Oscar A. Braunbeck; Efraim Albrecht Neto. "TRANSPORT LOGISTICS OF RAW MATERIAL AND WASTE OF SUGARCANE", p.487-504. In Luis Augusto Barbosa Cortez (Coord.). **Sugarcane bioethanol — R&D for Productivity and Sustainability**, São Paulo: Editora Edgard Blücher, 2014.
http://dx.doi.org/10.5151/BlucherOA-Sugarcane-SUGARCANEBIOETHANOL_45

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TRANSPORT LOGISTICS OF RAW MATERIAL AND WASTE OF SUGARCANE

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STALKS

The transportation of sugarcane basically involves transport of stalks from the field to the industrial plant where they will be processed. In Brazil, cane transportation is done predominantly by road. Trucks used in the transportation of cane carry wholestalk sugarcane or billeted cane, depending on the harvesting system used. Silva (2008) states that the transportation of cane is integrated along with the harvesting and loading operations forming what is called the harvest, load and transport system "CCT", responsible for the continuity of the milling rate.

Logistic operations

The CCT logistics is considered as the management of equipment, human resources and information necessary to deliver cane from the field to the mill's cane discharge zone, at a uniform mass flow rate using the available cane transportation fleet, operating the closest possible to full milling capacity, with varying crop yield and transportation distances along diferent production areas. According to Chiarinelli (2008) the challenge of CCT logistics, is to keep the mill in constant operation, in a condition that could be considered as just in time, working with very low machinery idle time, a cane stock close to zero, and each operation fully depending of the activities before and after it. It is common, in some plants, occurrences of discontinuity between the delivery of cane to the mill and the milling operation throughout the day due to miss-control of timing, resulting in traffic queues at the cane discharge zone. In other words, accumulation of excessive cane stok in the discharge zone and increase of the idle time of the cane transportation fleet, with corresponding reduction in transportation capacity.

Transport logistics involve both agricultural and industrial variables of the company, in addition to those inherent variables of transportation itself. Harvesting planning and the sugarcane reception system at the mill, are part of the dynamics of transport management.

Agricultural area

During the harvesting season sugarcane mills operate in a continuous process where the cane is supplied from several production areas known as "harvesting fronts". Regardless of the harvesting system used, manual or mechanized, these units are responsible for harvesting and loading the stalks in trucks and trailers for transportation to the mill. The "harvesting fronts" are strategically located so as to have an average weighted transport distance compatible with the fleet capacity.

Manual harvesting

In the manual harvesting process, cane cutters generally select and grab 4 or 5 stalks at a time and cut them at the base with a machete. Stalks are then gathered in piles aligned perpendicularly to the harvested lines, with a roughly parallel configuration among the stalks.

FIGURE 1 Loading of whole stalk harvested sugarcane.

This phase of the harvesting process has strong influence over the sugarcane transportation fleet performance as the parallel configuration of stacked stalks enables to reach higher cargo densities thereby enhancing performance of the transport operation. To reduce machine traffic on the cane stools the stacked stalks are positioned over the center line of a five row strip.

After the sugarcane stacks are formed the hydraulic grab loaders pick-up the piles and load them into a truck or wagon that follows by side of the loader (Figure 1). The loading operation is an important part of the transport logistics due to the significant amount of time dedicated to this operation as well as the delays associated with truck queues at the loading zone and time spent by loader in positioning maneuvers in the field. Lately the use of combined cargo vehicles (CVC) is becoming increasingly frequent in loading operations, these combinations require additional auxiliary operations and machinery such as coupling and uncoupling of trailers, extra tractors and trucks which demand extra time and also contribute with additional delays inherent to these operations that also should be considered as part of transport logistics.

It is important to remind that manual harvesting can also be carried out on green cane, but the performance of the workers drops dramatically, increasing the cost of both harvesting and loading operations as a consequence to the lower tonnage harvested and the low density of the cane grabbed by the loaders.

Mechanical harvesting

Mechanical harvesting of sugarcane can be accomplished by both whole stalk cane harvesters and chopped cane harvesters which are able to harvest both burnt and green cane when compared to whole stalk harvesters that can only harvest standing burnt cane. While whole stalk harvesters leave the harvested stalks in the field to be picked-up during subsequent loading operation, chopper harvesters simultaneously load the billets into the accompanying transport vehicle.

Today chopper harvesters are responsible for all the mechanically harvested cane in Brazil. Loading of billet cane has been consolidated through an internal transportation system of intermediate self tipping wagons which are loaded by the harvester on-the-go and then moved to a transfer zone outside the harvested areas where the load is transferred to the transportation trucks as shown in Figure 2.

FIGURE 2 (a) Self tipping wagon getting the cane from the harvester; (b) side dumping to the truck.

Mechanical harvesting significantly changes the logistics of cane transportation since the beginning of harvest planning, frequently there is no burning of sugarcane and transportation follows simultaneously the harvesting operation. In this case logistics should consider the interactions of harvester with wagons and road trucks (CVC). Interactions between these equipments involve loading and unloading time, waiting time and maintenance delays.

Industrial sector

The main task in the mill's industrial sector relative to cane transport logistics consists in unloading the cane loads brought by the trucks. This procedure is pretty much the same among most sugar mills. According to Silva and Alves (2003) when the trucks enter the mill they go through a scale to measure the loaded gross weight and about 30% of them follow to a procedure for load inspection called Technological Analysis, where a probe takes samples of the loads to determine its quality. Trucks are chosen randomly for this procedure, only exception being the loads from external cane suppliers that have all loads analised for payment procedures. After weighting and quality analysis the trucks head for discharge procedures, in this phase loads may be discharged directly into the mill feeding conveyor or left in the yard for storage. After unloading, billet trucks head directly to the weighting scale to measure the trucks empty weight. Wholestalk trucks go through a cleaning process of soil and cane stalks form the bottom of the body before they head to the weighting scale. After the empty weighting the trucks return to the field to begin a new cycle.

Delays of trucks standing idle in the cane discharge zone could be a consequence of an over sized transportation fleet or an error of logistics planning with negative impacts over investment and labor costs. If the fleet is optimally sized, the line up of trucks in the discharge zone implies in their absence in the field which causes a harvesting interruption followed by a later lack of cane at the mill.

Evolution of the sugarcane transportation

According to Chiarinelli (2008) factors such as low density loads, bad operational conditions and excessive return time of the trucks to the field contribute to increase the cost of cane transportation. Another issue concerning transport efficiency is the field average displacement to the mill. According to Macedo *et al.* (2008) recently the average field distance is estimated in about 20 km it will grow to around 30 km. The average displacement of the transportation trucks is directly related to the overall efficiency of the transport operation, in other words, when trucks operate in short distances the cycle time involves a larger number of

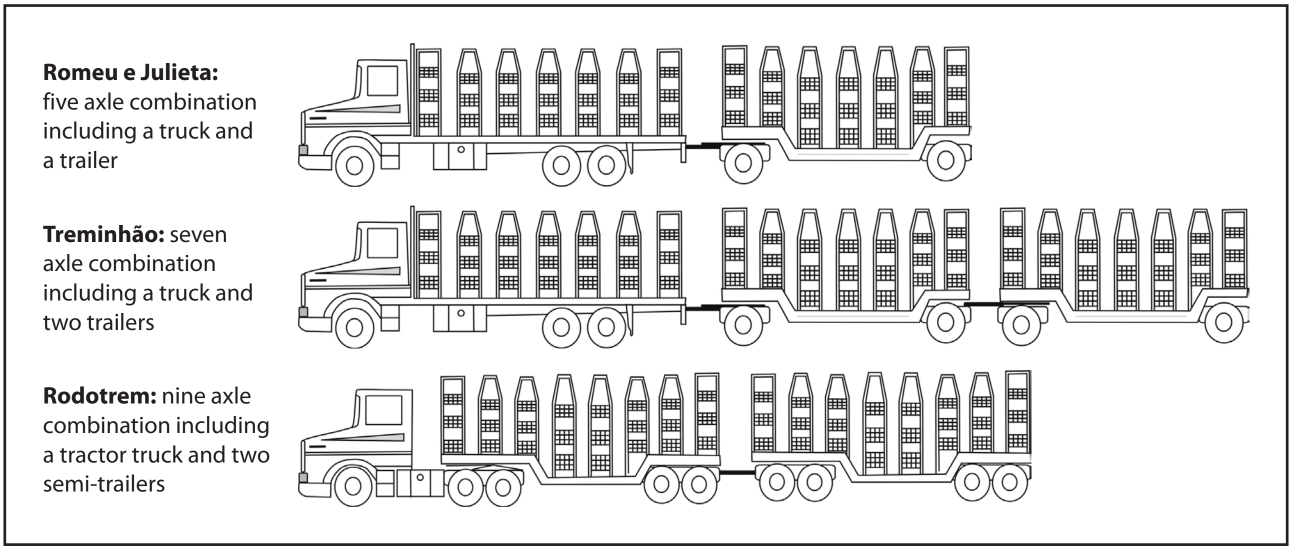

FIGURE 3 Transport combinations of track and trailer used for cane transport.

loading and unloading times during the day which makes it a critical point to the transport logistic management model.

The bulk density of the truck loads is another variable that significantly impacts transport efficiency. As it frequently happens, it is the volume and not the weight the legal limiting factor to truck load capacity. The chopper harvester can affect significantly bulk density of loads through the billet length the chopper is adjusted.

Combination Vehicle Load – CVC

The ethanol industry has evolved considerably in recent decades regarding cane transport equipment. Cane transportation was formerly done with two axles trucks carrying a load close to 10 tons per trip. Today tractor trucks using trailer combinations are used to transport a load of about 60 tonnes per trip working with up to nine axles. The transport combination to be used depends on factors such as the distances from the fields to the industrial plant and the conditions of trafficability over the roadway network. Currently there are three configurations or of track and trailer combinations : they are the “Romeu e Julieta”, the “Treminhão” and the “Rodotrem” (Figure 3) with load capacities of approximately 30, 45 and 60 tonnes respectively.

According to Silva (2008) the greatest advantage of “Rodotrem” is the high load capacity and the operation versatility of the “bate volta[1]” system, which maximizes the use of the tractor truck. Moreover, the advantage of the “Treminhão” is related to the larger number of hitch joints, which allows it to operate in areas with restricted space and smaller turning radius. An additional advantage of “Treminhão” is that in regions where there are restrictions for the use of long compositions during the night, when releasing the second trailer, 66% of the cargo is still transported, against only 50% of the load in the case of “Rodotrem”, when releasing the second semi-trailer.

On internal roads of the agricultural area, out of state or federal highways, some mills use track-trailer combinations where the truck pulls simultaneously more than two trailers, going up to 10 trailers in some cases. These combinations are used only on roads that do not have sharp turns or steep slopes. Besides the technological evolution of CVC’s significant advances related to truck bodies have also ocurred, such as weight reduction and body desin focused on reduced cane losses during the trip.

Considering the limitations imposed by the Brazilian legislation over transport vehicles, both

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[1] No stop tractor truck.

restricting the allowed load per axle and the over all dimensions, it seems unlikely to achieve significant gains of transport performance through research and development in the near future, especially when comparing this sector to those less developed and with greater earning potential, such as harvesting and planting.

Logistics operation

Considerig that the auxiliary time spent for loading and unloading trucks diminishes the performance of the transportat fleet, the mills adopted the system known as "Bate e volta" to reduce auxiliary times and increase the performance mainly of the tractor tracks. In this system the trailers are detached from the trucks and pulled by agricultural tractors during the loading and unloading operations, remaining only the accountable time of coupling and uncoupling at the field and at the mill, in the transport cycle of the truck. In this case, once the truck arrives at the harvest front, the trailers are unleashed and the truck passes ahead of the other equipment to be loaded, when this process is completed the truck moves to where the loaded trailers are coupled to it. In the case of mechanical harvesting tractors pull the self tipping wagons that take the cane from the harvesters to the trailers parked at the load transfer area. This logistic operation is particularly effective for shorter transport distances where the auxiliary time represents a larger fraction of the total cycle time.

The data associated with transport, harvesting, plantation and mill unloading are part of the database used for the optimization of transport logistics, helping to choose the location of the harvesting fronts so that the average distance of transport is compatible with the available capacity of the fleet and the average distance of the sugarcane remaining in the field is still compatible with the available fleet, even at the end of the season when the harvesting and transport capacity are reduced. The maturation of the sugarcane and crop yield are also involved in the design process and logistics management.

Diesel oil consumption

According to Macedo *et al.* (2008) the fuel consumption for operations involving the production of one ton of sugarcane during the season 2005/2006, was 2.64 l/t (diesel oil). The same author also points out that the consumption corresponding to transport, for a distance of 23 km, was 0.87 l/t. It thus appears that transport accounts for about 30% of the diesel used throughout the agricultural cycle.

With the growth in production of sugarcane the average distances of transport will increase gradually and the fuel consumption per ton of produced sugarcane will do the same. However, with the introduction of the CVC´s with large capacity, and increased efficiency the fuel consumption becomes less pronounced. This trend can be seen in Table 1 which shows the evolution of the distances and energy efficiency of trucks in two seasons, and a scenario for 2020.

The fuel consumption of diesel engines used for sugarcane transport is optimized within the standards of last generation of engines commercially available. In this line of evolution a possible improvement would be the replacement of diesel oil by ethanol. This alternative was implemented in the 1980s in several mills, mainly using additivated ethanol in conventional diesel engines or bi-fuel

TABLE 1 Evolution of the distance and energy efficiency of trucks.

Parameter	Units	2002	2005/2006	2020
Distance	km	20	23	30
Efficiency	t/km/L^{-1}	49.0	52.4	62.0

Source: Macedo *et al*. (2008).

engines with pure ethanol and a smaller fraction of diesel fed through a second injection pump for ignition. However, due to the lower cost of diesel oil these changes were interrupted. Presently, price trends are just the opposite so the new scenario opens again the possibility of using ethanol, even if only for the fleets owned by the mills. This would require engine development to make the necessary adaptations and ajustments.

Another option to reduce fossil fuel consumption would be the use of electrical transmissions in local roads with high traffic density, within the mill agricultural area and using co-genetated electricity.

Management operations

The management of sugarcane transportation is subject to interactions of several variables such as weather conditions, load density, fleet size and maintenance program, conditions of the roadway network, location of the harvest fronts; average distance from the mill and the harvesting areas, among others (Chiarinelli, 2008). New information technologies are essential to integrate efficiently the management of the harvesting, loading and transportation operations, with a systemic view of the process. Traditional methods treat each subsystem separately, or use average equipment performance values to manage the systems.

Transport logistics involves the synchronization of operations between the various areas of agriculture and industry. New technologies involving the automation of decision support processes, for example, the dynamic allocation of the trucks destination at the exit of the weighting scale, depending on the variables described above, contributes to achieve the objective of supplying sugarcane to the mills with lower cost and environmental impact.

Dynamic management

The technologies focused on agricultural remote sensing are in the process of adjustment and consolidation in the agricultural market, showing more reliability and efficiency. Telecommunication technologies allow monitoring the machine position in the field, making it possible the management processes in real time. The satellite technology and GPRS for real time monitoring of machines and vehicles is becoming progressively more accessible, both for equipment and services.

Obtained information is analyzed through accurate processing resources (GIS) and specific mathematical models that are linked to the corporate databases facilitating consultations through time and space to generate reports including complex relational information.

The new mobile communication technologies and long-range field agricultural systems process real-time information that traditionally would take days to become available.

An example of that is the proposition for monitoring and control of CCT by Cerri *et al.* (2008). The proposition is a simulation model for monitoring historical parameters of the area and events of the harvesters, trucks, and industry operation to perform the automatic dispatch of trucks with feedback in real time, using mathematical models based on spatial-temporal data. According to the authors, in addition to continuous monitoring, the proposed system allows the integration of agricultural and industrial information with logistics.

Need for research and development

Despite the limitations imposed by legislation on the size and configuration of transport compositions to increase load capacity of sugarcane transportation vehicles, research can still be focused on other types of vehicle, lighther structural materials and higher load densities to obtain reduction of cost and environmental impacts.

Most available systems for on-line data transmission prioritize the use of the communication by phone instead of via satellite due to the lower cost of transmission by phone lines. However, the satellites network (Iridium) ensures full coverage in remote areas where cellular communications does not. Therefore public policies focused on preferential tariffs for traffic information in the agricultural sector as well as funding for installation of towers GSM/GPRS in agricultural areas and creation of technical courses for training and retraining of personnel are desirable for the sector.

The large number of agricultural and industrial variables involved in establishing and operating the complex logistical process of sugarcane transportation demands a great deal of research and the development of algorithms and methodologies for collecting and analyzing data of the various parts involved in the process. These data are related to the transportation fleet, the structure for sugarcane reception at the mill, the sugarcane age and maturation curves, the climate and soil data as well as the conditions for of sugar and ethanol marketing throughout the harvesting season, among others.

According to the discussions presented in this article it can be stated that performance of sugarcane transportation has significantly improved as a result of contributions of intermediate transportation of sugarcane, mainly by reducing idle time of the equipment involved in the process. It is also possible to state that there still is a great potential for performance improvements in transport logistics through development and application of information technology resources.

CANE TRASH

The trash of sugarcane can be used as soil cover or fuel for power generation. Given the evolution of no-till farming for grains and the increasing demand for renewable energy it is suitable to think that in the near future, the use of trash should pass through both these paths. The fraction of trash agronomically used that are left on the field during harvest, does not require logistical arrangements for their handling. The rest of the trash must be separated from the stalks, transported and stored so that finally, during the period between harvest seasons, be loaded, transported and unloaded at the mill boiler or used in processes of fuel production.

Currently there are a few alternatives to the logistics of trash recovery that are an adaptation from the handling of livestock forage, considering that the trash volumes processed in this activity are much lower than those involved in the energy utilization of trash. This contributes to a high cost of trash recovery operation in large-scale mainly as a result of the low efficiency in the processes of collection, separation, compaction, size reduction and storage concerning this technology. Only the transport of the trash is made with high capacity vehicles, with load volume within the limits prescribed by law and for that so leaves the density as the resource to be optimized.

The recovery of trash has been practiced by two ways, first releasing them through the harvester over the soil forming a layer exposed to the sun. In the second path, the stalks, trash and some of the pointers are launched by the harvester to the transport vehicles, without contact with the soil, which is called an integral harvest, and later the stalks are separated at the plant, using a dry cleaning station. The option of leaving the trash over the soil keeps them in a natural process of drying for about 10 days, which reduces the moisture to about 20% (Ripoli, 2002). After this period the trash is concentrated in piles of higher density, with about 10 kg/m^{-1}*. This operation, called Windrow, has a negative effect on the quality of the material due to the large amount of mineral impurities that incorporates the raking over the soil. According to some authors the content of land incorporated into the trash reach up to 10% in extreme situations. The stacks left on the soil are collected through the processes of gathering and baling or gathering and chopping. In the first case the trash undergoes compactation and the second case a size reduction is performed to increase density of transportation load.

Trash density

The compaction of trash has limitations related to the low density achieved from recovered materials and low operating capacity of the equipment used. It can be consider that the cost of trash transportation decreases inversely to the proportion of the increase in density. There is a need to improve the compactation technologies focused on handling the large volumes of energetic biomass, such as trash. The density of the trash also has a direct relation to the storage costs, a process that is necessary for generating power through the whole year. There are currently several cases of compaction resulting in different densities, with different capacities, and different operational costs and investment demand. In the study conducted by Michelazzo (2005) principles of compaction ranging from zero or spontaneous compaction, and high pressure compaction as used in Briquetting Pellets were considered.

Trash recovery Systems

Among the most tested systems that were used in experiments of trash recovery are the full harvest, baling and chopping the bulk of which only uses the baling process of mechanical compaction.

Integrated harvesting

In this system, the machine harvests with the extractors turned off gathering stalks, trash and pointers all together. The mixture of stalks and trash are transfered to transporting wagons which then transfer them to the transportation trucks. The trash is then transported to the Mill where the stalks and trash are separated by a dry cleaning unit, through pneumatic and mechanical separation performed by polygonal rotating disks. One of the problems of this system is still the lack of processes and equipment to do the cleaning efficiently with acceptable sugar losses. Sotelo and Correa (1999) observed in a dry cleaning facility that the amount of trash separated was about 50 kg per tonne of processed cane. The dry cleaning facility is a Center of cane reception and cleaning used in Cuba, where the trash is reduced in size and separated by strong air currents. The composition of trash found by the authors was: tips, green leaves and shoots (59%), straw (28%), fragments of sugarcane (9%) and others (4%).

Baling

The trash left on the soil by the harvester is gathered and collected by the baler, which performs the compression of low pressure, with lashing, using a rod-crank or roller mechanism. The bales are released by the baler and remain in the field to be loaded later on and transported to the storage location. The bales can be lightweight, allowing the manual handling as traditionally practiced in the treatment of animals, or may be greater burdens that require mechanical handling. The CTC (1999) conducted studies which indicated that the use of large, prismatic bales (density of 170 kg/m^3), generates the best economic results in the recovery of trash. This results from the greater baling operational capacity and better volumetric occupation in the truck during transportation. In general, baling of the trash has the disadvantage of requiring a chopping process when the trash is intended for burning to improve the uniformity of feeding conditions for combustion in the boiler.

Chopped bulk

The trash left on the soil by the harvester is gathered and later on collected by the forage chopper, which reduces the size to pieces about 1 cm length, launching it to the transportation truck directly by its own inertia. This process of fine chopping with inertial loading does not involve the compaction thus resulting in a low load density of 85 kg/m^{-3} (Ripoli and Ripoli, 2004, Franco, 2003 and Ideanews, 2002). Carriers load the trucks that transport the chopped trash to the storage location.

The two alternatives described above for trash recovery, leaving trash on the soil or directly loading it in a carrier results in products with different qualities in terms of mineral impurities content. Logistics of trash recovery should consider whether the use will be the direct combustion or fuel production. Both options have different quality requirements associated with the impurities and microbiological processes developed during storage.

Performance of recovery systems

Considering that there are no consolidated logistical arrangements for handling trash, technically and economically defined, results of two techno-economic studies which address the main options that could be used for the trash recovery with the available technologies will be presented and analyzed. In the first study, the Sugarcane Technology Center (CTC), in a Project called Report BRA/96/G31, considered three alternatives listed below for mechanical harvesting of sugarcane:

Alternative 1: in this system the harvester keeps the extractor fans operating and the trash is left over the soil. Then, the spread trash is gathered and later on collected by baler that will leave the bales along the harvested areas. These bales are loaded in a truck using a hydraulic grab loader and then transported to the mill where they are shredded and fed to the boiler furnace.

Alternative 2: in this system, the harvester keeps the extractor fans off, so that the trash and sugarcane stalks are harvested together. Both are transported by transportation trucks to the mill's dry cleaning facility.

Alternative 3: the process of trash recovery is very similar to Alternative 2, however, the harvester works with the secondary extractor off and the primary operating at reduced speed. This configuration allows only part of the trash to be left in the field, thus performing only a partial cleanup.

The alternatives described above present quite different costs of trash recovery. Table 2 shows the cost of recovery about the three alternatives studied, one can observe that the cost of alternative 2 is superior to the others. This comes as a result of two factors, first the lower density of stalks and trash mixture results in higher transportation costs and secondly, the criterion of cost allocation that was adopted in the study by which any increase in transportation costs resulting from lower density is allocated to the trash, since it is a part of the load with a tonnage far below the stalks.

In the second study Michelazzo (2005) simulated the recovery of trash through a simulation model involving cost efficiencies and operational capabilities of each recovery system through the concept of maximum efficiency of the equipment according to the trend that followed mechanization of sugarcane cropping in the last decade. The study uses machines for windrow, collecting, consolidating, loading, transporting and reducing size of trash. The author considered the six systems listed below:

System 1 (bundling): in this system the trash is gathered and collected by the baler, through which it performs a low pressure compression, with lashing, using engine belts and rollers instead of the baler plunger. The bales are released by the baler and remain in the field to be loaded later on and transported to the storage zone, next to the boiler. At the time of burning, the bales are shredded to enhance combustion efficiency in the boiler.

System 2 (chopped bulk): in this system the trash is gathered and collected by the forage harvester, reducing the size of the trash and then by inertia loads the carrier until it reaches capacity so they can then load the transport trucks.

System 3 (briquetting): in this system, the process of windrow, chopping and internally transporting system is similar to the bulk chopped handling. After being raised and chopped by the forage harvester, trash is transferred to the carriers, transported through a short distance, and fed directly in the field into a briquetting press, which

TABLE 2 Cost of recovery of trash a (US$/t).

	Alternative 1	Alternative 2	Alternative 3
Trash put the plant*	9.61	23.23	2.74
Separation of trash and sugarcane	–	2.79	3.69
Processing trash	0.89	0.85	1.14
Total cost	10.50	26.87	7.57

* For alternative 1 is included the following: Windrow, baling, loading and unloading and transport. For alternatives 2 and 3 operations are: internal transport (bus) and transport to the plant (trucks).

Source: Report BRA/96/G31.

performs a high pressure compression, without lashing it with robes, using a rod-crank mechanism. Once hardening, the trash in the form of briquettes is transported to the mill by trucks.

System 4 (Pelletizing): this recovery system is equivalent to the trash briquetting, described above, only changing the configuration of the press to a continuous compression process, with the aid of helical coils that compress and force the material through a matrix perforated with enough compaction pressure to maintain the cohesion of the trash fibers making it unnecessary to use lashing to tie the trash blocks formed in the process.

System 5 (cotton bale): this recovery system is also equivalent to the trash briquetting, described before, only changing the configuration of the compression process. The piles are raised and the chopped by forage chopper and then transfers the material to carriers which then transfer the trash to a cotton stuffing machine in the field, in this case the carrier uses a feeding conveyor to uniformly transfer the trash to the Cotton Stuffing Machine. This machine operates in an intermittent process of low pressure compression by means of hydraulic pistons. The burden's own weight, due to its large size, ensures the maintenance of the higher density, thus not requiring lashing. The burden is transported to the mill by a self loading truck also called "roll on – roll off".

System 6 (integral harvesting): in this system, the harvester is harvesting the cane stalks together with the trash, keeping the extractor fans off. The mixed stalks and trash are transferred to carriers which then transfers to the transportation truck that takes the mixed material back to the mill where it is separated in a dry cleaning station.

This study adopted a trash yield of 20 t/ha with a withdrawal rate of 50%, so the amount of trash collected was 10 t/ha. The characteristics of compacted trash through the different systems are presented in Table 3.

The costs of recovery of trash obtained by Michelazzo (2005) for the six systems operating at a transport distance of 15 km are listed in Table 4.

Comparing the Project BRA/96/G31 and the study of Michelazzo (2005) it is possible to verify that there are 02 systems that were analyzed by both of which are condensed in Table 5. This table compares the cost of baling systems and integral harvesting. The bundling has a lower cost of $ 4.37 at Project BRA/96/G31 as a result of having used a prismatic baler producing larger and greater density of the bale. In addition, the prismatic bales allow better accommodation in the back of the truck and thus the load transported is much higher lowering transportation costs. The difference in cost is then attributed over baler performance and transportation efficiency.

However the study of Michelazzo (2005) presents a complete cost of the integral harvest system less than $ 20.00 to that obtained by the Project BRA/96/G31, this difference arises from the fact that the cost of transporting the whole system was divided among the stalks and trash

TABLE 3 Characteristics of dense trash by different processes.

Features	Round bale	Cotton bale	Briquette	Pellet
Density (*kg m*$^{-3}$)	170	160	1,000	1,200
Weight (*kg*)	231	10,000	2.4	0.01
Volume (*m*^{3})	1.36	62.5	0.002	0.00001
Height (*m*)	–	2.5	–	–
Width (*m*)	–	2.5	–	–
Length (*m*)	1.2	10	0.30	0.035
Diameter (*m*)	1.2	–	0.10	0.01

Source: Michelazzo (2005).

TABLE 4 Cost recovery of trash.

Recovery system	Cost (US$/t)
Baling	14.87
Stuck bulk	13.74
Briquetting	49.02
Pelletizing	28.67
Cotton bale	18.41
Integrated harvesting	6.87

Source: Michelazzo (2005).

in proportion to the tonnage of each component, in other words, 20% of the cost of transportation refers to the trash and 80% refers to the stalks. In the methodology adopted by the Project BRA/96/G31, the trash is penalized with all the extra cost of lower efficiency of transportation caused by the presence of trash.

Regardless of the criteria adopted for the calculation of costs is evident that the presence of trash affects the load density and that efforts should be focused on developing innovative technologies for the logistics of trash recovery to make this energy source more attractive and capable of winning economic space in a near future. The trash is still considered only as an impurity with no potential to generate economic benefits. The advances in technologies for production of a second generation of bio-fuels and valorization of renewable electric energy should also contribute to the economic feasibility of trash recovery.

Storage of cane trash

Trash conversion to energy, either in direct combustion processes or production of other fuels, requires storage to enable energy production out of the harvesting season.

Storage of trash for burning at boilers must consider properties such as density, moisture and impurity contents. Trash stored for hydrolysis must retain the chemical composition of fiber: lignin, cellulose and hemicellulose. The higher the amount of cellulose and hemicelluloses preserved in storage the higher will be the amount of ethanol produced. There are some technologies used for storage of agricultural forages that can be used in the case of cane trash. The most common options are stacking in the open, silo-bags, trench silos and inflatable canvas structures. Each alternative has different characteristics in terms of demand of labor and handling equipment, investments, land surveying and final product quality.

The storage of trash in the open is similar to what is currently done for bagasse. The silo-bag is widely used for agricultural storage of grains and forages in temperate climates. It may become a viable alternative for trash. The canvas inflatable structure is used by sugar mills for storage of sugar.

Some alternatives for trash storage were analyzed in a study done by CGEE (2007). This work considered 6 scenarios in order to identify those having the best cost effectiveness. The analysis contemplated the productivity, demand for investment and operating costs of a model distillery, using data provided by manufacturers of agricultural implements and machinery and the results presented in report BRA/96/G31.

Three storage conditions were studied by CGEE: trash stacked in the open; stored in canvas inflatable structures and stored in silos-bag. Two harvesting systems were considered for trash recovery: integrated harvesting and transportation of cane-trash mixture later separated by a dry cleaning station at the mill and conventional baling of trash recovered from the ground surface.

To determine the final costs of trash the CGEE study took into consideration the cost of trash operations used for collection and transportation from the field to the mill, obtained in the BRA/96/G31 report. The costs of storage and transportation from storage to the mill were simulated together with the cost of the storage structures.

TABLE 5 Comparison between the cost of trash in the studies presented (US$/t).

System recovery	Michelazzo (2005)	Report BRA/96/G31
Baling	14.87	10.50
Integral harvesting	6.87	26.87

The total cost of trash recovery for all scenarios is presented in Table 6.

The study concludes that trash density is the factor that most influence the final cost of storage and handling. Operational cost of storage in conjunction with capital cost of structures also contributes significantly to the cost of trash. The simulation study did not considered trash losses occurring during storage. Open storage has cost significantly lower than covered storage. Specific studies on mass losses and quality of trash for alternative systems of storage is needed. It will assist in choosing the appropriate type of handling and storage system for direct combustion or fuel production.

Closing remarks

The equipment available for the logistics cycle of cane trash was designed for production volumes much lower than those required to produce biomass energy. There is a high number of operations and related equipment participating of the logistics cycle. High-capacity equipment, operating in continuous processes for recovery, compaction, loading, transport and storage, in many cases involving new operating principles, are necessary to make the cost of trash recovery compatible with the market prices of electricity or bio-fuels. It should be noted that even if the trash allocated to the practice of no-till farming does not involve logistics processes there is usually trash in excess to be used for bio-energy and it requires logistics improvements.

Integral harvesting of trash and cane is currently the system with the lowest total cost available. However, further studies are needed to examine properly the increase of cane transportation costs incurred as a result of the lower load density resulting from trash mixed with cane. Separation of trash in the field, with appropriate density and without soil contact appears as a route of development with good potential to reduce transportation costs of both, stalks and trash. It also eliminates the contamination caused by mineral impurities introduced by the raking operation involved in the baling process.

Recovery processes involving trash disposal on the soil surface for natural drying and adaptation of the trash logistics to existing equipment, such as balers or forage choppers generate high cost and levels of soil contamination. Current technologies

TABLE 6 Total cost of trash recovery and storage for six scenarios (R$/t trash).

Recovery and storage system	Operational Cost (R$/t)		Cost storage structure (R$/t) (simulated)	Total (R$/t)
	Recovery * (Report BRA/96/G31)	Storage (simulated)		
Integral harvesting; Open storage (ρ = 100 kg.m^{-3})	27.67	15.82	0.00	43.5
Integral harvesting; Inflatable canvas (ρ = 100 kg.m^{-3})	27.67	15.82	51.84	95.3
Integral harvesting; Silo-bag (ρ = 200 kg.m^{-3})	27.67	15.23	22.14	65
Baled trash; Open storage (ρ = 200 kg.m^{-3})	37.34	15.03	0.00	52.4
Baled trash; Inflatable canvas (ρ = 200 kg.m^{-3})	37.34	15.03	25.92	78.3
Baled and chopped trash; Silo-bag (ρ = 200 kg.m^{-3})	37.34	20.43	22.14	79.9

* Exchange rate: 2.02 R$/US$; ρ: specific gravity.

Source: CGEE.

for trash recovery must be reviewed looking for improvements in the natural drying process and a reduction in the number of operations involved.

AGRO-INDUSTRIAL RESIDUES

Sugarcane industrialization produces waste materials such as vinasse, filter cake and boiler ashes that require handing operations with varying importance according to the quantities produced. According to the composition of the waste different field applications systems were developed in the form of solid or liquid fertilizer, always focused on reducing costs and environmental impacts. Filter cake and vinasse have high water content so any reduction of moisture content has a positive impact on the cost of transportation and distribution. In both cases the moisture content plays also an important role in deciding what distribution system to use.

Vinasse

Vinasse is a liquid residue of the ethanol distillation process. It is produced at a rate of about 11 liters per liter of ethanol, is the most important liquid effluent of the sugarcane industry. Some positive factors, such as the recovery of potassium, organic matter and water, together with the negative pollutant effect of vinasse make the logistics of distribution on ratoon cane a matter of high economic and environmental importance. The use of vinasse in fertigation requires transport, storage and distribution systems with acceptable environmental impact together with feasible operating cost and investment, at distant areas from the industrial plant. Choosing sugarcane fields eligible for fertigation depends on the topography, the distribution system and the field management strategies adopted. Currently there are companies applying vinasse on up to 70% of the cane fields (Nogueira *et al.*, 2008).

The distribution of vinasse on the soil involves four quite distinct stages: the primary transport from industry to the storage tanks, storage, the secondary transport from the tanks to the fertigated fields and finally the distribution on the sugarcane field. Each phase involves equipment, infrastructure, manpower and management techniques focused on economic and environmental goals that are the essence of logistics for vinasse distribution. The primary and secondary transport can be made by road transport or pipeline, using fossil fuel or electric co-generation. These are systems using different physical operating principles which in turn have different energy efficiencies and require different investments according to the nature of the equipment involved. Storage of vinasse is done in strategic locations according to the areas scheduled for fertigation and considering primary and secondary transport infrastructure available together with the application infrastructure and the harvesting schedule, always keeping in focus the increase of the fertigated area.

Transport and distribution of vinasse

Vinasse transportation to the fields can be done by tank trucks, pipelines or a combination of both. Different energy consumption per unit of transport can be achieved depending on the transport principle involved. According to Menezes *et al.* (1984) the energy consumed by tank trucks is mainly associated with the rolling resistance of tires on the road. In the case of the pipelines, energy consumption is mainly associated to the friction between the particles along the pipe.

Transport by tanker trucks

The transport tanks attached to trucks or trailers have been used since first began the vinasse fertigation process at the mills. Tanks mounted on trailed or semi-trailer carts can operate in the mode “bate e volta” (non stop) allowing only for the trailers to remain parked in the field during the application with travelling irrigator reels or during discharge into storage tanks. The tanks currently available in the market can have different configurations with volume capacity in the range of 16 to 45 m^3, built in fiberglass with high resistance to corrosion, Figure 4. The rapid spread of the tanker trucks transportation system in the mills and distilleries throughout the country can be explained by the simplicity and versatility of the system. The truck is able to execute all the operations involved in the logistic of the vinasse distribution cycle, all the way from the collection at industry to the application on the fields.

The logistics of vinasse distribution performed entirely by truck has some limitations related to operating costs and soil compaction caused by vehicle traffic on ratoon crops. According to the characteristics of the areas of each company there is a maximum distance economically feasible for vinasse fertilization.

Pipeline transport

Pipelines may be buried or set apparent on the ground surface, or even elevated for crossing roads or waterways. Closed underground ducts allow large amounts of fluids to be transported safely, reducing surface traffic, and facilitating the movement of farm machinery and transport vehicles for sugarcane, inputs and residues.

According to Luz (2005) pipelines are operated by pumps using electric motors or diesel engines, plus a set of accessory components such as valves and bends. The author also highlights the concept of movable pipelines to work for fluid elevation and also to operate as sidelines for final application of vinasse on the soil. It avoids the need for perennial pipelines.

Fluid transportation using open channels still requires pipeline networks to raise the vinasse to higher elevation reservoirs, strategically located, from which it flows gravitationally through master channels to truck loading stations, or flows to secondary networks for application via travelling irrigator reels. Since each company has specific conditions, both topographical and operational, there is great variability in the patterns of the duct type distribution systems.

According to Luz (2005) vinasse transportation using open ducts is more economical than pipelines or road transport. Ditches or open ducts prevent the contact of vinasse with the pipe and hydraulic equipment, preventing wear and corrosion. On the other hand open ducts can have significant vinasse losses when operating in very permeable soils, reducing the potential for fertigation and generating environmental impact. This system may also result in loss of acreage if the road layout is not adequately designed to keep roads parallel to the channels. The use of ditches requires a specific study for the local conditions in order to have adequate implementation and operational conditions.

Coating channel walls improves performance in terms of vinasse losses and reduction of flow friction as surface roughness is improved. Regulations including criteria and procedures for application of vinasse on agricultural soils (Technical

FIGURE 4 Tank truck (a) transferring the load to a storage tank (b).

Standard P4.231 CETESB) were published in the state of São Paulo. They require that master or primary channels of distribution be sealed with waterproof geomembrane or other form of equal or greater effect.

Conjugate transportation

Transportation cost of vinasse by tanker trucks can be reduced using a conjugate system where part of the road is replaced by ditches. So, instead of a single truck loading station located near the plant, ditches are used to feed multiple stations strategically distributed in the field. This reduces the number of trucks and part of the fossil fuel is replaced by co-generated electricity.

Integrated transport of vinasse and sugarcane

Considering that empty trucks return to the cane fields flexible tanks can be used for vinasse transportation in the way back of the truck from industry to the field. Flexible tanks are pillow shaped and foldable on the bottom of the truck body when cane is being transported. After unloading the vinasse the flexible tank is wound at one end of the truck body leaving the whole volume free to receive whole or chopped sugarcane. Similarly, after unloading the cane at the mill the flexible tank is extended on the bottom of the truck body and is ready to receive the load of vinasse. That way the combined cost of transporting cane and vinasse is lower. The integrated transport of sugarcane and vinasse had successful experience in commercial applications, but it requires more complex logistics planning in order to reduce the impact of loading and unloading time on the transportation cost. The use of tractor trucks pushing trailed or semi-trailed tanks, operating in the “bate e volta” mode, with efficient teams and infrastructure makes vinasse economically feasible at longer application distances.

Storage tanks

The logistics of vinasse distribution demands temporary storage using tanks as illustrated in Figure 4b. The tanks allow for changes in the rate of field application or even some interruption for repositioning of equipment in the field or during periods of high precipitation or interruptions required to perform repair and maintenance of equipment. Current law requires the sealing of the reservoirs with geomembrane or other techniques of equal or greater effect and also inspection wells to monitor infiltration.

Application of vinasse

The main systems for vinasse application are infiltration furrows, tank trucks and spraying. The use of infiltration furrows is restricted by the need of areas with suitable topography, Silva (1992). Tanker trucks using gravitational or pumped unloading was the distribution system most widely used in the past. It is versatile and simple, with adequate uniformity of distribution; however, there is a limit to the maximum distance from the loading station to the application areas where it can economically operate.

Sprinkler distribution became a commercial option as the irrigation methods were improved. That is the case of the semi-fixed sprinkler that captures vinasse from ditches and pumps it into main or secondary pipelines on which sprinklers are attached. In the 1980s the hydraulic cannon become popular, called the direct assembly. It comprises a pump attached to a cannon type sprinkler that moves along the ditches pulled by tractor, (Orlando Filho *et al*., 1993; Luz 2005). Currently, in the State of São Paulo, a conjugate system comprising a ditch, a diesel engine pump and a reel spool become popular.

FILTER CAKE

Filter cake is a residue coming out of the process of sugar clarification. It is produced at the rate of 30 to 40 kg per ton of cane processed. It is an organic compound in 85% of its composition, rich in calcium, nitrogen, potassium and phosphorus which vary according to the cane being processed. The cake is used as a complement for mineral or fluid fertilizers. It can be applied in the form of wet cake in dosages ranging from 15 to 35 $t.ha^{-1}$, when applied into the planting furrows, or may be applied on cane ratoons in dosages ranging from 80 to 100 $t.ha^{-1}$ when broadcasted over the soil surface or at a rate of 40 to 60 $t.ha^{-1}$ when distributed in between the ratoon rows (Cortez *et al.*, 1992). The high biochemical oxygen demand of filter cake may turn it into a polluting source, so adequate controls are required during the processes of storage and application. Optimization of the planning and logistics of storage and distribution of filter cake allow to extend its benefits to areas located further away from the plant and may also avoid increasing levels of heavy metals that are not absorbed by the plant and tend to percolate at risk of groundwater contamination, Ramalho and Amaral (2001).

The agricultural use of filter cake involves operations of storage, mixing, drying, loading, unloading, transporting and distribution. These operations take place between the mill hopper and the final deposition on the ground. dump trucks or self loadable “roll on – roll off” buckets are used to receive the cake at the mill hopper and damp it down at a nearby area. Transportation cost of filter cake with high moisture content, using dump trucks with low capacity, force to locate storage areas close to the mill. The material stored in the area undergoes processes of fermentation and drying that can be natural or boosted using a mixer as illustrated in Figure 5. Composting organic material undergoes microbial action under aerobic conditions, leading to a stabilized product in which the compounds have undergone mineralization with reduction of the C/N ratio to around 10.

Source: Centro de Tecnologia Canavieira.

FIGURE 5 Self propelled mixer composting filter cake.

Composting filter cake with poultry litter, gypsum, boiler ashes and cane trash improves concentration of nutrients and reduces the moisture content, which economically enables transportation over longer distances.

Filter cake remains in storage areas until the planting season. Bucket loaders transfer the cake to dump trucks for transport to the planting areas. Trucks tip down the cake into sized piles at specific locations to cover the planting areas in accordance with the quantities to be applied. Fertilizing with filter cake in more remote areas requires higher capacity trucks most likely the movable floor type instead of dump trucks.

During the planting operation the cake is loaded into distributor wagons using front loaders. The cake wagons are specifically designed to distribute the cake at the bottom of two furrows simultaneously. The mass to be handled in the case of fertilization with filter cake is about 40 times higher than conventional chemical fertilizers; intense traffic of wagon and tractor wheels takes place at the planting furrows. Conventional planting procedure includes soil tillage, furrowing, cake distribution and seed distribution to finally perform the seed coverage and application of pre-emergence herbicides.

Although filter cake fertilization is economically feasible with present application technology, especially for planting, logistics of filter cake distribution still offers a good potential for a sustainability increase by reducing costs, soil compaction and environmental risks.

Cost reduction of agricultural handling for filter cake can also be obtained if the mass to be handled is reduced without changing the nutritional value of the cake. Natural drying in the field or moisture reduction in the manufacturing process as well as reduction in the amount of mineral impurities incorporated to the cane during harvesting are some of the potential actions to be taken to reduce the mass to be handled.

The composting process complements the cake with nutrients and promotes moisture reduction; in addition it produces a homogeneous composite material adequate for a more precise metering process when precision agriculture is being practiced.

The renewal of the sugarcane plantations takes place in different plots spread all over the fields of the mill. These areas have different soil type, soil fertility, application records of filter cake and vinasse, distance to the plant and amount of chemicals with pollution potential stored in the soil. The number of variables involved and the complexity of the interrelations between them demand models and criteria to make optimal decisions both economically and environmentally on where and how much cake or compost should be applied. It is worth noting that the areas closest to the plant allow for greater productivity through higher cost of fertilizer and cultivation due to lower transportation costs of the production.

FINAL CONSIDERATIONS

The logistics of vinasse distribution and filter cake varies greatly from case to case. Field topography determines a set of operations and equipment with varied performance, operating costs and investment costs that lead to specific management. The criteria involved in both the design and management stages require the use of modeling and computer simulation to make decisions that lead to results close to the optimum economical and environmental.

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