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

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ABSTRACT: It was evaluated the energetic efficiency and operational parameters of a windrowing and prismatic baling, both from CASE NEW HOLLAND®, operations in sugarcane vegetal residues (green leaves, dry leaves and tops) picked mechanically in green cane. The area belongs to COSTA PINTO MILL (COSAN® Group) which was harvested mechanically by combines in the State of Sao Paulo, Brazil. The geographic location of the area is: Latitude 22°40'30"S, Longitude 47°36'38"W and Altitude of 605m. The variety was RB 82-5336, planted in 1.40m row spacing, with 78t.ha^{-1} yield. The vegetal residues analysis obtained 69.93% of leaves, 21.44% of stalks fractions, 2.27% of tops and 6.36% of total strange matter. The vegetal residues values were: gross heat of 18.43MJ.kg^{-1}, low heat of 17.00MJ.kg$^{'1}$ and useful heat of 12.94MJ.kg^{-1}. The vegetal residues average energetic potential was 342.48GJ.ha^{-1}. The treatments were simple, double and triple windrowing. The use of the rake and prismatic baler to pick up the residues was viable. The simple windrowing treatment presented the best results: effective capacity of 83.06t.ha^{-1}, fuel consumption of 0.18L.t^{-1} and 99.95% of positive energetic efficiency. The bales obtained in the treatment of triple windrowing presented the largest specific mass average of 221.11kg.m^{-3}. The soil amount in the bales increased with successive windrowing. The baling operation in the triple windrowing treatment obtained better results, presenting the effective capacities of 20.29t.h^{-1} and 1.45ha.h^{-1} and fuel consumption of for baled in 1.37L.t^{-1}. The high total energetic efficiency of 99.53% indicates that is technically viable the withdrawal of the vegetal residues.

Key Words: sugar cane; trash; windrowing; baling; energy efficiency; 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 prismatic baling 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 BB940, 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); prismatic baler (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.

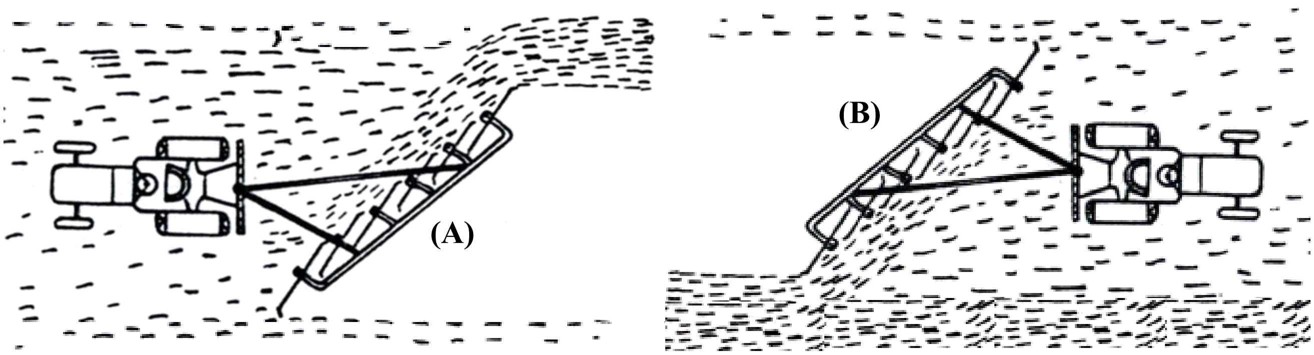

Figure 2 – Operation schematics of the simple windrowing (A) and double windrowing (B).

The third treatment (Figure 3) was characterized by a triple windrowing operation which consisted of three adjacent passages of the rake, one opposite to the other, in such a way that the residues are set in only one row. Actually what was done was a double windrowing followed by an extra passage of the rake over the double row.

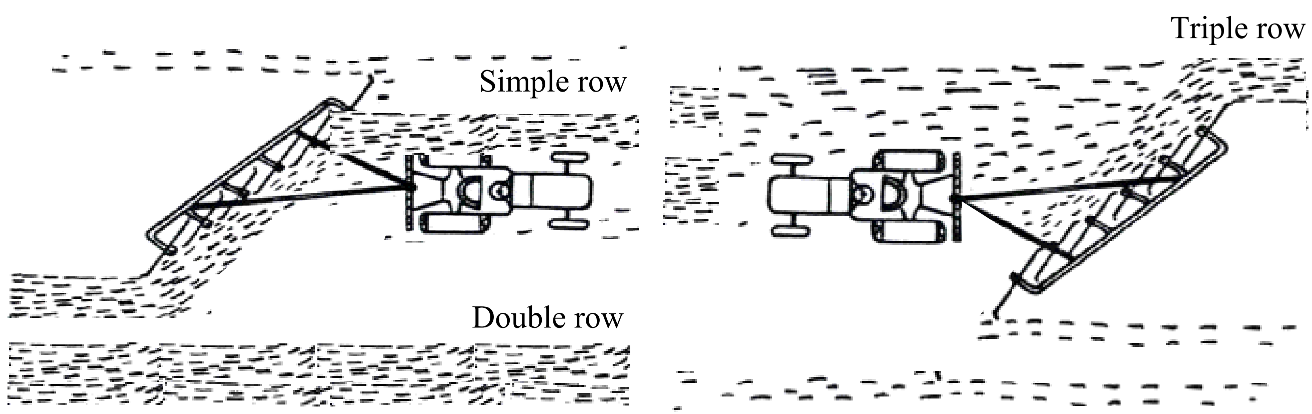

Figure 3 – Operation schematics of the triple windrowing.

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 the three 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.

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 remaining residues sampled before the baling presented an esteemed average yield of 27.01t.ha^{-1} with a coefficient of variation of 33.00%, and a humidity of 22.80% with coefficient of variation 31.00%, that is to say, an index of palhiço of 34.63% in relation to the industrialized stalks in the studied area.

Having considered the residues yield obtained in this study, it is possible to assure that one hectare of these residues has an energy equivalent as much as 16,226 L of ethanol or 73 EBP (Equivalent Barrel of Petroleum).

This value is superior to the 11.22 EBP per hectare found by Ripoli (2002) that studied the mapping of baled sugar cane residues and of its energy potential using Geographic Positioning Systems (GPS), because his methodology the amount of residues taken into account was the baled one and it didn't represent the total amount of residues in the area. Comparing the value found in this work with 30.89 EBP.ha^{-1} of residues obtained by Ripoli being (1991), it is clearly visible that they differed what could be explained due to the great variability of the sugar cane yield.

Table 1 shows the average results of some operational performance parameters of acting regarding the three different windrowing treatments done in this study. The analysis of Table 1 exhibited that with the exception of effective capacity, the averages comparison of the double and triple treatments, all the others were significant at the level of 5% of significance.

Table 1. Windrowing operational performance parameters.

Variables	Treatments		
	Simple	Double	Triple
Effective capacity (tons.h^{-1})			
Averages	83.06 **A**	65.53 **C**	69.17 **BC**
CV	0.04	0.10	0.03
Fuel consumption (L.ha^{-1})			
Averages	4.74 **C**	5.59 **B**	6.37 **A**
CV	0.04	0.10	0.03
Fuel consumption (L.ton^{-1})			
Averages	0.18 **C**	0.21 **B**	0.24 **A**
CV	0.04	0.10	0.03
Windrowing energetic balance (%)			
Averages	99,61 **BC**	99,77 **AB**	99,60 **C**
CV	0,001	0,001	0,002

Obs.: Averages followed by the same letters do differ between them at a 5% level of significance. CV= Coefficient of variation.

The simple windrowing treatment presented to highest effective capacity in this study, 27,75% over the double windrowing and 20.08% over the triple windrowing. Although the different methodologies as well as the general conditions of the field and the systems used, the obtained values of effective capacities of this study can be compared with 1.67 and 1.79 $ha.h^{-1}$ found by Ripoli (1991), to the establishment of order of greatness. For the comparison it is necessary the transformation of the results being applied the estimated average yield, obtaining this way for the simple, double and triple windrowing the respective values of 3.08; 2.45 and 2.56 $ha.h^{-1}$.

The hourly average of fuel consumption ($L.h^{-1}$) was lower to the presented by Ripoli (1991) of 8.37 and 7.32 $L.h^{-1}$, as well as the consumptions in $L.ton^{-1}$ were smaller than 0.40 $L.ton^{-1}$ for the three different windrowing treatments in this study. The differences found above should only be observed in relation with the order of greatness, the methodology and the different systems that presented a great dependence of the type of used potency sources and in different field conditions.

Table 2 shows the average results of the variables in the quantification of the bales specific masses, effective capacities, fuel consumption per ton, energy efficiency in both operations, besides the comparisons between averages obtained with the application of the test of Tukey.

Table 2. Baling operational performance parameters.

Variables	Treatments		
	Simple	Double	Triple
Specific mass of the bales ($kg.m^{-3}$)			
Averages	206.67 **C**	207.31 **BC**	221.11 **A**
CV	0.03	0.007	0.03
Effective capacity ($tons.h^{-1}$)			
Averages	10.78 **C**	16.29 **BC**	20.29 **AB**
CV	0.50	0.30	0.27
Effective capacity ($ha.h^{-1}$)			
Averages	1.45 **C**	1.99 **BC**	2.91 **A**
CV	0.28	0.42	0.36
Fuel consumption ($L.ton^{-1}$)			
Averages	1.37 **A**	1.49 **A**	1.40 **A**
CV	0.28	0.34	0.51
Windrowing and baling energetic balance (%)			
Averages	99.56 **BC**	99.71 **AB**	99.53 **C**
CV	0.001	0.001	0.002

Obs.: Averages followed by the same letters do differ between them at a 5% level of significance. CV= Coefficient of variation.

The comparisons of specific mass averages of the bales were significant for the simple/triple and double/triple windrowing treatments. The effective capacity (tons.h^{-1}) comparison was significant for the simple and triple windrowing treatments. The effective capacity (ha.h^{-1}) comparison was significant for the simple/triple and double/triple windrowing treatments. Fuel consumption (L.h^{-1}) was shown significant in the comparison among the three treatments averages. Energy balance averages in the windrowing and in the windrowing plus baling had the comparisons among significant made only to the double and triple treatments.

Based in Table 2 it was verified that the specific masses averages of the bales were superiors to the values found by Ripoli (1991) that obtained the specific masses of 141.94 and 104,63 kg.m^{-3} for granary residues. Howe & Sreesangkon (1990) found values of 99.60 and 146.90 kg.m^{-3} and Copersucar (1998b) studying the balers JS® 90, LIST® 1518 and NEW HOLLAND® 570 operating on windrowed residues found the specific masses of the bales of 118.00, 94.70 and 112.00 kg.m^{-3}, respectively. Copersucar (1998a) determined the a specific mass average of 138.50 kg.m^{-3} per bales obtained with a CLAAS® 1200 baler and the specific mass average of 245 kg.m^{-3} with a CASE® 8575 baler. Only the specific mass average of the bales obtained with the CASE® 8575 was larger than the values determined in this study. The advantage of obtaining of denser bales is the economy of the volume occupied in the transport and in the storage, the handling easiness and larger resistance to the weather conditions.

Regarding the capacities of the balers, the values determined in this study indicate that the triple windrowing treatment provided a larger effective capacity to the baling operation, followed by the double windrowing and than finally the simple one. This fact can be confirmed by Copersucar (1998b) that in baling tests, with and without windrowing, it was obtained bigger effective capacities for the windrowed treatments. The references of effective capacities found in the bibliography are from different type of system, therefore they difficult to be compared, especially due to different machine models and manufactures. The following comparisons just establish an order of greatness among the results obtained in this work to the values found in the bibliography. The effective capacities results from Copersucar (1998b) of 1.80; 2.70 and 9.00 tons.h^{-1} and from Howe & Sreesangkon (1990) of 2.21 and 2.49 tons.h^{-1} were smaller the one in Table 2. Copersucar (1998a) also presented values such as 11.40 and 22.0 tons.h^{-1} which were smaller than found in double and triple windrowing treatments, respectively.

The highest positive energy efficiency in this work considering windrowing and windrowing plus baling was from the second treatment (double windrowing) representing the best 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. It is desirable that the energy efficiency is positive and the highest possible, so that the withdrawal residues is 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 fuel consumption values obtained in this study with the ones found by Molina Júnior et al (1995) of 4.30 and 4.40 $L.h^{-1}$, it was observed for this work that the fuel consumption in all the treatments were superiors to the ones presented by the authors, although such comparison belongs has a small technical interest because compared systems with sources of different potency, besides the different local and method.

Table 3 shows the average values of the amounts of mineral strange matter (soil) present that were found in the bales, in both treatments.

Table 3. Average values of the amounts of mineral strange matter (soil) in the bales in both treatments.

Variables	Treatments		
	Simple	Double	Triple
Mineral Strange Matter (%)			
Averages	5.71 **A**	6.31 **A**	6.41 **A**
CV	0.32	0.30	0.29

Obs.: Averages followed by the same letters do differ between them at a 5% level of significance. CV= Coefficient of variation.

The mineral strange matter (soil) averages in the bale did not differ between them in a level of 5% of significance, with the application of the test of Tukey, as it could be observed in the Table 3. The windrowing of the residues incurs in a higher soil earth percentage in the bale, fact also observed by Copersucar (1998b) that did some testing in situations with and without windrowing. The amount of soil determined in the three different windrowing treatments increased with the raising of number of rake passages. The third treatment had de highest amount of soil and the first one de smallest, as seen in Table 3.

The values of soil percentage in the bales determined in this study come quite close to the ones found by Copersucar (1998b) with the windrowing of the residues before baling around 5.60% of soil for JS® 90 baler and 6.20% for ROL® 1518 baler. Comparing the soil amount of the bales obtained by Copersucar (1998b) of 2.80% for JS® 90 baler and 2.30% for the ROL® 1518 baler without windrowing, the average values in this study were superior.

The average amounts of soil determined in the Table 3 were approximate to the obtained by Abramo Filho et al. (1993), 6.92% in the residues, studying the residues from green cane mechanically harvested.

The soil percentage was smaller than the one obtained by Ripoli (1991) of 12.28% that was carried with the residues. This result possibly happened because the granary loading used was made by a conventional sugar cane loader.

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 esteemed 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 simple windrowing treatment presented the best results, with the highest effective capacity average and the smallest fuel consumption averages. The bales obtained in the triple windrowing treatment showed the biggest specific mass averages. The amount of soil found in the bales increased with the successive windrowing.

The baling operation of the triple treatment obtained the best results, presenting the highest effective capacities average and the smallest fuel consumption per ton of baled residues.

REFERENCES

ABRAMO FILHO, J.; MATSUOCA, S.; SPERANDIO, M.L.; MARCHETI, L.L.; RODRIGUES, R.C.D. Resíduo da colheita mecanizada de colheita de cana crua. **Açúcar & Álcool,** v.67, n.2, p.23-25, 1993.

COOPERATIVA DE PRODUTORES DE CANA, AÇÚCAR E ÁLCOOL DO ESTADO DE SÃO PAULO – PROJETO BRA/96/G31. Baling da palha. In: PROJETO BRA/96/G31: Geração de Energia por biomassa, bagaço da cana-de-açúcar e resíduos. **STAB. Açúcar, Álcool e Subprodutos**, v.16, n.6, p.44-46, jul./ago. 1998a.

COOPERATIVA DE PRODUTORES DE CANA, AÇÚCAR E ÁLCOOL DO ESTADO DE SÃO PAULO. Impactos ambientais do uso em larga escala de sistemas BIG-GT na indústria da cana-de-açúcar. In: PROJETO BRA/96/G31: Geração de Energia por biomassa, bagaço da cana-de-açúcar e resíduos. **STAB. Açúcar, Álcool e Subprodutos**, v.16, n.5, p.36-39, maio/jun. 1998b.

FNP CONSULTORIA & COMÉRCIO. **AGRIANUAL 2004**: anuário da agricultura brasileira. São Paulo, 2003. p.213-231.

GOMES, F.P. **Curso de estatística experimental.** Piracicaba: F. Pimentel Gomes, 2000. 477p.

HOWE, R.; SREESANGKON, P. **Costs and performance of equipment for baling sugar cane tops and leaves.** S. I. United States Agency of Internacional Development, 1990. 56p.

MIALHE, L. G. Desempenho operacional da maquinaria agrícola. In: MIALHE, L. G. **Manual de mecanização agrícola**. São Paulo: Ceres, 1974. p.117-126.

MOLINA JÚNIOR, W. F.; RIPOLI, T. C.; GERALDI, R. N.; AMARAL, J. R. Aspectos econômicos e operacionais do baling de resíduo de colheita de cana-de-açúcar para aproveitamento energético . **STAB. Açúcar, Álcool e Subprodutos**, v.13, n.5, p.28-31, maio/jun. 1995.

RIPOLI, M.L.C. Mapeamento do palhiço enfardado de cana-de-açúcar (*Saccharum spp*) e do seu potencial energético. Piracicaba, 2002. 91p. Dissertação (Mestrado) – Escola Superior de Agricultura ”Luiz de Queiroz”, Universidade de São Paulo.

RIPOLI, T.C.C. Utilização do material remanescente da colheita da cana-de-açúcar (*Saccharum spp*): Equacionamento dos balanços energético e econômico. Piracicaba, 1991. 150p. Tese (Livre Docência) – Escola Superior de Agricultura ”Luiz de Queiroz”, Universidade de São Paulo.