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Research Paper

Does straw mulch partial-removal from soil interfere in yield and industrial quality sugarcane? A long term study

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ABSTRACT

Sugarcane straw mulch left in the field after its mechanical harvest has become very valuable raw material for second generation ethanol and bioelectricity production. However, little information is available on how much straw mulch is needed to be left in the field so that agricultural productivity is not affected and high sustainability is provided for the bioenergy production system. The objective of this work was to evaluate the productivity and industrial quality of sugarcane after five years of cultivation when different amount of straw mulch is removed from the field. The experiment was installed in clay texture Eutroferric Red Latosol (Oxisol). Six treatments were evaluated: 0%, 25% (5 t ha^{-1}), 50% (10 t ha^{-1}), 75% (15 t ha^{-1}), 100% (20 t ha^{-1}) of straw mulch and burnt cane harvesting (where 100% of the straw mulch was burned). Evaluated parameters included sugarcane productivity (tons/hectare) and its industrial quality (Pol, soluble solids (°Brix), apparent purity and total sugars (TS)). Productivity was calculated at the end of the cycle whereas industrial quality parameters were evaluated during three phases i.e. 180, 240 and 350 days after cutting (DAC). Straw mulch of 50 and 75% were statistically at par with each other but resulted in higher sugarcane production with 47% more productivity as compared to 0 and 25% of straw mulch as well as burned cane harvesting. Straw mulch didn't affect the industrial quality; however, higher sugar production was supported by higher agricultural productivity, under low moisture condition. It is possible to remove 50% of straw mulch from the field for the production of second generation ethanol or bioelectricity, without any damage to the crop.

1. Introduction

Increasing global need for food and energy requires more sustainable mode of production in the most diverse sectors. In this sense, ethanol as a substitute for fossil fuels meets these global requirements due to its effectiveness in economic and environmental terms (Carvalho et al., 2016a). It is necessary for Brazil and United States (major world producers of ethanol) to increase their production from the current 80 to approximately 200 billion liters to meet the global demand of biofuel in 2021 (Goldemberg et al., 2014).

Sugarcane is grown in over 121 countries and is a good source for sugar and ethanol production. Over 80% of sugar produced in the world is obtained from sugarcane, whereas Brazil, India, China and Thailand account for 60% of the total production (Food and Agriculture Organization of the United Nations (FAO), 2016). In addition, ethanol from sugarcane is considered one of the world's purest biofuels (EMBRAPA, 2017). The major sugarcane producing areas of the world have recently adopted the practice of mechanical harvesting (Cardoso et al., 2013; UNICA, 2013), where sugarcane leaves and tips are cut off and left over the soil surface to form a mulch called straw mulch. More than 300 million Mg of straw mulch is produced per year worldwide (UNICA, 2013) that can be utilized to increase the production of ethanol (Carvalho et al., 2016b) or bioelectricity without increasing the area of cultivation.

One ton of straw mulch can produce 270 l of ethanol while one ton of sugarcane can produce 80 l of ethanol (Santos et al., 2012). In

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addition, it has great potential for bioelectricity generation as well. Brazil is leading the world in renewable electricity generation that fulfills 40% of the country's electricity demand, of which 16% comes from sugarcane bagasse (EPE, 2015), and straw mulch has twice the potential for energy generation than bagasse (Udop, 2017). Although straw mulch is an effective raw material for the production of ethanol, bioelectricity and others (Costa et al., 2013) but its indiscriminate removal from the field can not only reduce its positive effects on sugarcane made products (Resende et al., 2006; Anjos et al., 2017) but also on the sustainability of the production system (Christoffoleti et al., 2007; Garbiate et al., 2011; Silva et al., 2012; Sousa et al., 2012). Thus, the impact of straw mulch removal on productivity and the industrial quality of the crop should better be studied for its accurate management.

Straw mulch over the soil surface brings certain chemical, physical and biological changes in the agricultural environment, such as increase in the soil organic matters, decrease in the thermal fluctuations of soil superficial layers, increase in the water permeation with low evaporation, erosion control, increase of macro and micro fauna and changes in the weed flora (Inman-Bamber and Smith, 2005; Garcia et al., 2007; Christoffoleti et al., 2007; Cavenaghi et al., 2007; Guimarães et al., 2008; Tavares et al., 2010; Cardoso et al., 2013; Costa et al., 2014). These changes directly impact the development, productivity, industrial quality and longevity of sugarcane (Souza et al., 2005a).

Felipe (2010) points out that sugarcane juice (water (75–82%) and soluble solids (10–25%)), can be improved since it is influenced by several factors which compromise the final quality. Among these factors, few of the main include: crop management, soil moisture and temperature, harvesting system and climatic conditions. Accordingly, Souza et al. (2005a) verified that straw mulch incorporation to the soil at a depth of 0.30 m reduces total sugars and sucrose of sugarcane ratoons.

Several studies have reported the advantages of keeping straw mulch over the soil surface (Ball-Coelho et al., 1993; Resende et al., 2006). However, in some cases there was a difficulty in the plant emergence, causing regrowth failure and ultimate low yield (Campos et al., 2008; Campos, 2010). It is important to mention that studies on this subject do not address how much straw mulch would be sufficient to obtain such benefits or if the negative effects on the ratoon would be the same if smaller quantities were left over the soil surface. So, works are of prime importance which classifies the necessary amount of straw mulch that can be used as mulch over soil surface and which can be useful for soil-plant system, whereas the surplus can be used for the production of ethanol or bioelectricity, aiming at a sustainable global production of sugar and energy.

The objective of this work was to evaluate the productivity and industrial quality of sugarcane after five years of cultivation when different amount of straw mulch is removed from the field.

2. Material and methods

The experiment was conducted in an area which belongs to the Bandeirantes Sugar and Alcohol Plant, located in the city of Bandeirantes, latitude 23°06′S, longitude 50°21′W and altitude of 440 m. Based on the Koeppen climatic classification, the climate of the region is Cfa, with an average annual rainfall of 1300 mm. The average annual lighting period is 7.14 h^{-1} day.

The soil water balance (Fig. 1) during the time of research was calculated according to Thornthwaite and Mather (1955). Data for mean monthly and monthly total rainfall was provided by the meteorological station of the Instituto Agronômico do Paraná (IAPAR). The value of available water capacity (AWC) considered was 100 mm.

The soil of the area is classified as Eutroferric Red Latosol (Oxisol) (Empresa Brasileira de Pesquisa Agropecuária, 2013), with a clayey texture. Results from the chemical analysis of the soil carried out in September 2013 at a depth of 0–0.20 m, revealed the following values: pH ($CaCl_2$) 5.8, P (mg dm^{-3}) 36.9, Organic matter (g kg^{-1}) 34.4, Base saturation (%) 81.2; K, Al, Ca, Mg (mg dm^{-3}) 1251; 0,0; 1583; 230.97, respectively and CEC ($cmol_c$ dm^{-3}) 16. The textural analysis showed that soil was composed of 68% clay, 38% sand and 2% silt. No modification or fertilization of soil was necessary based on the chemical analysis of the soil. Weed infestation was extremely low and was controlled manually.

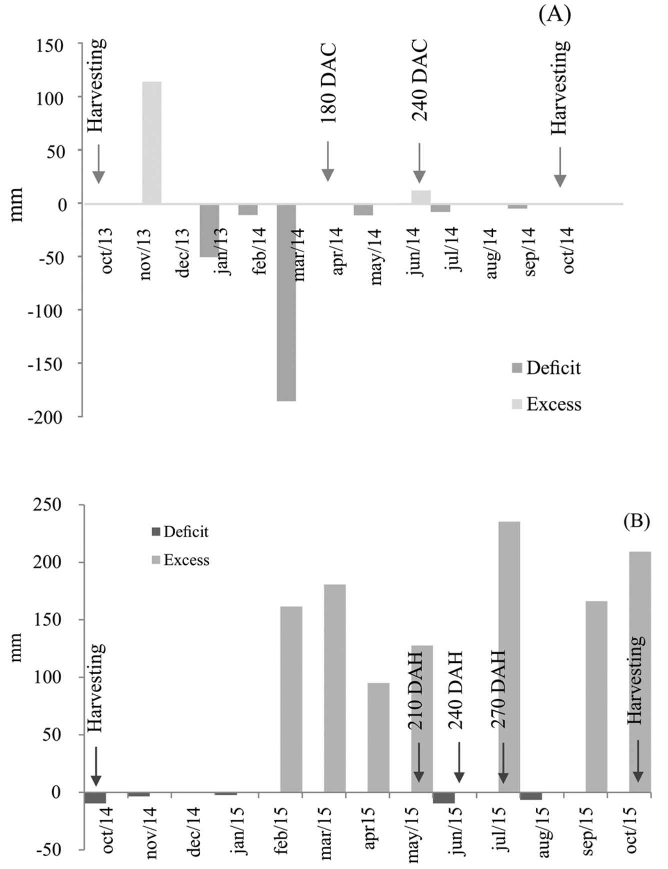

Fig. 1. Monthly water balance during the periods of third (A) and fourth (B) ratoons (harvest 2013/14 and 2014/2015, respectively), Bandeirantes, PR.

In the experimental area, sugarcane had been grown for the last 65 years, using manual harvesting with straw mulch removal by burning. In 2010, sugar mills adopted the mechanized harvesting system and the same method is adopted in the current experiment Fig. 2.

Sugarcanes (*Saccharum* spp. variety SP 801816) were installed in a randomized block design with 4 replications and evaluated during 4th and 5th cycle (third and fourth ratoon). The experimental plots were

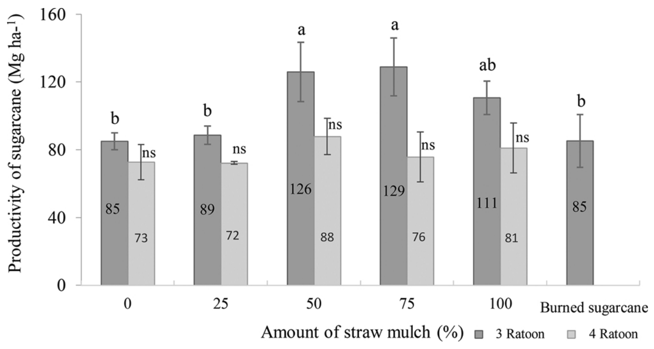

Fig. 2. Sugarcane production (Mg ha^{-1}) in relation to the straw mulch cover over soil surface (%), during third and fourth ratoon cycles (harvests 2013/2014 and 2014/2015, respectively.). The means followed by same letters do not differ significantly from each other, using Tukey test, at 3% probability.

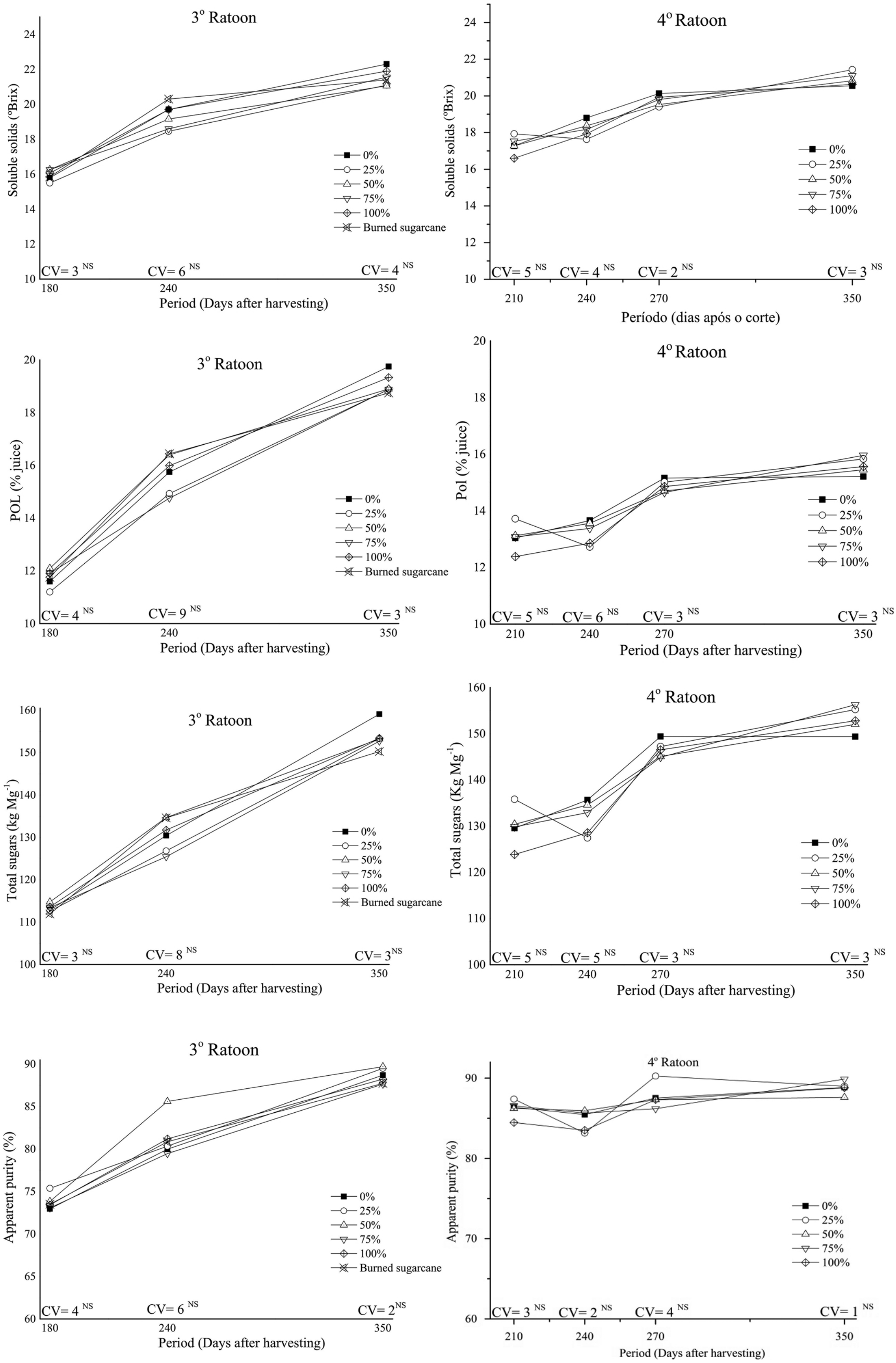

Fig. 3. Soluble solids (°Brix), Pol (% juice), Total Sugars (kg Mg^{-1} sugarcane) and Apparent purity (%) during third and fourth ratoon in relation to the straw mulch cover over soil surface (crop 2013/2014 and 2014/2015). Bandeirantes – PR. NS = Not significant, using Tukey test, at 5% probability.

10 m long (10 rows × 10 m) with row to row distance of 1.50 m. For the data collection, six central rows of nine linear meters were selected, totaling 54 linear meters, leaving 0.50 m at each end and two lateral lines as borders.

The experiment was carried out in August 2010, and straw mulch quantities corresponding to each treatment were added to the soil soon after the plantation. Third ratoon emerged in October 2013 and was harvested in October 2014. So, the obtained data of third and fourth ratoons corresponds four and five years under straw mulch cover, respectively.

Effects of six treatments were evaluated on the productivity and industrial quality of sugarcane juice, which included: 0%, 25% (5 t ha^{-1}), 50% (10 t ha^{-1}), 75% (15 t ha^{-1}), 100% (20 t ha^{-1}) of straw mulch and burnt cane harvest (this treatment was evaluated only until the third ratoon where 100% of the straw mulch was burned). For productivity in fresh stem weight (Mg ha^{-1}), stem from each plot were collected at 360 DAC and weighed. Leaves and tips were removed from the stem prior to weighing.

The quality parameters such as soluble solids (°Brix), Pol, total sugars (TS) and apparent purity were evaluated at 180, 240 and 350 days after cutting (DAC) during third ratoon, while during fourth ratoon at 210, 240, 270 and 350 DAC. For evaluations, ten sugarcane stems were selected from each plot and leaves along with its tip were removed.

A homogenous de-fibered stem sample of 500 g was taken for the analysis of industrial quality. Sugarcane juice extraction, wet bagasse weight, soluble solids and pol evaluation started immediately after the disintegration and homogenization of the samples. A hydraulic press with a minimum and constant pressure of 24.5 MPa (250 kgf/cm^2) for the duration of 1 min was used for the juice extraction (CONSECANA, 2006).

Percent soluble solids (°Brix) were evaluated from the extracted juice using automatic digital refractometer with a maximum resolution of 0.1 °Brix, expressed at 20 °C (CONSECANA, 2006).

Sucrose concentration was evaluated using an automated digital Saccharimeter with a resolution of 0,01°Z (1/100 of sugar degree), calibrated at 20 °C. Following equation was used for calculating Pol (S) (percent of apparent sucrose by weight): (CONSECANA, 2006): $S = LPol \times (0{,}2605 - 0{,}0009882 \times B)$. Where, LPol = saccharimetric reading of refined sugarcane juice with lead subacetate; and B = °Brix of sugarcane juice.

The apparent purity of sugarcane juice (Q) described as the ratio between pol percentage and °Brix, was calculated using the equation: $Q = 100 \times S \div B$. Where: S = pol of sugarcane juice and; B = °Brix of sugarcane juice (CONSECANA, 2006).

Total sugar (TS) was calculated using the equation: $TS = 10 \times PC \times 1.05263 + 10 \times ARC$. Where: 10 × PC = Pol per Mg of sugarcane; 1,05263 = stoichiometric coefficient for the conversion of sucrose to reducing sugars; 10 × ARC = reducing sugars per Mg of sugarcane (CONSECANA, 2006).

The data was analyzed using analysis of variance (ANOVA) and the means were compared via Tukey's test ($P < 0.05$) using the SISVAR software 5.0 (Ferreira, 2011).

3. Results

There was a significant effect of straw mulch that influenced crop productivity during the third ratoon cycle Fig. 2. Straw mulch treatments of 50 and 75% didn't differ significantly among each other ($p < 0.05$, 126 and 129 Mg ha^{-1}, respectively) but presented an increase of about 47% as compared to straw mulch removal of 0%. 25% and burnt cane system ($P < 0.05$, 85, 89 and 85 Mg ha^{-1}, respectively). During this cycle, water was available (Fig. 1) only during November 2013 and June 2014 (30 and 240 DAC, respectively). There was low water availability during the cutoff period (except November of 2013) to 240 DAC, with severe scarcity from 90 to 150 DAC (January to March), reaching 187 mm negative in the final month. At 240 DAC (June 2014) there was a little precipitation (12 mm), returning to the low water supply in the subsequent month, which continued until the end of the cycle.

Straw mulch treatments didn't show any significant influence over sugarcane productivity during fourth ratoon. During this cycle there was almost no water deficiency until 90 DAC, the lowest it got was 9 mm negative during November 2014, shortly after the cutoff period. After this stage, excess water was available to plants until the end of the cycle with averages monthly readings of 100 mm (except June and August 2015) reaching 240 mm (July 2015).

The results showed an increase in the soluble solids (°Brix), Pol, apparent purity and total sugar from 180 to 350 DAC with a patent increase up to 270 DAC during both ratoons (Fig. 3). At the end of third ratoon the average soluble solids were 21.6°Brix, Pol 19.1%, aperant purity 89% and total sugar 154 kg Mg^{-1} whereas for fourth ratoon cycle soluble solids were 20.9°Brix, Pol 15.6%, 89% apparent purity and total sugar 154 kg Mg^{-1}.

However, after five years of cultivation, straw mulch treatments did not influence the industrial quality (Fig. 3).

4. Discussion

Straw mulch treatments affected crop productivity where there was low water availability during the cycle followed by sever water deficiency, especially during the early stage (up to 180 DAC). Water deficiency during early stages causes severe damage to the plant and stem production, since development of aerial parts is hindered. However, at later stages the damage is trivial (Inman-Bamber and Smith, 2005). Silva et al. (2010) confirmed this information by observing that the water scarcity reduces the gas exchange and its conduction to the leaves. But when the conditions return to normal, the gas exchanges tend to return to normal but at slow speed, which can compromise the production of plant material throughout the cycle. On the other hand, one of the main benefits of soil cover is to provide greater water retention and infiltration, which improves the entire water and nutrient cycle. Peres et al. (2010) noticed that sugarcane straw mulch maintenance over the field reduced water losses by almost half as compared to no straw mulch. Carvalho et al. (2016a) also concluded that the straw mulch increases the infiltration and retention of water in the soil favoring the development of the microbiota.

Moreover, in the present study, 50 and 75% of straw mulch attenuated drought effects and improve crop production as compared to burning cane harvest which showed 50% less production. This information is critical for areas where straw mulch burning is still in practice and used on plants before the mechanized harvest due to the misconception that straw mulch cover over the soil surface somehow inhibit the sprouting and decrease the production. But in the current study, no such effects of straw mulch cover have been observed even after five years of cultivation. So, this information may therefor serve as a stimulus for the growers to abandon such practices.

In the present study the treatments with less than 50% of straw mulch did not reduce the effects of drought damage. Soil water storage (WS) evaluated at two depths 0.0–0.3 and 0.3–0.6 m, treated with different levels of sugarcane straw mulches (0; 25; 50; 75 e 100% (18.4 Mg ha^{-1})) showed that WS at any time period (total of four periods) was higher among the straw mulch treated soil as compared with bare land where the WS was recorded lower. These results were attributed to higher water loss through direct evaporation from unmulched soil. Maximum WS fluctuation occurred at the surface layer of 0.0–0.30 m, with 25% (4.2 Mg ha^{-1}) of straw mulch, whereas high level of WS was observed for 50, 75 e 100% of straw mulch that did not differ statistically between them. Low WS was recorded for uncovered soil in comparison to straw mulch covered soil at 0.3–0.6-m layer, however, with a lower intensity due to minimal water loss at this depth. So, keeping 50% of straw mulch cover (9.5 Mg ha^{-1}) is sufficient amount for improved soil condition, since the higher coverage levels did not promote a substantial gain in soil water storage (Anjos et al., 2017).

These results are in agreement with Aquino et al. (2017), who observed that straw mulch treatments above 50% increased the average production by about 29% as compared to burned cane system, 0 and 25% straw mulch, when there was severe water deficiency during the early stages of crop development. However no such effects were observed when there was surplus water present. But considering that one of the main and quickest advantages of straw mulch is to keep soil highly moisturized, so, it is expected that no such benefits can be achieved in water rich conditions.

These results are supported by Ball-Coelho et al. (1993), who confirmed that straw mulch increase the sugarcane productivity in those regions of the world which receives irregular or little rainfall, as well as by Costa et al. (2014) and Resende et al. (2006) after 16 years of cultivation. So it has been confirmed that straw mulch cover has significant effect on the cropping system, and may reflect in the short term on the final yield.

For the start of harvest the adequate soluble solids (°Brix) should be 14.4%. Purity of sugarcane juice should be above 80% at the beginning and 85% during the harvest (Fernandes, 2000). Regardless of the treatments, the cultivar can be considered rich which showed good qualities in terms of above mentioned factors and did not alter the industrial quality. Although straw mulch treatments didn't influence the industrial quality of the crop, high productivity did benefit sugar production. It is observed that straw mulch doesn't alter the industrial quality of the crop even after 16 years of cultivation; however it increases the sugar production by improving the productivity of the crop, especially during water deficit conditions for up to 50% (Resende et al., 2006).

However it is important to mention here that straw mulch incorporation may affect the industrial quality of the crop. Straw mulch incorporated up to the depth of 0.30 m reduced AT and apparent sucrose of 18 sugarcane cultivars (Souza et al., 2005b), a fact that has not been observed during the current study in any of the evaluated straw mulch treatments. For the better understanding and management of straw mulch these information regarding interference with quality and production should be considered before.

Despite the benefits of straw mulch already reported, there are some studies reporting low productivity with 100% straw mulch cover over the soil (Campos et al., 2008; Campos, 2010). It is important to point out that the positive and negative results of straw mulch in these studies are referred to the total quantity (100% of the straw mulch on the soil), and therefore not possible to know if there would be the same effect under lower straw mulch quantities.

During the current study it has been observed that 50% of straw mulch is sufficient enough to improve production and increase the sugar contents whereas the rest can be utilized for second-generation electric energy production, acquiring most of the benefits from the crop and without any prejudice to the sustainability of cropping system. Resende et al. (2006), have confirmed these facts and stress that maintaining straw mulch in the system is essential for crop productivity, system sustainability and long-term sugar production.

5. Conclusions

1. After five years of cultivation, shift from burning cane harvesting system to growing under straw mulch did not alter the quality of sugarcane juice but also improved its production.
2. Sugarcane straw mulch management through burning its straw mulch prior to its harvest reduces crop productivity by 49%.
3. Total or 75% of straw mulch removal from the field reduce the sugarcane production by about 47%.
4. Straw mulch cover of about 50% (10 t ha^{-1}) was sufficient to provide 47% increase in the production under water deficit conditions, and 50% of the surplus straw mulch can be removed from the field for industrial processes without adversely affecting crop productivity.

Conflict of interest

The authors declare that they have no conflict of interest and the authors are according to the submission.

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