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Sugarcane straw availability, quality, recovery and energy use: A literature review

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ABSTRACT

Sugarcane straw represents, under Brazilian conditions, approximately one third of the total primary energy of sugarcane in the field. Today, its use for energy is incipient and it is mostly wasted by either burning in the pre-harvest or left on the ground to decay. Besides its potential use as feedstock for energy production, there are several possible agronomic benefits of the straw blanket left on the ground such as soil protection against erosion, increase of soil organic carbon content, inhibition of weed growth, nutrient recycling and reduction of soil water losses, to name a few. The balance of the impacts and the economic and energetic value of the straw indicate that the amount of the straw left on the ground that could be considered optimal is dependent on the local conditions, agricultural practices, characteristics of the straw and intended final use. This work is meant to shed some light into this subject to help the understanding of the importance of the various impacts of the straw blanket on the ground, the availability and quality of the straw, the economics of straw recovery and use and the main criteria for determining the amount of straw that can be recovered for bioenergy or biofuels production.

1. Introduction

Sugarcane has been cultivated for centuries and sugar production has driven the several world breeding programs that resulted in the so called noble cane varieties in commercial use today. Initially, sugar was a high value specialty but has long ago become one of the cheapest food calories due to the drastic reduction in production cost. Sugarcane is not only a high yield food crop, but has demonstrated to be also an excellent energy feedstock due to its high primary energy content per Mg of cane. The higher heating value (HHV) of whole sugarcane (including 140 kg of straw, dry basis) is 7.4 GJ per Mg of cane stalks (with 70% moisture content), based on the average Brazilian cane quality. The energy products ethanol and bagasse, however, represent only 2.2 GJ Mg^{-1} or less than 30% of the primary energy [1]. Bagasse (the industrial fibrous residue from the juice extraction) is practically all consumed in the mill boilers to provide for the mill energy demand, and the fiber in the sugarcane leaves and tops (straw, also known as trash) is normally burned in the pre-harvest.

The practice of burning the sugarcane residues to facilitate harvest and transport operations has been widespread worldwide to reduce the cost of harvesting sugarcane, especially in non-mechanized operations (i.e. manual harvesting).

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Due to environmental, agronomic and economic reasons, the manual harvest of sugarcane has been gradually replaced by mechanical operations with maintenance of the dry leaves and tops (straw) on the ground, in a system called green cane management.

In Brazil there is a federal law establishing a time schedule for phasing out cane burning, i.e. 2018 in the areas where mechanical harvesting is possible with the current technology (slopes less than 12%) and non-defined date for ending cane burning in other areas. However, in São Paulo and Minas Gerais States, responsible for around two thirds of the sugarcane produced in Brazil, an Agro-environmental Protocol has been signed by all stakeholders of the sugarcane production chain establishing, among other issues, an anticipation of the end of sugarcane burning to 2014 in the mechanizable areas and to 2018 elsewhere.

The green management of sugarcane includes the deposition of large amounts of plant litter on the soil after each harvest, ranging from 10 to 20 Mg of dry matter per ha with a carbon (C) to nitrogen (N) ratio close to 100. The mulch formed influences the whole production process of sugarcane, including yields, fertilizer management, weed control, soil erosion and soil organic matter dynamics. The effects of keeping sugarcane straw on the soil have been studied with focus on root growth and turnover [2], soil nitrogen dynamics [3], soil erosion [4], soil temperature and water content [5], soil bulk density [6], soil aggregate stability [7] and soil carbon stocks [8].

There is an increasing amount of lignocellulosic material being left on the ground that could be partially recovered and used for energy purpose in the mills, thus improving the overall energy balance. However, more knowledge is needed on the quantification of the impacts on agriculture, the amount of straw available after the harvest, the decomposition rates, collection costs and, consequently, how much should be left in the field to optimize the sustainability of the sugarcane cultivation and processing.

The main objective of this paper is to gather information from the literature assessing the different impacts of leaving straw on the soil, considering the potential use in the industry as a supplement to bagasse and environmental and economic benefits – and also problems – in the agricultural area.

2. Sugarcane straw traits

2.1. *Straw availability and quality*

The first point to be investigated is the amount of residues on the standing crop and what is left on the ground after green cane harvesting. There is a wide variation on the data presented in the literature and sometimes the information presented does not allow a full comparison due to lack of details on the methodology, sugarcane varieties, yield and straw moisture content. Hassuani et al. [9] summarized the results of a seven-year project covering several aspects of sugarcane straw availability, quality, recovery routes and related costs, agronomic impacts, environmental impacts and final use for power generation in advanced systems (Biomass Integrated Gasification/Gas Turbine). The authors reported the straw availability for three different sugarcane varieties in three different ages (1st, 3rd and 5th harvest), in two different regions in the São Paulo State, with and without vinasse[1] application. The main results are summarized in Table 1.

In the reported cases the amount of straw varied from 10 to 18 Mg ha^{-1}, dry basis, and the straw (db) to stalk (wet basis) ratio was in the 11%–17% range. A literature survey indicated straw yields in the 7.4–24.3 Mg ha^{-1} (db) range, and straw to stalk ratio ranging from 9.7% to 29.5%. The averages were respectively 14.1 Mg ha^{-1} and 18.2% [9]. In potential assessments, it is normally accepted a range of 14%–18% of the straw to stalk ratio. Clearly, the total amount of straw available is highly dependent on the sugarcane yield.

With respect to straw characteristics, it is important to focus on the two most promising uses: fuel for power generation and feedstock for second generation biofuels. For the first case, it is mandatory to know the proximate and ultimate analyzes as well as the ultimate mineral analysis; the comparison with bagasse is important, since straw and bagasse can be burned in the same type of equipment, either mixed or separated. Tables 2–4 present these analyzes for the three main components of straw: dry leaves, green leaves and tops. This separation is made because these components have different characteristics and the participation of each one in the final composition of the recovered straw depends on the collection method and harvesting procedure (e.g., the tops may or may not be chopped off by the harvester). In the field experiments conducted, the average participation was 62%, 31% and 7% for dry leaves, green leaves and tops, respectively (dry basis).

It can be seen from Tables 2 and 3 that the three components of the straw and bagasse present similar results, except for the moisture content, meaning that the bagasse fired boiler could very possibly be used for straw burning in terms of combustion chamber design. On the other hand, the higher chlorine content, especially in the tops, may be a cause of corrosion in the boilers. However, there are important differences in the ultimate mineral analysis as shown in Table 4.

The most important differences among the straw components and bagasse are: the much higher potassium content in the straw, mainly in the tops, could cause deposits on the hot surfaces, corrosion and slagging of the ashes; the levels of calcium and magnesium in the straw, although higher than in bagasse, are not expected to cause problems in the boilers.

2.2. *Straw recovery and final use*

Despite the large energy potential associated with the sugarcane straw, very little efforts have been made so far to establish an appropriate collection route to harness such potential. Similarly to corn stover in the US [10], for sugarcane straw to become a reality for large biorefineries, innovations are needed between the field and delivery to the processors in the areas of collection, storage and transportation. As the attention has been mostly towards the harvesting of the cane stalks, it is still not clear for the industry the best way to collect the straw for energy applications. During the 1990's, the former Copersucar Technology Center (CTC) performed a set of field tests to evaluate some proposed unburned cane

[1] Vinasse is the liquid residue produced in ethanol distillation. In Brazil, it is usually recycled to the cane field as fertilizer.