Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 – Online
DOI: https://doi.org/10.18188/sap.v21i4.29990

REMAINING STRAW ON SOIL FERTILITY AND SUGARCANE PRODUCTIVITY IN THE CUTTING PERIODS

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SAP 29990 Received: 12/04/2021 Accepted: 02/08/2022
Sci. Agrar. Parana., Marechal Cândido Rondon, v. 21, n. 4, oct./dec., p. 411-422, 2022

ABSTRACT - The straw remaining from the sugarcane harvest can influence soil fertility and the crop in the field, depending on the amount and time these residues remain in the soil and the relationship they establish. with abiotic factors and microorganisms that act in the process. The objective was to identify the remaining straw levels (0; 5; 10 and 15 Mg ha^{-1}) on soil fertility keep and sugarcane productivity (third cutting), in tree periods cuttings - 1 (variety RB 855156), 2 (variety RB 835486) and 3 (variety RB 835054). For chemical attributes, samples were collected from soil with deformed structure at depths of 0-5; 5-10; and 10-15 cm, after the sugarcane harvest in 2012, before the establishment of the straw levels (initial) and after the ratoon harvest in the 2013 harvest (final), in periods cuttings 1, 2 and 3, respectively. the maintenance of 15 Mg ha^{-1} of crop residues does not increase nutrient levels in the surface soil layers, nor does it result in a reduction in organic matter values in the surface soil layers after one year of sugarcane cultivation, even with the complete removal of crop residues. There is feasibility for partial removal of crop residues without affecting soil chemical attributes in the subsequent crop season, considering that the maintenance of 5 Mg ha^{-1} promotes maximum productivity of stalks and sugars in the late-season harvest (3rd period).
Keywords: bunding, crop residues, mechanized harvesting.

PALHIÇO REMANESCENTE SOBRE A FERTILIDADE DO SOLO E PRODUTIVIDADE DA CANA-DE-AÇÚCAR EM ÉPOCAS DE CORTE

RESUMO - O palhiço remanescente da colheita da cana-de-açúcar pode influenciar a fertilidade do solo e a cultura no campo, em função da quantidade e do tempo em que esses resíduos permanecem no solo e da relação que esses estabelecem com fatores abióticos e de microorganismos que atuam no processo. Nesse contexto, objetivou-se, com este trabalho, identificar o nível de palhiço que mantenha fertilidade do solo e a produção da cana-de-açúcar (terceiro corte), em três épocas de corte - época 1 (variedade RB 855156); época 2 (variedade RB 835486) e época 3 (variedade RB 835054). Para as análises dos atributos químicos foram coletadas amostras de solo com estrutura deformada nas camadas de 0-5; 5-10; 10-15 cm, após a colheita da cana-de-açúcar em 2012, antes do estabelecimento dos níveis de palhiço (inicial) e após a colheita da soqueira na safra 2013 (final), nas épocas de corte 1, 2 e 3, respectivamente. A manutenção de 15 Mg ha^{-1} de palhiço não aumenta os teores dos nutrientes nas camadas superficiais do solo, assim como não ocorre redução nos valores de matéria orgânica nas camadas superficiais do solo, após um ano de cultivo da cana, mesmo com o recolhimento total do palhiço. Há viabilidade do recolhimento parcial do palhiço sem afetar os atributos químicos do solo na safra seguinte, visto que a manutenção de 5 Mg ha^{-1} promove produtividade máxima de colmos e de açúcares na colheita de final de safra (3ª época).
Palavras-chave: colheita mecanizada, enleiramento, resíduos vegetais.

INTRODUCTION

Approximately 83% of sugarcane production is concentrated in ten countries, Brazil is the largest producer of this crop, with around 37% of production, representing 746 million tons per year (FAO, 2021). The state of Mato Grosso do Sul stands out among the leading sugarcane producers, with an average productivity of 73.27 Mg ha^{-1} in the last four harvests (CONAB, 2022).

Sugarcane is a high-energy biomass crop, where the sugar is stored in its stalk and the lignocellulosic residue remaining after sugar extraction is used for the production of biofuels or other bioproducts (AWE et al., 2020). Furthermore, the plant residues left in the field (straw after harvesting have been more frequently used by the sugarcane sector as raw material for the production of bioenergy (SANTOS et al., 2022).

In sugarcane production systems, the importance of conservationist soil management practices has been observed, which include reducing soil mobilization and maintaining plant residues on the soil (SEGNINI et al., 2013). This practice, in particular, influences some chemical, physical, and biological properties in the agricultural environment (BODORNAL et al., 2018; CASTIONI et al., 2019; SANTOS et al., 2022), as well as

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the productivity and longevity of sugarcane (SILVA et al., 2022).

Because of the maintenance of quantities of remaining straw from the sugarcane harvest on the soil surface, without incorporation, the impacts on the conservation of soil organic matter and organic C can be highlighted (SEGNINI et al., 2013; BODORNAL et al., 2018; CASTIONI et al., 2019). Such impacts are the increase in root mass (MELO et al., 2020), the improvement in plant nutrition (CHERUBIN et al., 2019), and the increase in productivity stalks (MELO et al., 2020; AQUINO et al., 2018) and sugar (AQUINO et al., 2018). It should also be observed that the remaining straw contains a large concentration of macronutrients and micronutrients, thus contributing to the increase of several nutrients in the soil, such as nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, which can be used by the sugarcane crop (OLIVEIRA et al., 2014).

By maintaining 15 Mg ha^{-1} or 10 Mg ha^{-1} of remaining straw in the soil for four years, Castioni et al. (2019) observed an increase in the productivity of sugarcane stalks, concerning collections of 15 Mg ha^{-1} (total collection) and 10 Mg ha^{-1} (partial). Melo et al. (2020) also observed that the amounts of straw remaining in the soil, between 8 and 13 Mg ha^{-1}, are sufficient for root growth and improving sugarcane yield. On the other hand, the collection of straw that could be kept on the ground, according to Cherubin et al. (2019), is responsible for removing a large part of nutrients that could be further reused by the crop, thus making it evident the need to establish levels of remaining residues, to maintain the nutritional balance of sugarcane plants. In this context, the objective of this work was to identify the level of remaining straw that maintains soil fertility and sugarcane production (third ratoon) evaluated at different cutting seasons.

MATERIAL AND METHODS

The experiment was conducted on São Marcos Farm in partnership with Usina São Fernando Açúcar e Álcool, in the municipality of Dourados, state of Mato Grosso do Sul (MS), at an average altitude of 434 m. According to Fietz et al. (2017), and according to the Köppen-Geiger classification, the climate in the region is Cwa, humid mesothermal, with hot summers and dry winters. The monthly rainfall and average temperatures, presented in Figure 1, were obtained at the Meteorological Station of Embrapa Agropecuária Oeste, located in Dourados, MS, during the experiment.

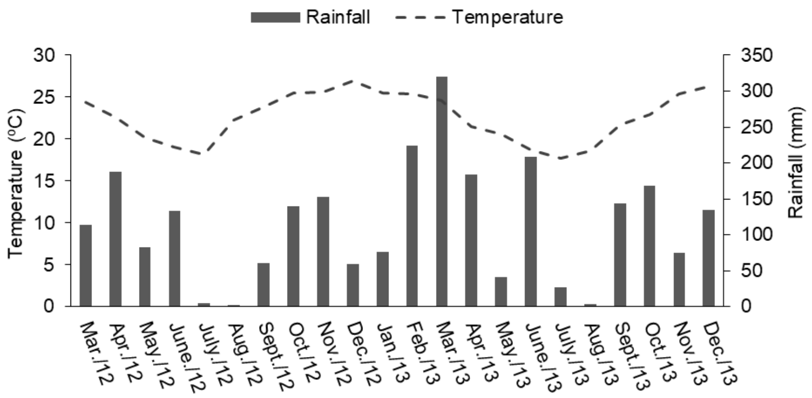

FIGURE 1 - Monthly average accumulated rainfall and temperature, 2012/13 crop.

The soil in the area is classified as a dystroferric Red Oxisol (SANTOS et al., 2018). The terrain is flat, with a slope of up to 3%, and the soil is deep and has a clayey texture (65 to 70% clay). After mechanized harvesting of the third-cut sugarcane, three areas were demarcated for the installation of experiments (Figure 2), each corresponding to a cutting season.

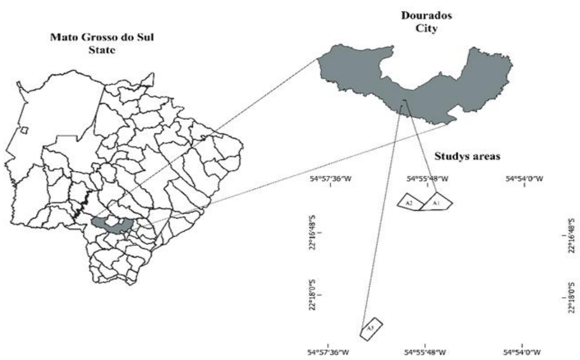

FIGURE 2 - Map of the experimental área location in the municipality of Dourados, state of Mato Grosso do Sul (MS).

The results of the soil particle size composition in the three experimental areas, corresponding to the respective sugarcane cutting seasons, are presented in Table 1. The chemical analyses of the soil for the characterization of the experimental areas are shown in Table 2.

TABLE 1 - Soil particle size composition at different sugar cane cutting seasons.

Layer (cm)	Season 1			Season 2			Season 3		
	Clay	Silt	Sand	Clay	Silt	Sand	Clay	Silt	Sand
0-5	666	150	184	558	184	258	624	165	211
5-10	666	150	184	558	184	258	624	165	211
10-15	682	134	184	576	166	258	635	158	207

TABLE 2 - Soil chemical characterization at the different sugar cane cutting seasons.

Season	Layer (cm)	pH ($CaCl_2$)	Ca	Mg	H+Al	K	P (Mg dm^{-3})	SB (Cmol dm^{-3})	CEC	V (%)	OM (g kg^{-1})
			------------ Cmol dm^{-3} ------------								
1	0-5	5.58	6.22	2.25	4.27	1.56	9.72	10.03	14.30	69.88	47.89
	5-10	5.62	6.30	2.28	4.22	1.55	9.72	10.13	14.35	70.35	46.45
	10-15	5.45	5.30	2.00	5.45	1.03	5.06	8.33	13.78	63.28	39.39
2	0-5	4.58	2.31	0.86	7.76	1.50	5.57	4.67	12.43	37.88	36.03
	5-10	4.53	2.04	0.71	8.16	1.37	4.24	4.11	12.28	34.11	32.58
	10-15	4.44	1.70	0.55	8.47	1.14	2.90	3.39	11.86	29.16	28.95
3	0-5	5.24	4.23	1.27	4.14	0.85	5.96	6.36	10.50	60.60	37.06
	5-10	5.25	4.09	1.25	4.32	0.65	4.84	5.99	10.31	57.87	35.19
	10-15	5.07	3.17	1.06	4.88	0.43	3.04	4.66	9.54	48.64	30.85

Ca = Calcium, Mg = Magnesium, H+Al = potential acidity, K = Potassium, P = Phosphorus, SB = Sum of the bases, CEC = cation Exchange capacity, V = base saturation, OM = Organic matter.

The experiment consisted of three harvest seasons, each season with a different variety of sugar cane depending on the maturation cycle. In the area harvested in the first season, on May 2, 2012, which had been cultivated with the early cycle variety RB 855156, the straw levels were established on May 7, 2012. Soil sampling was carried out on May 8, 2012 (initial) and on May 23, 2013 (final), 12 months after establishing the straw levels.

In the second season, on August 8, 2012, in the area harvested which had been cultivated with the intermediate maturity cycle variety RB 835486, straw levels were established on August 15, 2012. Soil samplings were carried out on August 16, 2012 (initial) and on August 19, 2013 (final), 12 months after establishing the straw levels. In the area harvested in the third season, on November 20, 2012, which had been cultivated with the late maturation cycle variety RB 835054, straw levels were established on November 27, 2012. Soil samplings were carried out on November, 282012 (initial) and on September 17, 2013 (final), 9.5 months after establishing straw levels. The harvest was brought forward in this plot due to strong frosts that caused the complete death of the sugarcane field.

Once the harvest was finished at the beginning of the experiment, before application of the treatments, the amount of straw in the area was evaluated, with values of 15.20 Mg ha^{-1} in season 1 and 18.64 Mg ha^{-1} in season 2. and 17.10 Mg ha^{-1} in season 3. The straw was completely removed from the area and returned with the mass values set for each plot. After installing the treatments, the experimental areas received the same management as the Plant's commercial areas - weed control through the application of herbicides and manual weeding; and fertilization carried out with 380 kg ha^{-1} of ammonium nitrate, and 360 m^3 ha^{-1} of vinasse through fertigation, split into three applications of 120 m^3 ha^{-1} with an interval of three to five days between applications.

For each of the three experimental areas (harvest season), a randomized block experimental design was used, in a split-plot scheme, with four straw levels (0; 5; 10, and 15 Mg ha^{-1}) and two collections with five repetitions. The plots were made up of six 15-m long sugarcane lines. All sampling was done solely in the four central lines of each plot, establishing the outer lines as lateral borders. Soil samples were collected in 0-5; 5-10 and 10-15 cm layers, after harvesting the sugar cane at the time of setting up the experiment (initial) and after the final harvest (final).

The soil samples were sent to the physical-chemical analysis laboratory at Embrapa Agropecuária Oeste, for pH quantification in $CaCl_2$ through potentiometry, potential acidity, and aluminum through titrimetry; phosphorus, using molecular absorption spectrometry; potassium, through flame emission spectrophotometry; calcium, magnesium, through atomic absorption spectrophotometry; and total carbon, using infrared absorption spectroscopy (TEIXEIRA et al., 2017). Base saturation (V%) was also calculated.

To evaluate the influence of treatments on sugarcane production, 12 months after harvest, the number of stalks, total recoverable sugar, and productivity of industrializable stalks and sugars were evaluated. The number of stems was obtained by counting them, in three central rows of 5 m, converting them into the number of stems ha^{-1}. In the central rows of each plot, three subsamples of 10 plants were collected, and by using the mass of these plants and the number of stems ha^{-1}, the stem productivity (TCH) was calculated. The sugar productivity estimate was made by multiplying the total reducing sugar (ATR) data by the TCH results, in each plot. The determination of ATR values was carried out through technological quality analysis according to the current methodology in the Sugarcane Payment System, by Sucrose Content (SPCTS), described by Fernandes (2003).

The data obtained in this work were subjected to analysis of variance, and the means were subjected to regression analysis for straw levels and the test of Tukey for collection times, with a 5% probability of error. The analyses were carried out with the aid of the SISVAR computer program (FERREIRA, 2014).

RESULTS AND DISCUSSION

It can be seen in Table 3the contents of calcium, magnesium, and potassium according to the straw levels and collection times, in the 0-5, 5-10, and 10-15 cm layers. For calcium, a difference was observed between the initial and final collection, with a reduction in calcium values in the final evaluation, except for the evaluation of the 0-5 layer in season 2 and the 10-15 cm layer in seasons 1 and 3 when no difference was found.

Regarding the levels of magnesium (Table 3), it is observed that there was a reduction of this nutrient in the soil in the final evaluation in the 0-5 cm layer (season 3) and the 5-10 cm layer (seasons 2 and 3); in season 1, without changing the values from the initial to the final collection.

By analyzing the potassium values between the initial and final collection, it is observed that there was a reduction in the levels of this nutrient in the soil in the final evaluation in the 5-10 cm layer (season 1) and the entire soil profile analyzed in seasons 2 and 3, with an increase in content only in the 0-5 and 10-15 m layers (season 1).

TABLE 3 - Values of pH, calcium (Ca), magnesium (Mg), and potassium (K) in the soil in the 0-5, 5-10, and 10-15 cm layers, for the three sugar cane cutting seasons and two evaluations (inic= initial and final).

Season	Layer	Ca		Mg		K	
		Initial	Final	Initial	Final	Initial	Final
	(cm)	--------------------------- Cmol dm^{-3} ------------------------					
1	0-5	6.43 a*	5.99 b	2.26 a	2.25 a	1.48 b	1.66 a
	5-10	6.48 a	6.12 b	2.31 a	2.26 a	1.61 a	1.49 b
	10-15	5.23 a	5.36 a	1.97 a	2.03 a	0.92 b	1.14 a
2	0-5	2.29 a	2.32 a	0.79 b	0.93 a	1.57 a	1.44 b
	5-10	2.22 a	1.85 b	0.75 a	0.67 b	1.52 a	1.22 b
	10-15	1.79 a	1.61 b	0.55 a	0.55 a	1.22 a	1.06 b
3	0-5	4.45 a	4.02 b	1.32 a	1.23 b	0.91 a	0.80 b
	5-10	4.42 a	3.76 b	1.32 a	1.18 b	0.80 a	0.51 b
	10-15	3.23 a	3.11 a	1.07 a	1.05 a	0.51 a	0.35

*Lowercase letters that are the same on the line do not differ from each other, according to the test of Tukey, at a 5% probability of error. Initial: collection at the time of treatment implementation. Final: collection after mechanized harvesting of sugar cane after one year of implementation. Season 1 (early cycle sugarcane, harvested at the beginning of the harvest); season 2 (medium cycle sugarcane, harvested in the middle of the harvest); season 3 (late cycle sugarcane, harvested at the end of the harvest).

Despite the reduction in the levels of calcium in the soil, the values obtained are considered high (>7.0 $mmol_c$ dm^{-3}), according to the interpretation table described by Raij et al. (1997). These results may have occurred because the maintenance of the straw promoted improvements in the production environment (temperature and soil humidity) which reflected in greater development of sugarcane and greater export of Ca in the harvested stalks; however, in this short period, the Ca levels released present in the residual straw was below the export rate. Experiments carried out by Franco et al. (2007), demonstrated that average amounts of Ca are released into the soil, where they found that only 15 kg ha^{-1} of the element present in straw becomes available to the soil after a sugarcane cycle.

The analysis of the magnesium values between the initial and final collection (Table 3), the reduction observed in its values, for the final evaluation in the 0-5 cm layer of season 3 and in the 5-10 cm layer of seasons 2 and 3, was likely to have occurred because of the structural function of this element; as a constituent of chlorophyll, the plant residue must be decomposed so that it is released into the environment and, consequently, made available for cultivation. According to Flores et al. (2014), the greater the number of days of decomposition, the lower the magnesium content in the straw, where, after 360 days, 23% of the total Mg content initially present in the straw is released. Despite finding a magnesium mineralization rate of 70%, Fortes et al. (2012) observed that, when straw from previous cuts is kept in contact with the soil for a longer time, this residue can release up to 82% of Mg in a year.

The comparison between the results obtained in this work with the aforementioned research works, clearly shows that there was not enough time for the total release of the Mg contained in the straw in just one year of evaluation and the small quantities that were made available to the soil did not supply all the demand of the crop, resulting in a decrease in soil levels, especially in seasons 2 and 3 of harvest, where the environments are classified as medium and high, respectively, in terms of exchangeable magnesium content. However, these were areas with fourth-cut sugarcane with inadequate levels of Mg and Ca, especially where the straw is intended to be partially or completely collected for the cogeneration of bioelectricity at the plant, these elements should be replaced by applying correctives to the ratoons to increase the longevity of the sugarcane crop.

Also, the low levels of Mg in the soil are because this element, even in soil with a clayey texture, can move in depth, as found by Zandoná et al. (2015) in a dystrophic Red Oxisol, with 650 g kg^{-1} of clay. These authors observed the effect of limestone and gypsum distributed in broadcast, without incorporation, on the redistribution of Ca to the layer from 0.10 to 0.20 m and of Mg to the layer from 0.10 to 0.40 m, and attributed the greater mobility of Mg, compared to Ca, not only the formation of the MgSO4 ion pair but also the fact that Mg is less strongly retained in the exchange complex, due to its larger hydrated radius and lower electronegativity.

The results obtained for K contents (Table 3) in most of the assessed treatments are in agreement with Otto et al. (2010), as, in most soils in the tropical region, K levels are normally low (normally less than 1.5 $mmol_c$ dm^{-3}), so there is a need to supplement this nutrient with fertilizers to enable sustainable productivity, and Potassium is one of the most important nutrients for sugarcane, it is the most extracted by the crop, mainly by ratoon sugarcane. However, in season 2, maintaining 15 Mg ha^{-1} increased levels of K in the soil in the 0-10 cm layer, highlighting the agronomic importance of this residue in recycling nutrients for the crop even after a year of cultivation.

Table 4 shows the levels of phosphorus, base saturation in the soil, and organic matter according to the straw levels and collection times, in the 0-5, 5-10, and 10-15 cm layers. For phosphorus (P) content in the soil, there was no significant interaction between straw levels and collections. Between the initial and final collection, a reduction in P values was observed in the final evaluation, after one harvest, except for the evaluation of the 0-5 cm layer (season 1) and the 10-15 cm layer - seasons 1 and 3. The analyses of V% values, between the initial and final collection, showed a reduction in the V% values in the final evaluation, except for the evaluation of the 0-5 cm layer (time 2) and the 10-15 cm layer cm in all harvest seasons in which no differences were observed.

TABLE 4 - Phosphorus content (P), base saturation (V%), and organic matter (OM) in the soil, in the 0-5, 5-10, and 10-15 cm layers for the three sugar cane cutting seasons and two evaluations (initial and final).

Season	Layer	P		V%		OM	
		Initial	Final	Initial	Final	Initial	Final
	(cm)	--------------------------- Cmol dm^{-3} -------------------------					
1	0-5	9.99 a	9.75 a	72.95 a	66.80 b	45.24 b	50.54 a
	5-10	11.05 a	8.38 b	72.91 a	67.80 b	47.13 a	45.78 a
	10-15	4.96 a	5.17 a	64.42 a	63.14 a	38.11 b	40.67 a
2	0-5	5.62 a	4.87 b	37.24 a	38.52 a	35.29 b	36.77 a
	5-10	5.27 a	3.21 b	37.01 a	31.22 b	33.78 a	31.38 b
	10-15	3.34 a	2.46 b	29.60 a	28.72 a	29.58 a	28.33 a
3	0-5	6.54 a	5.39 b	62.86 a	58.33 b	37.69 a	37.32 a
	5-10	5.74 a	3.93 b	61.07 a	54.67 b	36.89 a	33.48 b
	10-15	3.26 a	2.83 a	49.30 a	47.99 a	31.28 a	30.41 a

*Equal lowercase letters on the line do not differ from each other, according to the test of Tukey at a 5% error probability. Initial: collection at the time of treatment implementation. Final: collection after mechanized harvesting of sugar cane after one year of implementation. Season 1 (early cycle sugarcane, harvested at the beginning of the harvest); season 2 (medium cycle sugarcane, harvested in the middle of the harvest); season 3 (late cycle sugarcane, harvested at the end of the harvest).

After one year of sugarcane cultivation and regardless of the straw level, a significant increase in the OM content in the soil was observed in the 0-5 cm layer (seasons 1 and 2), while in the 5-10 cm layer cm, there was a change after 12 months and the 10-15 cm layer increased only in season 1, with no change for the other seasons.

The fertilization with phosphorus in the planting furrow resulted in a variation in the levels of this element in the soil from the very low to medium classes, where they remained in the classes considered very low or low, lower than 2.8 mg dm^{-3} of P (for 5, 10 and 15 Mg ha^{-1}) and between 2.8 and 5.4 mg dm^{-3} of P (total straw collection), respectively, for soils with more than 600 g kg^{-1} of clay, in the 10-15 cm layer, according to Alvarez et al. (1999). In addition, according to Raij et al. (1997), the levels were classified as very low. Regarding the reduction in P levels observed in the present work, after one year of cultivation (Table 4), it is possible to highlight the fact that P is a nutrient absorbed by sugarcane in low quantities, which contributes to its low availability in the straw. Results presented by several authors demonstrate availability of 3 kg ha^{-1} of P is irrelevant in the first harvest. It is observed that, from the third year onwards, the material can release 2 to 4 kg ha^{-1} of phosphorus, low values when considering the need for this nutrient in the soil by sugarcane (OLIVEIRA et al., 1999; FORTES et al., 2012).

The reduction in V% followed the responses of calcium, magnesium, and potassium, which are results similar to those reported by Maia and Ribeiro (2004) and Rossetto et al. (2008), who state that over sugarcane cultivation time, there is a significant reduction in calcium, magnesium, base saturation, cation exchange capacity, and organic carbon. The V% values for periods 1 and 3 are close to those indicated by Spironello et al. (1997) who recommend a V% equal to 60 for sugarcane cultivation in the State of São Paulo. Once again, the need for liming on ratoons throughout the sugarcane cycle is clear, especially in areas with straw collection, especially to reduce acidity and maintain adequate levels of Ca and Mg.

It was observed that in the 0-5 cm layer (seasons 1 and 2), after 12 months of coverage regardless of straw doses, there was a slight increase in the organic matter content in the soil and its constancy in the other seasons (Table 4), suggest that maintaining straw, regardless of its quantity, in just one year, does not significantly result in an increase in OM in the soil. This fact corroborates the results obtained in research works (SEGNINI et al., 2013; BODORNAL et al., 2018; CASTIONI et al., 2019) which state that the constant maintenance of quantities of straw remaining from the sugarcane harvest sugar on the soil surface, without incorporation, has positive impacts on the conservation of soil organic matter and organic C.

This is in agreement with Segnini et al. (2013) who found higher OM contents, in the 0-5 cm layer, both in direct planting and in conventional tillage for sugarcane cultivation, especially when straw was maintained on the soil in a cycle, which was also found by Bordonal et al. (2018) when observing, in two harvests, higher OM contents in the soil when higher levels of straw were maintained in the soil.

It is noteworthy that the amount of nutrients released by straw mineralization is strongly influenced by environmental factors, such as temperature and water availability, which affect both the production of dry phytomass in the aerial part and the accumulation of nutrients and the rate of mineralization of this vegetable mass. Also, according to Rossetto et al. (2008), straw can contribute to the recycling of 10.9; 2.6; 64.6; 27.5; 12.8, and 9.0 kg ha^{-1} annually of N, P, K, Ca, Mg, and S, respectively, and the use of these nutrients by sugarcane will depend on the rate of mineralization of the organic matter.

For sugarcane, at the beginning of the harvest (season 1), straw levels influenced the Ca content of the surface layer up to 10 cm. A quadratic behavior was observed in the 0-5 cm layer (Figure 3A), with the maximum Ca value of 6.41 $cmol_c\ dm^{-3}$ in the soil when 15 Mg ha^{-1} of straw was maintained there (Figure 3A). In the 0-10 cm layer, the data were represented by a cubic equation with a tendency towards higher Ca content with the maintenance of 5 Mg ha^{-1} of straw on the soil (Figure 3B).

For mid-harvest sugarcane (season 2), the influence of straw levels on soil calcium content was observed only in the 10-cm layer, which showed a linear reduction as the amount of straw was increased (Figure 3C). When analyzing the sugarcane at the end of the cycle (season 3), a quadratic behavior was observed for the calcium contents in the 0-5, 5-10, and 10-15 cm layers, depending on the straw levels (Figures 3D, 3E and 3F). In this area, a tendency towards lower Ca levels was observed in the three layers, when 5 Mg ha^{-1} of straw was maintained on the soil, but there was a tendency for its values to increase when amounts of 10 or 15 Mg ha^{-1} were maintained.

By analyzing the Mg contents in the first season, it is observed an effect of straw levels only in the 0-5 cm layer (Figure 4A), fitting the quadratic model. In the second season (middle of the harvest), an effect of straw levels was found on Mg contents, adjusting to quadratic models, in the 0-5 cm (Figure 4B); 5-10 cm (Figure 4C) and 10-15 cm (Figure 4D) layers. It is pointed out that, similar to what was found for Ca, intermediate values of remaining straw (5 and 10 Mg ha^{-1}) resulted in a significant decrease in the Mg content in the soil, when compared to the treatment with total straw removal (0 Mg ha^{-1}).

For the levels of potassium in the soil, as there was no significant effect of straw levels in the entire soil profile evaluated for harvesting times 1 and 3, nor the interaction between straw levels and evaluations for both environments, the results for season 2 were presented (Figure 5).

Significant responses to straw levels were observed, with interaction among the evaluations (initial and final) and the straw levels in the 0-5 and 5-10 cm layers (Figures 5A and 5B). A quadratic adjustment was found for straw levels in the initial evaluation, in both layers, but without a significant effect of straw levels on the potassium content in the soil in the final assessment. For the 10-15 cm soil layer, no interaction was found between the straw levels and evaluations, with only responses from straw levels, observing an adjustment in the quadratic equation (Figure 5C).

When 15 Mg ha^{-1} was maintained on the soil, after a year of sugarcane cultivation, a tendency for potassium levels to increase in the 0-10 cm layer was observed, compared to the other quantities of straw evaluated. By analyzing the effects of straw levels on soil phosphorus content up to a depth of 20 cm, it was observed a significant effect for the 10-15 cm layer in season 2 (Figure 5D).

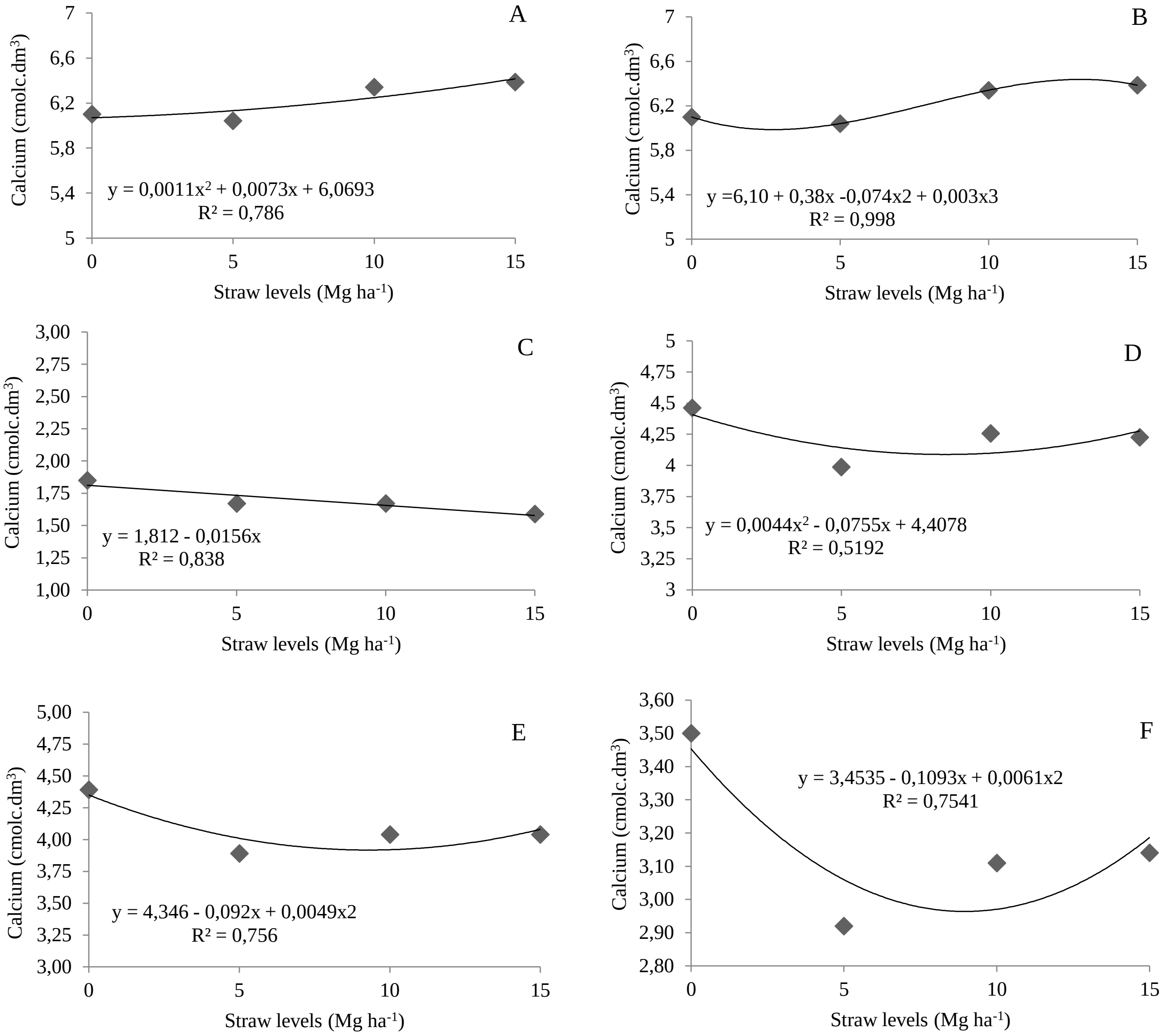

FIGURE 3 - Values of Calcium (Ca) values in the soil, subject to the respective straw levels, season 1, in the 0-5 cm layer (A); 5-10 cm (B); season 2, in the 10-15 cm layer (C) and season 3, in the 0-5 cm layer (D), 5-10 cm (E), 10-15 cm (F).

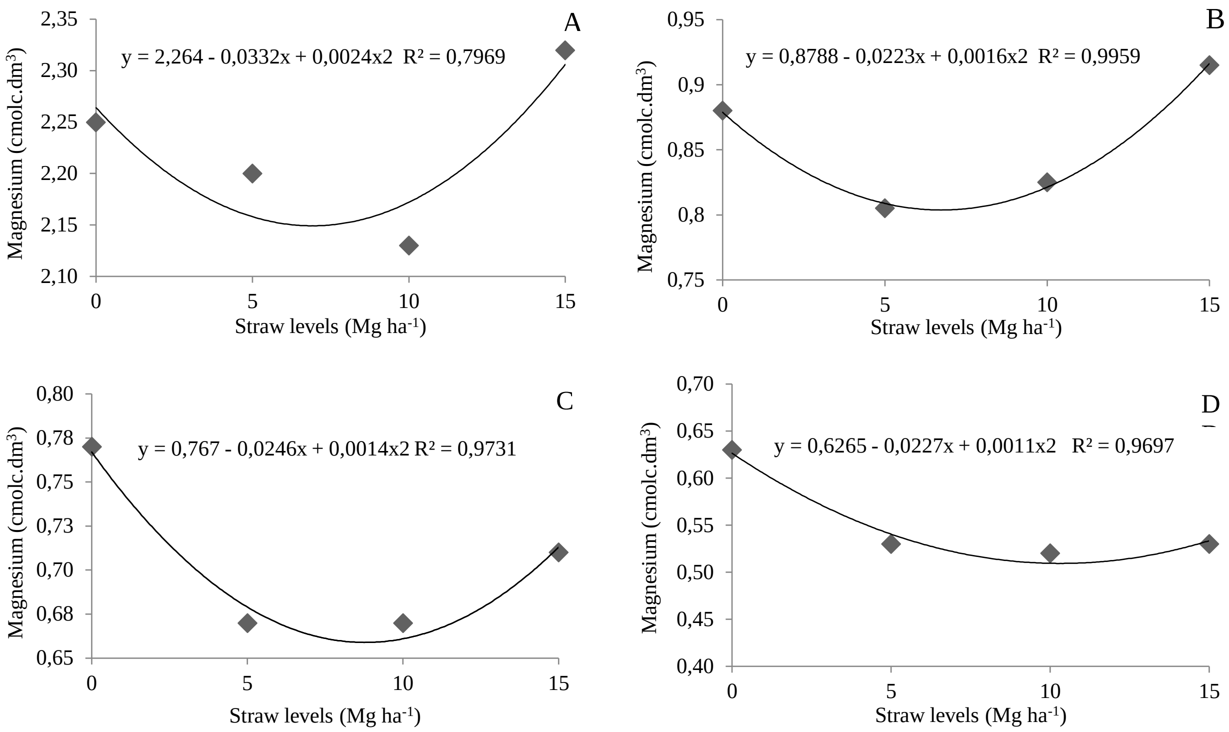

FIGURE 4 - Values of magnesium (Mg) in the soil subjected to the respective straw levels: Season 1, 0-5 cm layer (A) and Season 2, 0-5 cm (B), 5-10 cm (C) and 10-15 cm (D) layers.

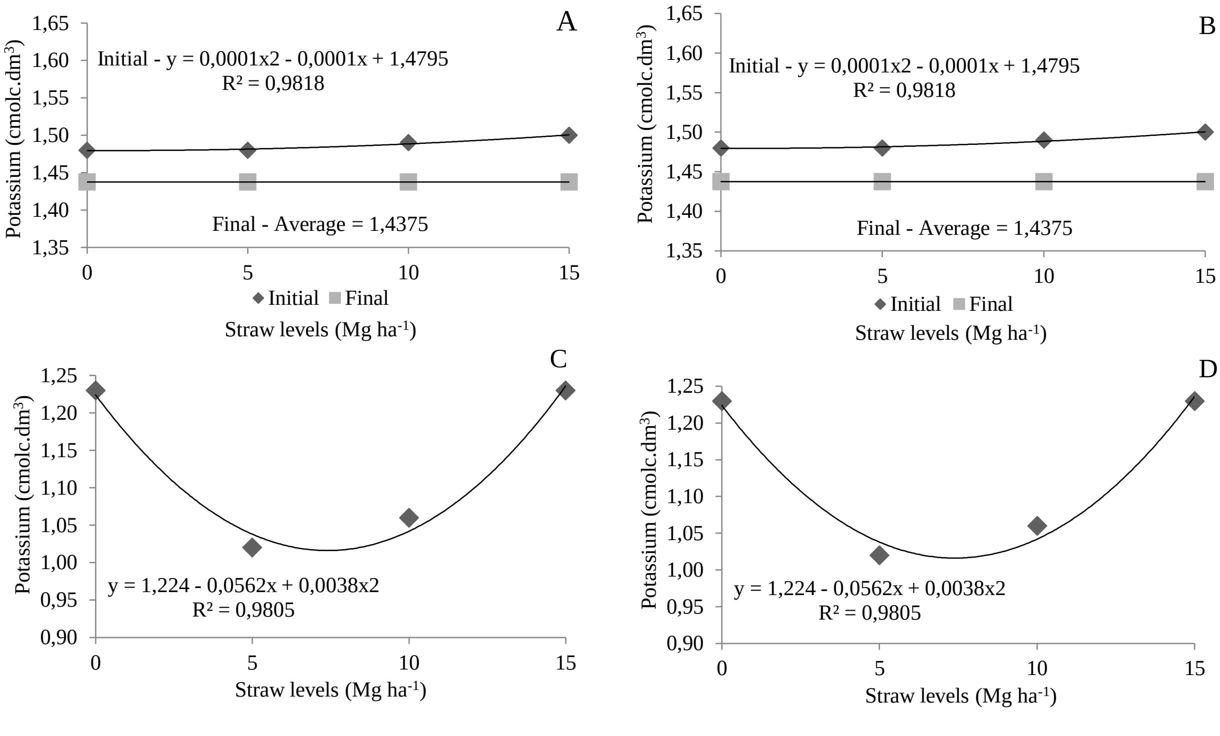

FIGURE 5 - Potassium (K) values in the soil, subject to the respective straw levels: season 2, 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C) layers and phosphorus (P) in the soil, subjected to the respective straw levels, 10-15 cm (D) layer.

Regarding V% analysis, it is observed that only for season 2 there was a significant effect of straw levels (Figure 6). For the 0-5 and 5-10 cm layers, there was a quadratic adjustment in the mean of the evaluations

(Figures 6A and 6B). Further, in the 10-15 cm layer, there was an effect only in the initial collection (Figure 6C), with a tendency towards lower values when D mediate amounts of straw were applied (5 and 10 Mg ha^{-1}). Such reduction in V% was followed by those observed in this work for Ca, Mg, and K.

The OM contents in the soil were not influenced by the straw levels in seasons 1 and 3 and the 0-5 cm layer for season 2. Therefore, the results for season 2 are presented in the 5-10 cm (Figure 6D) and 10-15 cm (Figure 6E) layers, where a tendency to reduce OM contents was observed as the amount of straw increased. However, significant reductions in OM levels were observed, which in practice did not influence sugarcane production in the second cutting season (mid-harvest).

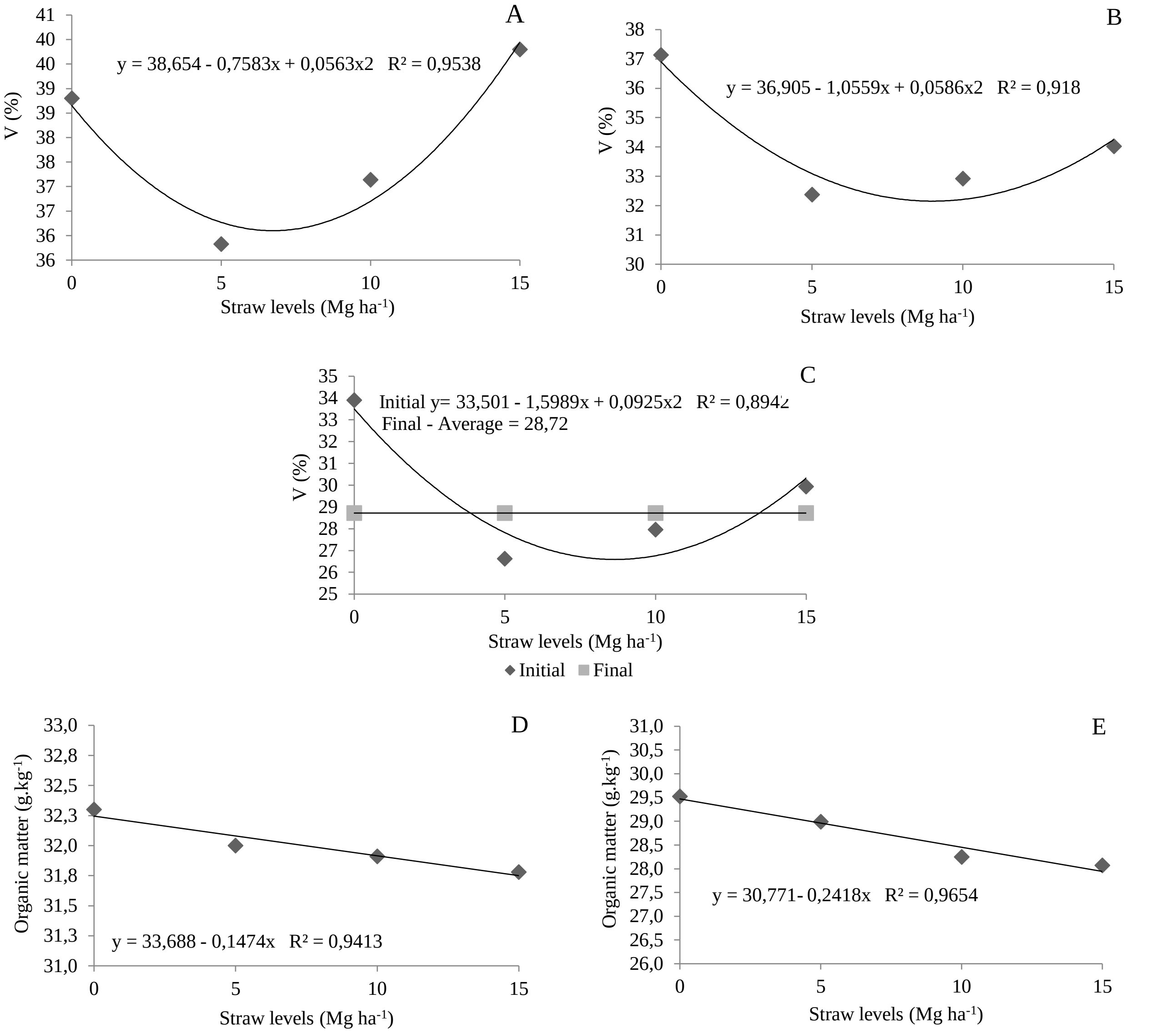

FIGURE 6 - Base saturation (V%), subjected to the respective straw levels: season 2, 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C) layers and organic matter in the soil, subjected to the respective straw levels: season 2, 5-10 cm (D) and 10-15 cm (E) layers.

Regarding sugarcane productive variables, the straw levels did not influence the number of stems ha^{-1} at 12 months after harvest, in the three sugarcane cutting seasons (Figure 7A). In seasons 3 and 1, an average of 85391 and 84318 stems ha^{-1} was observed and in season 2, a smaller number of stems ha^{-1} (64593). Concerning the harvest at the beginning of the season (season 1), the mid-season harvest (season 2), in an area cultivated with RB 835486, presented a lower number of stems ha^{-1}, probably because of the lower availability of water and temperature at ratoon sprouting and lower soil fertility in this plot. For the harvest at the end of the season (season 3), at 9.5 months of mechanical harvesting (MAC), there was no difference in the number of stalks ha^{-1} among the straw levels from 0 to 15 Mg ha^{-1}, at 9 .5 MAC, when the cultivar RB 835054 showed greater sensitivity to the presence of greater amounts of residual straw during the ratoon sprouting period, which resulted in lower tillering.

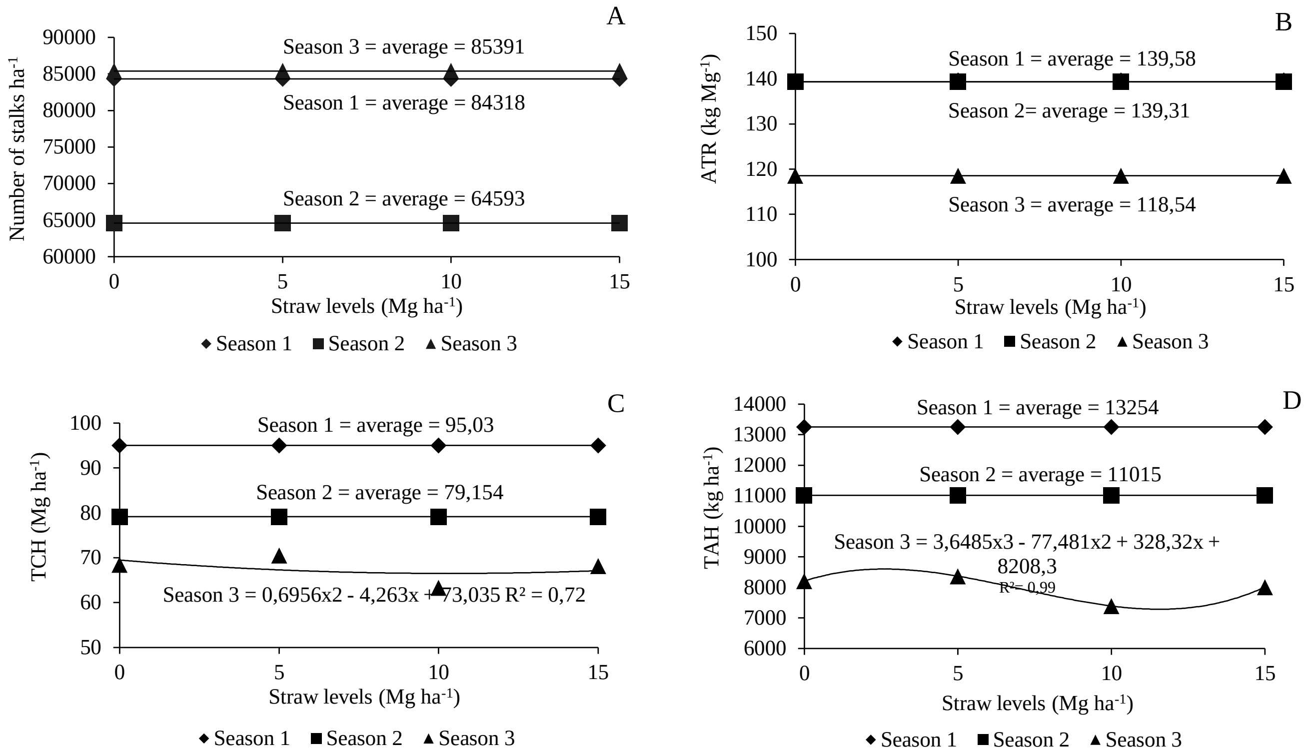

FIGURE 7 - Number of sugarcane stalks ha^{-1} (A), total reducing sugars (ATR) (B), stalk productivity (TCH) (C), and sugar productivity (TAH) (D) subjected to the respective levels of straw; season 1 (RB 85 5156), season 2 (RB 835486) and season 3 (RB 83 5054), evaluated 12 months after mechanical harvesting (MAC).

For total recoverable sugar content (ATR), no significant effect of the levels of straw was found for the three seasons (Figure 7B). Straw levels did not influence stalk productivity (TCH) in seasons 1 and 2, while in season 3, there were direct responses to different straw levels, in which the highest productivity (70.50 Mg ha^{-1}) was achieved when 5 Mg ha^{-1} of straw (Figure 7C) was applied. Sugar productivity (TAH) presented results similar to and directly proportional to those obtained for ATR and TCH, in which higher and constant values were obtained in seasons 1 (13253, 81 kg ha^{-1}) and 2 (11015.19 kg ha^{-1}). In addition, in season 3, where there was an influence of straw level, an increase in TAH was again observed with 5 Mg ha-1 of straw on the soil (Figure 7D).

The greater number of stalks at harvest in season 1 is due to the good adaptation of the cultivar RB 855156 (season 1) to the mechanized harvesting of raw sugarcane with the maintenance of straw over the ratoon, which combined with the harvest at the beginning of the season (adequate humidity and soil temperature), the application of 360 m^3 of vinasse through fertigation had an intense and rapid initial tillering. These characteristics of rapid and intense tillering in a mechanized raw sugarcane harvesting system can be attributed to factors such as more vigorous ratooning, earlier cultivar, and low sensitivity of the cultivar to the presence of straw or climatic conditions. For the harvest at the end of the season (season 3), at 9.5 MAC, when the cultivar RB 835054 showed greater sensitivity to the presence of greater amounts of residual straw during the ratoon sprouting period, which resulted in lower tillering. However, it should be observed that this was not a limiting factor for the establishment of the sugarcane crop, as at 9.5 MAC, on average, 12.8 industrializable stalks were obtained per meter, which is within the range recommended by Landell et al. (2002).

A lower ATR can be seen in season 3, which can be attributed to the late variety and, above all, to the influence of frost on the plants, causing them to be harvested earlier and, therefore, Leading to the accumulation of less sugar in the stalk.

It is noteworthy that the worst results for the production variables (Figure 3) obtained in season 3 are the result of the frosts responsible for bringing forward the harvest at that time. Despite this and the small effect of straw on such variables, it is noteworthy that maintaining an intermediate amount of straw in the field, at season 3, increased TCH and TAH of the late variety in the experimental region. In this sense, Melo et al. (2020) observed that maintaining quantities of straw in the soil, between 8 and 13 Mg ha^{-1}, is sufficient to support the physical conditions of the soil for root growth and improve sugarcane yield. Moreover, according to the same authors, a better distribution of roots increases the volume of soil explored, which can improve the absorption of water and nutrients by the plant.

Thus, the results observed in this study for soil fertility further reinforce the need to maintain quantities of straw in the soil continuously throughout the crop cycles, and that although the occasional maintenance of this straw has not adequately increased the fertility of the soil, other benefits resulting from maintaining straw for the soil-plant system such the increment in water availability and a reduction in soil temperature (SANTOS et al., 2022) and in the soil compaction (CASTIONI et al., 2019) can significantly impact the productivity and longevity of the crop.

Long-term experiments are necessary to demonstrate straw management strategies considering the edaphoclimatic and management conditions adopted in each production unit. Regardless of the soil management system, maintaining the straw remaining from the sugarcane harvest promotes the improvement of K and OM contents in the soil, by maintaining the chemical quality of the soil and improving stalk and sugar production levels in a sugarcane cycle, as well as its removal affects sugarcane leaf nutrition (ARCOVERDE et al., 2023).

CONCLUSIONS

Maintaining 15 Mg ha^{-1} of straw does not increase nutrient levels in the topsoil nor does there occur a reduction in organic matter values in the topsoil after one year of sugarcane cultivation, even with the total collection of straw.

A partial collection of straw without affecting the chemical attributes of the soil in the following harvest is possible since maintaining 5 Mg ha^{-1} promotes maximum stalk and sugar productivity at the end of the harvest (3rd season).

ACKNOWLEDGEMENTS

To the Coordination for the Improvement of Higher Education Personnel (CAPES), for the first author's doctorated scholarship, and to Usina São Fernando, for providing the area and supporting agricultural operations.

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