de caña se determina mediante el desarrollo de un nomograma durante el transcurso del estudio. La uniformidad mínima permitida es 0.60; con perdidas hasta 5%.

Se recomienda un nomograma para prognosticar los resultados del descogollador y establecer normas de trabajo para el operario.