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The relationship between straw and herbicide for controlling *Ipomoea* sp. in sugarcane ratoon

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Abstract: **Background:** A new agronomic management is used in sugarcane fields, due to the removal of part of the layer of straw on the soil surface for the cogeneration of energy, culminating in variable amounts of straw. **Objective:** The objective was to evaluate the population dynamics of weeds in different scenarios of straw removal; to evaluate the weed control and selectivity of sugarcane; to determine the amount of sugarcane straw that must remain in the soil to facilitate weed control in a sugarcane crop. **Methods:** The main treatments were the following straw amounts maintained on the soil surface: 0, 5, 10 and 15 Mg ha^{-1}. The secondary treatments were: application of sulfentrazone + tebuthiuron and without herbicide. The research was conducted for two years. **Results:** The main weeds found were two morningglories, *I. triloba* and *I. hederifolia*. With the increase in the straw removed from the soil, the density and dry mass of the weeds rised. The control percentage was close to 100% and the sugarcane was selective for the herbicides used. For both crop years evaluated, the absence of straw and herbicides showed inferiority in sugarcane productivity. **Conclusions:** The sugarcane straw removal for the energy cogeneration industry would be feasible with the removal of 5 Mg ha^{-1} of straw on soil surface, maintaining a layer of at least 10 Mg ha^{-1}.

Keywords: Sulfentrazone; Tebuthiuron; Morningglory; Phytointoxication

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1. Introduction

Sugarcane is a crop of high global relevance (Queiroz et al., 2022), being a raw material for sugar production, bioethanol production, in addition to its great potential for generating bioenergy. Sugarcane cultivation covers approximately 9 million hectares in Brazil, where the largest cultivation area is the Center-South region (85%), with emphasis on the state of São Paulo (4.4 million hectares) (Companhia Nacional de Abastecimento, 2022). In Brazil, most of the sugarcane production occurs via a conservation system called green cane, which, due to the non-use of fire prior to harvest, enables large amounts of straw on the soil surface, from 10 to 20 Mg ha^{-1} (Silva et al., 2019; Tropaldi et al., 2021). This maintenance of sugarcane straw on the soil surface can reduce the potential for weed infestation, both by limiting the temperature variation at the soil surface and by forming a physical barrier to be crossed by the germinating weeds. However, some species of the genus *Ipomoea* adapted to this change by germinating even in the presence of straw (Carvalho et al., 2017). The presence of straw caused a reduction in the population density of the species *Brachiaria decumbens*, *Sida spinosa* and *Digitaria horizonthalis*. On the other hand, no such reduction was observed for *Ipomoea triloba, Ipomoea hederifolia* and *Ipomoea quamoclit* (Carvalho et al., 2017).

Chemical weed control in green cane areas where straw is kept on the soil surface is already a complex process, as the straw layer can affect the effectiveness of herbicides with exclusive and/or preferential action on the soil, acting as a physical barrier that prevents herbicides from reaching the soil (Prado et al., 2013; Queiroz et al., 2022). But this weed management cannot be neglected given that losses of up to 80% in sugarcane yield can occur when there is a large weed infestation (Tropaldi et al., 2021). Herbicides intercepted by the straw layer on the soil surface are subject to retention, volatilization and photolysis, until they are transported to the soil (Queiroz et al., 2022). According to Queiroz et al. (2022), sulfentrazone applied to green cane and kept for 60 days without precipitation under normal conditions of solar radiation showed degradation of 62%. However, studies show that 20 mm of precipitation is sufficient to provide sulfentrazone and other herbicides intercepted by sugarcane straw available to the soil (Carbonari et al., 2016; Prado et al., 2013).

Recently, a new agronomic management approach began to be used in sugarcane fields, based on the removal of part of the layer of straw on the soil surface, for energy cogeneration (Carvalho et al., 2017). This removal can be total or partial, culminating in variable amounts of straw present on the soil surface in sugarcane-producing areas (Silva et al., 2019). Thus, there is a change in the management of weed control in sugarcane, due to the heterogeneity of straw on the soil surface, associated with the great adaptability of the weed community. Thus, research is needed to demonstrate which weed species are more adapted to the removal scenario, as well as to evaluate the efficiency of control and selectivity of the herbicide molecule used. In one scenario, where sugarcane straw was completely removed for bioenergy production in the industry, 66% of the soil surface was exposed (Christoffoleti, Nicolai, 2012). This effect can hamper weed management in these areas, as it favors the germination and emergence of monocotyledonous weeds, which would be easily controlled by the presence of a straw layer. Concenço et al. (2017) observed a process of straw accumulation on inter-rows, with higher levels of weed infestation compared to areas where there was no straw removal.

Agriculture is dynamic and changes in the sugarcane production system are constant. The partial removal of straw for bioenergy generation is a reality in the mills and it becomes more economically viable. Given this context: What are the effects of straw removal on the weed community and its control? Thus, the present work has the following objectives: 1 - to evaluate the population dynamics and the weed flora composition established in the different conditions of soil cover with sugarcane straw resulting from partial removal, treated or not with herbicides; 2 - to evaluate the development of sugarcane in different straw conditions and; 3 - to determine the amount of sugarcane straw that must remain on the soil surface, in a removal scenario, in order to avoid compromising or hampering the chemical weed control process in sugarcane cultivation.

2. Material and Methods

2.1 Experimental site

The experiment was set up at the Pedra farm, belonging to the Pedra Mill, whose geographic coordinates are 21º11'59''S; 47º37'11''W. The experimental field (ratoon cane) was conducted during the follow sugarcane crop cycle – 2016/2017 and 2017/2018. After the harvest of sugarcane and prior to the installation of treatments, soil sampling was conducted fertility and physical characterization of soil. The chemical attributes measured were: pH 5.3 ($CaCl_2$), Soil Organic Mater 19.9 g dm^{-3}, P 27 mg dm^{-3}, K, Ca, Mg, H + Al and Cation Exchange Capacity (mmolc dm^{-3}), respectively, 2.7, 27, 5, 30,64.2, and Base Saturation 54%. The levels (%) of sand, silt and clay in the soil were, respectively, 30, 18, 52%.

The sugarcane variety used in the area was RB85 5453, which presents good sprouting, adapted for soils with high fertility as occurred in the present study for beginning of harvest. The sugarcane was planted in 1.5 meters spacing between rows, the most commonly used spacing in the Center-South of Brazil and the previous cut at set up second ratoon was done in May, 2016. The research was conducted for two years Year 1 - second ratoon and Year 2 – third ratoon.

2.2 Experimental design

The experimental design used was randomized blocks in split-plot scheme with four replications. The main treatments (plots) were the different straw quantities on a dry basis, maintained on the soil surface: 0 Mg ha^{-1} (TR - total removal), 5 Mg ha^{-1} (PR - partial removal), 10 Mg ha^{-1} (PR - partial removal) and 15 Mg ha^{-1} (SR - without removal). The subplots were: i) application of herbicide, ii) without herbicide application. Each subplot was comprised of 8 lines of sugarcane, each 10 m in length. The straw quantities in each plot were adjusted manually after harvesting the field, having previously evaluated the humidity percentage to enable dry-base calculations. All the procedures described above (straw fractionation, herbicide associations, dose, application mode, and methodology for evaluating weeds) were repeated during the second experimental year 2017/2018.

The herbicide was always applied in total pre-emergence of sugarcane and weeds. The molecules utilized and the dose applied were defined according to the plan of the mill's agronomic team: sulfentrazone + tebuthiuron (800+900 g a.i ha^{-1}). The herbicides were applied utilizing a pressurized backpack sprayer CO_2 equipped with a 3m bar with 6 pulverization spray tips of the type AI110.02 spaced 0.5 m apart. The set was calibrated to distribute the equivalent of 200 L ha^{-1}, with bar height of 0.5 m, work pressure between 2.5 and 2.8 bar and displacement velocity of 1 m s^{-1}.

In Year 1, the herbicide treatments were applied in June of 2016, under the following weather conditions monitored during the application: temperature 28.5 ºC, air humidity 52%, wind speed 1.2 km h^{-1}. In Year 2, the application was done in July of 2017, under the following weather conditions: temperature 24 ºC, air humidity 58%, wind speed 0.8 km h^{-1}. For this, we used the same association of herbicides and doses as the previous year of the experiment.

2.3 Data collection and measurements

The parameters measured were: weed composition, by density and dry mass, control percentage of weeds attributed by visual notes on a percentage scale, phytointoxication percentage and sugarcane yield. The evaluations of the herbicide treatments were done at 30, 60, 90, 120 and 150 days after application (DAA).

The composition of the weed community was evaluated. The emerging flora was assessed utilizing sampling squares, with dimensions of 0.5 x 0.5 m randomly launched 8x in each subplot. Weeds covered by the squares were identified by morphological traits at the level of genus and/or specie and quantified via counting to obtain mean density. The weeds sampled were packed in paper bags, separated by specie, then sent for drying in an oven with forced aeration at a constant temperature of 75 °C, maintained until achieving weight stabilization, and finally weighed on a precision balance according to Kuva et al. (2008), thus obtaining the dry mass. The weed control efficacy of morningglories was evaluated on a scale from 0 to 100%, where zero represents absence of control and 100% all plants killed by the herbicide's effects (Gazziero, 1995). These control notes were established as a function of the untreated control kept without herbicides in pre-emergence throughout the experimental period. At the same moment, the possible injuries in the sugarcane crop were evaluated by phytointoxication percentage attributing also notes as a percentage in relation to control plants (Gazziero, 1995).

At the moment of harvest the biometric evaluation was done in each plot to characterize the biomass production by sugarcane plants, in June 2018, before the mechanical harvest 322 DAA. For three rows with length of 2 meters located in the central area of the plot, the stalk biomass production in Mg ha^{-1} was quantified.

Throughout the experimental period, the weather conditions were monitored by an automated weather station installed near the area, whereas the weather metadata and water balance were calculated according to the methodology described by Thornthwaite and Mather (Figure 1). Across the experimental period, the rainfall accumulated was higher in the first year than in the second year (1,223 vs. 937 mm), while the annual mean temperature was similar between the years.

2.4 Statistical analysis

All data were submitted to ANOVA variance analysis (Test F) at 5% probability. Attending to the principles of data normality, the means of the variables were compared by Tukey's test ($p<0.05$). The statistical analysis were performed using the software AgroEstat.

3. Results and Discussion

3.1 Weed density

At 120 DAA Year 1 straw layers of 10 and 15 Mg ha^{-1} showed higher densities (1 and 0.5 plants m^{-2}) in relation to the condition of 5 Mg ha^{-1} of straw (0.2 plants m^{-2}) - Table 1. At 150 DAA, there was no interaction between the straw amount and the application or not of herbicide, and the occurrence of *I. triloba* increased by 70% compared to the previous evaluation. The highest density was recorded in the treatment without straw and without herbicide with an eight-fold increase in density compared to treatments with the presence of straw on the soil surface. The straw layer maintained in the green cane system acts as a physical barrier for seedlings in emergence, and alters the water balance, the thermal amplitude in the surface layers of the soil, and the quantity and quality of light reaching the soil surface (Queiroz et al., 2022). This behavior has a

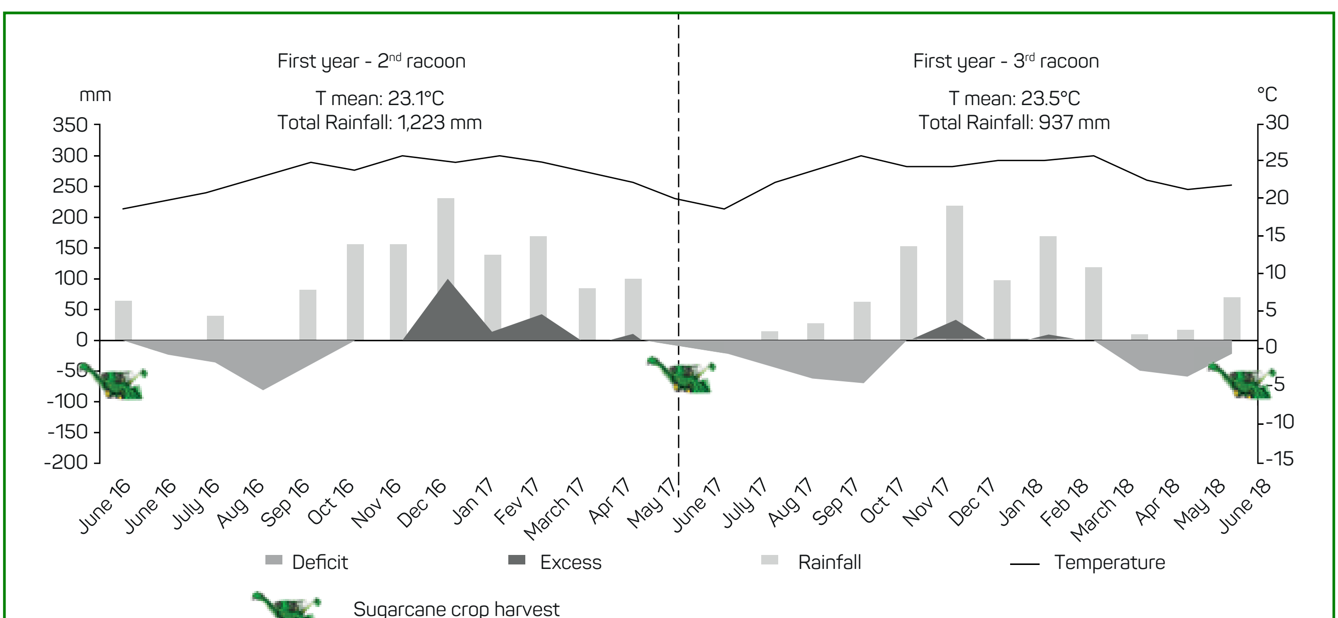

Figure 1 - The water balance calculated during the experimental periods Year 1 and Year 2 according to the methodology described by Tornthwaite & Mather, 1955. Blue arrows refers to the herbicide application time

great influence on the germination of weed species (Pitelli, 1995) and consequently on the species composition of communities. Morningglory species usually show germination regardless of the amount of straw present in the soil (Azania et al., 2002).

In the presence of the herbicide treatment sulfentrazone + tebuthiuron (800 + 900 g ha^{-1}), the density of *I. triloba* was null at 150 DAA, indicating that the control was excellent, regardless of the straw layer (Table 2). At 120 DAA in Year 2 there was a minimum presence of *I. hederifolia* (0.13 plants m^{-2}) in the herbicide treatment, while under the untreated control , *I. hederifolia* occurred at much higher densities (average 4.34 plants m^{-2}). The straw layer of 5 Mg ha^{-1} and 0 Mg ha^{-1} showed higher densities in relation to the highest amounts of straw (15 and 10 Mg ha^{-1}). The lower straw amounts promoted three times the density of *I. hederifolia* compared to the higher straw amounts kept in the soil after the green cane harvest (Table 2). At 150 DAA in the untreated control , the straw layers of 5 Mg ha^{-1} and 0 Mg ha^{-1} also presented higher densities in relation to the treatments with 10 and 15 Mg ha^{-1} of straw on the soil surface. In the treatment with herbicide application (sulfentrazone + tebuthiuron), the species density was close to zero at 150 DAA, indicating that the control was excellent for *I. hederifolia*, regardless of the straw amount on the soil surface (Table 2).

Table 1 - Summary of the analysis variance for the weed density (plants m^{-2}) at 120 and 150 DAA, weed dry mass (g m^{-2}) at 150 DAA, weed efficacy (%) at 120 and 150 DAA, phytointoxication (%) at 30 DAA and sugarcane yield (Mg ha^{-1}) at 322 DAA in the two years of evaluation Year 1 and Year 2 as a function of herbicides treatments (T) and sugarcane straw (S) amount kept on the soil after harvest

	Weed density		Weed dry mass	Weed efficacy		Phytointoxication	Yield
	120 DAA	150 DAA	150 DAA	120 DAA	150 DAA	30 DAA	322 DAA
-----Year 1-----							
Treatment (T)	0.15	0.16	0.21	0.33	0.22	0.25	0.71
Straw (S)	0.00**	0.00**	0.00**	0.60	0.68	0.00**	0.47
T x S	0.03*	0.19	0.09	0.19	0.44	0.12	0.30
-----Year 2-----							
Treatment (T)	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.03*
Straw (S)	0.31	0.80	0.44	0.12	0.16	0.09	0.11
T x S	0.02*	0.64	0.39	0.31	0.37	0.16	0.24

Table 2 - Density results (plants m^{-2}) of *I. triloba* - Year 1 and *I. hederifolia* - Year 2, verified at 120 and 150 DAA (days after application) with the presence and absence of the association of herbicides in the different amounts of straw (0, 5, 10 and 15 Mg ha^{-1})

Year 1 - *Ipomoea triloba*						
	120 DAA			150 DAA		
Straw	**Herbicide**	**Untreated Control**	**Average**	**Herbicide**	**Untreated Control**	**Average**
0	0.16 Aa	0.19 Ba	0.17	0.0	1.50	0.75 A
5	0.00 Aa	0.25 Ba	0.12	0.0	0.37	0.19 A
10	0.00 Ab	1.06 Aa	0.53	0.0	0.87	0.44 A
15	0.00 Ab	0.56 ABa	0.28	0.0	0.72	0.60 A
Average	0.04	0.51		0.0 b	0.87 a	
CV		10			13	
Year 2 - *Ipomoea hederifolia*						
	120 DAA			150 DAA		
Straw	**Herbicide**	**Untreated Control**	**Average**	**Herbicide**	**Untreated Control**	**Average**
0	0.13 Ab	6.00 ABa	3.06	0.00	4.38	2.19 A
5	0.00 Ab	6.38 Aa	3.19	0.00	3.38	1.69 A
10	0.25 Aa	2.63 BCa	1.44	0.13	2.13	1.13 A
15	0.13 Aa	2.38 Ca	1.25	0.25	3.13	1.69 A
Average	0.13	4,34		0.09 b	3.25 a	
CV		8			6	

** significant at 1% by the F test; * significant at 5% by the F test; ns: not significant. Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other by Tukey's test at 5% probability level

3.2 Weeds' dry mass

Both morningglory species, *I. triloba* and *I. hederifolia*, did not differ in dry mass between the different amounts of sugarcane straw, in the evaluation at 150 DAA. In treatments with herbicide adoption, zero or minimal amounts of flora were recorded, ensuring optimal control with the use of sulfentrazone and tebuthiuron molecules in association with the presence of straw. In the untreated control there was the presence of morningglories. Year 1 presented 2.5 times more dry mass of *I. triloba* compared to Year 2 with *I. hederifolia* (Table 3), that is, more plants per square meter of *I. hederifolia*, but smaller plants with lower vegetal development and lower weight. In the straw layer of 10 Mg ha^{-1}, the dry mass of *I. triloba* was lower than in the other treatments (Table 3). However, there is no relationship between increase or decrease in weed dry mass and the total or partial removal of straw on the soil surface. For *I. hederifolia* Year 2 the presence of 15 Mg ha^{-1} of straw on the soil presented a lower dry mass than the other treatments (Table 3).

The highest values of dry mass were recorded for 0 Mg ha^{-1}, regardless of the morningglory species. The plant density also recorded higher amounts of morningglory plants per square meter in the lowest straw amounts, reaffirming the importance of keeping as much straw as possible in the soil after harvest to contribute to the weed control present in the production system of sugarcane, especially the morningglories. This greater density and dry mass of the morningglories in the smallest straw layers deserves attention, given the great impact that these plants also have at harvest time (Azania et al., 2002). Morningglories (*Ipomoea* ssp.), belonging to the Convolvulaceae family, are voluble and climbing plants that intertwine in the culms, house their fruits and seeds at the height of the canopy of the sugarcane plants and are carried to medium or long distances by the harvesters. Among the main characteristics of this family is the large production of diaspores, around 50 to 300 per plant (Kissmann, Groth, 1999; Toledo et al., 2017). In addition to interference problems through competition, these weeds hamper the management operations (Azania et al., 2002). The efficient control with herbicide combinations is very important for the control of morningglories in green cane harvesting systems to minimize the negative impacts arising from their presence in the sugarcane crop (Santos et al., 2022).

3.3 Weed control efficacy

Regardless of the straw layer kept in the soil after harvest (0, 5, 10 and 15 Mg ha^{-1}), the evaluation period (120 and 150 DAA), weed species evaluated (morningglories), the herbicide treatment composed of sulfentrazone in association with tebuthiuron provided excellent control of *I. triloba* and *I. hederifolia* (Table 4). Control of 100% was verified for *I. triloba* and values above 98.7% for *I. hederifolia* (Table 4). The results obtained corroborate other reports in the literature, in which there was excellent control of *I. triloba* by tebuthiuron applied on sugarcane straw. The herbicide tebuthiuron has high solubility (2.57 g L^{-1} at 20 °C) and thus requires less precipitation to be extracted from the straw, released into the soil and made available for weed uptake (Prado et al., 2013). Similar results were obtained by Tofoli et al. (2009), who, when evaluating the tebuthiuron dynamics in sugarcane straw, reported that the first 20 mm of precipitation were fundamental for the process of transposition of the herbicide to the soil, regardless of the straw amount (Prado et al., 2013). Thus, maintaining a straw layer on the soil can reduce the infestation potential of some weeds, but it can also affect the transposition of herbicides applied in pre-emergence (Carbonari et al., 2016; Prado et al., 2013; Santos et al., 2022), thus requiring rain to achieve satisfactory control of the morningglories. Santos et al. (2022) verified excellent control of *I. triloba* when evaluating the herbicides tebuthiuron and sulfentrazone in green cane.

In a green cane scenario, excellent morningglory control was verified after the application of isolated and associations herbicides (Bidóia et al., 2019; Santos et al., 2022; Toledo et al., 2017). At 120 DAA two treatments, association of tebuthiuron with isoxaflutole, and sulfentrazone, showed excellent control levels of *Ipomoea hederifolia* (99 to 100%)

Table 3 - Results of the dry mass of morningglories - g m^{-2} - (*I. triloba* - Year 1 and *I. hederifolia* - Year 2) at 150 DAA for the evaluated treatments, as a function of straw amount (0, 5, 10 and 15 Mg ha^{-1}) and absence or presence of chemical control (sulfentrazone + tebuthiuron) of weeds

	Year 1 – *Ipomoea triloba*			Year 2 – *Ipomoea hederifolia*		
Straw	Herbicide	Untreated Control	Average	Herbicide	Untreated Control	Average
0	0.00	18.15	9.07 A	0.00	7.55	3.77 A
5	0.00	16.18	8.09 A	0.00	5.19	2.59 A
10	0.00	4.22	2.11 A	0.30	7.20	3.75 A
15	0.00	16.22	8.11 A	0.22	2.83	1.52 A
Average	0.00 b	13.70 a		0.13 b	5.69 a	
CV		44			9	

** significant at 1% by the F test; * significant at 5% by the F test; ns: not significant. Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other by Tukey's test at 5% probability level

Table 4 - Percentage results (%) for control of morningglories (*I. triloba* - Year 1 and *I. hederifolia* - Year 2) at 120 and 150 DAA for the evaluated treatments, as a function of straw amount (0, 5, 10 and 15 Mg ha^{-1}) and absence or presence of chemical control (sulfentrazone + tebuthiuron) of weeds

Year 1 - *Ipomoea triloba*						
	120 DAA			150 DAA		
Straw	Herbicide	Untreated Control	Average	Herbicide	Untreated Control	Average
0	100.0	0.0	50.0 A	100.0	0.0	50.0 A
5	100.0	0.0	50.0 A	100.0	0.0	50.0 A
10	100.0	0.0	50.0 A	100.0	0.0	50.0 A
15	100.0	0.0	50.0 A	100.0	0.0	50.0 A
Average	100.0 a	0.0 b		100.0 a	0.0 b	
CV		0			0	
Year 2 - *Ipomoea hederifolia*						
	120 DAA			150 DAA		
Straw	Herbicide	Untreated Control	Average	Herbicide	Untreated Control	Average
0	99.5	0.0	49.7 A	100.0	0.0	50.0 A
5	100.0	0.0	50.0 A	100.0	0.0	50.0 A
10	99.0	0.0	49.5 A	98.7	0.0	49.4 A
15	99.5	0.0	49.7 A	98.7	0.0	49.4 A
Average	99.5 a	0.0 b		99.4 a	0.0 b	
CV		2			3	

** significant at 1% by the F test; * significant at 5% by the F test; ns: not significant. Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other by Tukey's test at 5% probability level

in green cane (RB85 5156). And by associating tebuthiuron with amicarbazone in pre-emergence, the control of *I. hederifolia* was satisfactory (> 80%) (Bidóia et al., 2019). When, for reasons of logistics, sugarcane producers and mills do not perform the initial pre-emergence application on the crop, a 46% reduction in yield can occur when infested with *I. hederifolia* (Silva et al., 2009); thus, strategies to control morningglory are necessary to increase sugarcane yield (Santos et al., 2022). Sulfentrazone (600 g ha^{-1}) applied in association with clomazone produced an excellent transposition of the herbicide through the sugarcane straw layer (Tropaldi et al., 2021).

The herbicide sulfentrazone is regularly applied in green cane systems, conservation systems with straw present on the soil surface (Carbonari et al., 2016) and in pre-emergence of weeds due to its high solubility (Carbonari et al., 2016; Queiroz et al., 2022). When applied correctly, sulfentrazone efficiently controls monocots, dicots and sedges. Sulfentrazone promotes good control of weeds in sugarcane, especially weeds that are difficult to control such as morningglory (*Ipomoea* sp) (Walsh et al., 2015), and as recorded in the present work, excellent control of *Ipomoea* by associating sulfentrazone with tebuthiuron. The herbicide tebuthiuron, widely used in the green cane production system, is selective in pre-emergence and controls the main weeds of the crop (Moraes et al., 2016). The herbicide acts by inhibiting photosynthesis, through the inhibition of electron transport in photosystem II that occurs in chloroplasts. Sulfentrazone is a protoporphyrinogen oxidase (PPO) inhibitor herbicide (Mallory-Smith, Retzinger, 2003). Thus, the evaluated herbicides require the presence of light and oxygen for herbicidal activity. And the herbicides showed synergism when associated due to the excellent control of the morningglories they presented in the different straw amounts and in both years analyzed.

The transport of herbicides intercepted from sugarcane straw to the soil is dependent on several factors, such as the amount and origin of the residue, the characteristics of the herbicide and climatic conditions, as well as the interval between application and occurrence of precipitation (Carbonari et al., 2016; Queiroz et al., 2022; Silva, Monquero, 2013). The adequate distribution of precipitation (Figure 1) may have facilitated the transposition of the herbicides from the layers of sugarcane straw to the soil so that the herbicides were absorbed, translocated and thus enabled to perform their function of providing excellent control of these weeds.

3.4 Sugarcane selectivity: phytointoxication and yield

In green cane experiments assessments of phytointoxication and sugarcane yield are carried out jointly to evaluate the selectivity of the studied sugarcane variety. Selectivity is understood as the ability of a given herbicide to eliminate weeds found in the crop without reducing the yield (Martins et al., 2005).The two initial evaluation

Table 5 - Phytointoxication percentage (%) of sugarcane at 30 and 60 DAA submitted to the association of sulfentrazone + tebuthiuron herbicides in different amounts of straw (0, 5, 10 and 15 Mg ha^{-1}) for the evaluations carried out in a two-year experiment Year 1 and Year 2

	30 DAA			60 DAA		
	Year 1					
Straw	Herbicide	Untreated Control	Average	Herbicide	Untreated Control	Average
0	14.2	0.0	7.1 A	0.0	0.0	0.0 A
5	13.5	0.0	6.7 A	0.0	0.0	0.0 A
10	15.0	0.0	7.5 A	0.0	0.0	0.0 A
15	12.7	0.0	6.4 A	0.0	0.0	0.0 A
Average	13.87 a	0.0 b		0.0 a	0.0 a	
CV		15			0	
	Year 2					
Straw	Herbicide	Untreated Control	Average	Herbicide	Untreated Control	Average
0	12.5	0.0	6.2 A	0.0	0.0	0.0 A
5	10.0	0.0	5.0 A	0.0	0.0	0.0 A
10	10.7	0.0	5.4 A	0.0	0.0	0.0 A
15	9.5	0.0	4.7 A	0.0	0.0	0.0 A
Average	10.7 a	0.0 b		0.0 a	0.0 a	
CV		4			0	

** significant at 1% by the F test; * significant at 5% by the F test; ns: not significant. Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other by Tukey's test at 5% probability level

Table 6 - Sugarcane yield in Mg ha^{-1} related with straw layer on the soil surface (0, 5, 10 and 15 Mg ha^{-1}) and adoption or not of herbicide application (sulfentrazone + tebuthiuron) for the two years evaluated Year 1 and Year 2

		Year 1			Year 2	
Straw	Herbicide	Untreated Control	Average	Herbicide	Untreated Control	Average
0	124	119	122 A	99	88	93 A
5	116	122	119 A	96	95	96 A
10	120	111	116 A	95	95	95 A
15	118	114	116 A	103	105	104 A
Average	120 a	117 a		98 a	96 b	
CV		12			9	

** significant at 1% by the F test; * significant at 5% by the F test; ns: not significant. Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other by Tukey's test at 5% probability level

times are represented, whereas the others do not justify the presentation because they showed 0% phytotoxicity in all treatments in the studied variety RB85 5453 (Table 5).

The sugarcane phytointoxication by the association of the herbicides sulfentrazone + tebuthiuron (800+900 g ha^{-1}), symptoms were observed initially, but were quickly overcome (Year 1 and Year 2), becoming imperceptible at 60 DAA for all treatments, that is, regarding this parameter analyzed, sugarcane was selective. In Year 1, the average phytointoxication percentage for all straw amounts was 14%, with the lowest phytointoxication in the layer of 15 Mg ha^{-1}. The Year 2 was similar with an average phytointoxication of 11% (Table 5). Possible effects of partial herbicide retention by the straw did not impact the degree of phytointoxication of the crop or its recovery from the initial symptoms. Toledo et al. (2017) evaluating the herbicide treatments on the RB855156 variety: diuron + hexazinone + sulfumeturon-methyl, amicarbazone, amicarbazone + isoxaflutole, sulfentrazone, imazapic and tebuthiuron + isoxaflutole, there were also no significant symptoms of phytointoxication of the herbicides when applied in total pre-emergence until 120 DAA (Toledo et al., 2017).

The straw amount kept on the soil surface did not differ in stem yield between the two years (Table 6). In Year 2 the highest yield was obtained in the treatment with the straw layer of 15 Mg ha^{-1}, presenting 10 Mg ha^{-1} more than the average of 0, 5 and 10 Mg ha^{-1}. In the two years analyzed, the average crop yield was positively influenced by the herbicide use, where the average yield of stalks was 2.5 Mg ha^{-1} more in the application of herbicides when compared to the control (Table 6).When comparing the crop season, there was an 18% reduction of stalk yield, of approximately 10 Mg ha^{-1} from Year 1 to Year 2, that is, a decrease from the third to the fourth ratoon, a process that is natural in sugarcane production.

The sugarcane straw remove for the bioenergy production industry, according to the evaluations carried out, (Silva et al., 2021) would be feasible with the removal of only 5 Mg ha^{-1} of sugarcane straw, maintaining a straw layer of at least 10 Mg ha^{-1}. By this approach, a possible control of the straw layer in the morningglories and a contribution by chemical control may obtain success in the control of the weeds in ratoon cane.

4. Conclusions

The control of the morningglories (*I. triloba* and *I. hederifolia*), in a green cane system, lacks the adoption of herbicides, where the choice of sulfentrazone + tebuthiuron molecules is a very efficient association for green cane system, harvested at the beginning of the harvest season, with pre-emergent application. Furthermore, when the herbicide is applied, there is an increase in production, which is associated with a reduction in weed competition, especially in morningglory species that have the potential to interfere with sugarcane growth.

A relevant aspect observed in our research was the reduction in the morningglory population when high straw amounts were kept on the soil (values greater than 10 Mg ha^{-1}), which is verified by the fact that morningglory species are highly adapted to the cultivation of green cane. In this context, it is possible to remove part of the residual straw for energy cogeneration 5 Mg ha^{-1}, without harming weed control or yield in the sugarcane crop.

Authors' contributions

All authors read and agreed to the published version of the manuscript. RAC, SGQC, LMSM, MAK, and JLNC: Conceptualization of the manuscript and development of the methodology. SGQC, M.A.K., and LMSM: data collection and curation. RAC, SGQC, MAK, and LMSM: data analysis. RAC, SGQC, MAK, and JLNC: data interpretation. JLNC: funding acquisition and resources. SGQC, MAK, and JLNC: project administration. JLNC: supervision. RAC, SGQC, and LMSM: writing the original draft of the manuscript. RAC, SGQC, LMSM, MAK, and JLNC: writing, review and editing.

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