REFEREED PAPER

SUGARCANE LEAVES AND TOPS: THEIR CURRENT USE FOR ENERGY AND HURDLES TO BE OVERCOME, PARTICULARLY IN SOUTH AFRICA, FOR GREATER UTILISATION.

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Abstract

Sugarcane tops and leaves, which are becoming more available in the fields due to mechanical harvesting, could be an extra source for the sugarcane industry to produce more energy or alternative products in the form of electrical power using cogeneration, or as cellulosic ethanol. One ton of sugarcane, after harvesting, leaves a residue of around 140 kg of trash in the field. This amount of biomass has the same energy content of dry bagasse from the same ton of cane. However, the logistics of trash collection should be addressed before trash utilisation projects are developed. The experience in countries such as Brazil and India in recent years provides a good overview of trash collection and processing methods. In this paper, operational and capital costs, the type of agricultural machinery and factory equipment used, as well as obstacles to effective use of trash in agricultural and factory operations, are discussed. The authors also consider the obstacles, presented by the current situation in the South African sugar industry, which would require effective solutions to make extensive use of cane trash for energy purposes a reality.

Keywords: sugarcane, trash, baling, cost, renewable energy, harvesting, electricity generation, leaves, tops

Introduction

Sugar producers have to increase their revenue from sugarcane to survive because of increased international competition which has led to frequent low sugar prices on the world market, and competition from the alternative sweeteners market which affects the global consumption of sugar. One way to increase the returns, other than through sugar and molasses sales, is to exploit the energy potential of leaves and tops (LT). If used effectively, LT can generate electricity that has an escalating commercial value as a result of increasing energy costs.

However, utilisation of LT for energy purposes has its own challenges. The purpose of this paper is to give a realistic overview of current options for utilising the energy content of LT to generate further income and assist future decision-makers on the options likely to be most successful.

Effect of LT delivered to the mill together with the cane stalks

If cane is processed in the factory in its entirety i.e. with no effort made to remove the LT, the impacts on sugar extraction are:

- Reduced cane throughput, from 440 tons per hour when predominantly burnt and topped cane is processed to 330 tons per hour when cane that has been harvested green with adhering leaves but mostly tops removed, representing a reduction of 25 % during a factory trial at Sezela (Bernhardt et al., 2000);
- Reduced sucrose throughput (16.2 tons pol/hr for unburnt topped cane compared with 24.5 tons pol/hr for burnt topped cane), which represents a reduction of 34 %, and 13.5 tons pol/hr for cane with tops and LT, representing a 45 % reduction in sucrose throughput in comparison with processing burnt and topped cane (Reid and Lionnet 1989);
- Reduced earnings for the farmer. The cane payment formula, calculating recoverable value Recoverable Value (RV) used in South Africa (Wynne et al., 2009), corrects the sucrose content of the delivered cane by a negative factor linked to the amount of fibre in the cane;
- Increased bagasse production in the mill. Unburnt and topped cane i.e. cane with leaves attached but tops removed, has a bagasse % cane that is 46.5 and unburnt, untopped cane has a bagasse % cane of 48.3 in comparison to the 32.1 % for burnt, topped cane. This was tested at the Maidstone trials, representing relative increases of 45 % and 50 %, respectively (Reid and Lionnet 1989);
- Increased sucrose losses in final molasses from 9.5 % to 10.75 %, representing a 13 % increase in sucrose losses in the final molasses (Bernhardt et al., 2000); and
- Increased colour in the raw sugar produced from 1 300 to 1 600 ICUMSA units, representing an increase of 23 % (Bernhardt et al., 2000).

Background to the South African sugar industry

The harvesting of sugarcane in South Africa is mostly done by a manual labour force and, in some instances, by mechanical or chopper harvesters. In addition to manual harvesting techniques, sugarcane is also burnt prior to harvesting and there are two major reasons for this. The first is that the labour force is generally not interested in harvesting cane that is unburnt as it impacts on their productivity and thus the amount of money that they can earn. The cane cutter or farm worker who cuts cane is paid per ton of cane cut and stacked, with the average rate in the industry being around 3.48 tons per day. When green cane is harvested, the productivity is reduced significantly, with some sources estimating a reduction of up to 50 %. This means the worker would receive a lower income and the farmer would have to employ roughly two times the workforce to harvest the same amount of cane (Canegrowers, 2015). This payment system clearly does not take into account the value of the additional fibre from LT.

The other consideration for farmers when harvesting cane and deciding on green versus burnt cane is the impact that green cane will have on their remuneration. The South African sugar industry follows a complex cane payment system that is largely based on the ERC formula as developed by van Hengel (1974). The RV percentage in cane, which was introduced in the 2000/2001 season (Wynne et al., 2009), is calculated as follows:

$$RV\% = S - dN - cF$$

Where:

S = Sucrose % cane

N = Non-sucrose % cane

F = Fibre % cane

d, c = Factors – calculation details in (Wynne et al., 2009)

The impact of delivering additional LT, listed as F in the cane payment formula, to the mill is an important consideration for the farmer. This would impact on the fibre percentage in the RV price calculation and is perceived to have a negative impact on the RV percentage that the grower will achieve. The c factor is, however, extremely low at 0.02 and thus, multiplied by the fibre percentage in the grower's cane, actually has minimal impact on proceeds that the grower could receive (BFAP, 2014). Significant increases in LT delivery would, however, have significant impact on the payment to growers through the RV cane payment system. If significant quantities of LT were to be delivered to the factory the current South African payment system would need to be revised to reflect the value of the LT and thus compensate farmers for the increased costs of making LT available for energy or other purposes.

Benefits of green cane harvesting

There are economic benefits to be gained by leaving the trash and tops, or a portion thereof, on the field. These are related mostly to savings in fertiliser costs and conservation of soil health by returning organic material to the field, maintaining moisture levels in the soil, prevention of soil erosion, and potentially reduced Eldana levels due to healthier cane (Deepchand and Rao, 2012). These benefits have been extensively studied and reported on. This article will mention only some of the appropriate research and will not deal with the agronomic benefits of LT (Raison 1979, Van Antwerpen and Meyer 1996, Graham et al., 2000, Graham et al., 2001). It should, however, be noted that excessive volumes of LTLT pose problems and a fire risk, which the grower needs to take into consideration.

The milling process faces certain advantages when utilising unburnt cane, i.e. cane that has been harvested green, with LT removed, as it is generally lower in non-sucrose constituents (ethanol, glucose and fructose, and colour), especially if there is a delay between harvesting and delivery at the mill, as reported by Lionnet (1986), Cox and Sahadeo (1992) and Smith (1993).

A farmer intending to make some of the LT available to earn extra income from the sugarcane crop will have to decide how much and what portion of the LT will be left in the field. The authors of this paper recommend that if LT is to be utilised for energy purposes without losing the benefit of maintaining soil health, the tops should be left in the field because their nutritional value is superior to that of the dry leaves, and the leaves should be transported to the factory where they can be used to generate additional energy e.g. in the form of steam and/or electricity. In the case of mechanical harvesting, separating tops from leaves and collection of leaves would introduce additional complications.

LT characteristics, its uses and energy value

The biomass from sugarcane is a significant source of energy-rich material from which electricity can be generated (Hassuani, Leal et al. 2005)). Studies conducted by the Sugarcane Technology Center - CTC (Paes and Oliveira, 2005) for several varieties and cutting stages showed that the amount of LTis directly proportional to the amount of stalks in a ratio of 140 kg of LT, on a dry basis, for each ton of stalks, with the following distribution (Table 1):

Table 1. LT Distribution in the stalks

	(%) Wet Basis	(%) Dry Basis
Dry Leaves	71	81
Wet Leaves	24	17
Tops	5	2

Source: Paes and Oliveira (2005)

The energy of sugarcane is distributed as described in Table 2. The three main components extracted from stalks: juice (sugar or ethanol), fibres (bagasse), and leaves (LT) have the same level of energy content so currently only two-thirds of total energy potential is utilised.

Table 2. Sugarcane energy content

1 ton of stalks	Energy (MJ)
140 kg of sugar	2.340
280 kg of bagasse (50 % moisture)	2.110
280 kg of LT (50 % moisture)	2.110
Total	6.560

Source: CTC

Research in Mauritius (Prince and Gerard 2015) estimates that the energy content of LT, at 15 % moisture, is 3 600 kWh/ton (1.3 x 10^{10}J) while one ton of coal has an energy value of 3 x 10^{10}J (Energy Content of fuels, 2016). In a number of countries, LT are being used as a boiler fuel and it is estimated that every ton of LT that is baled has the potential to replace roughly one ton of mill wet bagasse as a fuel (Deepchand and Rao, 2012).

There are other potential products, such as furfural, pulp and paper, alcohol, chemicals and textiles that can be made from LT (Deepchand and Rao, 2012) but the authors felt that they could not adequately describe their exploitation in this paper.

LT Collection Methods

In Brazil, two different methods for LT collection are currently used. Both strategies are very recent and they involve a change from traditional harvesting methods. However, no method is superior as both strategies can be suitable, depending on the condition and design of the sugar mill. According to Pierossi and Fagundes (2016), the two methods are:

- A partial cleaning harvesting system where LT is harvested, chopped and transported together with the sugarcane billets without laying it down on the ground; and
- A baling system where LT is removed from stalks after harvesting and remains in the field for seven to 10 days to decrease moisture and is then collected by several agricultural operations. Figure 1 shows the operations for both systems considering different levels of vegetal impurities.

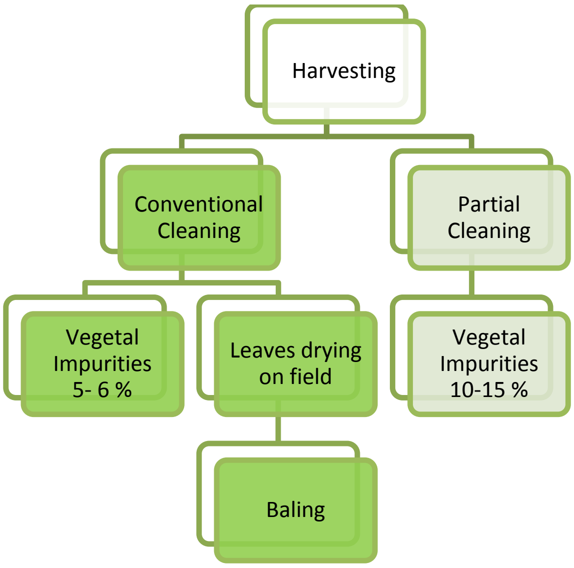

Figure 1. Methods for collection LT from sugarcane.

Sugarcane mechanical harvesting is based on separation of leaves and tops from stalks by using air flow. The stalks are chopped and transferred to the truck as billets and the LT are removed and remain on the ground. It is, however, common to have vegetal impurity levels around five to 6 % in transit.

The most important benefit from a Dry Cleaning Station is better quality on sugarcane because studies conducted by Kent (2007) showed that removing LT from the crushing process can bring benefits to sugar production. According his results, each 1 % increase in vegetal impurities has the following impacts:

- 2,3 % decrease in crushing capacity;
- 0,1 % decrease in extraction;
- 0,3 unit decrease in juice purity; and
- 0,1 % increase in bagasse moisture.

With the development of Dry Cleaning Stations, which are equipment designed with the main purpose of separating vegetal impurities (LT) and mineral impurities (soil) from the cane at the mill before cane crushing, sugar mills started to decrease the cleaning capacity of mechanical harvesters by reducing extractor speeds and transporting a higher level of vegetal impurities with cane billets. This made it possible to deliver higher amounts of LT (10 to 15% vegetal impurities) to be separated at the dry cleaning station where the LT was separated from the billets through ventilation.

The main feature of the partial cleaning system is the low impact on the daily operations at the mill. The density, however, is negatively impacted on by the increase in vegetal impurity content representing an important factor in the composition of costs of this operation. Studies conducted by Marchi et al (2005) showed that density in transit was reduced by as much as 35 % when vegetal impurities increased from 5 % to 15 %.

Another aspect that must be considered is LT moisture as the systems need to be compared on a dry basis due to high variations in moisture content. In the partial cleaning system, LT has a moisture level around 35 to 40 % while in the baled system LT moisture level is approximately 15 %.

The baling system described here uses large square balers with each bale typically weighing 450 kg with dimensions of 0,9 x 1,2 x 2,4m. Baling is performed from four to seven days after harvesting to ensure that the LT moisture will decrease from around 35 % - 40 % to 15 %, which is the optimal moisture content for baling. The operations involved in baling are described in Figure 2 and must be performed in this sequence:

Figure 2. Baling System

During the baling process, the first operation is windrowing which is performed when LT achieves a moisture content of 15 % and is conducted by using a wheel rake, grouping LT in triangular windrows and enabling a uniform feeding system for balers. This also reduces the number of passes required to collect the product. The typical width is 7.5 m. The way it is conducted affects the amount of mineral impurities (soil) added to the bale and the operational performance of the baler.

There are two different types of balers; rectangular and round balers, but on sugarcane applications, rectangular balers (Figure 3) are more suitable because of bale density and the amount of LT. The baler collects the LT contained in the windrow, compressing it into rectangular bales tied with longitudinal strings and then the bales are deposited automatically onto the ground as they are produced.

Courtesy: New Holland Latin America

Figure 3. Rectangular baler in operation.

Several types of equipment can perform the bale collection and the most efficient is the automatic bale wagon that collects bales continuously and groups them into piles along the roads to avoid truck traffic on the field. Bales are loaded into a truck using a forklift mounted on a tractor, or a telehandler, and are then transported to the factory.

The costs of baling LT depends largely on the set-up that the grower chooses for this operation. The set-up can be as simple as employing labour to gather the material but this is both time-consuming and inefficient. In order to optimise the cost of harvesting and transporting LT, the material has to be bulked up and compressed. The requirements for such a set-up include in-field gathering of material by a trailer and a hay rake combination. The material would then be baled, which requires a tractor towing a baler. Transporting the bales from the field to a loading zone would typically require a forklift or bell loader to be employed. Transport from the field to the processing plant would also incur an additional cost if this was done separately. The total cost in South Africa to run this equipment is estimated at R293 per ton. This cost of harvesting and transporting alone is expensive as the farmer will have to make a return on this (Canegrowers, 2016).

Factory Processing and Storage

The two baling systems have different characteristics and thus the processing unit in the industry performs different operations. The LT bales must be unloaded and twine must be removed, debaled, screened and shredded to be used in the boiler. The sequence of required operations is shown in Figure 4 but there are facilities that do not have all the operations and Figure 5 shows a bale processing facility in Brazil.

Figure 4. Bale processing operations

Courtesy: Fragmaq Indústria de Máquinas - Brazil

Figure 5. Bale processing facility in Brazil

These facilities were recently introduced in the Brazilian sugarcane industry and the first facilities were based on mobile shredders and partial systems with low performance. In recent years, the industry has improved in size and performance with very efficient systems to handle large amounts of bales (70 to 100 k t/year).

Bale unloading is the first operation and its technology depends on the scale of production. The system can be simple with loaders mounted on tractors, or sophisticated with automatic cranes fitted with load and moisture sensors.

Twine removal is very important especially in large-scale projects as one ton of bale requires 450 g of twine, which means that in a 100 000 ton bale operation 45 tons of twine will have to be handled per year. The equipment used in twine removal is very simple and easy to operate.

Debaling and shredding could be performed as two continuous operations, but once shredding has been completed it is not possible to clean the LT in the screening process as the particle size will be small and most of the biomass will be carried with soil through the rotating screens.

Screening is very important to remove the high level of mineral content on bales and must be performed after debaling. The use of rotating screens makes it possible to achieve a high efficiency in soil removal.

The dry cleaning station was designed to clean chopped sugarcane and the operations include LT separation from the billets, the screening and the shredding processes. There are several different projects with a large range of efficiencies and variation in performance during day and weather conditions and separated LT with variation of moisture.

The best solution for most of the sugar mills is an integrated set-up with both systems due to the better quality on cane billets as a result of the removal of vegetal impurities and the utilisation of LT from both routes, resulting in the complete utilisation of sugarcane LT.

The storing of bales can be arranged in stacks and this demands a lower area in comparison to LT from the partial cleaning system but, due to the lower moisture content, it is necessary to ensure that safety precautions are implemented due to a risk of fires. In both systems, it is better to use LT in a real time strategy and to avoid any storage thereof.

Situation in Brazil, Mauritius, South Africa and India

In Brazil, sugarcane is now the second most important primary source of energy after oil (Leal 2015). There has been a gradual increase in the electrical power supplied to the grid by sugar mills in Brazil from 1.1 TWh in 2005 to 19.4 TWh in 2014 (Leal, 2015). Much of this increase has been made possible by a shift from low pressure (10 – 22 bar) to high pressure (45 – 65 bar) boilers, with bagasse as the main feedstock. Currently, 177 out of a total of 355 sugar mills in Brazil supply electrical energy (19 TWh) to the grid, representing 4 % of the total consumption. If the availability of LT is to be taken into account, this has the potential to increase to 129 TWh (27 % of the total consumption).

At present, the US$ 70 m SUCRE Project (Leal 2015) is being conducted by the Brazil Bioethanol Science and Technology Laboratory (CTBE) to gather data on the economic viability to utilise LT for electricity generation. Three to four sugar mills will participate in this project to ensure that the data gathered represents commercial reality, and to solve current technical, information, regulatory and financial barriers. This project is partly sponsored by the Global Environment Facility GEF (US$ 7.8 m), CTBE (US$ 3.8 m) and significantly by the participating mills (US$ 55.8 m).

In Mauritius, the use of fibre from sugarcane for electricity was stimulated by targeted programmes such as the Bagasse Energy Development Programme (BEDP) of 1991 (Autrey, 2015). The major partners were the government, the World Bank and the local sugar mills. This programme resulted in the building of new power plants, upgrading existing ones, improving appropriate technology, and conclusion of favourable financial agreements and pricing structures. It included a tax rebate on electricity generated from bagasse as well as a refund of export duty on sugar for the installation of energy-efficient equipment. As a result of these incentives, the first state of the art co-generation plant, TerraGen, was built in 1998 using an 82 bar boiler. A second similar modern co-generation plant, La Baroque, was completed in 2007. At present, 26 % of the electricity generated in Mauritius is from bagasse (Autrey, Leal et al. 2016). The government has set a target of 35 % of the power in Mauritius to be from renewable sources, which includes LT, by 2025. Currently, a joint project between Omnicane and TerraGen to investigate the potential of cane LT for electricity generation is underway. It is reported (Prince and Gerard 2015) that 10 tons LT per hectare of sugarcane from mechanically harvested fields can be obtained. The LT supplements bagasse and the surplus energy is sold to the grid.

In India, LT balers have been developed. The Indian balers have the ability to bale the LT, approximately eight to 10 tons of material, from a hectare in three to four hours. A government initiative, the India New Climate Action Plan (Chandramouli, Sundara Raman et al. 2015), aims to avoid all in-field burning of cane to reduce Greenhouse Gas Emissions and to utilise the available LT for energy generation.

In South Africa, research is currently being conducted to develop a burner that can burn off the leaves from cane stalks and chopper harvested billets thus eliminating the need to collect LT separately in the field (Bernhardt 2015). The idea is to transport the LT adhering to the stalks/billets to the factory and burn the leaves in a controlled manner in the burner without damaging the sucrose in the cane, performing the same function as in-field burning. The energy captured is to be used for steam generation which can be used to generate electricity.

Hurdles

There are a number of hurdles that need to be addressed in order to make the utilisation of LT for energy purposes a viable source of revenue. This is largely due to the complex nature of handling the LT and the complications and negative impacts that come along with increased compaction in the field as well as increased traffic flow. The major hurdles can be classified as follows:

Institutional hurdles

- The investment required to provide the connection to the grid, particularly if this has to be borne by the sugar company, which could make it extremely expensive (Leal, 2015).
- The current electricity tariffs make investment in technology that uses LT as an energy source risky.

Technical hurdles

- The technology necessary to collect, bale, transport and process LT is expensive. Furthermore, the collecting equipment will exacerbate soil compaction.
- In countries such as South Africa, where harvesting is mainly done by hand, separate collection of LT is becoming a labour issue.
- Adaptation of feeding systems into the milling process is necessary as existing boilers are designed to process bagasse only.

- The technology to remove LT from cane at the factory is likely to generate a lot of dust and would require storage facilities.
- Storage of LT to provide year-round operation may not be viable.

Information hurdle

- The information available at present is insufficient to accurately predict total investment required and realisable financial returns.

Conclusions

LT is a very valuable source of energy and, potentially, an even more important source of fibre. This is becoming more relevant as consumers demand sources of green and renewable energy. Cane tops and leaves can offer this solution and this paper has explored different methods and strategies that can be employed to achieve this goal. In addition, the utilisation of LT for energy purposes is a strategic issue for sugarcane industries, not only from an environmental perspective, but also in terms of protecting the industry from economic decline, and expanding the industry as a major employer of people.

However, it needs to be understood that there are a number of hurdles that need to be overcome to make the utilisation of LT for electricity generation an economically viable option. One of these hurdles is the introduction of appropriate electricity tariffs, tax incentives, investment options and technology development as these appear to be the major factors that need to be achieved in order to bring about an advancement in this important source of renewable energy. Projects that focus on gathering the necessary information in sugar-producing countries to overcome the obstacles peculiar to each country are needed to gain appropriate experience and expertise. Such projects need to deal with the cost of transporting LT as this is the biggest challenge to any operation as the material is extremely bulky and expensive to harvest and transport. It is thus thought that the best way of transporting LT will be for the green cane to go directly to the mill and be separated there. This would reduce the grower's payload by 30 % and increase costs accordingly, but it avoids the use of expensive additional technology to collect, transport, store and then process the LT at the mill.

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