CHANGES IN GREEN CANE HARVEST RESIDUE DURING STORAGE

By

C.O. BRICEÑO and J.S. TORRES
Centro de Investigación de la Caña de Azúcar de Colombia (CENICANÁ), Cali, Colombia S.A.

Abstract

In order to determine the principal changes that occur in green cane harvest residue during storage, a two-phased monitoring program was established. Two forms of storage and exposure in the open were investigated. To establish the changes in temperature in the interior of the piles compared with the ambient temperature, thermocouples were installed at different depths in the depots. In addition, samples were taken daily to determine moisture and pH, and observe deterioration, changes in colour, or increases in fragility, decomposition and odour. The observations made it possible to detect physical changes such as colour, dryness, brittleness and odour, which may be associated with the deterioration of the material. Substantial changes that would confirm deterioration were not perceived. Although there was an increase in temperature and a decrease in moisture of the residue, the values obtained did not reach the 70–80°C mentioned in the literature for commercial piles of bagasse. It is, however, feasible to reach these levels with larger sized deposits and densification, but under a roof. The correlations among maximum temperatures reached, pH and moisture had high coefficients of determination (R²), but they should be taken only as indicators of trends.

Introduction

The volume of cane harvest residue in Colombia is high. It ranges from 30–80 t/ha, but it is not currently in use for direct combustion in boilers at all. It is necessary to learn how to store these residues for later replacement of carbon or bagasse to generate energy. The tendency is to chop it up using a Claas forage harvester, with modifications to its original design; thus the storage systems have to be suitable for chopped residue (Torres and Villegas, 1999) with some compaction, but not baled.

It was expected that not only the difficulties for achieving adequate conservation will be equal to or greater than those encountered for bagasse, but that there would also be opportunities for applying the thermal phenomena developed within the piles. For these reasons, CENICANÁ set up a program to observe and monitor the harvest residue stored under a roof and in the open. The aims were to quantify the physical and chemical changes of the material during periods of minimum two months’ storage and try to establish the causes of these changes.

Materials and methods

The monitoring program comprised two phases: the first one, to specify areas and volumes of study, equipment and methodologies, for which results are presented in this document. The second phase will cover future evaluation of procedures and resources, and gathering and analysis of information. In the first phase of the study, two two-month periods of observation were established to determine the development of microorganisms, organic decomposition, morphological alterations, changes in pH, temperature, moisture, colour and densification of the material.

During the first period (27 Oct.–20 Dec. 1999), approximately 5 t of residue chopped with a Class–CENICANÁ machine, were piled out in the open, forming an oblique truncated cone (Franco, 2000). For purposes of comparison, a 6-t pile of bagasse, in the form of an oblique cone, was also left out in the open. Neither of the two piles was submitted to compression, and a program of taking daily samples was established. The material extracted from the previously defined points was taken to the laboratory. Temperature was measured in situ using an RTD sensor and a universal transmitter of temperature. Simultaneously, records of daily rainfall were taken to relate the possible thermal and moisture changes with the rainfall.

For the second monitoring period (10 July–11 Sept. 2000), it was decided to construct two cylinders of metal netting, 1.90 cm high by 85 cm in diameter (Betancourth, 2000). This was done on the basis that the central portion of a residue pile can be represented by a cylinder and that this geometric form is also used by the balers.

Three hours after the harvest, the residue was picked up in the field. Its composition was: high proportion of tops (50%) and leaves (30%) and, to a lesser extent, stools and roots (1%), dry stalks (3%), suckers (6%), leaf sheath and dirt (10%). The residue appeared fresh. Using the Class machine, the residue was chopped to 2 mm of length that gave off a strong odour of recently cut grass.

In this second period, the temperature of the residue piles was monitored continuously with 11 Type-T thermocouples (copper-constantan), of which 10 were placed in the piles and one was left to take the ambient temperature. To determine the pH and moisture, a 200 g sample was taken once a day from different depths (Figures 1, 2 and 3) and sent to the laboratory.

KEYWORDS: Moisture, Temperature, pH, Green Cane, Harvest Residue.
Two weeks after making the cylinders of harvest residue, it was decided to form two piles (truncated cones) of bulk bagasse for comparison with the previous piles of residues. Each new pile contained about 1200 kg of bagasse. One pile was covered and the other exposed in the open. T-type thermocouples were used to monitor temperature.

Results and analysis

First period

The temperature developed inside the residue and the bagasse was not the same throughout the pile. It was observed that the temperature depended on the distance of each site from the periphery and on the climate. In the case of the bagasse, the maximum temperatures were less variable over time.

Rain not only wet the exterior of the piles but also penetrated some internal spaces that did not have material. Thus, high moisture was obtained at different points and depths, leaving portions of the material partially dry, which resulted in temperature and moisture readings that had no well-defined trend. When correlating the highest temperatures reached for the residue and the moisture detected (Figure 1), there was a tendency to have lower moisture values when the temperatures were highest in the interior of the piles. The range of moisture values was quite different from those obtained in the field 4–5 days after the harvest, where it fell from 65% to 35% on sunny days (Torres et al., 1998).

The bagasse had a more rapid response with respect to moisture loss when the inner temperature increased (Figure 1). For both the bagasse and the residue, not much deterioration was observed, but there was brown lixiviate with an acid pH (4.7–6.5).

The results of this first period convinced us to design another shape for the pile, establishing a continuous reading system of the temperatures at different depths. The samples were taken more frequently in order to determine moisture, pH and physical changes. Besides that, it was decided to place one of these deposits under a roof.

![Diagram](image-url)

**Fig. 1**—Trends of the internal temperature of residues and bagasse as a function of their moisture (only maximum temperatures were taken into account) at different depths, rainfall and ambient temperature during the first period (27 Oct–20 Dec 1999).

<table>
<thead>
<tr>
<th>RESIDUES</th>
<th>y = -27.354Lnx + 176.71</th>
<th>R² = 0.9858</th>
</tr>
</thead>
<tbody>
<tr>
<td>SELECTED ISSUES</td>
<td>DATE</td>
<td>HOUR</td>
</tr>
<tr>
<td>1</td>
<td>Nov-17-99</td>
<td>03:00 PM</td>
</tr>
<tr>
<td>2</td>
<td>Oct-27-99</td>
<td>09:00 AM</td>
</tr>
<tr>
<td>3</td>
<td>Dec-21-99</td>
<td>01:00 PM</td>
</tr>
<tr>
<td>4</td>
<td>Dec-14-99</td>
<td>04:00 AM</td>
</tr>
<tr>
<td>5</td>
<td>Nov-2-99</td>
<td>01:00 PM</td>
</tr>
<tr>
<td>6</td>
<td>Nov-6-99</td>
<td>04:00 PM</td>
</tr>
<tr>
<td>7</td>
<td>Oct-27-99</td>
<td>09:00 AM</td>
</tr>
</tbody>
</table>

| BAGASSE | y = -0.0003x³ + 0.0052x² - 3.7816x + 147.66 | R² = 0.9967 |
| SELECTED ISSUES | DATE | HOUR | Temperature (°C) | Moisture (%) | Amb. Temp. (°C) | Rainfall mm | Radiation (KWh/m²) | Depth m |
| 1 | Oct-29-99 | 01:00 PM | 60.1 | 74 | 26.3 | 0 | 0.717 | 2 |
| 2 | Nov-2-99 | 09:00 PM | 61 | 61 | 23 | 0 | 0.000 | 2.5 |
| 3 | Nov-4-99 | 08:00 PM | 61.3 | 68.6 | 24.5 | 0 | 0.000 | 2 |
| 4 | Nov-24-99 | 01:00 PM | 62.2 | 52 | 27 | 0.1 | 0.063 | 2.5 |
| 5 | Nov-30-99 | 02:00 PM | 63.2 | 48.2 | 29.1 | 4.9 | 0.037 | 2 |
| 6 | Nov-17-99 | 02:00 PM | 63 | 49 | 31 | 0 | 0.707 | 2.5 |
| 7 | Nov-6-99 | 03:00 PM | 64 | 47 | 28.6 | 0 | 0.257 | 2 |
| 8 | Nov-6-99 | 02:00 PM | 65 | 39.2 | 32 | 0.7 | 0.790 | 2.5 |
Second period

The highest temperature (64.9°C) for the residue, out in the open or under cover, placed in cylinders of metal netting, was reached after the first 8 days of the experiment. The temperature then fell until it reached, on some occasions, only 2°C above ambient temperature.

During the first weeks, the temperature tended to increase from the centre of the pile outwards. This phenomenon lasted for several days. Afterwards, this situation was inverted, and it was noted that the heat came from the outer layers when the day was very sunny. The temperature increased on the surface of the pile because it was in contact with the environment. At the end of the monitoring period, values under the ambient temperature were recorded in the central part of the piles.

For the two piles differences were found in the moisture, ranging from 1–38%. The effects of transferring the mass (water and wind with particles) and energy (sun and wind) were more pronounced in the material left out in the open than in the material under a roof. Given the little depth (diameter) of the cylinders, the effects occurred relatively rapidly, which did not occur in a regular pile.

During the first three weeks the pH values for both the cylinder under cover and the one left out in the open were practically the same (4.8). Then the residue under cover tended to have a pH over 7.0, while the residue out in the open had a pH under 6.0. In the last weeks of observation, this tendency was maintained.

These results indicate that for the residue left outside, the pH tends to rise in rainy periods and to
fall in dry periods; while the contrary occurs in the residue under cover.

No visible deterioration of the material was observed, and there was no lixiviation.

**Behaviour of the bagasse**

The two piles of bagasse (out in the open and under roof) had a sustained decrease of the interior temperature (48°C–42°C) over time to 27°C–36°C, with no major alterations in its slope. This behaviour was partly due to the climate during the period of observation.

The moisture of both deposits was similar during the two first weeks, differing by only 2–4% moisture (38–40%); but then the pile out in the open began to gain more moisture.

The pH ranged from 5–6 during the first week, after which it fluctuated (decreasing and increasing) in the two deposits. For the material out in the open, the pH rose to 6.2 during the second week, but in the last week it fell to 4.2, which indicates possible decomposition. Nevertheless, there was no visible deterioration of the material, nor was there any lixiviation.

**Correlations between temperature and moisture**

There are numerous cases (Kinoshita, 1997) where there is a direct relationship between temperature and moisture due to the nature of the residue. Also, it is possible that the state of aggregation, density (compaction), chip size and the different climatic states could influence the results.

---

![Graph showing trends of PH for residues (covered and out in the open) as a function of their temperature (only maximum temperatures were taken into account) at different depths, rainfall and ambient temperature during the second period (10 July–11 Sept 2000).](image)
The trends recorded were not stable but, for cases of maximum daily temperature, the behaviour was similar to that which could have been obtained with a regular transfer of mass and energy (Figure 2). The behaviour of the bagasse, both covered and out in the open, showed less variation.

For relationship between pH and temperature, a marked difference was found between the covered residue and that left in the open in comparison with deposits of bagasse (out in the open and under cover). This indicates that there is an effect due to rainfall, the state of aggregation, density and size of the components.

In any case it was established that at lower temperatures there are greater possibilities of having an acid pH (Figure 3).

Looking at the information relative to each point in Figures 1, 2 and 3 (ambient temperature, percent moisture, rainfall and solar radiation), it can be confirmed that the behaviour of the materials studied has a direct relation to these variables.

The simple analysis of correlation among pH, temperature and moisture shows high coefficients of determination ($R^2$). This means that a high percentage of the variability of the moisture is explained by the behaviour of the temperature. Nevertheless, because selection of maximum temperatures only and also because of the reduced number of readings for some of the monitoring, the resulting expressions can only be taken as trends of the real behaviour. These trends should be corroborated with more elaborate monitoring in the near future.

Conclusions

Although the behaviour of the residue piles (both out in the open and under cover) was quite similar to that of the deposits of bagasse, it was characterised by reaching higher internal values for temperature and pH. The higher values were obtained in the material under cover.

The formation of large deposits of material favours the development of higher temperatures inside the piles in shorter time, together with a longer time at this temperature level. In this case, the central part of the piles was protected from intensive mass and heat transfer with the immediate layers or from seeking equilibrium with the surrounding areas.

Depending on the densification, there are spaces with trapped air, which act as very effective natural insulation.

The study included direct observations of physical changes (colour, dryness, brittleness and odour). An attempt was made to associate these observations with the deterioration of the material. It was not, however, possible to perceive substantial changes that would confirm any deterioration. Visually, the occurrence of a microbial attack was not perceived, nor were reactions of thermal or biological decomposition detected in the residue or in the bagasse during the monitoring. Only a slight odour of alcohol was noted in the case of the bagasse.

Although an increase in temperature and a decrease in the moisture content of the residue were found, the values did not reach the levels reported in the literature (Lois, 1994) for commercial piles of bagasse (70–80°C). It is feasible to reach these levels with larger sized deposits and greater densification, but under a roof.

Although the rates of increase in temperature and decrease in moisture were highly variable, the range observed is considered promising. Thus, it was impossible to reach in a short time the level detected in chopped residue spread out in the field and submitted to the action of the sun. In this last case, for 3–4 days of summer, the moisture fell from 70–65% to 45–35%. These levels were reached in the piles but from 10–12 days.

It is recommended that these observations be continued in order to determine the best way to store the residue for better drying, less deterioration and lower operating costs.

Acknowledgments

The authors are grateful to Engineers A.L. Gómez, C.A. Madriñán and the students A.P. Franco and I.D. Betancourth who contributed time and effort to this study.

REFERENCES


CONPORTEMENT DES RÉSIDUES DE LA CANNE PENDANT L’ENTREPOSAGE

C.O. BRICEÑO et J.S. TORRES
Centro de Investigación de la caña de Azúcar de Colombia, (CENICAÑA), Cali Colombia S.A.

Résumé

Mots clefs: Humidité, température, pH, canne verte, résidu.

CAMBIOS EXPERIMENTADOS POR LOS RESIDUOS DE COSECHA EN VERDE DURANTE SU ALMACENAMIENTO

C.O. BRICEÑO y J.S. TORRES
Centro de Investigación de la Caña de Azúcar de Colombia (CENICAÑA), Cali, Colombia S.A.

Resumen
Con el propósito de establecer los principales cambios que sufren los residuos de cosecha sin quemar de la caña de azúcar durante su almacenamiento, se estableció un programa de seguimiento en dos fases diferentes con dos formas de almacenamiento y exposición a la intemperie de residuos y de bagazo como elemento de contraste.

Para establecer los cambios de temperatura al interior de los arrumes comparados con la temperatura ambiente, se instalaron termocúpulas a diferentes profundidades de los depósitos. Además, se tomaron muestras diarias y localizadas para determinación de humedad y pH, observación de deterioro, cambio de color, aumento de fragilidad, descomposición y olor.

Las observaciones permitieron detectar cambios físicos tales como color, sequedad, aspecto quebradizo y olor que se trataron de asociar con el deterioro del material sin llegar a percibirse a simple vista cambios sustantivos que comprobaran este deterioro.

Aunque efectivamente se obtiene un aumento de temperatura y una disminución de humedad en los residuos, los valores obtenidos no se alcanzó el nivel de 70 a 80°C señalado en la literatura para arrumes comerciales de bagazo, sin embargo es factible llegar a estos niveles con depósitos mayores en tamaño y densificación pero bajo techo.

Las correlaciones entre temperaturas máximas alcanzadas, pH y humedad tuvieron altos coeficientes de determinación (R²), pero se deben tomar únicamente como indicadores de tendencia.

Palabras claves: Humedad, Temperatura, pH, cosecha en verde, residuos de cosecha.