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The Sugar Cane Vegetal Residues Unloaded in the Sugar Mill: Operational Costs and Physical Characteristics

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ABSTRACT: Brazil produced in 2002/03 season 317.87×10^6 tons of sugar cane stalks and 36.88×10^6 tons of vegetal residues (green leaves, dry leaves and tops) in a planted area of 4.61×10^6 hectares (ha). These residues have a useful heat of $3,613.14 \text{ Mcal.t}^{-1}$. Currently most of this biomass is burned as a pre-harvest practice. The doubt persists in the system type that it must be adopted to pick up, load, transport and unload this biomass at the sugar mill boilers. This study analyzed 22 variables related to operational costs and physical characteristics of these residues in a field situation using a JOHN DEERE® 6850 forage harvester with two different treatments: T1 and T2 (two types of rakes) with 6 repetitions each one. The geographic location of the studied area that belongs to COSTA PINTO MILL (COSAN® Group) is: Latitude $22^\circ 40' 30'' \text{S}$ and Longitude $47^\circ 36' 38'' \text{W}$. The adopted methodology was proposed by Ripoli et al. (2002). The obtained results at a 5% level of significance showed that both treatments did not differed significantly between them. Some of the results were, where EBP stands for Oil Equivalent Barrel: Windrowing ($T1 = \text{US\$}0.17.\text{EBP}^{-1}$ and $\text{US\$}9.59.\text{ha}^{-1}$, $T2 = \text{US\$}0.08.\text{EBP}^{-1}$ and $\text{US\$}4.27.\text{ha}^{-1}$); Pick up ($T1 = \text{US\$}1.31.\text{EBP}^{-1}$ and $\text{US\$}44.29.\text{ha}^{-1}$, $T2 = \text{US\$}1.37.\text{EBP}^{-1}$ and $\text{US\$}48.36.\text{ha}^{-1}$); Transportation ($T1 = \text{US\$}1.27.\text{EBP}^{-1}$ and $\text{US\$}14,30.\text{ha}^{-1}$, $T2 = \text{US\$}1.33.\text{EBP}^{-1}$ and $\text{US\$}14,80.\text{ha}^{-1}$); Unloading at the sugar mill ($T1 = \text{US\$}0.30.\text{EBP}^{-1}$ and $\text{US\$}3.39.\text{ha}^{-1}$, $T2 = \text{US\$}0.32.\text{EBP}^{-1}$ and $\text{US\$}3.51.\text{ha}^{-1}$); Total ($T1 = \text{US\$}3.05.\text{EBP}^{-1}$ and $\text{US\$}71.57.\text{ha}^{-1}$, $T2 = \text{US\$}3.10.\text{EBP}^{-1}$ and $\text{US\$}70.94.\text{ha}^{-1}$). Confronting the obtained data with the ones in the bibliography, this system revealed itself more expensive than the baling system or the integral harvest system using combines.

Key Words: sugar cane; harvest residues; forage machinery; costs; evaluation.

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INTRODUCTION

The sugar cane culture in Brazil always presented a great economic importance and now it occupies the third position among the most important cultures in the world agricultural scenery (FNP, 2004).

The modifications suffered by the Brazilian Sugar & Alcohol Sector in the last years, as the sector's deregulation and the environmental legislation regulating the sugar cane burning as a pre-harvest practice has demanding larger competitiveness and technology incorporation, and they include smaller market expansion perspectives for traditional products, such as sugar and alcohol, and the handling matter of the remaining vegetal residues in the ground.

According to Ripoli et al. (2003) the amount of residues can reach values up to 30 tons.ha⁻¹ (based in humid weight) and it is composed of green leaves, dry leaves, tops, stalks and/or stalks fractions and soil stuck on those constituents. These residues bring benefits to the productive system improving the chemical physical characteristics of the soil, controlling weed plants and as an excellent biomass to be used in energy co-generation. Thus it is necessary the development of systems that would make possible its collection from the field and posterior transportation to the mills, where it would be burned separately or with to the bagasse.

This study had the purpose to characterize the residues previously windrowed by two types of rakes, picked by a forage harvester and placed in the mill and also to determinate the total costs. The working hypothesis is that the different rakes chosen to be studied did not reflect any influence in the characteristics of the picked up residues.

MATERIAL

The field tests were accomplished in an area that belongs to COSTA PINTO MILL (COSAN[®] Group), city of Piracicaba, state of Sao Paulo, Brazil. The geographical location of the area is Latitude 22°40'30"South, Longitude 47°36'38"West and Altitude of 605m. The sugar cane variety was RB85-5113, planted in 1.40m row spacing, in its second cut, with 11 months old and 108 tons.ha⁻¹ average yield of stalks. The sugar cane plot has a 6% slope with a 9.63 hectares area and it was harvested by CAMECO[®] sugar cane harvester with belts tracks and powered by a CAT[®] 3306 engine.

The two chosen rakes to be used in the field tests were: one from DMB[®] with four vertical disks (Figure 1A) pulled by FORD[®] 6610 tractor and the other type with a cylindrical windlass, brand JOHN DEERE[®], model 256 (Figure 1B) pulled by a MF[®] 299 tractor.



Figure 1 – DMB[®] rake (A); JOHN DEERE[®] rake and (B) and partial view of the area (C).

To pickup the vegetal residues it was used a forage harvester from JOHN DEERE[®]; model 6850 (Figures 2A and 2B). Two VOLKSWAGEN[®] (6x4) trucks were also needed to transport the residues from field to the mill, with a volumetric capacity of 55m³ (Figures 2B and 2C).



Figure 2 – Side view from de JOHN DEERE[®] forage harvester (A), harvester in operation with the truck (B) and unloading proceeding of the residues in the mill (C).

In the masses determinations were used: load cell from KIOWA[®] with load capacity of 1,000kg and reading precision of 10⁻¹kg, with indicative microprocessor Micro PC SODMEX[®], platform scale for trucks, with load capacity of 30,000kg and reading precision of 5kg.

Time determinations of the machines routes used two digital chronometers CASIO[®], with reading precision of 10⁻²s.

The fuel consumption was determined using two graduated burettes with maximum capacities of 500mL and 1,000mL and reading precision of 5mL.

For the determinations of the bales dimensions, baling distances and areas demarcation it was used metallic measuring tapes with 5m long and fiber glass measuring tapes with 50m long, both brand ESLON[®] and reading precision of 10⁻²m.

To estimate the amount of sugar cane residues existing in the studied areas it was used a 1m square frame sides made of iron.

A standard probe, brand CODISTIL[®], from the Technological Analysis Lab from Costa Pinto Mill was used for raw material sampling.

A FANEM[®] stove, model 315SE, with adjustment of temperature from 37°C up to 220°C.

Semi-analytic scales, brand METTLER[®], model P11, and load capacity of 5kg and precision of reading 10^{-2} g.

The equipments used for the soil determinations were: analytic scale, brand METTLER[®], model H10, with load capacity of 160g and reading precision of 10^{-4} g; knives shredder; porcelain cups; FORMITEC[®] stove with maximum temperature of 1,000°C and screens for soil granulometry analysis.

It was also used: plastic and paper bags; stakes; duct tape; labels; strings; metallic tripod for support of the load cell; aluminum cans; field and laboratory worksheets; pens; sieves and pails.

METHOD

Five soil samples were taken casually in each type of windrowing areas, in a 0 to 5 cm depth, with the purpose soil type and its humidity determinations in during the windrowing operations. The samples were conditioned in aluminum cans, tightly shut and taken to the Agricultural Machines Lab in the Rural Engineering Department of ESALQ/USP where the standard gravimetric method based in the dry soil mass in stove in temperatures of 105 to 110°C was used.

For the determination of the soil granulometry it was used Steel & Bradfield (1934) method that seeks the clay fraction. The sand fraction sand was made with humid screening (it sifts 270, diameter of 0.053mm) followed by dry screening fractioning. The field tests were accomplished using two sets of tractors and rakes. The windrowing in both treatments was the so called “double type” characterized by two adjacent passages of the rake, one opposite to the other, in such a way that the residues are set in only one row. Each treatment of the harvester had six repetitions, considering each repetition the necessary course of the forage harvester to completed one truck load.

During the repetitions it was timed each operational cycle, considering the machine moving time (effective); maneuvering time; operational time (effective plus maneuvers) and other times such as when the machine got stuck and also stops due to the metal detector.

According to Ripoli (1996) the manipulation effectiveness is the relationship between the amount of existent raw material and the amount picked up by the machine, which is the parameter that qualifies the withdrawing operation of the raw material from the field. The higher this value the better the machine performance.

Each truck load that corresponded to an operational cycle (repetition) of the forage harvester had its load gross and net weight obtained in a scale located in the Costa Pinto Mill patio.

After each repetition of the forage harvester to find the humidity and amount of soil in the picked up material it was randomly removed five samples out of the truck load. Those samples were conditioned in plastic bags, identified and sealed to avoid loss humidity and taken to the Agricultural Machines Lab. The samples were transferred for paper bags and placed in stove for 48 hours at 65°C temperature to obtain the dry weight of the residue plus the amount of soil.

The dried samples were once again weighted to find out the masses. The humidity was calculated in function of the humid mass of the material as Equation 1 shows.

$$UPRec(\%) = \left[\left(\frac{MU - MS}{MU} \right) \times 100 \right] \quad (1)$$

Where: MU = Humid mass; MS = Dry mass and UPreC (%) = Sugar cane residue humidity.

To determinate the soil percentage present in the truck loads transported to the mill, as to quantify the same variable samples of losses, those samples were washed to have the soil removed. A double washing procedure was made in pails with clean water to assure the complete removal of the soil. To quantify with accuracy the amount of soil, the water with soil particles was sifted, and the remaining residues in the sieves, added to the sample.

After been washed once again the samples were paper bagged, identified and taken to the stove for more 48 hours with temperature of 65°C for the determination of the dry weight of the clean residues without soil.

The amount of humid residue with soil picked up during the forage harvest operation was determined by weighing the trucks corresponding to each repetition and the extrapolation of this value to a hectare was done according to Equation 2.

$$PRecUT = \left[\left(\frac{CLiq}{AR} \right) \div 1000 \right] \quad (2)$$

Where: PRecTU = Humid sugar cane residue harvested with soil (t.ha⁻¹); CLiq = Truck net load (tons.repetition⁻¹) e AR = Repetition area (ha.repetition⁻¹).

To find the values corresponding to the dry picked up material without soil, after the lab washing and drying procedures of the samples, the mass evaporates and without palhiço earth corresponding to each sample it was extrapolated considering the total mass picked up by hectare (residues+water+soil).

For the determination of the amount of existent soil in the picked up residues per hectare, the amount obtained in laboratory, corresponding to each sample was extrapolated considering the total mass of palhiço picked up in each hectare.

To determine the specific mass of the picked up sugar cane harvest residues it was necessary to consider the volumetric capacity of the truck that transported the material, according to the Equation 3.

$$C_{pv} = A \times L \times P \quad (3)$$

Where: C_{pv} = Volumetric Capacity (kg.m^{-3}); A = Truck bucket height (m); L = Truck bucket width (m) e P = Truck bucket length (m).

The specific mass was calculated considering the residues mass transported in each truck (repetition) according to the Equation 4.

$$ME = \left(\frac{CLiq}{C_{pv}} \right) \quad (4)$$

Where: ME = Specific mass (kg.m^{-3}); $CLiq$ = Net truck load (kg) e C_{pv} = Volumetric capacity (m^3).

The variable energy per hectare is function of the amount of dry residues without soil picked up by hectare and of its useful heat power, according to the Equation 5.

$$En = (P_{RecSS} \times PCU) \quad (5)$$

Where: En = Energy (EBP.ha^{-1}); P_{RecSS} = Dry sugar cane residue harvested without soil (tons.ha^{-1}) e PCU = Useful heat power of the harvested sugar cane residue (EBP.ton^{-1}).

The manipulation efficiency of the harvester was determined by Equation 6.

$$EFM = \left[\frac{P_{RecUT}}{(P_{RecUT} + P_{RemUT})} \right] \times 100 \quad (6)$$

Where: EFM = Manipulation efficiency (%); P_{RecUT} = Humid sugar cane residues with soil (tons.ha^{-1}) e P_{RemUT} = Sugar cane residues remaining with soil (tons.ha^{-1}).

The values of transportation costs and total costs were supplied by COSTA PINTO MILL (COSAN[®] Group)

RESULTS AND DISCUSSION

The soil granulometry analysis showed levels of 28.34% of clay, 23.33% of silte and 47.83% of sand. The humidity of the treatment T1 and T2 presented average values of 15.85% and 17.98%. The statistical analysis of the soil humidity averages confirmed the existence of a significant difference between them at a 5% level of probability. The analyzed variables are presented in the Table 1.

Table 1. Statistical of the studied variables.

Variables	Treatments			
	T1	CV	T2	CV
PRecUT (tons.ha ⁻¹)	13.96 ^a	12.45	15.24 ^a	10.87
PRecSS (tons.ha ⁻¹)	8.37 ^a	10.72	8.40 ^a	10.75
TRec (%)	6.46 ^a	23.22	8.38 ^a	47.58
UPRec (%)	33.40 ^a	11.57	36.37 ^a	13.30
PUC (tons)	4.64 ^a	10.50	4.81 ^a	8.94
PSC (tons)	2.79 ^a	9.31	2.66 ^a	11.58
ME (kg.m ⁻³)	278.46 ^a	12.45	304.04 ^a	10.87
En (EBP.ha ⁻¹)	20.49 ^a	15.78	17.55 ^a	10.39
EFM (%)	60.40 ^a	9.60	61.00 ^a	14.58
Ctransp (R\$.EBP ⁻¹)	1.27	-	1.33	-
Cdesc (R\$.EBP-1)	0.30	-	0.32	-
CTotal (R\$.ton ⁻¹)	7.40	-	7.15	-
CTotal (R\$.EBP ⁻¹)	3.06	-	3.10	-

^{a,b} Averages followed by different letters presents significant differences. PRecUT = Humid picked up residue with soil; PRecSS = Dry picked up residues without soil; Trec = Soil amount in the picked up residue; UPRrec = Humidity of the picked up residue; PUC = Humid residue in the transport unit; PSC = Dry residue in the transport unit; ME = Specific mass of the residue in the transport unit; In = Energy in the residue; EFM = Manipulation effectiveness; Ctransp = Transportation costs; CDesc = Unloading costs; Ctotal = Total costs; CV = Coefficient of variation. Currency exchange adopted US\$1.00=R\$2.89.

In the treatment T1 the average of humid picked up residue with soil was of 13.96 tons.ha⁻¹ and in treatment T2 was 15.24 tons.ha⁻¹, values that didn't indicate significant differences in the F Test for

variance analysis. In this study, the used rakes didn't provoke significant differences in the amounts of picked up residues, in spite of have happened machine glutting in the treatment T1 that could have harmed the operation.

The humid picked up residue with soil obtained value was superior to ones found by Ripoli et al. (1990) of 9.70%; Ripoli (2001) of 10.00% and Ripoli (2002) of 8.95%. The averages obtained for dry picked up residues without soil were 8.37 and 8.40 tons.ha⁻¹, for the treatments T1 and T2 respectively, having no significant statistical differences. The differences in each treatment demonstrated the existence of repetitions with higher residues humidity.

The averages found in this study for the variable soil amount in the picked up residue were 6.46% and 8.38% for the treatments T1 and T2, and in spite of the different values have shown no statistical difference. The coefficient of variation for those treatments according to Gomes (1990) can be considered high for T1 (23.22%) and very low for T2 (47.58%). These high variation coefficients are due the width amplitude of values presented in each repetition.

Once again the variations inside each treatment were provoked due to the differences in the characteristics of each set of tractor and rake used to windrow the residues. The higher residue dragging from the rake the higher the amount of soil in the material and also higher is the strange matter retention when the residue has a higher humidity.

The values found of soil percentage in the picked up residues are variable, the average value obtained in the present study was 7.47% which higher than the ones found by Abramo Filho et al. (1993) of 6.92%, Copersucar (1998) of 5.90% and Torrezan (2003) of 6.31%.

The humidity of picked up residue placed in the mill was 33.40% for treatment T1 and 36.37% for T2 with no significant statistical difference. It is possible to say that along with the picked up residue is it also been taken more than 30% in “water” to the mills.

The manipulation effectiveness of the withdrawal operation did not present significant differences, T1 presented average of 60.40% and T2 of 61.05%. The coefficient of variation of T1 (9.60%) was considered low and T2 (14.58%) considered medium.

The total amount of residues on the ground was 23.09 tons.ha⁻¹ in T1 and 25.18t.ha⁻¹ in T2. The manipulation effectiveness was found by the ratio between the amount of picked up residue (13.96 tons.ha⁻¹ in T1 and 15.24 tons.ha⁻¹ in T2) and the amount of remaining residues (9.13 tons.ha⁻¹ in T1 and 9.93 tons.ha⁻¹ in T2), presenting similar values differing only 0.60%.

The amounts of picked up residue in each treatment were quite close, so much when it is spoken in humid picked up residue with soil and dry picked up residues without soil. The averages found for the two variables in both treatments did not present significant differences. This is due to the fact of the

volumetric capacity of both trucks used in the transport the residues are similar (50.14 and 54.57 m³) and both transport units were used in two treatments. The low density of the residues incur in a relative small amount of material transported to the mill per trip, therefore the incorrect use of the trucks can make the withdraw system more expensive. This was more evident when the truck arrived in the mill to unload the material where it was easily seen the accommodation of the residues particles, demonstrating that there was more space to be filled. Being dry palhiço, this becomes still more evident, once in both cases, each load facilitated the transport of less than three tons of dry palhiço without earth.

The different average values for the variable specific mass of the residues were 278.46 kg.m⁻³ (T1) and 304.04 kg.m⁻³ (T2) with no significant differences. The coefficients of variation for both treatments were considered medium.

The importance of this variable resides in the need of evaluating the behavior of the transported residue inside the bucket on each load. The low specific mass incur in the low amounts of residues transported in each load occasioned to the so called air packs that are formed during the loading. With the truck vibration during the trip to the mill this material tends fit more comfortably.

The average amount of energy in equivalent barrel of petroleum (EBP) per hectare, available in the picked up material in treatments T1 and T2 was, respectively, 20.49 and 17.55 EBP.

To calculate the total costs to have the sugar cane vegetal residues placed in the mill it was necessary the costs of all involved operations: windrowing, residues pick up, transportation and unloading which are all shown in Table 2.

Table 2. Total costs of sugar cane vegetal residues placed in the mill.

Operations	Treatment T1			Treatment T2		
	US\$.ton ⁻¹	US\$.EBP ⁻¹	US\$.ha ⁻¹	US\$.ton ⁻¹	US\$.EBP ⁻¹	US\$.ha ⁻¹
Windrowing	0.42	0.17	9.59	0.17	0.08	4.27
Pick up	3.17	1.31	44.29	3.17	1.37	48.36
Transportation	3.08	1.27	14.30	3.08	1.33	14.80
Unloading	0.73	0.30	3.39	0.73	0.32	3.51
Total	7.40	3.05	71.57	7.15	3.10	70.94

Obs.: Currency exchange adopted US\$1.00=R\$2.89.

To calculate the vegetal residues transportation costs from the experimental area to the mill, in a distance of approximately 16 miles, COSTA PINTO MILL (COSAN[®] Group) informed that it was the

cost unload material was US\$3.08 per ton. It is possible to verify that the two treatments had similar values. Both treatments presented the same cost value in US\$ per ton supplied by the COSAN[®] Group and the existing difference among the treatments was originated due to the higher residues humidity in treatment T2, affecting the useful heat power in this treatment. The cost of the unloading operation was also the same for T1 and T2, US\$0.73 per ton.

Treatment T2 presented a higher cost than T1 probably because of the residues humidity modifying the useful heat power and the amount of material transported by each truck.

The total costs for both treatments were very similar in the three different adopted units. The T1 windrowing costs were very much higher than T2, but in the other stages of the process that cost were diluted. Thus, in terms of costs, there was no difference between the two studied rakes.

Many authors studied baling operations and found costs values such as Molina Jr. (1991) of US\$15.55.ton⁻¹; Copersucar (2001) of US\$20.00.ton⁻¹; Lopez (1987) US\$9.00.ton⁻¹ and Teixeira & Graminha¹ (2001) of US\$7.10.ton⁻¹ and the value found in this study was US\$7.28.ton⁻¹ which is acceptable when confronted the bibliography data.

CONCLUSIONS

The use of the different rake did not influence in a significant way the characteristics of the picked up residues. The condition of the windrowed rows in function of different rakes did not influence significantly in the operational performance of the forage harvester.

The granary harvest system using a forage harvester under the operational point of view can be considered as a viable option in the handling of the harvested sugar cane residues, seeking its pick up and use in the energy co-generation. The total amount of existent residues in the sugar cane field had similar values in both treatment; and there was not significant difference in the operational performance forage harvester, when considering the studied parameters in this work.

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¹Internal report from Da Barra Alcohol & Sugar Mill. 2001.

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