Industrial Crops & Products 111 (2018) 794–806

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Original research paper

Sugarcane straw removal effects on plant growth and stalk yield

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A R T I C L E I N F O

Keywords:
Crop residue management
Bioenergy production
Harvesting season
Plant responses
Sugarcane

A B S T R A C T

There is growing interest in sugarcane straw removal from the field to use as raw material for bioenergy production. In contrast, sugarcane straw removal may have negative implications for many soil ecosystem services and subsequent plant growth. A two-year experiment was conducted at Bom Retiro and Univalem mills within the dry and wet seasons for assessing the impact of straw rates removal on plant production. The experimental design was randomized blocks with five treatments proportional to 0, 25, 50, 75 and 100% of straw removal. Plant parameters evaluated included: tillering, phytomass accumulation, stalk yield and stalk industrial quality. Straw removal increased plant tillering at Bom Retiro mill in both seasons and within dry season at Univalem mill, however the plant population at the end of each ratoon cycle was not affected by straw management. Phytomass yield across each ratoon cycle was fit to a sigmoidal model ($R^2 \geq 0.92$, $p < 0.05$). Time necessary for plant completes its lag-phase is higher at the treatments applied in the dry season, whereas there was no time-pattern for plants to complete the linear and stationary growth phases. Moderate amounts of straw: 4–9 Mg ha^{-1} (dry base) on soil surface enhanced stalk yield. Different rates of straw removal did not affect stalk industrial quality. Overall, partial straw removal, at least in the short-term, could be a win–win situation, sustaining sugarcane yields and providing feedstock for bioelectricity cogeneration and/or 2G-ethanol production.

1. Introduction

Brazil is the world's largest sugarcane producer, with 8.8 Mha cultivated and an estimated production of 648 million Mg of stalks and 26.4 billion L of ethanol in the 2017/2018 cropping season (Companhia NacionaldeAbastecimento e Conab, 2017). During sugarcane mechanical harvest, an average of 15 Mg ha^{-1} dry mass of straw (*i.e.*, a mix of dry and green leaves) remains in the field (Landell et al., 2013). Sugarcane straw presents high heating value (Menandro et al., 2017) and accounts for about 30% of total energy potential of aboveground biomass of the crop (Santos et al., 2012). Therefore, sugarcane straw can be an important feedstock for bioenergy production (*i.e.,* bioelectricity and second-generation ethanol) (Khatiwada et al., 2016; Lisboa et al., 2017; Menandro et al., 2017). Consequently, there is growing interest within the sugarcane industry to remove straw from the field for other uses.

In contrast, sugarcane straw removal may have negative implications on many soil ecosystem services (Cantarella et al., 2013; Carvalho et al., 2016; Cherubin et al., 2017). Several studies have shown the benefits of straw retention including: carbon accumulation (Cerri et al., 2011; Galdos et al., 2017), nutrient cycling (Fortes et al., 2013; Galdos et al., 2017), water storage and infiltration (Cheong and Teeluck, 2016; Valim et al., 2016; Nxumalo et al., 2017), protection against soil erosion (Valim et al., 2016) and biological activity (Paredes Junior et al., 2015).

Based on available literature, Carvalho et al. (2016) suggested that at least 7 Mg ha^{-1} of sugarcane straw should remain in the field to avoid reducing sugarcane yield and increasing environmental degradation. According to de Aquino et al. (2017), the maintenance of 10 Mg ha^{-1} of sugarcane straw was enough to sustain plant growth and yield in an Oxisol. In the same soil type, de Oliveira et al. (2016) observed the highest stalk yields under 9.6 and 4.7 Mg ha^{-1} of straw retained for the cane-plant and first ratoon cycles, respectively. Variation in the minimum amount of sugarcane straw needed to sustain soil and plant yields likely depends on soil type, crop management, topography and climate conditions (Marin et al., 2014; Seebaluck and Leal, 2015; Carvalho et al., 2016; Cherubin et al., 2017; Galdos et al., 2017). Thus,

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https://doi.org/10.1016/j.indcrop.2017.11.049
Received 22 July 2017; Received in revised form 18 November 2017; Accepted 27 November 2017
0926-6690/

the sustainable sugarcane straw retention rate still needs to be experimentally determined (Carvalho et al., 2017) over a range of conditions. Further studies are also necessary to better understand potential trade-offs between retaining sugarcane straw in the field to enhance soil quality or removing straw for use as a feedstock for meeting bioenergy demands (Menandro et al., 2017).

Recent studies have begun quantifying sugarcane straw removal effects on plant growth, yield (de Aquino et al., 2017; de Oliveira et al., 2016) and industrial quality (de Aquino et al., 2016). Additional studies that encompass contrasting soil, growing season conditions, and harvesting seasons (*e.g.*, dry and wet season) are still necessary to better understand the agronomic impacts of straw removal on sugarcane yield. In this context, we conducted a two year experiment (two sites and two harvesting seasons) within the main sugarcane-producing region in Brazil (*i.e.*, central-southern) for assessing the impact of five rates of straw removal on plant tillering, growth, stalk yield and industrial quality of stalk. The hypothesis tested was that sugarcane straw can be partially or integrally removed for bioenergy production without impairing sugarcane yields. Moreover, the optimum straw removal rate is the same in both edaphoclimatic condition and harvesting season.

2. Materials and methods

2.1. Study sites

The field experiment was conducted at two sites within southeastern Brazil that represents typical producing-areas of sugarcane. These areas are located in São Paulo state, near Capivari at Bom Retiro mill (Lat. 22°59′42″ S; Long. 47°30′34″ W) and near Valparaiso at Univalem mill (Lat. 21°14′48″ S; Long. 50°47′04″ W) (Fig. 1).

Within each study site, treatments were applied during the dry and wet seasons and maintained for two years. At both sites, sugarcane was planted in February/2013 and the treatments were applied after cane-plant (first cycle) harvesting in 2014. The timeline of the experiments is shown in Fig. 2.

Sugarcane varieties CTC 14 and RB 867515 were cultivated in Bom Retiro and Univalem mill, respectively. At both sites, sugarcane was planted using an alternating double row spacing of 1.5 and 0.9 m within the same area.

The regional climate for the Bom Retiro site is humid subtropical – Cwa type (Köppen classification) characterized by dry winter and hot summer, with a mean annual temperature of 21.8 °C and annual precipitation of 1289 mm (Fig. 3A). At the Univalem site, the climate is tropical – Aw type, characterized by dry winter, with a mean annual temperature of 23.4 °C and annual precipitation of 1241 mm (Fig. 3B). Rainfall at both sites is concentrated in the spring and summer (October to April), while the dry season is in the autumn and winter (May to September).

2.2. Experimental design

In order to remove different rates of sugarcane straw from the field, we set up the harvester varying the angular velocity on the primary extractor fan and keep the secondary extractor fan off or on. Initially, our goal was to remove the amount of straw proportional to 0, 25, 50, 75 and 100% of the straw yield in each area. However, in the field conditions, we did not achieve the exact proportion, but the rates were very close to those intended (Table 1). More details about harvester set up and the efficiency of mechanical straw removal procedures were described in Lisboa et al. (2017). The experimental design was randomized blocks with five treatments (*i.e.*, straw removal rates), as presented in Table 1, and four replications (plots of ~50 × 25 m).

At the installation of each experiment, a composed sample of sugarcane straw was collected for characterizing the initial carbon and macronutrients contents (Table 2).

Carbon and nitrogen concentration in plant tissue were determined by an elemental analyzer (Leco© Truspec®, St. Joseph, Michigan). Phosphorus, K, Ca, Mg and S concentrations were determined following methods described by Malavolta et al. (1997).

2.3. Evaluation of sugarcane response to residue removal management

We evaluated sugarcane responses to straw removal in different phases of plant development over the annual crop cycle (Fig. 4) in the first and second ratoon. The evaluations started with the monitoring of tillering dynamics in the early phases, then biometric evaluations to follow the plant growth dynamic. Finally, crop yield (stalk and straw) and stalk industrial quality were evaluated in the late phase during harvesting.

2.3.1. Plant tillering

Plant tillering evaluations consisted of counting the number of

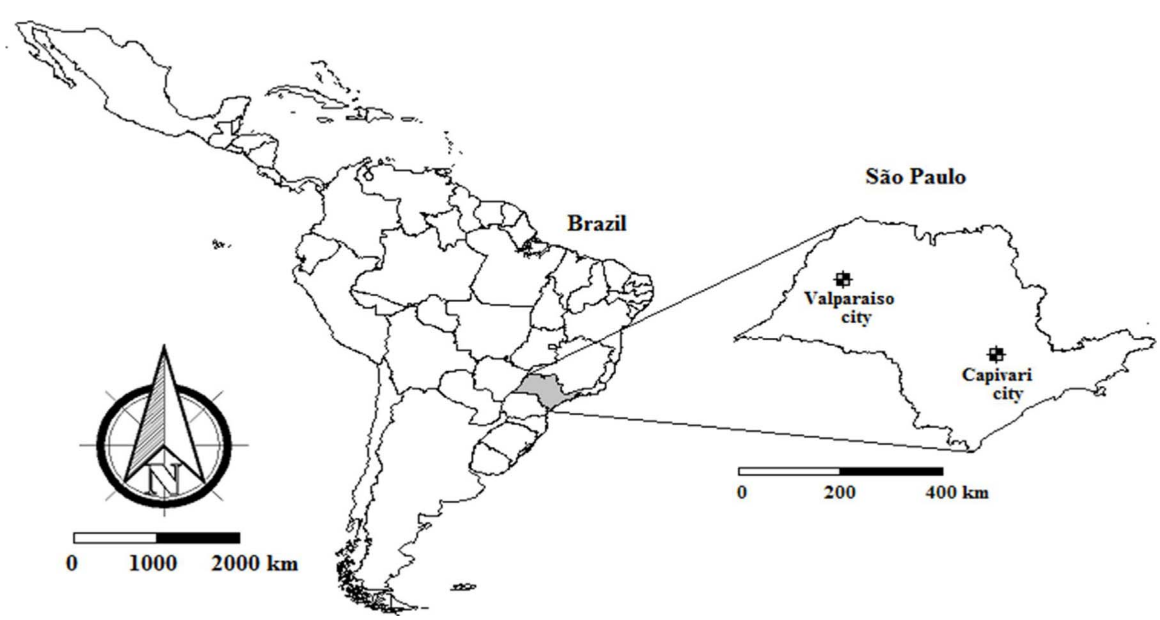

Fig. 1. Geographic location of the study areas.