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Straw removal of sugarcane from soil and its impacts on yield and industrial quality ratoons

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ABSTRACT: Mechanical harvesting leaves in its wake a considerable amount of straw in the field, which can be effectively utilized to improve the soil condition and sugarcane yield. However, there is no specific information as to the quantity of straw mulch required to achieve such effects and as to whether it can be used in other sectors for bioelectricity and ethanol production. The aim of this research was to evaluate the effect of removing different amounts of straw from the field and its impact on the yield and industrial quality of sugarcane ratoons. The experiment was carried out on Rhodic soil where six treatments were evaluated including 0 %, 25 % (5 Mg ha^{-1}), 50 % (10 Mg ha^{-1}), 75 % (15 Mg ha^{-1}), 100 % (20 Mg ha^{-1}) straw on the soil surface and burned sugarcane (where 100 % of the straw was burned). The influence on yield and industrial quality was calculated using total soluble solids, Pol (Apparent sucrose content), apparent purity, total sugars, reducing sugars and fiber. Shifting the harvesting system from burned cane to growing under straw mulch improved crop yield as well as favoring sugar contents during water deficit conditions. The straw left on the soil did not affect industrial quality in any way during the trials; however, under drought conditions, treatments with 50 and 75 % of straw resulted in a 76 % higher yield compared to burned sugarcane, and 29 % more than the 0 %, 25 % to 100 % treatments of straw mulch thus favoring higher sugar production. The removal of 50 % of the straw caused no damage to the sugarcane crop.

Keywords: biomass, management of straw, mulching, *Saccharum* spp., technological characteristics

Introduction

Brazil is the world's largest producer of sugarcane and recently adopted the mechanical harvesting system in the main production areas (Dinardo-Miranda and Fracasso, 2013; Oliveira et al., 2014). However, the impacts of this new practice on yield and industrial quality have not been fully understood. Under this system, leaves, tips and portions of the stalk are trimmed and spread on the soil making a dead ground cover called straw with up to 30 Mg ha^{-1} of dry mass (Christoffoleti et al., 2007; Carvalho et al., 2013).

The development of sugarcane is also influenced by physicochemical changes in the crop environment which are reflected in both yield and industrial quality (Garcia et al., 2007; Guimarães et al., 2008; Carvalho et al., 2013; Fortes et al., 2013; Inman-Bamber and Smith, 2005). The incorporation of 70 % of the straw up to a depth of 0.30 m reduces total sugars and the apparent sucrose of sugarcane in the raw cane system (Souza et al., 2005). Ball-Coelho et al. (1993) observed a 43 % increase in sugarcane yield when grown under straw. However, there was no mention of the ideal amount required to obtain such benefits nor what the effect of smaller amounts of straw on the soil surface would be.

The surplus straw left on the ground can be utilized for other beneficial purposes including the production of bioethanol and bioelectricity and its addition to the national energy grid. The aim of this research was to evaluate the effect of removing different amounts of sugarcane straw from the field and its impact on the yield and industrial quality of sugarcane ratoons.

Materials and Methods

Experiment installation and growing conditions

The experiment was carried out on a Rhodic Eutrudox type soil with texture (61 % clay, 2 % silt, and 37 % sand) in the county of Bandeirantes, in the state of Parana at 23° 06′ S latitude and 50° 21′ W longitude, and at an altitude of 440 m above sea level. The average duration of daylight in the area is 7.14 h d^{-1} and annual average precipitation is 1,300 mm.

The monthly air temperature and rain data were obtained from the meteorological station of the Agronomical Institute of the state of Parana (IAPAR). Climatological water balance of the area (Figure 1) was calculated by the Thornthwaite and Mather (1955) method. The amount of available soil water capacity (AWC) considered was 100 mm.

The experiment started in Aug 2010, when soil down to a depth of 0.60 m (Table 1) was chemically analyzed prior to planting. In the experimental area, sugarcane has been cultivated for the last 65 years, using manual harvesting with straw removal by burning. In 2010, sugar mills adopted the mechanized harvesting system with no burning of straw.

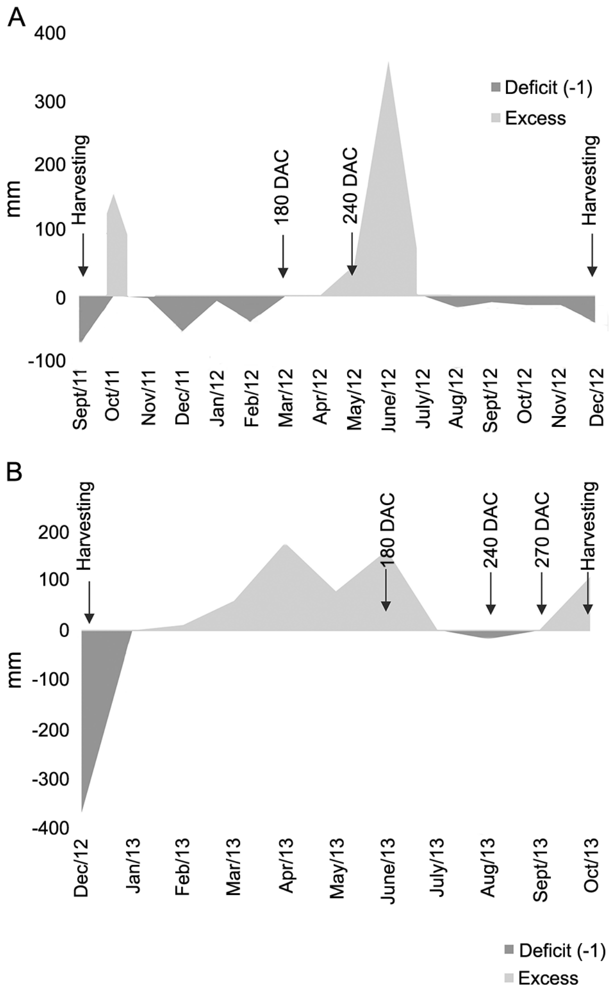

Figure 1 – Monthly water balance extract occurring during the first cycle (A) and second ratoon (B) of sugarcane cv. SP801816 grown under different amounts of straw (%) on the soil surface; DAC = days after cutting. Bandeirantes, Paraná, Brazil.

Table 1 – Chemical analysis of the Rhodic Eutrudox soil, in a depth range of 0-0.60 m. Bandeirantes, Paraná, Brazil.

Depths	pH	OM	P	K	Ca	Mg	H+Al	CEC	BS
m	$CaCl_2$	g kg^{-1}	mg dm^{-3}	———	cmolc dm^{-3}	———			%
0.0-0.1	5.4	26.8	8.6	2.5	7.8	1.7	3.1	15.1	19.4
0.1-0.2	5.9	41.6	71.3	3.6	7.9	1.9	2.9	16.3	82.3
0.2-0.3	6.1	34.9	31.0	3.7	8.0	2.1	3.0	16.8	82.1
0.3-0.4	6.2	30.9	5.1	4.6	8.1	2.1	2.2	17.0	86.9
0.4-0.5	6.3	37.6	9.0	4.2	7.3	2.0	2.4	15.9	84.8
0.5-0.6	6.3	28.2	5.3	3.2	6.1	2.1	2.4	13.8	82.7

P utilized Mehlich extractant; CEC = Cation exchange capacity; BS = Base sum; OM = Organic matter.

The experiment was installed in a randomized block design with four replications. For each plot, 10 rows of sugarcane (cv. SP801816) were selected with a length of 10 m (10 rows × 10 m) and a space between rows of 1.50 m. For the collection of data 6 central rows with a linear length of 9 m, were selected over two consecutive cycles e.g. the first and second ratoon. Six treatments were evaluated in the experiment: 0 %, 25 % (5 Mg ha^{-1}), 50 % (10 Mg ha^{-1}) 75 % (15 Mg ha^{-1}) and 100 % (20 Mg ha^{-1}) of straw on the soil, and burned sugarcane (in this case 100 % of the straw was burned).

Sugarcane yield

The yield (Mg ha^{-1}) was calculated at 450 days after harvest (DAH) (Dec 2012) during the first ratoon, and at 300 DAH (Oct 2013) for the second ratoon, by weighing all the stalks from the plots.

Industrial quality

The components of industrial quality evaluated included total soluble solids of juice (°Brix), Pol (%), total sugars (TS), apparent purity (%), reducing sugars (RS) and fibers at 180, 240 DAH and at harvest (370 and 270 DAH, respectively for the first and second ratoons). For each evaluation period, ten stalks per plot were harvested and taken immediately to the quality control laboratory of sugarcane plant and analyzed using the CONSECANA (2003) method.

Immediately after planting in Aug of 2010, the corresponding quantities of straw for each treatment were added to the soil. At the time of harvest (repeated annually), the straw in the field was collected and weighed. After that, straw was redistributed in the field in accordance with the assigned treatments. Thus, the data obtained from the first and second ratoons are, respectively, equivalent to 2 and 3 years of growing under straw mulch.

The data were analyzed using analysis of variance (ANOVA) and the F test. Additionally, Duncan tests ($p < 0.05$) were carried out using the statistical software SISVAR program, v. 5.0 to compare means (Ferreira, 2011).

Results and Discussion

Sugarcane yield

Straw mulch yields were influenced positively during the first ratoon (Table 2), though there was no meaningful difference in the results between the treatments of 50 and 75 % straw mulch, which presented the highest yield (194.30 and 193.67 Mg ha^{-1}, respectively) representing an increase of 76 % over the yield previously obtained by the burned sugarcane treatment (110.33 Mg ha^{-1}) and 29 % higher than an average of the 0 %, 25 %, and 100 % of straw treatments. In the second ratoon, there was no effect of straw mulch on the sugarcane yield (Table 2).

These results, observed during the first ratoon cycle, were due to a prolonged drought season occurring during this period. In this cicle, sugarcane crop faced water deficit conditions for up to 180 DAH, except during October 2011. Water availability increased only at 240 DAH, thereby affecting the initial stages, when an

Table 2 – Sugarcane yield (Mg ha^{-1}) cv. SP801816 grown under different amounts of straw (%) left on the soil surface during the first and second ratoons (2011/12 and 2012/13 crops). Bandeirantes, Paraná, Brazil.

Treatments (% straw)	Productivity (Mg ha^{-1})	
	First Ratoon	Second Ratoon
0	148.0 b	95.3^{ns}
25	147.0 b	93.3
50	194.3 a	105.9
75	193.7 a	105.7
100	156.2 b	103.2
Burned sugarcane	110.3 c	97.3
CV (%)	11.5	12.7

Means followed by the same letter in column are not significantly different by Duncan test at the 5 % significance level; ns = not significant.

adequate water supply is essential for the development of the crop. This might be the reason why crop showed low yields when grown with less than 50% straw. Inman-Bamber and Smith (2005) emphasize that damage caused to the plant, such as closure of stomata due to the accumulation of abscisic acid in the roots, root mortality, decrease in both the metabolism and productivity of the stalks due to periods of water stress, which are greater when they occur in the first phases of the crop, as they interfere in or delay the development of the shoot. However, when they occur at a later stage in such a period of rapid crop growth, the yield of the stalks is affected only marginally. Awe et al. (2015) reported that water deficiency reduces gas exchange and its conduction to the leaves. When the water deficit is interrupted, the gaseous exchanges tend to go back to normal, though at a slower rate, which can compromise crop production for the entire cycle. This may explain the lower yields obtained (Table 2) in treatments where the soil remained uncovered (burned cane and 0 % of straw) or with a low straw level of cover(25 %).

During the second ratoon, there was an excessive soil moisture condition between 45 and 210 DAC (Figure 1B), followed by a soil water deficit condition 240 DAC only (Figure 1B). One of the main benefits provided by short-term straw mulching is the maintaining of higher moisture and a lower temperature in the surface layers of the soil favoring micro and macrobiota and crop productivity (Braunbeck and Magalhães, 2010). Thus, during rainy periods, a difference in sugarcane yield between treatments was not expected to occur.

Resende et al. (2006) observed that the maintenance of the straw provided an increase of 28 % in the production of the stalks over 12 cycles, which confirms the results of the present study.

Industrial quality

There was an increase in total soluble solids (°Brix), Pol, apparent purity, and TS from 180 DAC until the harvest period in both ratoons. During the first ratoon at 180 DAC, the average soluble solids, pol, total sugars, apparent purity, reducing sugars and fiber were recorded at a level of 7.0 °Brix, 10 %, 109.08 kg Mg^{-1}, 66 %, 3 % and 11 %, respectively. During the second ratoon, soluble solids, pol, total sugars and apparent purity showed an increase in value i.e. 16.7 °Brix, 14 %, 135.28 kg Mg^{-1} and 81 %, whereas reducing sugars and fiber decreased to 0.7 % and 8 %, respectively. At 240 DAC, the parameters studied presented a small increase during both ratoons except reducing sugar which decreased. At the end of the cycle, mean values during the first ratoon were as follows: total soluble solids: 18.2 °Brix, pol: 15 %, TS: 134.95 kg Mg^{-1}, apparent purity: 82 %, reducing sugars: 1 % and fiber: 14 %. For the second ratoon the averages observed were: soluble solids: 20 °Brix, pol: 17 %, TS: 159.6 kg Mg^{-1}, apparent purity: 82 %, reducing sugars 0.7 % and fiber 11 %. However, there was no significant difference between treatments for both ratoons. Regardless of the treatments applied, the cultivar was considered as a sucrose rich cultivar, attaining up to 14 % and 80 % total soluble solids and purity of juice, respectively (Fernandes, 2000).

The reducing sugar content (RS) (%) decreased at 180 DAC until harvest during both ratoons. At the end of the cycle, the values reached 1.0 % at 350 DAC in the first ratoon and 0.7 % at 270 DAC in the second ratoon. It is noted that the values for RS (%) were close to 1.0 % for both ratoons, which are the recommended readings at the beginning of the sugarcane harvest (Fernandes, 2000). Similar results were observed by Souza et al. (2005) when 100 % of the straw was left in the field.

There was an increase in the concentration of fiber at harvesting in both ratoons, attaining 13 % in the first ratoon. The climatic conditions and the number of days in the field (350 days) favored the highest fiber content. In the second ratoon, the concentration of fiber was 11 %. Fernandes (2000) considered 12 % fiber as a standard value.

Industrial quality of sugarcane was not significantly affected by the water deficit conditions. However, sugar production was favored in the drought period by the increased productivity of the crop with 50 % of the straw mulch. This shift of harvesting system from burned harvesting (practiced for 65 years) to keeping straw as soil mulch did not affect the industrial quality of sugarcane since its adoption three years ago.

Resende et al., 2006 observed that keeping straw on the soil surface did not affect total soluble solids (°Brix), Pol, fiber, apparent purity nor sugarcane juice percentage after 16 years of cultivation. However, the increased production of stalks can favor the production of sugar by 59 %. When straw was incorporated into the soil there was a reduction in total sugars and apparent sucrose of the rattons (Souza et al., 2005). Thus, this information is very important for straw management and its effect on the quality and production of sugarcane.

Despite the benefits obtained from keeping straw on the soil surface, there are a number of studies which report a reduction of up to 16 % in final production

(Campos, 2010; Awe et al., 2015). It is noteworthy that the majority of negative results for straw management such as budding failure and decreases in yield reported in the literature were drawn from 100 % of the straw mulch situations, thus excluding the opportunity to carry out any evaluation of the effect of lower straw quantities.

In the present study, removing only 50 % of the straw was enough to increase crop production (194.3 Mg ha^{-1}, $p < 0.05$), but beyond this level (75 % and 100 % of straw), there was no response (193.67 and 156.20 Mg ha^{-1}, respectively). Any excessive amount can be utilized for the production of second generation ethanol and electric energy cogeneration which will thereby maximize the energy utilization of the crop without prejudicing the sustainability of the growing system.

Conclusions

The deployment of a harvesting system that did not involve burning straw increased the sugarcane yield and favored sugar production during water deficit conditions. The burned sugarcane harvesting system and total removal or removal of 75 % of the straw mulch from the field reduced sugarcane production. Keeping 50 % (10 Mg ha^{-1}) of straw mulch in the field can increase production during conditions of drought, and the rest of the straw (50 %) from the field can be used for the generation of industrial power, without affecting crop productivity. It was also concluded that keeping straw mulch on the soil surface does not affect the quality attributes of sugarcane destined for industrial use.

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