SUCRE
Sugarcane Renewable Electricity

GUIDELINES FOR SUGARCANE

STRAW REMOVAL TO PRODUCE ELECTRICITY

Renewable energy in Brazil comprises 43.5% of the energy matrix, in which 17.4% is derived from sugarcane (EPE, 2019). Together with bioethanol, sugarcane lignocellulosic biomass (bagasse and straw) is an important raw material for bioenergy production. Currently, the sugar-energy industry produces bioelectricity mainly from sugarcane bagasse, however, as industrial technologies become more advanced, the interest in using sugarcane straw is increased.

This has created a trade-off associated with straw use and leading several questions such as: How much sugarcane straw is available for bioelectricity production? Is it possible to remove straw without compromising soil conservation? What are the impacts of straw removal on soil greenhouse gas (GHG) emissions, soil quality and sugarcane yield? When and where is suitable to remove straw? These questions motivated SUCRE (Sugarcane Renewable Electricity) Project team to develop a **Guideline for strategic sugarcane straw removal to produce bioelectricity**. This Guideline covers the region of South-Central Brazil, which represents 92% of the sugarcane area in the country (CONAB, 2019). This issue paper describes the scientific knowledge obtained over more than five years of studies, and suggests strategies for sugarcane straw removal.

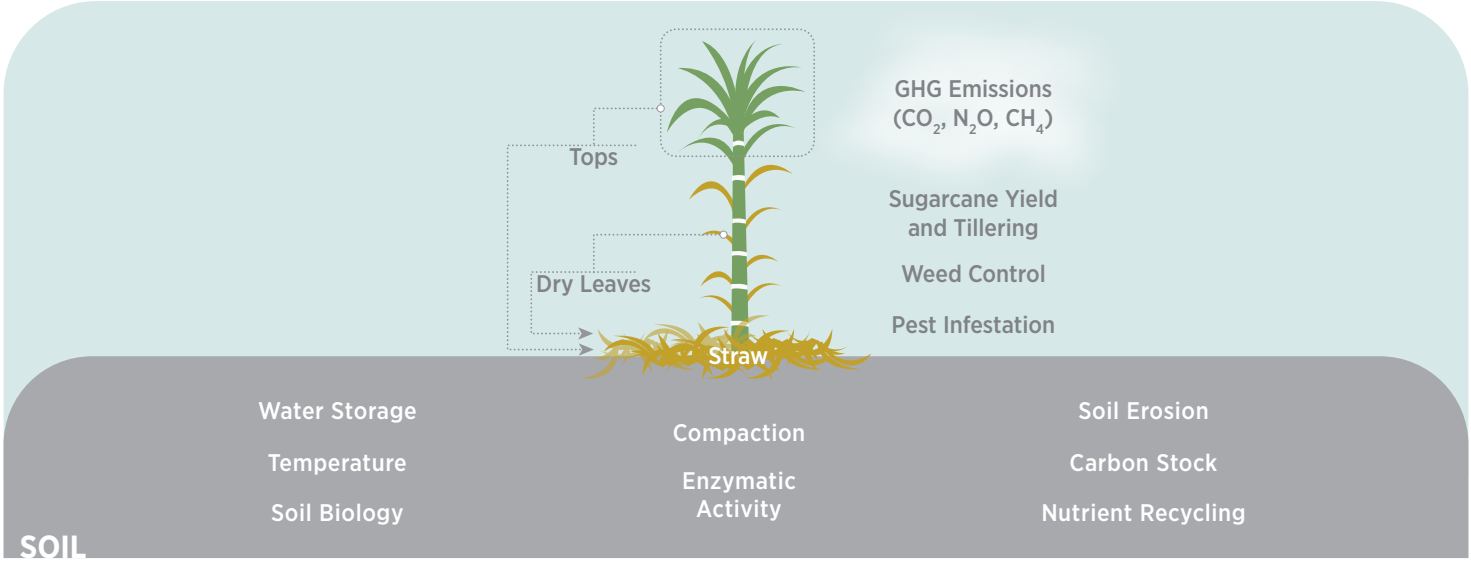
Knowledge background. Many information was needed to create this Guidelines. The methodology initiated with a broad study aiming to characterize straw, composed by tops and dry leaves, in the main areas under sugarcane production. The study showed that tops and dry leaves differ in their potential for nutrients recycling and for second-generation ethanol and bioelectricity production (Menandro et al., 2017). Due to these differences, tops are more recommended to be kept in the field while the dry leaves should be preferred for removal. In addition, this study showed the productive potential of 120 kg of straw (dry basis) per ton of stalks (wet basis). So, a ratio of 12% can be used to estimate straw production in sugarcane fields of South-Central Brazil.

In parallel, a major literature review on the impacts of straw removal on soil quality, GHG emissions and biomass production of sugarcane was performed (Carvalho et al., 2017). Overall, the literature information was more qualitative and was not enough to establish the amount of straw liable to be removed without compromising soil health and sugarcane yields. Based on this statement, SUCRE Project team established a broad experimental scheme in South-Central Brazil. For five years, SUCRE's team conducted 26 field experiments and collected thousands of samples of soil, plant, water and gases. The experimental results, together with literature data, showed that the maintenance of straw on the field is associated with several ecosystem services, and then its removal could provide changes in nutrient cycling, soil water storage, soil temperature, erosion control, soil biological activities, soil carbon stocks, soil compaction, GHG emissions, pest population, weed control as well as sugarcane yield (Bordonal et al., 2018; Gonzaga et al., 2018,2019; Castioni et al., 2018,2019; Castro et al., 2019; Carvalho et al. 2017, 2019; Corrêa et al., 2019; Menandro et al., 2019; Tenelli et al., 2019).

The main conclusions of these studies suggested that the impacts of straw removal are site-specific, mainly dependent on climate conditions, soil types, crop management and the amount of straw produced. Since climatic conditions are a major factor in the responses to straw removal, the definition of an agroclimatic zoning of straw removal was also done. A climatological database was used for each of the 3,304 points comprised by Brazil's South-Central region and by applying specialist's opinion in a multicriteria assessment. It was assumed that straw removal effects on sugarcane yields are driven by minimum temperature, solar radiation and precipitation. This spatial climate analysis allowed the creation of a map with suitability classification of straw removal (Hernandes et al., 2019).

Once there is not a unique and simple recommendation for a sustainable straw removal, SUCRE developed this Guidelines by creating a decision-making tool and a step-by-step procedure that guide the decision makers to perform a strategic sugarcane straw removal to produce bioelectricity.

Sugarcane straw removal strategies. Based on the knowledge background, specialist's opinion and on agroclimatic zoning,



principles for straw removal were defined. These principles were the basis of a decision-making tool developed in a structured hierarchical way considering the soil erosion risk and the impacts on sugarcane yield.

Overall, nine principles were defined and subdivided into four categories: excluding factors, climatic suitability factors, restrictive factors and responsive factors. The excluding factors were defined by the sugarcane cycle stage and the efficiency of the straw mulch on soil conservation after soil tillage practices, such as: (i) replanting area and (ii) soil tillage. The climatic suitability was defined considering the agroclimatic zoning of straw removal in order to classify areas according to their (iii) suitability for straw removal and (iv) solar radiation incidence. The restrictive factors are those that limit straw removal due to impacts on soil conservation (i.e., soil erosion risk) composed by (v) soil slope and (vi) minimum amount of straw on soil surface. Lastly, responsive factors are those that could be favorable or not for straw removal due responses of sugarcane yield and soil conservation related to (vii) harvesting season (viii) soil texture and (ix) water availability (i.e., soils naturally with excess of water or complementation through irrigation management).

The application of these nine principles covers a decision-making tool based on a hierarchical logic that the first level defines the priority areas for straw removal. As the hierarchy moves down, it is possible to define the immediate level in meaningful terms of the decision making. At the end of each follow-up, it is possible to classify the sugarcane fields into three categories: "suitable", "restricted to 7 Mg ha^{-1}" or "unsuitable" to straw removal.

"Suitable" areas are those where the set of factors do not significantly affect soil conservation and there are no negative impacts or even gains in sugarcane yield under straw removal. Such areas are those subject for soil tillage practices, areas without water restriction (soil naturally with excess of water or areas under irrigation) or areas in regions with high climatic suitability to straw removal. Areas "restricted to 7 Mg ha^{-1}" are normally those where straw removal would not negatively impact sugarcane yield, but straw plays an important role in soil conservation. Finally, the "unsuitable" areas are those where straw removal can promote significant sugarcane yield losses. Such areas were located in regions with low climatic suitability to straw removal and straw mulch on soil surface will benefit sugarcane yield. This decision--making tool is the "backbone" for step-by-step strategies for sugarcane straw removal. The first version of the decision-making tool can be found in Menandro et al., 2020.

From farms database to visual maps: step-by-step for strategic straw removal. This Guideline for sugarcane straw removal is structured in five steps and the final result will indicate "how much" straw is available and "when", "where" is recommended to remove sugarcane straw at local level. The first step (I) is to organize information about sugarcane cultivated areas. Basic information, such as soil slope, soil texture, harvest date, cycle stage, irrigation and sugarcane yield are usually composing the farms database with the information needed. The second step (II) is the estimation of total straw production using a ratio of 12%. After that, areas are submitted to hierarchical-key using the decision-making tool (III) to define if it is suitable, restricted or unsuitable for straw removal. To facilitate the application of these three steps, a digital tool was developed by SUCRE Project which automatically classifies sugarcane fields. This tool is open for users and available upon request in SUCRE's page at LNBR website. With the definition of the straw removal suitability, a potential map (IV) can be obtained. This step consists of using the digital tool aligned with GIS techniques and produce visual maps of the cultivated area. A tutorial for using the digital tool and elaborated visual map is available in SUCRE's webpage. Finally, specific conditions such as pest infestation, impacts on soil quality, operational viability of straw removal and climate adversities, can certainly influence users on the decision-making. Therefore, specific adaptations (V) must be considered by the decision maker and new straw removal scenarios can be obtained at local level.

In summary, this pioneering Guideline improves the information accuracy of the amount of straw produced in the sugarcane areas, "how much" straw is available for removal and "where" and "when" removing sugarcane straw. This Guidelines is a great advantage over the previous standard recommendation and can allow a most efficient use of this biomass, helping to meet the trade-off between bioelectricity production and suitable sugarcane production system.

STEP-BY-STEP FOR STRATEGIC SUGARCANE STRAW REMOVAL

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