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Soil fertility, nutritional status, and sugarcane yield under two systems of soil management, levels of remaining straw and chiseling of ratoons

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ABSTRACT: Conservation management practices with minimum soil mobilization, maintenance of amounts of straw in the soil, and chiseling of ratoons interrows can be beneficial to soil quality, nutrition and sugarcane yield; however, the combination of these practices and their influence over the culture cycle should be better understood. This study aimed to assess the effects of levels of remaining straw and chiseling in the cultivation of ratoons on soil fertility, nutritional status and yield of stalks and sugar in one sugarcane cycle (five ratoons), under no-tillage and conventional tillage systems. The study was performed in Dourados municipality, Mato Grosso do Sul, Brazil, in areas with a Oxisol (*Latossolo*) with very clayey texture. Design in randomized blocks was adopted, with four repetitions, in a subdivided portions scheme. Portions were composed of levels of remaining straw (0, 50 and 100 %), annually, and collected alternately in odd years (0I) and even years (0P) established after the plant harvest; sub-portions were composed of systems with and without chiseling. In the fourth ratoon, leaf diagnosis was made with quantification of macro-nutrient contents, and during the fifth ratoon soil samples were collected for chemical analyses. By the end of the cycle, accumulated yields of stalks and sugar were determined. In both management systems, keeping 100 % of straw improved soil fertility and kept higher yield levels in one sugarcane cultivation cycle, while chiseling did not influence soil fertility, nutrition and sugarcane yield. The use of no-tillage farming for sugarcane cultivation proved to be feasible in corrected environments, and did not reduce stalk and sugarcane yield. Straw removal influenced nutrient leaf contents, regardless of soil management.

Keywords: conservation practices, straw, no-tillage farming system.

INTRODUCTION

Sugarcane is one of the main cultures produced worldwide, and is cultivated in over 100 countries. Approximately 83 % of sugarcane production is concentrated in ten countries, and Brazil is the world's largest producer, with around 37 % of the world's production, which represents 746 Mg yr^{-1} (FAO, 2021). Sugarcane is a culture with high biomass energy, with sugar stored in its stalk, and is used as raw material for ethanol and sugar production. Moreover, the lignocellulosic waste generated after sugar extraction can be used for the production of biofuels or other bioproducts (Awe et al., 2020).

Though the sugarcane sector has significantly used straw as raw material for bioenergy production (Santos et al., 2022), its maintenance in the field may result in improvement in the chemical, physical and biological soil properties, like increase in organic matter content (Bordonal et al., 2018), reduction in thermal fluctuations in surface layers (Santos et al., 2022), increase in water infiltration, conservation of water content (Santos et al., 2022), erosion control (Valim et al., 2016), besides reduction in susceptibility to compaction (Castioni et al., 2019). These changes directly affect the soil conditions, the growth of roots, and sugarcane development, yield, quality, and longevity (Melo et al., 2020).

Studies intending to propose conservation practices of soil management in different edaphoclimatic environments for sugarcane production are essential for the sustainability of these systems, mainly in environments with soil under physical and/or chemical restrictions and under water deficit in periods of the year. So, practices of management of soil cultivated with sugarcane can be selected to provide an appropriate balance between soil sustainability, high yields, and minimizing costs (Marasca et al., 2016). In this context, no-tillage farming can be a feasible alternative, as its use has demonstrated promising results in sugarcane yield and can be a more economical method of cultivation when compared to conventional tillage systems (Moraes et al., 2016; Arcoverde et al., 2019).

Potentials and limitations of each type of soil should be considered in the adoption of the management system in sugarcane production environments where there is intense traffic of machines throughout the cycle; in case of clay and heavy clay soils, for example, higher susceptibility to soil structural degradation has been observed due to compaction. Machine traffic in agricultural operations during the sugarcane cycle is the main responsible for soil compaction next to the planting row, where roots are prevalent in surface layers (up to 0.40 m) and next to clumps, up to 0.30 m (Sá et al., 2016).

Since sugarcane roots growth is concentrated next to the planting row center, soil tillage with chiseling only in the row presents itself as an alternative to conventional management with chiseling in total area, resulting in economic and environmental gains, with no impact on plant growth (Mazaron et al., 2022). Thus, the practice of soil chiseling between ratoons rows in ratoons presents the potential to mitigate soil compaction, improve physical and water attributes, and availability of nutrients to the plants. However, the use of this technique has raised controversy, since its feasibility for sugarcane production (Sá et al., 2016), and its efficiency in mitigating soil compaction has been questioned, because it has a temporary effect (Nunes et al., 2015; Sá et al., 2016). The mechanical chiseling on soil may have negative effects, decreasing soil organic carbon level and reducing the soil aggregates size and stability with soil revolving (Nunes et al., 2015).

Decision-making on straw management in sugarcane production involves economic, agronomic, environmental, and logistic aspects, and should be guided in each region, based on the culture and soil responses to the removal of straw, according to the local specific characteristics of soil, climate, and culture management (Castioni et al., 2019). However, results obtained in research demonstrate the importance of keeping amounts of remaining straws from sugarcane harvest on the soil surface, without incorporation, due to the positive impacts on the soil organic matter conservation and the organic C (Segnini et al., 2013; Bordonal et al., 2018; Castioni et al., 2019), increase of root mass

(Melo et al., 2020), improvement of plant nutrition (Cherubin et al., 2019) and increase in stalk productivity (Melo et al., 2020; Aquino et al., 2018) and sugarcane yield (Aquino et al., 2018). The removal of straw that could be kept on the soil may remove most nutrients that could later be reused by the culture, which demands establishing adequate levels of remaining residues to keep sugarcane nutritional balance (Cherubin et al., 2019).

Therefore, recommendations of straw management combined with other soil conservation practices are necessary for the sustainability of these production systems by soil and water conservation, mitigation of compaction and its negative implications in sugarcane yield and longevity, and other ecosystemic services (Castioni et al., 2019). In this context, the following question arises: what is the impact of adopting no-tillage, associated or not with the keeping of the remaining straw and chiseling of ratoons, on the fertility and sugarcane yield in one cultivation cycle (five ratoons)?

We hypothesized that no-tilage coupled with keeping amounts of remaining straws from sugarcane harvest on the soil surface, is an efficient management strategy to attenuate soil chemical degradation and increase stalk yield of sugarcane, compared to the traditional system (conventional tillage). This study aimed to assess the effects of levels of remaining straw and chiseling in the cultivation of ratoons on soil fertility, nutritional status and yield of stalks and sugar over one cycle of sugarcane (five ratoons) under no-tillage and conventional tillage systems.

MATERIALS AND METHODS

Localization and characterization of the experimental area

The research was conducted over a sugarcane cycle, during the first, second, third, fourth and fifth ratoons (2014/2015, 2015/2016, 2016/2017, 2017/2018 and 2018/2019). The soil in the area is classified as Oxisol [Rhodic Eutrudox] (Soil Survey Staff, 2014) and *Latossolo Vermelho distroférrico* (Santos et al., 2018), having on the layer 0.00 to 0.10 m 722 g kg^{-1} of clay, 120 g kg^{-1} of silt and 158 g kg^{-1} of sand; on the layer 0.10 to 0.20 m 743 g kg^{-1} of clay, 104 g kg^{-1} of silt and 153 g kg^{-1} of sand; and on the layer 0.20 to 0.40 m 780 g kg^{-1} of clay, 79 g kg^{-1} of silt and 141 g kg^{-1} of sand.

The experiment was conducted in the municipality of Dourados, Mato Grosso do Sul State, Brazil (latitude 22° 25’ 86” S, longitude 54° 97’ 47” W, altitude 410 m) (Figure 1). The climate in the region, according to the classification system by Köppen-Geiger, is Cwa, humid mesothermal, with hot summers and dry winters (Fietz et al., 2017). According to data from Dourados meteorological station from Guia Clima (www.cpao.embrapa.br/clima/), from January 2015 to December 2019, in 2015, 2016, 2017, 2018 and 2019, accumulated rainfall and average temperatures of approximately 1,707 mm and 23.3 °C, 1,341 mm and 22.4 °C, 996 mm and 23.4 °C; 1,314 mm and 23.0 °C, 890 mm and 24.1°C, respectively, were recorded (Figure 2).

Experiment treatments, design and conduction

The experiment was implanted in September 2014, after mechanized harvest of the plant-cane from cultivar RB966928, recommended for medium restriction environments (Ridesa, 2010). The experiment started after the renewal of the area cultivated with sugarcane, which was subject to mechanized harvest, without removing the residual straw from the previous cycle (2006 to 2012) and cultivated with soybean in the 2012/13 crop.

In 2012, at the time of the cane field renovation, conventional tillage was performed in a portion of the area and, in the other portion, no-tillage farming was adopted. In both areas, chemical elimination of the last ratoon re-growth was made by applying 6.0 L ha^{-1} of glyphosate herbicide + 1.8 L ha^{-1} of 2.4-D herbicide in spray volume of 150 L ha^{-1}. Corrective application was performed later (2.0 Mg ha^{-1} of phosphogypsum,

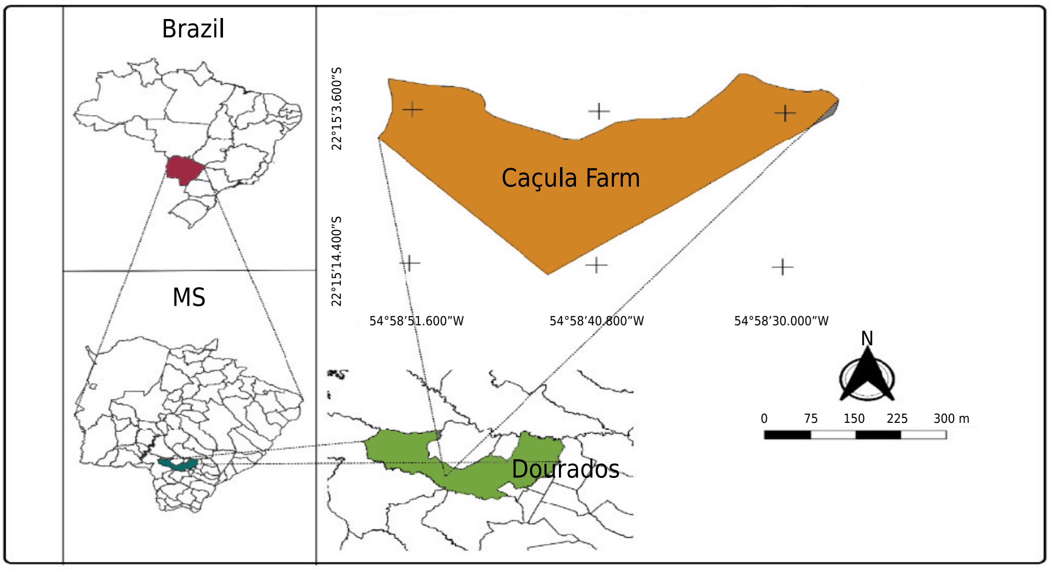

Figure 1. Geographic localization of the experimental area.

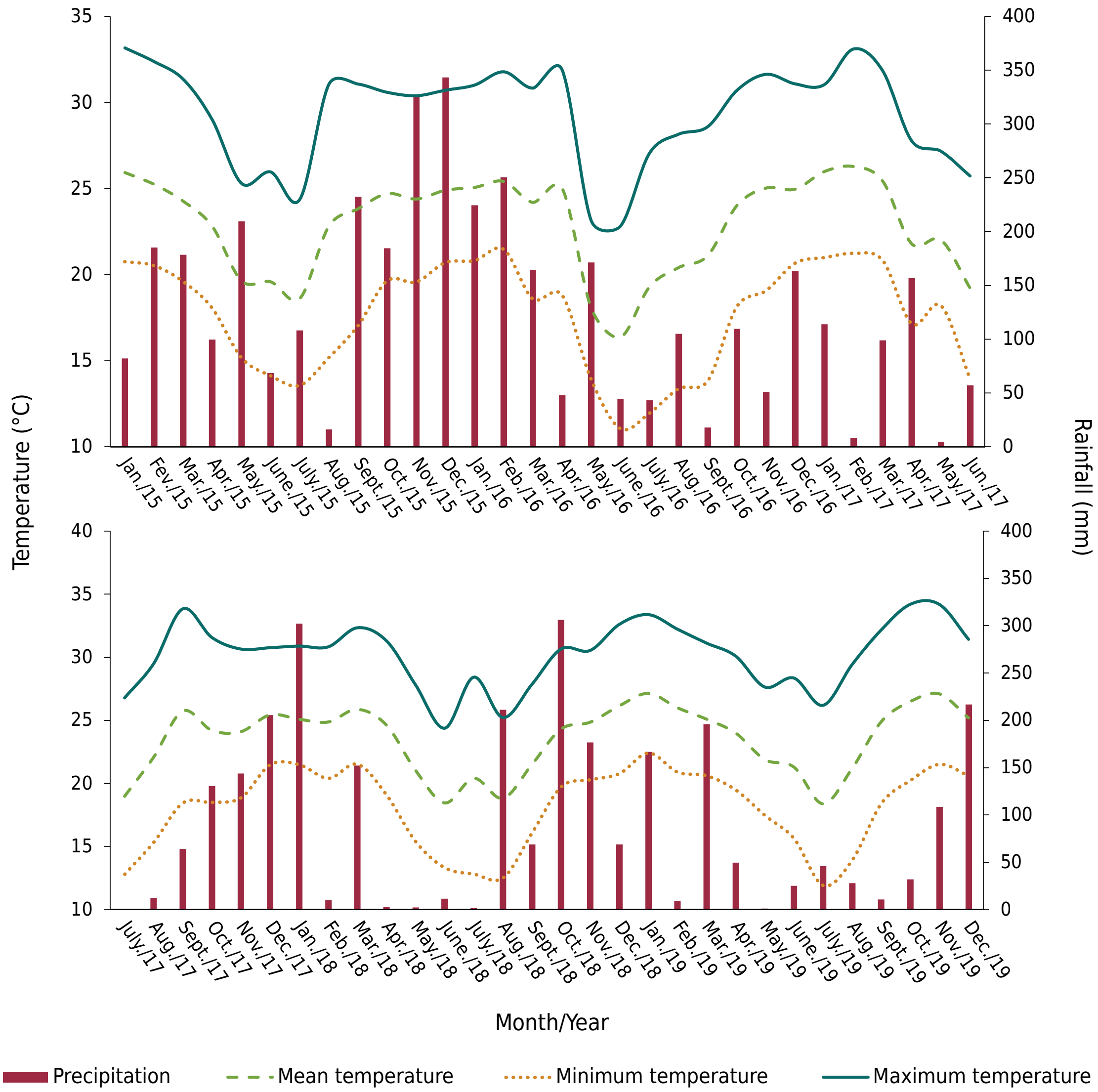

Figure 2. Monthly accumulated rainfall and monthly average temperatures obtained from 2015 to 2019. Source: Embrapa Western Agriculture, Dourados, MS.

and 4.0 Mg ha^{-1} of dolomitic limestone) on the soil surface. In the conventional tillage area, correctives and residual straw were incorporated into the soil using harrowing with disc harrow, subsoiling, harrowing with intermediate harrow and harrowing with leveling harrow. The planting fertilizer used in the experimental area was 600 kg ha^{-1} of formula N-P-K 05-25-25. A dose of 120 kg ha^{-1} of N was applied 150 days after planting, along with cultural practices (hilling-up).

In each of these areas (no-tillage or conventional tillage), the experiment was conducted with randomized blocks design, with four repetitions, in scheme of subdivided portions. The portions were composed by levels of remaining straw: without straw removal (100 %), partial straw removal (50 %), straw total removal (0 %), annually; and alternately, with full removal of straw in odd years (0 odd – 0I, removal after first (2014/2015), third (2016/2017) and fifth (2018/2019) cuttings, which corresponds to plant cane and second and fourth ratoons, respectively) and total removal of straw in even years [0 even – 0P, removal after second (2015/2016) and fourth cuttings (2017/2018), which correspond to first and third ratoons, respectively]. The effects of soil chiseling in ratoon cultivation (with and without chiseling in sugarcane interrows) were assessed in sub-portions. The 30 experimental units were composed of six sugarcane rows, 1.5 m apart, with 15 m in length.

After the plant-cane harvest, in September 2014, the levels of remaining straw were applied to the portions (without straw removal – 100 %, straw partial removal – 50 %, straw total removal – 0 %, and straw total removal in odd year – 0I), using a hay rake model AL 1290, make New Holland, and bailer make New Holland, model BB 1290, and for collection of bales a trailer, New Holland, model AC 1290. The partial collection (50 %) was defined through regulation of the straw hay rake height. The implantation of treatments (0, 50, 100 %, 0I and 0P) resulted in the quantities of remaining fresh straw presented in figure 3. Treatments 0 Even (0P) and 0 Odd (0I) were conceived as strategies in the production unit operational planning to meet the demand for straw collection from the soil in recently harvested areas. Both treatments refer to the total removal of straws, after cuttings, in alternate years. Therefore, such strategies of straw collection aimed at satisfactorily meeting agronomic, operational and economic demands in the sugarcane production system.

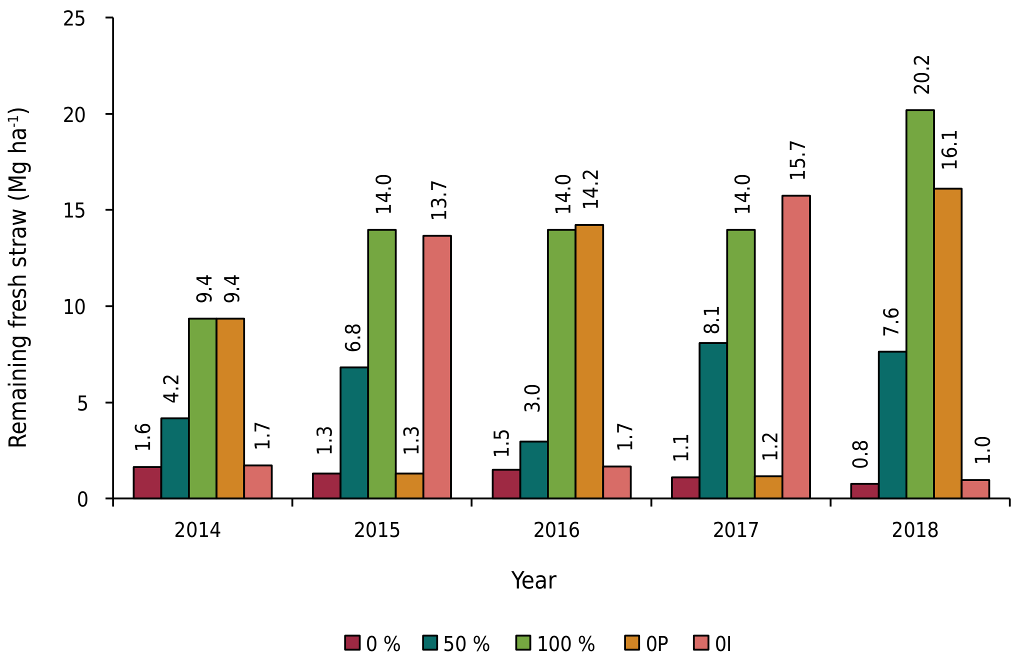

Figure 3. Amount of remaining fresh straw kept each year in the different straw levels.

Treatments without and with soil chiseling were applied to the sub-portions using for that Novo São Francisco cultivator with simple rod, make DMB, with two semi-parabolic subsoiling rods and winged tips, two 23” cutting discs and two clod-breaking rollers, with a single rod in the center of each planting row at approximately 0.3 m depth.

Fertilizations in the first (2014/2015), second (2015/2016), third (2016/2017), fourth (2017/2018), and fifth cuttings (2018/2019) (respectively, first, second, third, fourth, and fifth ratoons) were applied 30 days after harvest, with 120 kg ha^{-1} of K_2O as, potassium chloride, manually, on the soil surface, parallel to the planting row (in both sides) and 150 kg ha^{-1} of N as, urea, distributed and incorporated with a ratoon plow. In the treatment without chiseling, this application was made on the soil surface, parallel to the planting row, on both sides, using the same set of tractor/plow without chisels. After the harvest of the third ratoon, in 2017, 4 Mg ha^{-1} of dolomitic limestone was applied to the whole experimental area. The chronology of the processes executed during the experiment is summarized in figure 4.

Soil samping and chemical analyses

After implanting the soil management systems, in 2012, soil samples were collected in each of these systems in layers of 0.00 to 0.10, 0.10 to 0.20, and 0.20 to 0.40 m. The sample comprised 20 simple samples, randomly collected in the experimental area, aiming at the chemical characterization of the soil (Table 1). In 2019, after the harvest of the fifth ratoon, two trenches were open in each sub-portion, transversal to the cultivation row, in the cane interrow, apart 0.15 m from the plants, with 0.60 m in length, 0.40 m in width, and 0.40 m of depth. In one of the trenches’ wall, perpendicular to the cane row, soil samples were collected in layers of 0.00 to 0.10, 0.10 to 0.20 and 0.20 to 0.40 m, with a PVC gutter and stainless steel spatula. A slice of soil was cut with around 0.01 m thickness, 0.60 m in length and width, corresponding to the sampling depth.

Soil samples were taken to Embrapa Western Agriculture in Dourados, MS, physical/chemical analyses laboratory for determination of pH($CaCl_2$) by potentiometry; potential acidity and aluminum by titration; phosphorus, by molecular absorption spectrometry; potassium, by flame emission spectrophotometry; calcium and magnesium by atomic absorption spectrophotometry, and total carbon, by infrared absorption spectroscopy (Teixeira et al., 2017).

Leaf diagnosis

In 2018 (fourth ratoon), in each experimental unit, one leaf sample was collected (leaf +3, third leaf with visible ligula on the plant upper portion), in twelve plants, four months

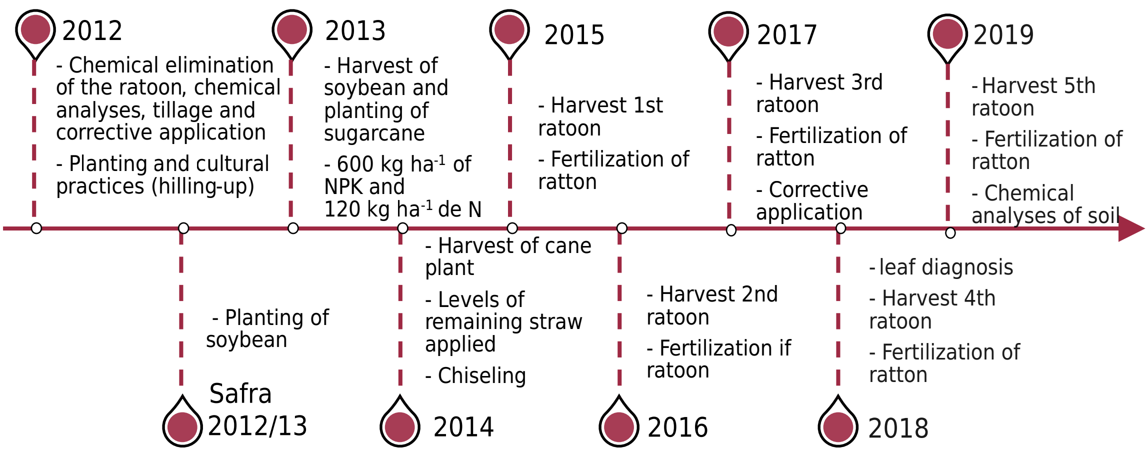

Figure 4. Chronology of the processes carried out during the conduct of the experiments.

Table 1. Soil chemical characterization in the layers of 0.00-0.10, 0.10-0.20 and 0.20-0.40 m after implantation of no-tillage (NTS) and conventional tillage (CTS) systems in 2012

Management	pH($CaCl_2$)	Al^{3+}	Ca^{2+}	Mg^{2+}	CEC	K	P	M	V	OM
		$cmol_c$ dm^{-3}				mg dm^{-3}		%		g kg^{-1}
					0.00 to 0.10 m					
NTS	5.1	0.0	5.7	2.7	13.9	84.2	5.0	0.0	63.1	39.3
CTS	5.7	0.0	7.0	2.5	13.2	90.0	7.1	0.0	73.1	42.2
					0.10 to 0.20 m					
NTS	4.7	0.3	2.7	1.5	10.6	44.2	2.9	6.8	41.5	30.7
CTS	5.3	0.0	4.7	1.9	11.3	54.2	2.8	0.5	59.9	32.0
					0.20 to 0.40 m					
NTS	4.1	1.2	0.8	0.4	11.4	20.8	1.0	47.6	11.8	21.1
CTS	4.1	1.1	1.0	0.5	9.7	23.3	1.3	40.5	15.7	21.6

Al: aluminum; Ca: calcium; Mg: magnesium; CEC: cation exchange capacity; K: potassium; P: phosphorus; M: Al saturation; V: base saturation; OM: organic matter contents.

after sprouting. The samples were formed by the middle third of leafs, excluding the main vein. At Embrapa Western Agriculture physical/chemical analyses laboratory, the samples were dried in forced air circulation oven at 65 °C for 72 h and crushed in Wiley type mill, using 20-mesh sieve (0.85 mm). The chemical analysis of the leaf tissue samples was made as described in Nogueira et al. (2005), determining N, P, K, Ca, Mg and S.

Stalk and sugar yield

The yield of stalks and sugar was estimated by the end of the first (2014/2015), second (2015/2016), third (2016/2017), fourth (2017/2018), and fifth (20189/2019) ratoons, by manual collection of two sub-samples of 10 industrializable stalks, collected in two distinct points in the useful area of each portion (4 rows of 15 meters). Stalk yield (TCH) was obtained later, expressed in Mg ha^{-1}, with data from the mass of sugarcane bundles and the number of stalks per hectare, using a simple rule of three. Sugarcane yield estimation (TSH) was made by multiplying data from total reducing sugars (TRS) by TCH results, in each experimental unit. The determination of TRS values was made through technological quality analysis, according to the methodology in force at SPCTS (Sugarcane payment system by sucrose content) described in Fernandes (2003). Finally, the sum of average data of TCH and TSH was made, and values accumulated in five ratoons were obtained.

Statistical analysis

The results of soil and sugarcane leaf chemical analyses, as well as stalk (TCH) and sugar (TSH) accumulated yield data, underwent variance analysis by each management system (no-tillage or conventional), as a double factor between straw management and soil chiseling. Means were compared with the Tukey test at 5 % probability level, with the statistic program SIRVAR® (Ferreira, 2014).

RESULTS

Soil chemical properties

Comparison of contents of Ca^{2+} + Mg^{2+} observed in the initial characterization (Table 1) and those determined after five cuttings of cane ratoons (Table 2) enabled to verify the reduction in the availability of these nutrients in layers 0.00-0.10 and 0.10-0.20 m, in both soil management systems (no-tillage - NTS or conventional tillage - CTS), despite the application of 4 Mg ha^{-1} of dolomitic limestone in the third ratoon (in 2017). This reduction in Ca^{2+} + Mg^{2+} content was more expressive in the area cultivated under CTS

(41.5 and 29.4 % reduction in layers 0.00-0.10 and 0.10-0.20 m, respectively), against NTS (24.3 and 1.4 % reduction, respectively). On the other hand, in the 0.20-0.40 m layer, there was an increase in Ca^{2+} + Mg^{2+} availability, higher in NTS (66.7 %) than in CTS (25.3 %).

Table 2 shows the interaction of the effects of straw levels and chiseling in the two systems of soil management. In the NTS area, it was observed tendency of significantly higher contents of Ca^{2+} + Mg^{2+} under conditions of full removal of straw (0 % of straw) in the three layers of soil assessed; on the other hand, where there was no soil chiseling, the effect of straw levels was less evident, with tendency of significantly higher contents on the surface layer and lower in the 0.20 to 0.40 m layer in the treatment without straw removal (100 % of straw). In the area cultivated under CTS, without chiseling, there were lower nutrient availabilities in the 0P treatment (in all layers assessed), 50 %, and 0I (in the two lower layers). With regard to chiseling effects, it was observed that, in NTS,

Table 2. Sum of Ca^{2+} and Mg^{2+} contents in 0.00 to 0.10, 0.10 to 0.20, and 0.20 to 0.40 m layers of a Oxisol, under the effect of soil chiseling and levels of remaining straw, after five cuttings of sugarcane, in two systems of soil management

Straw level	Ca^{2+}+Mg^{2+}											
	No-tillage						Conventional tillage					
	Chiseling						Chiseling					
	With		Without		Average		With		Without		Average	
	cmol$_c$ dm^{-3}											
	0.00 to 0.10 m											
0 %	9.1	Aa	7.7	ABb	8.4	A	5.8	ABa	5.8	ABa	5.8	A
50 %	6.9	Ba	6.7	Ba	6.8	B	4.9	Ba	5.4	ABa	5.1	A
100 %	7.9	ABa	8.5	Aa	8.2	A	5.1	Bb	6.3	Aa	5.7	A
0I	4.6	Ca	4.4	Ca	4.5	C	6.6	Aa	5.7	ABb	6.2	A
0P	3.6	Ca	4.3	Ca	3.9	C	5.2	Ba	4.9	Ba	5.0	A
Average	6.4	a	6.3	a	6.4		5.5	a	5.6	a	5.6	
C.V. (%) for straw level:					9.3						11.2	
C.V. (%) for chiseling system:					11.6						7.1	
	0.10 to 0.20 m											
0 %	5.8	Aa	4.3	Ab	5.0	A	4.0	Ab	6.3	Aa	5.1	AB
50 %	3.8	BCa	3.8	Aa	3.8	B	4.5	Aa	3.8	Ba	4.1	B
100 %	3.3	Ca	4.1	Aa	3.7	B	5.5	Aa	6.2	Aa	5.8	A
0I	3.0	Ca	4.0	Aa	3.5	B	4.5	Aa	3.9	Ba	4.2	B
0P	5.0	ABa	4.3	Aa	4.7	AB	4.8	Aa	3.4	Bb	4.1	B
Average	4.2	a	4.1	a	4.1		4.6	a	4.7	a	4.7	
C.V. (%) for straw level:					17.8						16.1	
C.V. (%) for chiseling system:					15.1						10.3	
	0.20 to 0.40 m											
0 %	2.6	Aa	2.2	Aa	2.4	A	1.5	Ab	2.5	Aa	2.0	A
50 %	2.2	ABa	2.3	Aa	2.2	AB	2.0	Aa	1.6	Cb	1.8	A
100 %	1.6	Ca	1.6	Ba	1.6	C	1.9	Ab	2.2	ABa	2.1	A
0I	1.8	BCa	2.1	ABa	2.0	BC	1.7	Aa	1.8	BCa	1.7	A
0P	1.9	BCa	1.7	Ba	1.8	C	1.9	Aa	1.7	Ca	1.8	A
Average	2.0	a	2.0	a	2.0		1.8	b	1.9	a	1.9	
C.V. (%) for straw level:					11.1						12.7	
C.V. (%) for chiseling system:					11.1						7.5	

In each sampling layer, and each cultivation system, means followed by the same lowercase letter in the line and uppercase in the column do not differ from each other, by the Tukey test at 5 %. 0I: with collection of straws in Odd years; 0 P: collection of straws in even years.

soil surface disaggregation in sugarcane interrows resulted in higher contents of Ca^{2+} + Mg^{2+} in layers 0.00 to 0.10 and 0.10 to 0.20 m, only in the 0 % straw treatment; and in CTS, chiseling provided an increase in these nutrients availability in treatments 0I (only in layer 0.00 to 0.10 m), 0P (0.10 to 0.20 m) and 50 % of straw (0.20 to 0.40 m) and reduction in the 0 % straw treatment (in layers 0.10 to 0.20 and 0.20 to 0.40 m).

The application of 150 kg ha^{-1} of P_2O_5 in the planting furrow was not sufficient to provide appropriate availability of this nutrient in the soil (Table 1). The comparison of values presented in tables 1 and 3 shows a reduction in P availability in the soil in the three layers assessed, and this reduction was more pronounced in the area cultivated under CTS (63.5, 41.4 and 16.9 % reduction in layers 0.00 to 0.10 m, 0.10 to 0.20 m and 0.20 to 0.40 m, respectively) against NTS (25.6, 34.1 and 4.0 % reduction, respectively).

It was observed that, in NTS, chiseling resulted in a significant reduction in P content of the soil surface layer, mainly under the absence of straw removal (100 % of straw). On the other hand, a significant increase was observed in this nutrient availability with the 100 % straw treatment, only when associated with the absence of chiseling (Table 3). In the area under CTS, with chiseling, higher P content was observed in treatment 0P, layers 0.00 to 0.10 and 0.20 to 0.40 m. However, in treatment 0P, there was complete removal of straw (in 2017, after the fourth cutting) two years before soil samples collection (in 2019), and there is no plausible explanation for the fact that this same effect was not observed in the treatment with total removal of straw annually – 0 % of straw (Table 3). When the soil was managed with implements but without chiseling, there was a significant effect on the levels of straw only in layer 0.10 to 0.20 m, with reduction in P availability in the treatment 0P. With regard to the effect of soil surface revolving in interrows, it was observed that chiseling promoted a significant increase in P content in the three soil layers assessed, but only in treatment 0P (Table 3).

The supply of 150 kg ha^{-1} of K_2O to the planting furrow resulted in K contents (Table 1) considered high (from 71 to 120 mg dm^{-3} of K), according to Alvarez et al. (1999), in both soil management systems, in the layer of 0.00-0.10 m, and medium (from 41 to 70 mg dm^{-3} of K) in layer of 0.10-0.20 m. However, the cover fertilization with 120 kg ha^{-1} yr^{-1} of K_2O proved insufficient to keep the plants' demand, resulting in reduced average content of this nutrient in the three soil layers these. Such effect was more pronounced in the area cultivated under CTS (Table 4). It should be noted that this reduction in average contents of K resulted in the change of availability classes to medium and low (from 16 to 40 mg dm^{-3} of K) in layers of 0.00 to 0.10 and 0.10 to 0.20 m, respectively.

It was observed that maintaining 100 % of straw, with or without soil chiseling, in both soil management systems, resulted in higher K contents of this element in the 0.00 to 0.10 m layer (Table 4). This result was also observed in the 0.10 to 0.20 m layer, only where associated with chiseling. The chiseling effect, on the other hand, was less evident. However, noted that this agricultural practice promoted both increase in K availability (where associated to the 100 % straw treatment, in both soil management systems, in the 0.10 to 0.20 m layer), as well as reduction when associated to treatment 0I in conventional planting and in layer 0.00 to 0.10 m, and the 100 % straw treatment, under NTS, in 0.20 to 0.40 m layer).

In the area under NTS, base saturation V% (62.8 %) was kept practically unchanged in the surface layer against the value observed at the beginning of the experiment (63.1 %); and in lower layers, increases in these values were observed, mainly between 0.20 to 0.40 m (Table 5). In the area with CTS, on the other hand, a reduction in V% in up to 0.20 m of depth was observed, and an increase in values in the 0.20 to 0.40 m layer, similar to what was observed with contents of Ca^{2+} + Mg^{2+} (Table 5). However, it should be noted that in the 0.20 to 0.40 m layer, increase in V was proportionally higher in CTS, though there was a more pronounced increase in contents of Ca^{2+} + Mg^{2+} in the NTS treatment.

Table 3. Phosphorus contents extracted by Mehlich-1 in 0.00 to 0.10, 0.10 to 0.20, and 0.20 to 0.40 m soil layers of an Oxisol, under soil chiseling and levels of remaining straw, after five sugarcane cutting, in two systems of soil management

Straw level	Phosphorus											
	No-tillage						Conventional tillage					
	Chiseling						Chiseling					
	With		Without		Average		With		Without		Average	
	mg dm^{-3}											
	0.00 to 0.10 m											
0 %	4.2	Aa	3.2	Ba	3.7	A	2.7	Ba	2.1	Aa	2.4	A
50 %	4.5	Aa	3.4	Ba	3.9	A	2.7	Ba	2.2	Aa	2.4	A
100 %	3.0	Ab	6.8	Aa	4.9	A	2.3	Ba	2.3	Aa	2.3	A
0I	2.7	Aa	3.0	Ba	2.8	A	2.5	Ba	2.7	Aa	2.6	A
0P	3.6	Aa	2.8	Ba	3.2	A	4.4	Aa	2.0	Ab	3.2	A
Average	3.6	a	3.8	a	3.7		2.9	a	2.3	b	2.6	
C.V. (%) for straw level:					30.3						20.0	
C.V. (%) for chiseling system:					24.4						23.3	
	0.10 to 0.20 m											
0 %	2.0	Aa	1.8	Aa	1.9	A	1.4	Aa	1.7	ABa	1.6	A
50 %	1.5	Aa	1.9	Aa	1.7	A	1.7	Aa	1.7	ABa	1.7	A
100 %	1.9	Aa	1.9	Aa	1.9	A	1.7	Aa	1.6	ABa	1.7	A
0I	1.6	Aa	2.0	Aa	1.8	A	1.6	Ab	2.1	Aa	1.9	A
0P	2.7	Aa	1.8	Aa	2.3	A	1.8	Aa	1.1	Bb	1.5	A
Average	1.9	a	1.9	a	1.9		1.6	a	1.7	a	1.7	
C.V. (%) for straw level:					35.8						24.6	
C.V. (%) for chiseling system:					26.4						14.0	
	0.20 to 0.40 m											
0 %	0.9	Aa	1.1	Aa	1.0	A	0.8	Ba	1.1	Aa	1.0	A
50 %	0.8	Aa	1.0	Aa	0.9	A	0.9	Ba	1.0	Aa	1.0	A
100 %	0.9	Aa	1.0	Aa	1.0	A	1.2	Ba	1.0	Aa	1.1	A
0I	1.0	Aa	1.0	Aa	1.0	A	1.1	Ba	0.9	Aa	1.0	A
0P	0.9	Aa	1.0	Aa	0.9	A	2.1	Aa	0.7	Ab	1.4	A
Average	0.9	b	1.0	a	1.0		1.2	a	0.9	b	1.1	
C.V. (%) for straw level:					20.5						21.1	
C.V. (%) for chiseling system:					14.2						25.0	

In each sampling layer, and each cultivation system, means followed by the same lowercase letter in the line and uppercase in the column do not differ from each other, by Tukey test at 5 %. 0I: without collection of straws in Odd years; 0 P: without collection of straws in even years.

The effects of straw levels on V% were relatively similar to what was observed for contents of Ca^{2+} + Mg^{2+}, and in the NTS area, with chiseling, there was higher V% in the 0% straw treatment, in the 0.00 to 0.20 m layer. On the other hand, in the CTS area, higher V% were observed in treatments 0I (only where associated to chiseling, in the surface layer), 0 % and 100 % of straw (only without chiseling in the 0.10 to 0.40 m layer) (Table 5).

As compared to initial values, reductions in organic matter contents (OM) in the soil (Table 6) were observed in NTS treatment (22.3, 19.5 and 4.2 %, in layers 0.00 to 0.10 m, 0.10 to 0.20 m and 0.20 to 0.40 m, respectively), similar to what was observed in CTS (27.3, 17.8 and 4.5 %, respectively). In the NTS area, associated to chiseling, straw levels of 0, 50, and 100 % provided significantly higher OM than in treatments where straw collection was made in alternated years (0I and 0P). Where this soil management

Table 4. Potassium contents in 0.00 to 0.10, 0.10 to 0.20, and 0.20 to 0.40 m soil layers of an Oxisol under the effect of soil chiseling and level of remaining straw, after five sugarcane cutting, in two systems of soil management

Straw level	Potassium											
	No-tillage						Conventional tillage					
	Chiseling						Chiseling					
	With		Without		Average		With		Without		Average	
	mg dm⁻³											
	0.00 to 0.10 m											
0 %	68.3	Aa	37.5	Ba	52.9	A	62.5	ABa	68.3	ABa	65.4	B
50 %	47.5	Aa	77.5	ABa	62.5	A	85.3	Aa	43.3	Bb	64.3	B
100 %	78.8	Aa	87.5	Aa	83.1	A	81.3	Aa	92.5	Aa	86.9	A
0I	47.2	Aa	80.0	ABa	63.6	A	32.2	Bb	71.3	ABa	51.7	B
0P	58.8	Aa	75.0	ABa	66.9	A	46.3	Ba	68.8	ABa	57.5	B
Average	60.1	a	71.5	a			61.5	a	68.8	a		
C.V. (%) for straw level:					28.7						13.7	
C.V. (%) for chiseling system:					26.4						23.6	
	0.10 to 0.20 m											
0 %	33.3	Ba	23.3	Bb	28.3	BC	32.5	ABa	28.3	Aa	30.4	A
50 %	28.3	Ba	26.3	ABa	27.3	BC	34.2	ABa	27.5	Aa	30.8	A
100 %	46.3	Aa	25.0	Bb	35.6	A	40.0	Aa	26.7	Ab	33.3	A
0I	23.8	Ba	23.8	Ba	23.8	C	22.5	Ba	24.2	Aa	23.3	A
0P	25.0	Bb	35.8	Aa	30.4	AB	25.8	Ba	27.5	Aa	26.7	A
Average	31.3	a	26.8	b	29.1		31.0	a	26.8	b	28.9	
C.V. (%) for straw level:					9.7						18.2	
C.V. (%) for chiseling system:					17.5						16.5	
	0.20 to 0.40 m											
0 %	17.5	Aa	19.2	Aa	18.3	A	13.8	Ba	17.5	Aa	15.6	B
50 %	19.2	Aa	20.0	Aa	19.6	A	17.5	Ba	20.8	Aa	19.2	AB
100 %	18.3	Ab	22.5	Aa	20.4	A	27.5	Aa	19.2	Ab	23.3	A
0I	17.5	Aa	20.8	Aa	19.2	A	14.2	Ba	17.5	Aa	15.8	B
0P	15.8	Aa	18.3	Aa	17.1	A	17.5	Ba	16.7	Aa	17.1	B
Average	17.7	b	20.2	a	18.9		18.1	a	18.3	a	18.2	
C.V. (%) for straw level:					17.0						15.2	
C.V. (%) for chiseling system:					10.5						14.8	

In each sampling layer, and each cultivation system, means followed by the same lowercase letter in the line and uppercase in the column do not differ from each other, by the Tukey test at 5 %. 0I: without collection of straws in Odd years; 0P: without collection of straws in even years.

system was associated with the absence of chiseling, the highest values were found in 50 and 100 % straw treatments, and both effects were restricted to the most superficial layers. On the other hand, chiseling significantly reduced this variable value in the 0.00 to 0.10 m layer, under the absence of straw removal (100 % of straw). In the CTS area, however, significantly higher OM was observed in the 100 % straw treatment associated with superficial revolving of the interrow in layers of 0.00 to 0.10 and 0.10 to 0.20 m, while significantly lower values were observed in treatment 0P, associated with absence of chiseling, also in the two more superficial layers (Table 6).

Table 5. Base saturation (V, %) in 0.00 to 0.10, 0.10 to 0.20 and 0.20 to 0.40 m soil layers of Oxisol, under the effect of soil chiseling and level of remaining straw, after five sugarcane cutting, in two systems of soil management

Straw level	Base saturation											
	No-tillage						Conventional tillage					
	Chiseling						Chiseling					
	With		Without		Average		With		Without		Average	
	%											
	0.00 to 0.10 m											
0 %	84.4	Aa	72.6	Ab	78.5	A	55.5	BCa	53.8	Aa	54.7	A
50 %	67.4	Ba	66.8	Aa	67.1	B	55.0	BCa	52.9	Aa	53.9	A
100 %	82.5	Aa	75.8	Aa	79.1	A	47.6	Cb	58.3	Aa	53.0	A
0I	47.1	Ca	47.1	Ba	47.1	C	64.7	Aa	53.0	Ab	58.9	A
0P	39.2	Ca	45.4	Ba	42.3	C	56.5	ABa	52.0	Aa	54.3	A
Average	64.1	a	61.5	a			55.9	a	54.0	a		
C.V. (%) for straw level:					6.1						6.3	
C.V. (%) for chiseling system:					8.9						6.5	
	0.10 to 0.20 m											
0 %	66.9	Aa	49.2	Ab	58.0	A	54.4	Aa	59.4	Aa	56.9	A
50 %	46.6	BCa	42.5	Aa	44.5	B	49.7	Aa	43.7	Ba	46.7	A
100 %	39.2	Ca	47.2	Aa	43.2	B	54.5	Aa	60.1	Aa	57.3	A
0I	35.6	Cb	46.8	Aa	41.2	B	50.9	Aa	53.1	ABa	52.0	A
0P	53.9	ABa	49.3	Aa	51.6	AB	51.0	Aa	42.7	Ba	46.9	A
Average	48.4	a	47.0	a	47.7		52.1	a	51.8	a	52.0	
C.V. (%) for straw level:					11.7						10.8	
C.V. (%) for chiseling system:					11.7						11.8	
	0.20 to 0.40 m											
0 %	34.1	Aa	29.7	ABa	31.9	AB	23.7	Ab	35.4	Aa	29.5	A
50 %	32.2	Aa	32.6	Aa	32.4	A	26.4	Aa	21.1	Bb	23.7	B
100 %	25.8	Aa	23.1	Ba	24.5	C	25.7	Ab	33.5	Aa	29.6	A
0I	26.4	Aa	31.4	ABa	28.9	ABC	24.9	Aa	23.9	Ba	24.4	B
0P	26.2	Aa	23.8	Ba	25.0	BC	24.2	Aa	24.5	Ba	24.5	B
Average	28.9	a	28.1	a	28.5		25.0	b	27.7	a	26.3	
C.V. (%) for straw level:					13.0						8.0	
C.V. (%) for chiseling system:					11.6						7.4	

In each sampling layer, and each cultivation system, means followed by the same lowercase letter in the line and uppercase in the column do not differ from each other, by the Tukey test at 5 %. 0I: without collection of straws in Odd years; 0P: without collection of straws in even years.

Nutritional diagnosis

Nitrogen, P and K contents in sugarcane leaves are presented in figure 5. In general, lower contents of N (only in NTS, without chiseling), P, and K occurred under total removal of straw (0 % straw) and N (in the CTS area), and K where removal occurred only in even years (0P). The chiseling effect was observed only for leaf contents of K, with a reduction of values where chiseling in interrows occurred.

The analysis of leaf contents of Ca, Mg and S (Figure 6) shows that, in the NTS area, levels of straw influenced only Mg contents, and the same values were observed for treatments 0 % (with or without chiseling), 100 % and 0I (only where there was chiseling). In the CTS area, straw removal significantly affected the three nutrients, generally with lower values for treatment 0I.

Table 6. Contents of organic matter (OM) in 0.00 to 0.10, 0.10 to 0.20 and 0.20 to 0.40 m layers of Oxisol, under the effect of soil chiseling and level of remaining straw, after five sugarcane cutting, in two systems of soil management

Straw level	Organic matter											
	No-tillage						Conventional tillage					
	Chiseling						Chiseling					
	With		Without		Average		With		Without		Average	
	g kg^{-1}											
	0.00 to 0.10 m											
0 %	33.4	Aa	30.3	Ba	31.9	A	28.8	BCb	32.4	Aa	30.6	BC
50 %	29.9	ABa	31.7	ABa	30.8	AB	27.7	Cb	33.2	Aa	30.4	BC
100 %	31.2	ABb	35.7	Aa	33.5	A	33.1	Aa	33.6	Aa	33.3	A
0I	27.5	Ba	29.2	Ba	28.4	B	31.7	ABa	30.5	ABa	31.1	AB
0P	27.8	Ba	28.2	Ba	28.0	B	28.7	BCa	27.4	Ba	28.0	C
Average	30.0	a	31.0	a	30.5		30.0	b	31.4	a	30.7	
C.V. (%) for straw level:					5.2						4.4	
C.V. (%) for chiseling system:					5.9						4.4	
	0.10 to 0.20 m											
0 %	26.2	Aa	25.8	Aa	26.0	A	22.5	Bb	29.2	ABa	25.9	A
50 %	23.0	Aa	25.5	Aa	24.2	A	26.2	ABb	31.0	Aa	28.6	A
100 %	25.1	Aa	25.9	Aa	25.5	A	28.7	Aa	25.3	BCb	27.0	A
0I	23.8	Aa	24.9	Aa	24.3	A	26.4	ABa	24.2	BCa	25.3	A
0P	22.9	Aa	24.3	Aa	23.6	A	25.9	ABa	23.5	Ca	24.7	A
Average	24.2	a	25.3	a	24.7		25.9	a	26.6	a	26.3	
C.V. (%) for straw level:					8.3						9.2	
C.V. (%) for chiseling system:					6.5						5.9	
	0.20 to 0.40 m											
0 %	20.0	Aa	21.6	Aa	20.8	A	19.8	Aa	22.2	Aa	21.0	A
50 %	18.9	Aa	21.8	Aa	20.4	A	20.9	Aa	20.7	Aa	20.8	A
100 %	20.8	Aa	21.5	Aa	21.1	A	23.0	Aa	20.4	Aa	21.7	A
0I	19.6	Aa	20.2	Aa	19.9	A	20.3	Aa	19.5	Aa	19.9	A
0P	19.0	Aa	18.8	Aa	18.9	A	20.6	Aa	18.8	Aa	19.7	A
Average	19.7	a	20.8	a	20.2		20.9	a	20.3	a	20.6	
C.V. (%) for straw level:					8.3						8.6	
C.V. (%) for chiseling system:					8.0						9.3	

In each sampling layer, and each cultivation system, means followed by the same lowercase letter in the line and uppercase in the column do not differ from each other, by the Tukey test at 5 %. 0I: without collection of straws in Odd years; 0 P: without collection of straws in even years.

Sugar and stalks yield

Stalk and sugar productivity data (Table 7) show that, regardless of chiseling presence, TCH and TSH values were significantly higher where total straw was kept on the soil surface (100 % of straw). For TCH, in five ratoons, noted values accumulated of 474.4 and 439.7 Mg ha^{-1} (averages of approximately 95.0 and 88.0 Mg ha^{-1}) in NTS and CTS, respectively. This increase in yield is probably associated to the fact that maintenance of 100 % of straw on the surface provided higher availability of K (Table 4) and increase in OM (Table 6) on the superficial layer of the soil (0.00 to 0.10 m) with reflections in the significant increase in leaf K content. It should be noted that, in general, total removal of straws in alternated years, odd (0I) or even (0P), resulted in yield equal or inferior to that with collection of 50 % of straws. As to the chiseling effect, in the average of all straw levels treatments, there was trend of reduction of TCH, but significantly only in CTS. In the NTS area, chiseling did not affect yield.

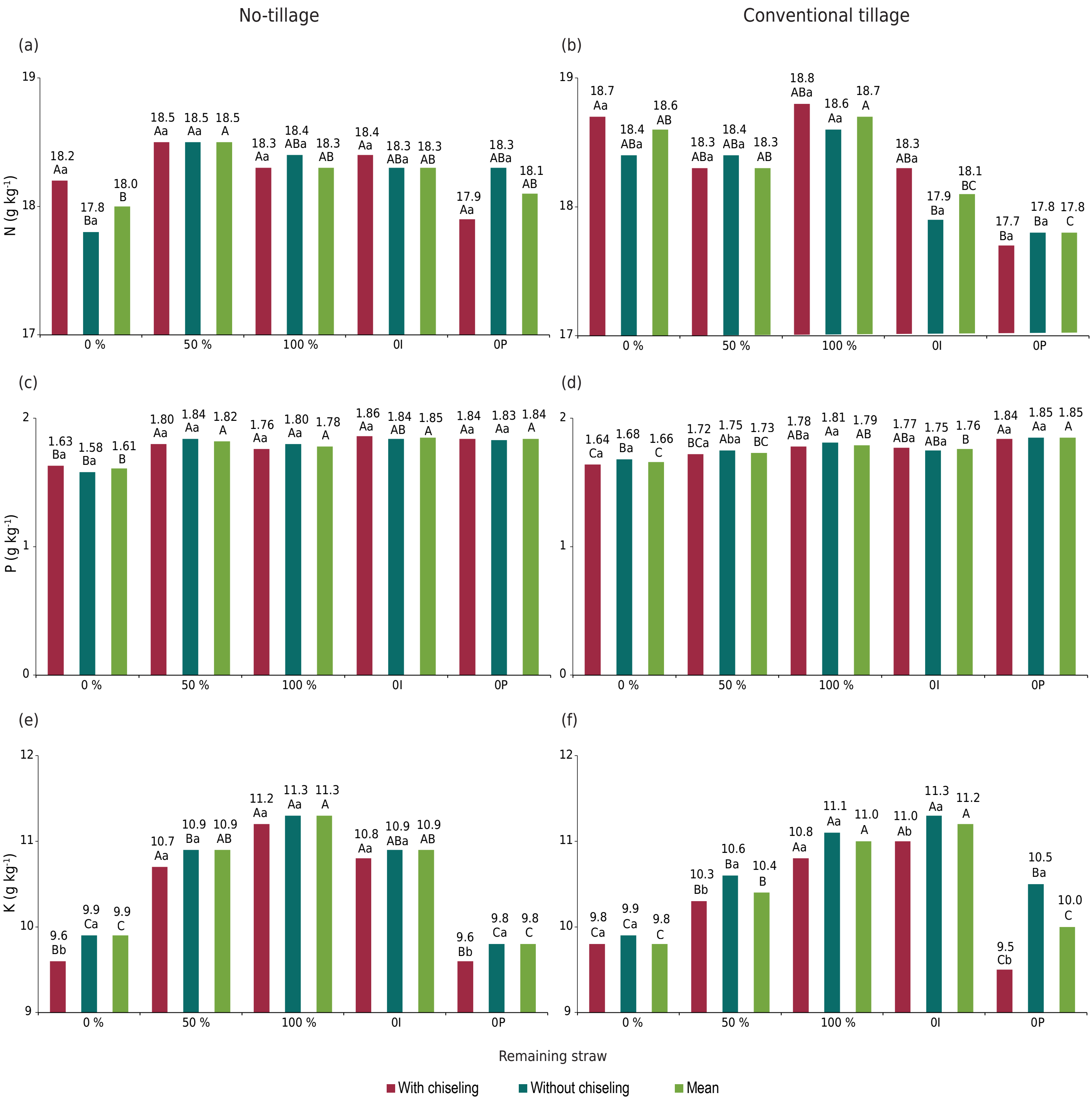

Figure 5. Leaf contents of N, P and K of sugarcane (fourth cutting) subject to soil chiseling and levels of remaining straw, in two systems of soil management. Bars with the same letter, lowercase for chiseling and uppercase for remaining straws levels, did not differ by Tukey test at 5 %. 0I: without collection of straws in Odd years; 0 P: without collection of straws in even years.

The amount of remaining straw with 100 % maintenance (14.3 Mg ha^{-1}), superior to the average of 5 cuttings obtained for 50 %, 0P and 0I – 5.9; 6.8 and 8.4 Mg ha^{-1}, respectively (Figure 3), was associated with in TCH and TSH increase. On the other hand, the average yield of the five levels of straw and the two chiseling systems under NTS resulted in average stalk yield of 83.9 Mg ha^{-1}, similar to the values obtained for the CTS (82.44 Mg ha^{-1}), and far above the average yield of the last four crops in Mato Grosso do Sul - 73.27 Mg ha^{-1} - (Conab, 2022), indicating this system feasibility in chemically corrected environments, without physical or biological restrictions in the soil.

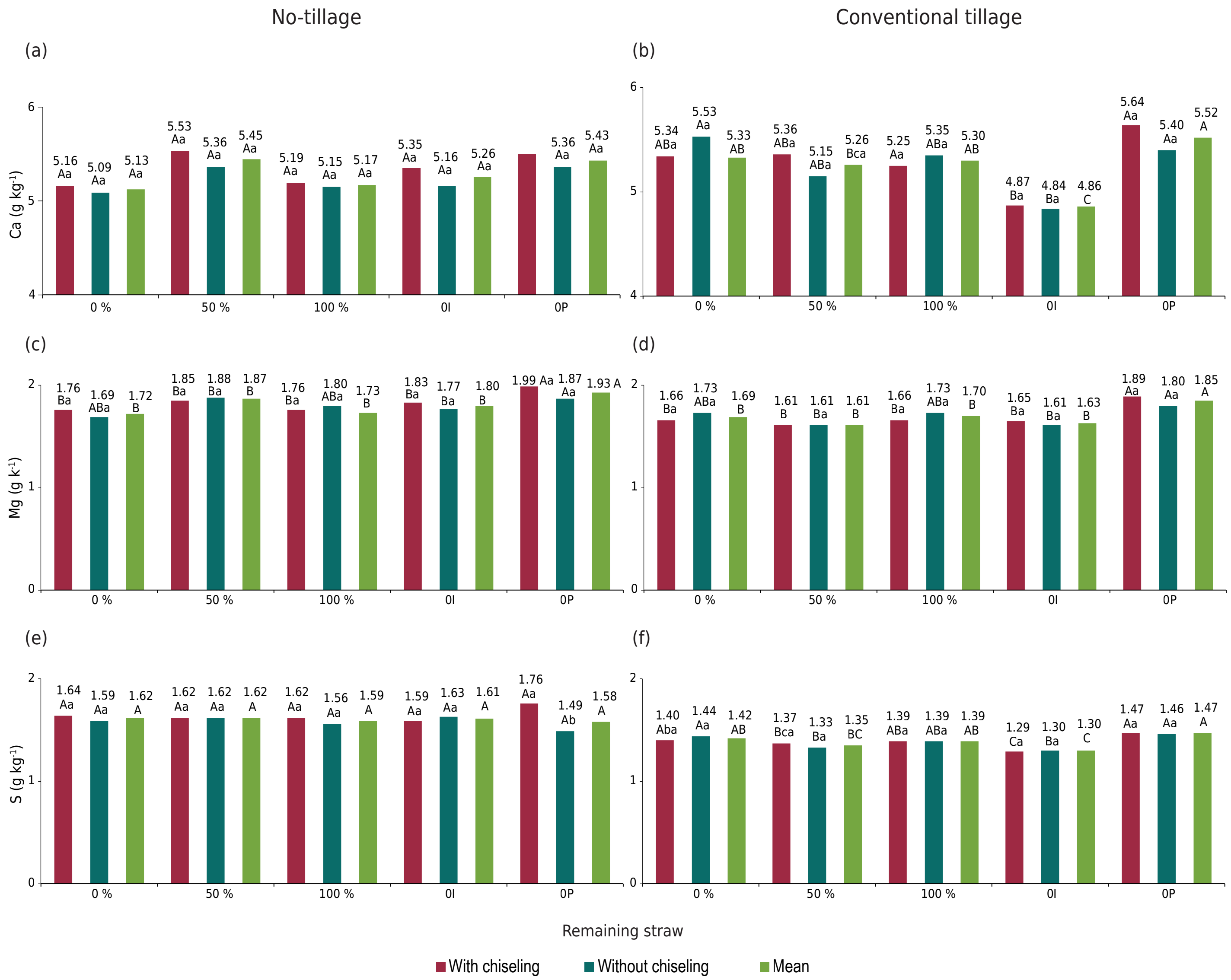

Figure 6. Leaf contents of Ca, Mg and S of sugarcane (fourth cutting) subject to soil chiseling and levels of remaining straw, in two systems of soil management. Bars with the same letter, lowercase for chiseling and uppercase for remaining straws levels, did not differ by Tukey test at 5 %. 0I: without collection of straws in Odd years; 0 P: without collection of straws in even years.

DISCUSSION

Soil chemical properties

In the 0.00 to 0.10 m layer, Ca^{2+} + Mg^{2+} contents remained in the availability class considered very good, according to Alvarez et al. (1999), while in the 0.10 to 0.20 m layer, these nutrients contents remained in the class considered good in NTS treatment, and went to the very good class in CTS; while in the 0.20 to 0.40 m layer, the contents went from low class to medium in both management systems.

Due to P fertilization in the planting furrow, P contents in the soil varied from very low to medium classes, where contents remained in classes considered very low or low for soils with more than 600 g kg^{-1} of clay, in the 0.00 to 0.10 m layer, and very low in layers 0.10 to 0.20 and 0.20 to 0.40 m (Alvarez et al., 1999). In the CTS area, contents of this element in the soil varied from very low to medium classes in all layers (according to Alvarez et al., 1999), however, the initial content in this layer was already medium (7.0 mg dm^{-3}), while in the NTS treatment this content was low (5.0 mg dm^{-3}) (Table 1).

Table 7. Mean values of stalk yield (TCH) and sugar yield (TSH) of sugarcane accumulated in five cuttings (ratoon), subject to soil chiselling and levels of remaining straw, in two systems of soil management

Straw level	No-tillage						Conventional tillage					
	Chiseling						Chiseling					
	With		Without		Average		With		Without		Average	
	TCH											
	Mg ha^{-1}											
0 %	435.3	ABa	443.7	Ba	439.0	B	378.6	Cb	394.7	Ba	386.7	C
50 %	419.2	Ba	432.3	Ba	426.0	B	408.6	Bb	424.1	Aa	416.4	B
100 %	460.5	Ab	488.4	Aa	474.4	A	431.5	Aa	444.3	Aba	437.9	A
0I	387.7	Ca	385.0	Ca	386.4	C	416.5	ABa	425.5	ACa	421.0	AB
0P	381.2	Ca	362.0	Cb	371.6	C	404.8	Ba	392.7	Ba[1]	398.8	C
Average	416.8	a	422.3	a	419.5		408.0	b	416.3	a	412.2	
C.V. (%) for management system:						5.9						5.0
C.V. (%) for straw level:						5.5						4.2
	TSH											
	Mg ha^{-1}											
0 %	69.7	Aa	70.4	Ba	70.0	B	59.7	Cb	64.6	BCa	62.2	D
50 %	65.5	BCb	68.6	Ba	67.1	B	64.9	Bb	68.0	ABa	66.4	BC
100 %	72.2	Ab	76.7	Aa	74.4	A	68.4	Ab	70.8	Aa	69.5	A
0I	61.0	Ca	60.5	CDa	60.0	C	66.3	ABa	68.2	Aa	67.3	AB
0P	61.3	Ca	57.4	Cb	59.2	C	64.6	Ba	63.3	Ca	64.0	CD
Average	65.8	a	66.8	a	66.3		64.8	b	67.0	a	65.9	
C.V. (%) for management system:						5.8						4.7
C.V. (%) for straw level:						6.3						4.3

In each cultivation system, means followed by the same lowercase letter in the line and uppercase in the column do not differ from each other, by Tukey test at 5 %. Means followed by the same lowercase letter in the line and uppercase in the column and number (compare in the line the systems of soil management in each combination of straw level and chiseling) do not differ from each other, by Tukey test at 5 %. 0I: without collection of straws in Odd years; 0 P: without collection of straws in even years.

In an experiment conducted in Typic Haplustox, with sandy-loam texture, in a commercial green sugarcane plantation in Pirassununga, state of São Paulo, Crusciol et al. (2014) applied 1.7 Mg ha^{-1} of gypsum mixed with Ca and Mg silicate, on the second ratoon straw, and observed, after a year, significant increases in Ca, Mg and K contents, and consequently, in V values up to 0.60 m of depth. In this experiment, Rossato et al. (2017) report that, where the same gypsum dose was associated with dolomitic limestone, there were significant increases in Ca, Mg and K contents, and in V up to 0.60 m of depth. On the other hand, Costa (2011) observed, in assessment made 48 months after surface application of 2.1 Mg ha^{-1} of gypsum associated with the application of up to 4.0 Mg ha^{-1} of dolomitic limestone in Oxisol, that the gypsum increased Ca availability and reduced changeable contents of Mg also in the 0.00 to 0.60 m layer. Costa (2011) also observed that K availability in the profile assessed was not changed by gypsum application, suggesting that both Mg and K might have been leached to deeper layers of soil, due to the association of these cations with SO_4^{2-}. In Typic Haplustox with clay texture (610 g kg^{-1} of clay), Inagaki et al. (2016) assessed the effect of gypsum doses (0, 3, 6 or 9 Mg ha^{-1}) combined with application methods of 4.5 Mg ha^{-1} of dolomitic limestone (with or without incorporation), fifteen years after these inputs application, and observed more pronounced increases in Ca availability and V in the 0.20 to 0.40 m layer, where the acidity corrective was incorporated to the soil, against the throwing distribution on the surface.

The amount of nutrients released for mineralization of straw is strongly influenced by environmental factors, like temperature and water availability, which affect both the accumulation of phytomass and nutrients by shoot tissues and the mineralization rate of this vegetal mass. According to Nogueira et al. (2005), release of nutrients from straw mineralization is also influenced by the time elapsed after cutting, due to change in contents of structural carbohydrates present in the plant material, mainly hemicellulose and cellulose. For this reason, these authors observed that P, K, Ca, Mg and S are released in significantly higher rates in straw of sugarcane recently harvested and deposited on the soil, against the remaining straw from the previous cutting. According to Rossetto et al. (2008), the straw can contribute, annually, to the recycling of 10.9, 2.6, 64.6, 27.5, 12.8, and 9.0 kg ha^{-1} of N, P, K, Ca, Mg and S, respectively. Increase in K contents in the soil at depth up to 0.40 m, in areas with 100 % straw from green cane harvest with five cuttings and under CTS, shows the agronomic relevance of this residue in nutrient recycling for the culture.

In this study, the higher contents of soil organic matter, in superficial layers, in areas with total straw and annual chiseling, can be associated with two factors principal. The first factor is related to the fact that whole residue of the previous cycle was incorporated to the soil by harrowing in soil preparation, and mineralized over time. The second factor is that chiseling, even where localized, promotes higher soil aeration and slight incorporation of the straw deposited on the surface, which may have contributed to the maintenance of these higher levels of organic matter in the surface layer. Segnini et al. (2013) verified higher OM in the 0.00 to 0.05 m layer, both in NTS and CTS. Bordonal et al. (2018) observed, in two crops, higher OM in the soil with higher levels of remaining straw.

Nutritional diagnosis

Values of leaf contents, mainly K contents, are below the range considered suitable for ratoon cane [20 to 22, 1.8 to 2.0, and 13 to 15 g kg^{-1} of N, P and K, respectively, according to Malavolta et al. (1997)]. Though the treatments influenced N and P contents, there was no change in the class (deficient) established for the plant nutritional status. Therefore, the supply of 30 kg ha^{-1} of N and 150 kg ha^{-1} of K_2O in the planting furrow, added with 120 kg ha^{-1} in hilling-up, and 150 kg ha^{-1} yr^{-1} of N and 120 kg ha^{-1} yr^{-1} of K_2O in the ratoon 30 days after each cutting, was insufficient to meet the plant demands. For P, on the other hand, leaf contents were very close to the lower limit (1.8 g kg^{-1}) of the value range considered appropriate, despite the low or very low P availability in the soil, so that small increases were sufficient to change the nutritional status from deficient to appropriate.

For Penatti (2013), P extraction by sugarcane is the smaller across macronutrients. The P and K leaf contents do not present direct relation with the availability of these nutrients in the soil (Tables 3 and 4, respectively). This can be related to the dilution effect, where higher soil availability of a given nutrient can increase the production of shoot phytomass more, than the increase in absorption rate, resulting in relatively lower leaf content. Faroni et al. (2009) verified a reduction in N contents in F + 1 leaf, while assessing different doses of N in plant cane, along with the increase in yield, assigning this result to the nutrient dilution due to the plant greater growth.

Leaf contents of Ca are mostly found in the range of values considered appropriate for ratoon-cane (Malavolta et al., 1997), while Mg contents and, S contents, are classified as low or insufficient, despite the high initial availability of Mg (Table 1). Moreover, as observed for P and K, leaf contents of Ca and Mg did not present direct relation with these nutrients availability in the soil (Table 2).

Stalk and sugar yield

Increase in sugarcane productivity was associated with the fact that maintaining 100 % of straws on the surface provided greater K availability (Table 4) and increase in OM (Table 6) in the superficial soil layer (0.00 to 0.10 m), reflecting an increased leaf K content, though nutritional diagnosis still indicates that the plants presented deficiency of this nutrient (Figure 5).

Soil chiseling of sugarcane ratoons could be dispensable, considering the edaphoclimatic and management conditions in this study area, based on the results obtained for soil fertility and sugarcane production. This management practice is questionable as to the effectiveness in the long-term improvement of the soil physical and water quality and, consequently, sugarcane production (Prado et al., 2014; Sá et al., 2016), mainly where associated with soil CTS operations (Gomes, 2017). Sá et al. (2016) observed that soil chiseling in sugarcane ratoon interrows does not interfere with the mass of roots, the soil physical properties or stalk and sugar yield. Likewise, Prado et al. (2014) did not observe the effects of chiseling after sugarcane harvest in soil physical properties of the 0.15 to 0.30 m layer, or in sugarcane production and technological characteristics. On the other hand, Garbiate et al. (2016) observed that the use of dual action plow at 0.30 m depth reducted soil surface compaction (0.00 to 0.15 m layer) and increased ratoon cane production, when compared to treatments without chiseling or using simple chisel plow with chiseling at 0.15 and 0.30 m soil depth. Therefore, it is possible that the simple chisel plow action at 30 cm of depth used in the present study may not be effective in soil disaggregation, and, therefore, in the expected improvement of water infiltration and availability, to the extent of overcoming management systems without chiseling.

This increase in stalk and sugar yield in treatments without removal of straw (100 % straw) corroborates Castioni et al. (2019) as they kept 15 or 10 Mg ha^{-1} during four years, and these amounts increased sugarcane stalks yield against treatments that removed 15 Mg ha^{-1} (full removal) and 10 Mg ha^{-1} (partial). Melo et al. (2020) also observed that maintaining 8 to 13 Mg ha^{-1} of straw on the soil, is sufficient to sustain the soil physical conditions for root growth and to improve sugarcane yield. The benefits resulting from keeping the straw for the soil-plant system are associated to an increase in water availability and a reduction of soil temperature (Santos et al., 2022), reduction of soil compaction (Gomes, 2017; Castioni et al., 2019) and increase in soil C content (Bordonal et al., 2018; Castioni et al., 2019). Dias and Sentelhas (2018) reinforced that keeping the straw minimizes the effects of water deficit as the main factor associated with reductions in sugarcane productivity in several regions of Brazil that presented well-defined dry season.

So, keeping 100 % of straw proved determinant to improve soil fertility, leading to increase in K and OM in the soil surface layers and the plants nutrition over one cycle of sugarcane cultivation.

CONCLUSIONS

Keeping 100 % of the remaining sugarcane straw increased K and organic matter in the soil surface layer (0.00 to 0.10 m) and yield of stalk and sugar over one sugarcane cultivation cycle in the no-tillage or conventional systems of soil management.

Soil chiseling of sugarcane interrows does not affect soil fertility, sugarcane nutrition and production, when cultivated under conventional or no-tillage systems.

No-tillage in sugarcane proved to be feasible in environments corrected, and did not reduce stalks and sugar yield.

Straw removal affects leaf contents of nutrients, regardless of soil management.

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