Windrowing and Cylindrical Baling of Sugar Cane Vegetal Residues: Some Operational Parameters and Energetic Efficiency

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ABSTRACT: The objective of this study was to analyze the sugar cane vegetal residues collection, as well as determining its energetic potential, using a rake and cylindrical baler, both from NEW HOLLAND® under two different windrowing process (simple and double). The field tests were carried out in an area that belongs to COSTA PINTO MILL (COSAN® Group) in the city of Piracicaba, Sao Paulo State, Brazil. The geographic location of the area is: Latitude 22°40"30'S, Longitude 47°36"33'W and altitude of 605m. From the trash analysis, before the baling, the following average results were obtained: 69.93% of leaves; 2.27% of stalks fractions; 21.44% of tops and 6.36% of total strange matter. The estimated residues yield was 27.01 tons.ha^{-1} with a gross heat of 18.43 MJ.kg^{-1}, low heat of 17.01 MJ.kg^{-1}, useful heat of 13.32 MJ.kg^{-1}, average moisture of 20.76% and an energetic potential of 494,875.09 MJ.ha^{-1}. In the windrowing operations (simple and double) the averages of the 5 out of 13 analyzed variable presented differences between them in a 1% level of significance in the Tukey Test. The averages comparison of the results for bale's specific mass and the effective capacities (ton.h^{-1}) e (ha.h^{-1}) had been significant at a 5% level in the Tukey Test. The comparisons of the averages for the results had been significant to 1% level. The strange matter averages of the bales did not differed between them.

Key Words: sugar cane; trash; windrowing; baling; evaluation.

INTRODUCTION

The Brazilian Sugar & Alcohol Sector is the main source of biomass energy in the country. In the year of 2004 the cultivated area will be close to 5.2 million hectares, with a sugar cane yield above 357 millions tons of industrialized stalks (FNP, 2004). Today still exists in the Brazilian sugar cane fields the burnings operation as pre-harvest practice; however the society exercises a strong pressure for the elimination of such practice in the proximities of the urban centers, besides there is a Law nº11.241 that imposes a deadline to that. The sugar cane burning incur in a great biomass loss, which could be used for the co-generation of electric energy in the mills and distilleries, besides, this burning generates many environmental impacts.

Therefore it is necessary and justified the development of systems that allows the use of the sugar cane harvest residue for energy ends, transforming the existing mills and distilleries in also producing plants of electric energy through the co-generation.

The objective of this work was to evaluate some operational performance parameters of windrowing operations and <u>cylindrical baling</u> on sugar cane harvest residues and its energy efficiencies.

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 22º40'30"South, Longitude 47º36'38"West and Altitude of 605m. The sugar cane variety was RB82-5336, planted in 1.40m row spacing, in its third cut, with 11 months old and 78tons.ha^{-1} average yield of stalks. The sugar cane plot was harvested by CAMECO® sugar cane harvester with crawlers and powered by a CAT® 3306 engine.

The chosen rake to be used in the field tests was type oblique cylindrical moulinet, brand NEW HOLLAND®, model 256, with 2.60m width, powered by a soil wheel (Figure 1A) and the baler used was one of cylindrical bales, brand NEW HOLLAND®, model 658, with a effective pick up head width of 1.98m, twine type tying system (with sisal or polypropylene) (Figure 1B). A NEW HOLLAND® 4x2 tractor, model TM 120 (120hp); a conventional sugar cane wheel loader from MOTOCANA® and two load trucks to transport the bales to the mill where also used.

Figure 1 – Rake in operation (A); baler with cylindrical bale (B) and partial view of the area (C).

In the masses determinations were used: load cell from KIOWA® with load capacity of 1,000kg and reading precision of 10^{-1}kg, 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^{-2}s.

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^{-2}m.

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 37ºC up to 220ºC.

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; mill of knives; porcelain cups; FORMITEC® stove with maximum temperature of 1,000ºC and screens for soil granulometry analysis.

METHOD

The preparation of the treatments was accomplished using the rake to windrow the residues of the mechanized harvest of raw sugar cane. The first treatment (Figure 2A) was characterized by a

simple row, which consisted of only one rake passage on certain area. The second treatment (Figure 2B) was characterized by a double windrowing which consisted of two adjacent passages of the rake, one opposite to the other, in such a way that the residues are set in only one row.
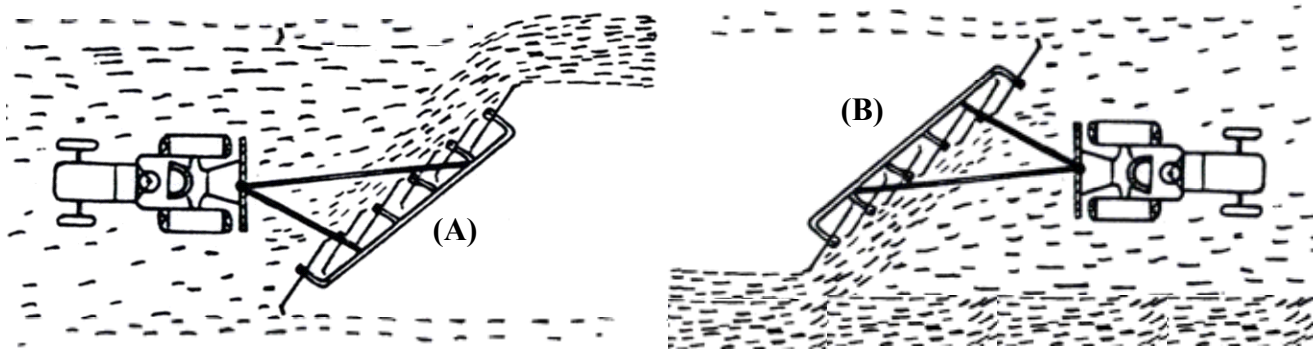

Figure 2 – Operation schematics of the simple windrowing (A) and double windrowing (B).

It was considered for the times and movement's determinations of the simple windrowing a closed operational cycle, beginning in the start of the movement of the tractor to the complete stop in the end of the course, where the over head maneuvers were not considered.

In the beginning of each treatment, with tractor and rake leveled, the fuel tank was completed with diesel, until a well known mark in its opening. At the end of each treatment, using graduate burettes, the volume of fuel was once again completed to the same initial known mark, obtained then in milliliters, the consumed amount of fuel that corresponded to the execution of each windrowing type treatment.

In both treatments, the determinations of the lengths and windrowed areas were accomplished using measuring tapes, where five repetitions were taken, casually, along the length of the area, following the trajectory of the tractor and rake. The widths of the areas, in both preparations of the treatments, were also obtained using measuring tapes, and taken randomly as the perpendicular distance to the course of the equipment.

In the baling operation it was considered as a repetition the action of to picking up certain amount of windrowed residues and deposited it in form of a bale, taking in consideration the traveled distance, the time, the fuel consumption and the corresponding area covered resultant of the windrowing type done. Due to the different treatments it was obtained different amounts of bales (each bale is equal to one repetition). Out of the total amount of bales four units of each treatment were chosen casually for samples retreat for lab analyses.

The amount of fuel consumed in each repetition was obtained dividing proportionally the volume consumed in the treatment by the corresponding traveled distances to obtain each bale produced.

The bales had its dimensions measured with tape and with the use of a load cell attached to a sugar cane loader's clutch, the masses of the bales were determined, looking forward to come up with the volumes and respective specific masses.

According to Ripoli (1991), the energy efficiency is "... the relationship between the amount of energy in the form of fuel consumed by the machines involved in the operations and the amount of energy that exists in the form of residues". The author determined Equation 1 to calculate this efficiency.

$$EE = \left(1 - \frac{FC}{EPR}\right) \cdot 100 \tag{1}$$

Where: EE (%) = Energy efficiency (EE);

FC (MJ.kg^{-1}) = Equivalent fuel consumption (FC);

EPR (MJ.kg^{-1}) = Energy potential of the residue (EPR).

To sample the baled residues, the bales were loaded with sugar cane loader into trucks and transported to the mill. Then two separated samples were extracted per bale, using the standard probe of the Technological Analysis Lab for humidity and soil determinations.

The masses of the samples gotten in the probe were found using a load cell. Separately, each one of them was sifted in screens of 2.5 mm mesh, what allowed the passage of the soil and particles of vegetable material. Two sub-samples (of each sample) of the material that didn't go trough that screen were collected to determinate of the amount of soil in the bale.

For the finest separation between the vegetable particulate and soil, the resulting material of the screening was submitted by a battery of sieves of soil granulometry analysis, and the remaining after the passage of this finest sieve was the soil and a very fine vegetable particulate.

The obtained material was subdivided in five sub-samples. Each small sub-sample was taken to the stove for 24 hours at 104ºC to eliminate the humidity and then those samples where "burned" in for 4 hours at a temperature of 700ºC. After the burning process the samples were placed in a specific area to have their temperature decreases. The masses of soil and ashes were then found using cold cups under normal temperature conditions.

One of the two sub-samples of each bale obtained by the probe, removed after the screening in 2.5 mm mesh of the samples was washed with water to eliminate the soil stuck to the present residues

in the sample and, then, they were dried in the sun. The other sub-sample was maintained with the stuck material. The following step was to crush the sub-samples (washed and not washed) to have them transformed into powder with aid of knife shredder.

Each sub-sample of the shredded material was divided in five parts that also were burned in stove at 700ºC. It was obtained from the washed sub-samples only the masses of ashes of the vegetable material and from the not washed sub-samples the masses of ashes of the material vegetable plus soil. From the ashes and ashes plus soil masses it was obtained the respective percentages based in the sub-sample mass before being taken to be burned in stove.

To determinate the soil percentage stuck to the leaves the percentage of ashes in the washed straws was subtracted out of the percentage of ashes in the not washed straws.

The basic methodology adopted for the balers was proposed by Mialhe (1974) that takes in consideration the Effective Capacity as the main parameter in two different units: "baled residues mass per unit of time" and "baled residues area per unit of time". Concerning the rake it was used this same methodology to find its performance parameters.

In the statistical analysis the experimental unit was the bale made out of residues of the sugar cane harvest and each bale represented one repetition. Two treatments casually distributed inside of an area with one given sugar cane variety were harvested in the same day. Out of the total of obtained bales, four out of each treatment was casually chosen for amount of soil determination. The statistical analysis was made considering the experiment as entirely casual and it compared the difference among the averages of the obtained variables through the test of Tukey at the level of 5% of significance, according to Gomes (2000). The calculations were accomplished using the software SAS[®].

RESULTS AND DISCUSSION

The esteemed average yield of the residues was 27.01 tons.ha^{-1}, the residues index was 34.63% in relation to the industrialized stalks in the studied area and the humidity was 22.8%. The estimated yield of residues, in dry base was 20.33 tons.ha^{-1} or 26.06% in relation to industrialized stalks yield. This value is confirmed by Ripoli et. al. (1990) that the residues varied from 17 to 31% in its weight in comparison to percentage of industrialized stalks. Ripoli et. al. (1991) found a 77.71 tons.ha^{-1} yield with a residues yield of 21.61 tons.ha^{-1} and 46.11% humidity, representing an index of palhiço of 28%.

The values found in this study are similar to others found in the bibliography, with a slight advantage in relation to presented humidity. This difference could be due to climate variation in the

hour of the material was collected. Thus, the values of residues percentage are inside of the found by these two citations in previous paragraph.

Confronting the values presented by Ripoli (1991) with the ones obtained, the value of the high heat power of 18.43 MJ.kg^{-1} with humidity of 22.8% is larger than the obtained by the author. In the same way, the low heat power of 17.01 MJ.kg^{-1} with humidity of 22.8% of this study was smaller than mentioned in Ripoli´s work.

Figure 3 shows the average results of operational performance and energy efficiency regarding the simple and double windrowing obtained in this study which differed significantly at the level of 1% of significance in the test of Tukey.
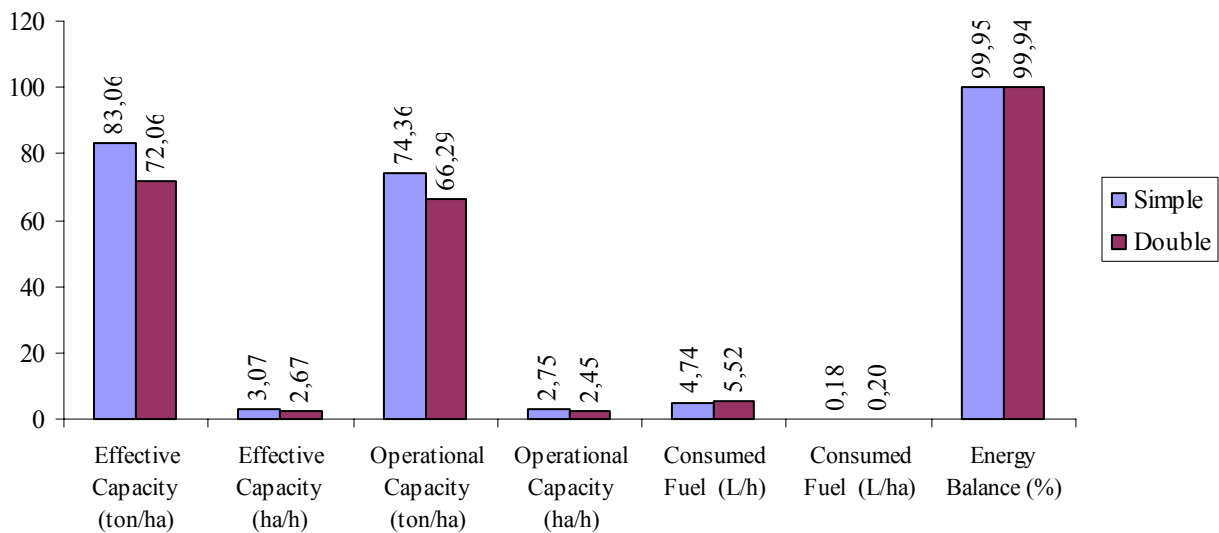

Figure 3 - Average values of the studied parameters for the simple and double windrowing.

The simple windrowing presented a higher effective capacity in this study, superior to the double windrowing in 27.75%. The obtained values of effective capacity of this work when compared with the ones from Ripoli (1991) were superior to the ones determined by that author: 1.67 and 1.79 ha.h^{-1}. The average consumption of fuel per ton was smaller than the values found by Ripoli (1991) which was of 0.40 L.ton^{-1}. In relation to the consumption of fuel per ton the values of this study were smaller than the obtained by Ripoli (1991) for the two windrowing forms presented.

The differences found above should only be observed in relation with the order of greatness, the methodology, the different systems that present a great dependence of the type of used potency sources and in different field conditions.

Figure 4 shows the average results of the variables in the quantification of the bales specific masses, effective capacities, fuel consumption per ton, energy efficiency in the windrowing, in the

baling and in both operations, besides the comparisons between averages obtained with the application of the test of Tukey.
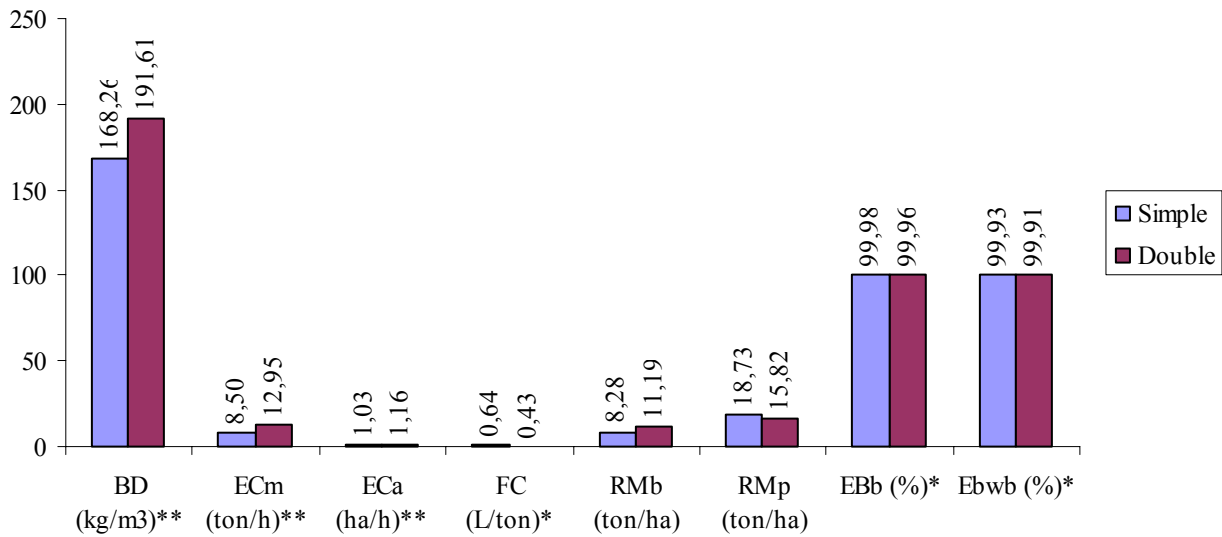

Figure 4 – Average values of the studied parameters, in the simple and double windrowing (BD = Density of the bale; ECm and ECa = Effective capacity; FC = Fuel consumption per ton; RMb = Estimated baled residues mass; RMp = Estimated picked up residues mass; EBb = Baling energy balance; EBwb = Windrowing and baling energy balance), *5% of significance and **1%.

The tests accomplished by Molina Jr. (1991) and Molina Jr. et al. (1991) were done with the same baler model. Although for Molina Jr. et al. (1991) the residue of sugar cane crop was resulted of manual crop, windrowing operation and its very higher humidity to the found value by Molina Jr. (1991a), it was observed that the density went practically to same in the two studies, suggesting that so much the humidity didn't influence in the compaction of the baled residue. And in this study the value of the specific mass was higher to the values found by other citations, in the double windrowing and, for the simple windrowing the values approached the ones mentioned by Lopez (1987), suggesting that the density of the bale is influenced by the type of the formation mechanism of the bale used in each baler type. From the comparisons it was verified that the specific mass of the bales (DF) had the averages differed to each other at 5% of significance with the test of Tukey.

The advantage of obtaining bales with larger specific masses is the economy of the volume occupied in the transport and in the storage, the handling easiness and larger resistances to the bad weather.

For the effective capacity – ECm (tons.h^{-1}) and ECa (ha.h^{-1}) the comparison was significantly different for the two treatments at the level of 5%. The values determined in this study for to the effective capacities indicated that the double treatment provided a larger effective capacity to the baling operation. Copersucar (1998) concerning baling tests, with and without windrowing operations, obtained larger effective capacities for the treatments with windrowing operation, values such as 1.80 and 2.70 tons.h^{-1}, Howe & Sreesangkon (1990) of 2.21 and 2.49 tons.h^{-1} and Molina Jr. et al (1995) of 0.96 and 1.26 tons.h^{-1} they were smaller to the ones obtained.

The higher positive energy efficiency in this work, considering the baling and the windrowing plus baling was the simple treatment, what represents the best relationship between the available energy in the residues and the equivalent energy of the fuel used. It is desirable that the energy efficiency is positive and the highest possible, so that the pick up of the palhiço turn to be technically viable. The energy efficiencies were not determined by Molina Jr. et al. (1995), even so they can be estimated from the data, 99.01 and 98.65%, using the equation proposed by Ripoli (1991). These values are smaller than the ones found in this study, because according to the authors, in its conclusions, the source of used potency was not adapted to the baler.

Comparing the averages of the two treatments for the variables FC (L.ton^{-1}), EBb (%) and EBwb (%) they differed at the level of significance of 1% through the test of Tukey.

The fuel consumption per ton of baled residue (FC), found by Molina Jr. (1991a) was 4.17 L.t^{-1} practically the double of the value found by Molina Jr. et al. (1991) which was 2.30 L.t^{-1} operating with the same baler model in the two studies. The average values of this study were of 0.64 L.t^{-1} to the simple windrowing and 0.43 L.t^{-1} in the double windrowing, smaller than the values mentioned in the bibliography. It was observed that the value of this variable can suffer alterations due to the accommodation of the residue to be baled (windrowed or not), for the tractor model used in the operation and also of the baler model to be used in the baling operation.

The average values of RMb (tons.ha^{-1}) and MRp (tons.ha^{-1}) didn't have any significant difference through the test of Tukey at the level of 1 and 5%. The amount residues picked up of the field in relation to the existent mass is mentioned in the bibliographies by following authors: Lopez (1987) of 83%, Howe & Sreesangkon (1990) of 71%, both Molina Jr. (1991a) and Molina Jr. et al. (1995) of 34,34% and, finally, Molina Jr. et al. (1991b) of 27.72%.

Lopez (1987) and Howe & Sreesangkon (1990) presented higher values than Molina Jr. (1991) and Molina Jr. et al. (1991) and the values found in this study were 31% for the simple treatment and

41% for the double treatment. The double treatment approached the value found by Molina Jr. (1991) in spite of not having had windrowing operation.

Table 1 shows the average values of the amounts of mineral strange matter (soil) present that were found in the bales, in both treatments.

Table 1. Average values of the amounts of mineral strange matter (soil) in the bales in both treatments.

Variable	Balings	
	Simple Treatment	Double Treatment
Mineral Strange Matter (%)		
Averages	10.57	8.07
CV	41.45	31.84

CV = Coefficient of variation.

The results of that study obtained by the samples, to identify the percentage of mineral strange matter in the baled residue demonstrated that the method to detect the contamination of the bale for the soil was efficient. The analysis of the averages of the studied variables, compared through the test of Tukey at the level of 1% and of 5% of significance, which did not deferrer to each other, in the three analyzed variables. However, the analyzed values of the study were higher to the found in another author's citations. This could have happened due to for example, the climatic conditions, the quality of the surface of the soil, the residue baled humidity, the work speed, if the experimental area was windrowed or not, the different sugar cane varieties, the model of tractor used and the type windrowing. In this study, the simple windrowing had larger soil percentage than the double one due to the pick up head cylinder of the baler that was working closer to the ground (soil) during the baling of the residues.

CONCLUSIONS

The pick up of the sugar cane residue from the operational point of view, as well as the determination of its energy potential is viable, after the mechanized harvest without burning, using an the studied rake and a cylindrical forage baler.

The estimated average yield of the residues before the windrowing and baling operations has presented a great variability. Due to the residues heat power it could be used to substitute the use of non renewable fuels in the mills and distilleries.

The effective and operational capacities data of the rake showed advantages in the operation of simple windrowing. The data of the effective and operational capacities of the baler showed advantages for the double windrowing.

The specific mass average of the bales in the double windrowing was higher in relation to the simple windrowing and the index of total soil in the bales average for the simple windrowing treatment was superior to average obtained in the double windrowing.

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