Chemical management of weeds in cassava crop, cultivar 'Santa Helena'[1]

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ABSTRACT

The objective of this study was to evaluate the selectivity of cassava cultivar 'Santa Helena' and the efficiency of weed control using herbicides applied alone or tank mixed with and without sequential applications. Two experiments were carried out, both in a randomized block design with four replications. The treatments for the 1st experiment were: Hand hoeing (weed-free control); No hand hoeing (non-weeded control); sulfentrazone (500 g ha^{-1}); sulfentrazone/[clomazone + clethodim] (500/[1125 + 120] g ha^{-1}); sulfentrazone/mesotrione (500/240 g ha^{-1}); S-metolachlor (1920 g ha^{-1}); S-metolachlor/[clomazone + clethodim] (1920/[1125 + 120] g ha^{-1}); S-metolachlor/mesotrione](1920/240 g ha^{-1}); [sulfentrazone + S-metolachlor]/[clomazone + clethodim] ([500 + 1920]/[1125 + 120] g ha^{-1}); [sulfentrazone + S-metolachlor]/mesotrione ([500 + 1920]/240 g ha^{-1}). The treatments of the 2nd experiment were: Hand hoeing (weed-free control); No hand hoeing (non-weeded control); glyphosate (360 g ha^{-1}) + hand hoeing; glyphosate + sulfentrazone (360 + 500 g ha^{-1}); glyphosate + flumioxazin (360 + 50 g ha^{-1}); glyphosate + clomazone (360 + 1125 g ha^{-1}); glyphosate + S-metolachlor (360 + 1920 g ha^{-1}); glyphosate + sulfentrazone + clomazone (360 + 400 + 900 g ha^{-1}); glyphosate + sulfentrazone + S-metolachlor (360 + 400 + 1440 g ha^{-1}); glyphosate + flumioxazin + clomazone (360 + 40 + 900 g ha^{-1}); glyphosate + flumioxazin + S-metolachlor (360 + 40 + 1440 g ha^{-1}). In the first experiment, only the treatments S-metolachlor, S-metolachlor/[clomazone + clethodim] and S-metolachlor/mesotrione did not present efficient weed control, causing reduction in yields; the other treatments were crop selective and efficient. In the second experiment, all treatments showed excellent levels of weed control up to 65 DAA and were crop selective. It is concluded that applications of tank mixtures, sequential mixtures and the use of glyphosate mixed with pre-emergent herbicides constitute excellent alternatives of weed management strategies in 'Santa Helena' cassava.

Keywords: herbicide; selectivity; *Manihot esculenta*.

INTRODUCTION

Cassava has been largely cultivated in many parts of the world such as Asia, Africa, South America, Central America and Oceania, mainly because of the high adaptability and rusticity of this plant (FAO, 2018). However, a great problem occurs due to the interference of weed plants, which can cause reductions of up to 100% (Biffe *et al*., 2010). Thus, chemical control has been used as the main method of weed management (Silveira *et al*., 2012).

In Brazil, there are few herbicides registered, which limits the options that producers have to develop management strategies using pre-emergent or post-emergent herbicides during the critical growth period of cassava (Costa *et al*., 2013a). Among the herbicides registered for use are the photosystem II inhibitors (ametryn and metribuzin); carotenoid inhibitors (clomazone and isoxaflutole); PPO inhibitors (carfentrazone-ethyl and flumioxazin); cell division inhibitor (S-metolachlor); and ACCase inhibitors (clethodim and fluazifop-P-butyl) (MAPA, 2018). Considering the registered herbicides, it can be seen that there are no alternatives for the control of non-grass dicot or monocot species at post-emergence; therefore, in

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general, control has exclusively been done with the use of pre-emergent herbicides.

The residual effect of pre-emergent herbicide should preferably last from the time of application (which occurs at planting) to the end of the critical interference prevention period (CIPP) of weeds on the crop, which varies from 25 to 75 days after the emergence of cassava plants (Albuquerque *et al*., 2008). However, only a single application at pre-emergence is not sufficient to ensure control of weed plants during the CIPP of this crop. The use of tank mixtures and sequential applications have been proven to be interesting options to increase the spectrum of action and residual effect of herbicides on diverse crops such as cotton, soybean and maize (Arantes *et al*., 2014; Maciel *et al*., 2015; Vieira Júnior *et al*., 2015). These management strategies can also be used in cassava crops if we also consider that sulfentrazone and mesotrione are cassava selective herbicides and are alternatives for use at pre-emergence and post-emergence and tank mixed with other herbicides (Scariot *et al*., 2013; Costa *et al*., 2013a; Costa *et al*., 2015a).

Other strategy that can be adopted especially in areas where the conventional tillage is used where the soil is turned over by plowing and harrowing is when for any reason there is some delay in planting, and recurrence of weed plants in the area may occur. In this case, to avoid mechanical control and another soil disturbing operation, weed control could be done at planting with application of glyphosate mixed with residual herbicides.

Thus, it is believed that weed competition with crops can be controlled by using tank mixtures and/or sequential applications of herbicides to ensure a longer residual period and control efficiency within the CIPP of the crop, and when tillage is used, the application of a mixture of residual herbicides with glyphosate using the plant-and-apply system can be an alternative for the suppression of weeds that have already emerged, thus avoiding another soil disturbing operation (mechanical weed control).

Given the above, this study aimed to assess the selectivity of cassava cultivar ‘Santa Helena’ (‘Fécula Branca’) and the effectiveness of weed control using herbicides applied alone or tank-mixed with or without sequential applications.

MATERIAL AND METHODS

Two simultaneous experiments were carried out under field conditions during the 2015/2016 growing season. The experiments were conducted at the Experimental Station of IAPAR in Porto Mendes/PR, district of Marechal Cândido Rondon/PR, located at the following geographic coordinates: latitude 24º29’18’’ S and longitude 54º18’11’’ W, and approximate altitude of 218 m. Weather conditions including average temperature and rainfall across the time period when experiments were conducted are presented in Figure 1.

The area was previously cultivated with second-crop maize and after being harvested, which occurred in the second half of August, the area was tilled with one plowing and two harrowing operations, using conventional tillage, to prepare the soil for planting the cassava crop. The chemical analysis of soil presented the following characteristics: pH ($CaCl_2$) = 5.33; Organic matter (g dm^{-3}) = 27.34; P (mg dm^{-3}) = 15.67; H + AL, K, Ca, Mg, Base Saturation and Cation Exchange Capacity (cmol$_c$ dm^{-3}) = 2.95; 0.87; 6.51; 1.60; 8.98; 11.93, respectively; and V% = 72.27. The soil textural composition consisted of 24.6% clay, 61.2% silt and 14.1% sand.

The experimental design used for both experiments consisted of randomized blocks with four replications. The treatments assessed in the first experiment are described in Table 1, as well, for the second experiment, the list of treatments is shown in Table 2.

The cassava cultivar used in the experiments was ‘Santa Helena’, better known as ‘Fécula Branca’ [White Starch] cassava. Tillage was conducted 20 days before planting (DBP) with simultaneous application of base fertilizer (250 kg ha^{-1} of the formulated fertilizer 00-14-19).

Planting of cassava cuttings in both experiments occurred in Sept 30, 2015, using a cassava planter (Planti Center, Bazuca model), two planting rows, spacing of 0.9 x 0.7 m. Cassava cuttings with the same sizes were selected, which one containing three buds. The plots were 3.6 m wide and 5 m long, and only the two central rows were considered as the net area, with 3.6 m in length.

The first application of the treatments was conducted in Oct 13, 2015, at the pre-emergence of cassava plants and weed plants for both experiments. At the time of herbicide applications, the cassava cuttings exhibited initial rooting and shoots with approximately 1 cm long. Temperature, relative air humidity and wind speed at the time of application were: 23.9 ºC, 62% and 4.6 km h^{-1}, respectively.

The sequential application in the first experiment occurred approximately 50 days after the first application (DA1stA), and the weather conditions at the time of application were: temperature of 29 ºC, 59% relative air humidity and 4.3, km h^{-1} wind speed. The growth stage of the monocot plants (*Digitaria insularis*, *Zea mays* (volunteer maize), and *Sorghum halepense*) at the time of application corresponded to 2 to 4 tillers, and for dicots (*Bidens pilosa*, *Commelina benghalensis*, and *Richardia brasiliensis*), the plants had 8 to 12 pairs of leaves. In the treatments with hand hoeing (control), four hoeing operations were conducted, at 0, 15, 30 and 45 days after planting of the cassava cuttings.

The herbicides were applied using a backpack pump sprayer pressurized with CO_2 at 2.6 kgf cm^{-2}, with a sixnozzle boom (model MagnoJet AD 11002), 50 cm spacing, and flow rate of 200 L ha^{-1}.

The phytotoxicity levels in the cassava plants and weed control in the first experiment were assessed at 19, 33, 46, 55 and 65 days after the first application (DA1stA) and 5 and 15 days after the second application (DA2ndA) for the treatments with sequential herbicide application. In the second experiment, the phytotoxicity levels in the cassava plants were assessed at 19, 33 and 46 days after application (DAA), and weed control was determined at 19, 33, 46, 55 and 65 DAA. The toxicity and control scores, based on the scale proposed by the Sociedade Brasileira da Ciência das Plantas Daninhas (SBCPD, 1995), were used, where 0 (zero) corresponded to no visible injury and 100 (hundred) to the death of cassava plants or weed plants.

Harvesting was done 12 months after planting when the plants in the two central rows of the plots were collected, disregarding one plant at each end of the rows. The roots were weighed using a digital scale (error=0.05 kg) and, afterwards, yield (t ha^{-1}) was determined. The starch content (%) was determined by the hydrostatic balance method proposed by Grossman & Freitas (1950), using a sample of 3.0 kg of roots from each plot.

The results were subjected to ANOVA F-test, and when significant they were tested by the Scott Knott test at the level of 5% of probability using the statistical analysis software SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSIONS

1st experiment

During the phytotoxicity evaluation period (Table 3), at 19 DA1stA, the cassava plants did not exhibit any toxicity symptom caused by pre-emergent application of sulfentrazone and S-metolachlor, but at 33 DA1stA, the

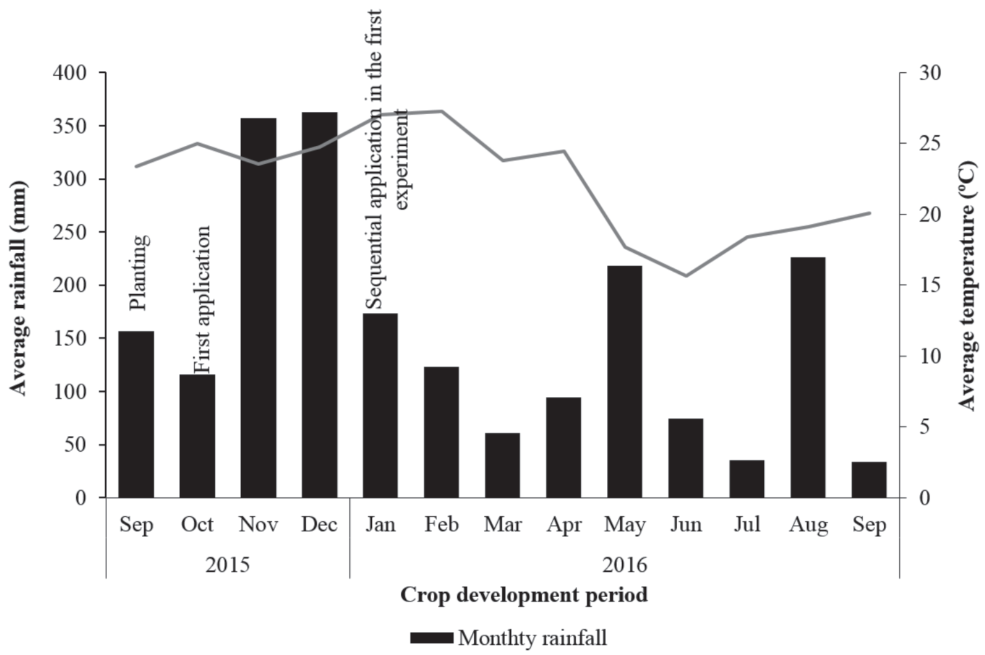

Figure 1: Meteorological data of average rainfall (mm), average temperature (ºC) during the period of conduction of the experiment between the 2015 and 2016 growing seasons.

Table 1: Treatments used for weed control and selectivity in cassava plant, cultivar 'Santa Helena'. First experiment

Treatments/sequential applications	**Dose (g a.i. ha^{-1})**	**Application mode**
No hand hoeing (non-weeded control)	——	——
Hand hoeing (weed-free control)	——	——
sulfentrazone	500	Pre
sulfentrazone/[clomazone + clethodim]	500/[1125 + 120]	Pre/[Post][2]
sulfentrazone/mesotrione[1]	500/240	Pre/Post[2]
S-metolachlor	1920	Pre
S-metolachlor/[clomazone + clethodim]	1920/[1125 + 120]	Pre/[Post][2]
S-metolachlor/mesotrione[1]	1920/240	Pre/Post[2]
[sulfentrazone + S-metolachlor]/[clomazone + clethodim]	[500 + 1920]/[1125 + 120]	[Pre]/[Post][2]
[sulfentrazone + S-metolachlor]/mesotrione[1]	500 + 1920/[240]	[Pre]/Post[2]

[1]0.5% v/v of mineral oil; [2]sequential application at 50 days after the first application (DA1stA)

plants exhibited slight toxicity symptoms (<15%). Cassava plants have a slow initial growth and can emerge in up to 15 days under favorable conditions (Souza *et al*., 2017). Thus, the injuries found at 33 DA1stA coincide with the period of emergence of fibrous roots, which favored absorption of the active ingredients.

At 46 DA1stA, all injury symptoms caused by the first herbicide application disappeared completely in all treatments.

At 5 DA2ndA (55DA1stA), mild symptoms were observed, mainly caused by carotenoid inhibitors (clomazone and mesotrione), with injuries characterized by loss of pigments, turning the plant leaves' color white (Dias *et al*., 2015). Regarding clethodim, Oliveira Jr. *et al*. (2001) point out that for being an ACCase inhibitor, it is a highly selective herbicide in cassava crops, not causing injuries.

At 15 DA2ndA (65 DA1stA), only the plants treated with clomazone + clethodim exhibited symptoms of toxicity, but at levels considered low, not impairing the crop development.

For the weed control data at 19 DA1stA, three groups were formed. Group A comprised sulfentrazone, sulfentrazone/[clomazone + clethodim], sulfentrazone/ mesotrione, [sulfentrazone + S-metolachlor]/[clomazone + clethodim], [sulfentrazone + S-metolachlor]/mesotrione (Table 4). Group B was made up of S-metolachlor, S-metolachlor/[clomazone + clethodim], S-metolachlor/ mesotrione, and Group C comprised only the control treatment (no hoeing).

Table 2: Treatments used for weed control and selectivity in cassava plants, cultivar 'Santa Helena'. Second experiment

Treatments	Dose (g a.i. ha^{-1})	Application mode
No hoeing (non-weeded control)	——	——
Hand hoeing (weed-free control)	——	——
glyphosate + hand hoeing	360	Pre
glyphosate + sulfentrazone	360 + 500	Pre
glyphosate + flumioxazin	360 + 50	Pre
glyphosate + clomazone	360 + 1125	Pre
glyphosate + S-metolachlor	360 + 1920	Pre
glyphosate + sulfentrazone + clomazone	360 + 400 + 900	Pre
glyphosate + sulfentrazone + S-metolachlor	360 + 400 + 1440	Pre
glyphosate + flumioxazin + clomazone	360 + 40 + 900	Pre
glyphosate + flumioxazin + S-metolachlor	360 + 40 + 1440	Pre

Table 3: Phytotoxicity levels (%) after pre-emergent and post-emergent application of herbicides alone and tank mixed, with or without sequential application on cassava cultivar 'Santa Helena'

Treatments	Days After the 1st Application (DA1stA)				
	19	33	46	55	65
	Days After the 2nd Application (DA2ndA)				
	-	-	-	5	15
	(%)				
Hand hoeing (weed-free control)	0.00	0.00 d	0.00	0.00 d	0.00 c
sulfentrazone	0.00	10.00 b	0.00	0.00 d	0.00 c
sulfentrazone/[clomazone + clethodim]	0.00	11.25 a	0.00	17.50 a	12.50 a
sulfentrazone/mesotrione	0.00	12.50 a	0.00	9.50 c	0.00 c
S-metolachlor	0.00	5.62 c	0.00	0.00 d	0.00 c
S-metolachlor/[clomazone + clethodim]	0.00	5.00 c	0.00	13.00 b	9.87 b
S-metolachlor/mesotrione	0.00	8.75 b	0.00	9.25 c	0.00 c
[sulfentrazone + S-metolachlor]/[clomazone + clethodim]	0.00	13.25 a	0.00	16.25 a	12.25 a
[sulfentrazone + S-metolachlor]/mesotrione	0.00	10.00 b	0.00	9.50 c	0.00 c
Treatment (Calculated F)	—	21.51**	—	79.53**	69.79**
Block (Calculated F)	—	2.14^{ns}	—	3.50**	0.24^{ns}
CV (%)	—	2152	—	18.56	36.19
Overall average	—	8.48	—	8.33	3.84

** significant at the level of 1% probability by F-test; ns - not significant. Means followed by the same lowercase in column do not differ from each other by the Scott Knott's test at the 5% probability level.

The groups formed at 19 DA1stA remained the same until the next assessment, at 15 DA2ndA (65 DA1stA), and the treatments of Group A provided better control of weeds compared with the Group B treatments.

Group A maintained a high level of control at 5 and 15 DA2ndA, so that at the end of the assessment period, they exhibited a satisfactory control rate, between 83.25 and 89.25%. These results indicate that the initial application of sulfentrazone alone or tank mixed with S-metolachlor had a high residual period, and such prolonged residual effect can dispense with or delay the second application of clomazone + clethodim and mesotrione.

The initial application of S-metolachlor provided a satisfactory weed control (75 to 85%) in a relatively short period (19 DA1stA). This outcome can be explained by the low spectrum of control of the species present in the area in comparison with the residual effect provided by sulfentrazone. Thus, the ideal strategy would be to reduce the time interval between the first application of S-metolachlor and the second application of clomazone + clethodim mixtures or mesotrione alone, in order to extend the residual effect with the use of clomazone, or to carry out an application of clethodim or mesotrione to suppress the weed plants that escaped control, still at their initial growth stages.

In other study conducted in the same region and time of year, Scariot *et al*. (2013) found that the application of sulfentrazone (600 g ha^{-1}) and S-metolachlor (1920 g ha^{-1}) on cassava crops (cv. 'Cascuda') controlled 90.3 and 88.3% of weed plants, respectively, by 105 days after application. It can be seen that the residual effect of S-metolachlor applied with the same dose as the one used in the present work was higher in 86 days. This fact can be related to the difference between the precipitation rate in the two studies, i.e., in the study by Scariot *et al*. (2013), 210 mm of rainfall was recorded for the first month of assessment, while in the present study only 100 mm of rainfall occurred in the same period.

S-metolachlor has a high coefficient of sorption (Koc = 200 mL g^{-1}) and high solubility in water (488 mg L^{-1}), and these physicochemical parameters indicate, respectively, a high potential of adsorption by soil colloids and solubilization of the active substance in water, and the low rainfall rate occurred in the early stages of the crop development can explain the short residual period of S-metolachlor. Likewise, sulfentrazone has a low coefficient of sorption

(Koc = 43 mL g^{-1}) and solubility (110 mg L^{-1}), indicating less adsorption in soil colloids at low precipitation levels (Rodrigues & Almeida, 2005).

Galon *et al*. (2017) pointed out that the efficiency of herbicides can be directly associated with environmental factors such as rainfall and temperature as well as soil-related factors such as clay content and type, organic matter, pH, and others, which are factors that influence the Koc of herbicides.

It should be noted that the herbicide applications occurred 13 days after planting the crop and, considering that the treatments of Group A provided an average control of 86.5% for a period of 65 DA1stA, it can be concluded

Table 4: Average control (%) of weed plants after pre-emergent and post-emergent application of herbicides alone and tank mixed, with or without sequential application on cassava cv. 'Santa Helena'

Treatments	**Days after the 1st Application (DA1stA)**				
	19	**33**	**46**	**55**	**65**
	Days after the 2nd Application (DA2ndA)				
	-	**-**	**-**	**5**	**15**
	(%)				
No hand hoeing (non-weeded control)	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
sulfentrazone	94.75 a	92.25 a	92.25 a	90.00 a	85.00 a
sulfentrazone/[clomazone + clethodim]	88.75 a	89.50 a	90.00 a	92.50 a	86.25 a
sulfentrazone/mesotrione	94.75 a	93.75 a	92.50 a	91.25 a	89.25 a
S-metolachlor	84.50 b	65.00 b	47.00 b	39.75 b	23.25 b
S-metolachlor/[clomazone + clethodim]	75.75 b	60.50 b	40.00 b	37.50 b	25.00 b
S-metolachlor/mesotrione	77.50 b	55.25 b	33.75 b	28.75 b	21.25 b
[sulfentrazone + S-metolachlor]/[clomazone + clethodim]	93.25 a	89.25 a	85.00 a	88.75 a	83.25 a
[sulfentrazone + S-metolachlor]/mesotrione	92.00 a	90.00 a	89.00 a	86.25 a	88.75 a
Treatment (Calculated F)	80.79**	23.01**	84.09**	81.23**	140.86**
Block (Calculated F)	0.11ns	2.89ns	2.14ns	4.13*	1.31ns
CV (%)	8.59	18.01	11.70	12.68	11.23
Overall average	77.91	73,55	63.27	61.63	55.77

**, * significant at the level of 1 and 5 % of probability by F-test, respectively; ns - not significant. Means followed by same lowercase in column do not differ from each other by the Scott Knott's test at the 5% probability level.

that the total period of control was 78 days after planting (DAP). This weed-free period corroborates the data obtained by Alburquerque *et al*. (2008), who determined that the CIPP for cassava cv. 'Cascuda' was 25 to 75 DAP. Biffe *et al*. (2010) determined that the CIPP for cassava cv. 'Fécula Branca' was 18 to 100 DAP.

The yield results showed a direct relation with the control of weed plants (Table 5), considering that the Group formed by the most effective treatments were also those that were more cassava selective. Therefore, the treatments that showed cassava root yields similar to the ones found in the hand-hoeing treatment (considered selective) were in Group A: sulfentrazone, sulfentrazone/[clomazone + clethodim], sulfentrazone/mesotrione, [sulfentrazone + S-metolachlor]/[clomazone + clethodim], [sulfentrazone + S-metolachlor]/mesotrione.

The average yields of Group A were 37.5% higher than in Group B. On the other hand, the average yields for the treatments included in Group B (S-metolachlor, S-metolachlor/[clomazone + clethodim], S-metolachlor/mesotrione) were 90.1% higher than the control treatment (no hand hoeing), indicating that they are potentially selective. Furthermore, the reduced production of roots can be due to the low efficiency in the control of weed plants in the CIPP of cassava crop.

Group C, constituted only by the control treatment (no hand hoeing) exhibited roots production 95.4% lower that the hand-hoeing control treatment. According to Alabi *et al*. (2001) & Costa *et al*. (2013c), losses caused by the interference of weed plants can reach 87 to 96%, showing that the crop is highly sensitive to weed interference.

Many authors have pointed out that some herbicides used in cassava crops do not cause yield reductions. Scariot *et al*. (2013), with application of sulfentrazone (600 g ha^{-1}) and S-metolachlor (1920 g ha^{-1}) did not observe yield reductions for cassava cv. 'Cascuda'; Costa *et al*. (2013b) also did not observe yield reductions with application of clomazone (1080 g ha^{-1}) and S-metolachlor (1920 g ha^{-1}) in cv. 'Baianinha'; Costa *et al*. (2013a), for the cv. 'Cascuda', with application of clethodim (240 g ha^{-1}) and mesotrione (120 g ha^{-1}) with addition of oil (0.0; 0.5; 1.0 % v v^{-1}), found no differences in yields, demonstrating the herbicide selectivity in cassava.

Only for the no-hoeing plot, it was not possible to determine the starch content due to the low production of roots. The other treatments form a single group, with an average of 27.9% starch content. Several authors, among them Abreu *et al*. (2010), Franciscon *et al*. (2016), Costa *et al*. (2014), and Costa *et al*. (2015b), have pointed out that pre-emergent and post-emergent application of herbicides do not cause reductions in starch content.

Based on the results obtained, it could be seen that sulfentrazone had high selectivity, being considered an excellent option for weed control, whether applied alone or mixed with S-metolachlor, and that a sequential application could be delayed, so as to prolong the residual effect of control, eliminating weed competition for a period beyond the crop's CIPP. For S-metolachlor, the residual period was relatively short, possibly due to the occurrence of low rainfall, indicating that sequential herbicide applications could be done earlier.

Table 5: Average yields and starch content after pre-emergence and post-emergence application of herbicides alone and tank mixed, with or without sequential application on cassava cultivar 'Santa Helena'

Treatments	**Root yield**	**Starch content**
	(t ha^{-1})	**(%)**
No hand hoeing (non-weeded control)	1.23 c	0.00 b
Hand hoeing (weed-free control)	26.93 a	27.66 a
sulfentrazone	23.92 a	27.62 a
sulfentrazone/[clomazone + clethodim]	19.24 a	27.84 a
sulfentrazone/mesotrione	20.48 a	28.02 a
S-metolachlor	12.35 b	27.70 a
S-metolachlor/[clomazone + clethodim]	11.78 b	28.92 a
S-metolachlor/mesotrione	13.31 b	28.77 a
[sulfentrazone + S-metolachlor]/[clomazone + clethodim]	20.04 a	27.03 a
[sulfentrazone + S-metolachlor]/mesotrione	23.05 a	28.11 a
Treatment (Calculated F)	9.14**	342.99**
Block (Calculated F)	1.22^{ns}	1.79^{ns}
CV (%)	25.27	3.29
Overall average	17.23	25.16

** significant at the level of 1% of probability by F-test; ns - not significant. Means followed by same lowercase in column do not differ from each other by the Scott Knott's test at the 5% probability level.

2nd experiment

The phytotoxicity-related results showed that only at 33 DAA, cassava plants exhibited injuries, but with very low phytotoxicity rates (< 1the 2.5%) (Table 6). Four groups were formed for the assessment conducted at 33 DAA, and Group A, made up of glyphosate + clomazone and glyphosate + sulfentrazone + S-metolachlor mixtures, exhibited the highest toxicity rates (11.9%).

Group B, formed by the treatments consisting of glyphosate + flumioxazin; glyphosate + S-metolachlor; and glyphosate + flumioxazin + S-metolachlor, also exhibited phytotoxicity symptoms, but less intensive (8.6%). Group C, which was formed by the treatments containing of glyphosate + sulfentrazone; glyphosate + sulfentrazone + clomazone and glyphosate + flumioxazin + clomazone, exhibited an average of 5.4% toxicity symptoms in cassava plants. Group D, which was formed by the hand hoeing treatment and glyphosate + hand hoeing treatment, did not exhibit any visible injury, which indicates that glyphosate was not phytotoxic with pre-emergent applications. At 46 DAA, the symptoms disappeared completely, similarly to what occurred in the first experiment (Table 3).

The results of the weed controls performed show that all treatments provided good efficiencies (>80%) at 19 DAA (Table 7). In general, the control was effective for 65 DAA, but three groups were formed.

Group A was the most efficient group in weed control (96.4%) and comprised mixtures of glyphosate + hand hoeing; glyphosate + sulfentrazone; glyphosate + S-metolachlor; glyphosate + sulfentrazone + clomazone; glyphosate + sulfentrazone + clomazone; glyphosate + sulfentrazone + S-metolachlor. Group B exhibited an average control of 88.4% and comprised the following mixtures: glyphosate + flumioxazin; glyphosate + flumioxazin + clomazone; glyphosate + flumioxazin + S-metolachlor; glyphosate + clomazone. Group C was formed only the by the no-hoeing treatment.

It can be seen that the glyphosate mixture did not affect the residuals’ efficiency. In this regard, Costa *et al*. (2015b) observed optimal control with application of S-metolachlor (960 – 3840 g ha^{-1}) and flumioxazin (50 – 125 g ha^{-1}) on cassava cv. ‘Baianinha’. Therefore, the mixture of glyphosate with residual herbicides can be a good choice for the control of weed plants that already emerged, thus avoiding the need for mechanical practices (tillage).

Based on the weed control results, a criterion to be used when deciding on the best treatment could be the cost of control, as all products mixed with glyphosate, applied alone or in combination with other herbicides, exhibited an effective weed control. According to Vencill *et al*. (2012), the use of herbicides with different mechanisms of action and the mixture with glyphosate can be advantageous when one considers to increase the number or weed species to be controlled. Furthermore, when using more than one mechanism of action, the possibility of evolving to herbicide-resistant weeds diminishes.

The yield results described in Table 8 show that there were significant differences between the hoeing and no-

Table 6: Phytotoxicity rates (%) after pre-emergent application of different herbicides tank mixed with glyphosate on cassava cultivar ‘Santa Helena’

Treatments	Days After Application (DAA)		
	19	33	46
		(%)	
Hand hoeing (weed-free control)	0.00	0.00 d	0.00
glyphosate + hand hoeing	0.00	0.00 d	0.00
glyphosate + sulfentrazone	0.00	5.00 c	0.00
glyphosate + flumioxazin	0.00	8.00 b	0.00
glyphosate + clomazone	0.00	11.25 a	0.00
glyphosate + S-metolachlor	0.00	9.50 b	0.00
glyphosate + sulfentrazone + clomazone	0.00	6.25 c	0.00
glyphosate + sulfentrazone + S-metolachlor	0.00	12.50 a	0.00
glyphosate + flumioxazin + clomazone	0.00	5.00 c	0.00
glyphosate + flumioxazin + S-metolachlor	0.00	8.38 b	0.00
Treatment (Calculated F)	—	29.75**	—
Block (Calculated F)	—	0.78^{ns}	—
CV (%)	—	23.64	—
Overall average	—	6.58	—

** significant at the 1% probability level by F-test; ns - not significant. Means followed by same lowercase in column do not differ from each other by the Scott Knott’s test at the 5% probability level.

hoeing treatments, mainly caused by the interference of non-controlled weeds.

According to Peressin (2011) and Johanns & Contiero (2006) in cultivar 'Santa Helena (Fécula Branca)', weed interference can cause cassava yield losses of up to 90%. According to Silva *et al*. (2012), cassava crop has a low competitive ability compared with weeds, which may cause severe yield reductions.

Concerning the starch content results, there were no differences between the treatments, as the use of herbicides applied alone or in mixture did not present starch content reductions. In a similar study by Costa et al. (2014) using glyphosate (720 g ha^{-1}), glyphosate + flumioxazin (720 + 83 g ha^{-1}) and glyphosate + clomazone (720 + 1080 g ha^{-1}), these authors neither found root yield reductions nor starch content reductions for cv.

Table 7: Mean values of weed control (%) after pre-emergent application of different herbicides tank mixed with glyphosate on cassava cultivar 'Santa Helena'

Treatments	Days After Application (DAA)				
	19	33	46	55	65
			(%)		
No hoeing (non-weeded control)	0.00 b	0.00 c	0.00 b	0.00 c	0.00 c
glyphosate + hand hoeing	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
glyphosate + sulfentrazone	99.50 a	98.75 a	99.50 a	96.25 a	96.75 a
glyphosate + flumioxazin	96.25 a	95.00 b	93.75 a	89.25 a	88.25 b
glyphosate + clomazone	87.00 a	92.50 b	78.00 a	76.25 b	88.75 b
glyphosate + S-metolachlor	98.25 a	95.00 b	91.00 a	91.75 a	92.75 a
glyphosate + sulfentrazone + clomazone	99.25 a	98.75 a	98.25 a	97.25 a	94.50 a
glyphosate + sulfentrazone + S-metolachlor	100.00 a	98.75 a	99.75 a	98.25 a	98.00 a
glyphosate + flumioxazin + clomazone	92.25 a	95.50 b	85.00 a	93.00 a	89.00 b
glyphosate + flumioxazin + S-metolachlor	91.25 a	93.75 b	89.50 a	83.75 b	87.50 b
Treatment (Calculated F)	62.21**	328.14**	31.80**	46.50**	268.54**
Block (Calculated F)	2.56^{ns}	4.22*	3.28*	1.91^{ns}	2.90^{ns}
CV (%)	9.00	3.89	12.83	10.62	4.34
Overall average	86.37	86.80	83.47	82.57	83.55

**, * significant at the 1% and 5% probability level by F-test, respectively; ns - not significant. Means followed by same lowercase in column do not differ from each other the Scott Knott's test with 5% probability.

Table 8: Average yield rates and starch content after pre-emergent application of different herbicides tank mixed with glyphosate on cassava cultivar 'Santa Helena'

Treatments	Root yields	Starch content
	(t ha^{-1})	(%)
Hand hoeing (weed-free control)	20.91 a	27.71
No hoeing (non-weeded control)	5.80 b	27.03
glyphosate + hand hoeing	19.22 a	27.31
glyphosate + sulfentrazone	17.07 a	27.52
glyphosate + flumioxazin	18.94 a	27.38
glyphosate + clomazone	17.33 a	26.53
glyphosate + S-metolachlor	18.35 a	23.08
glyphosate + sulfentrazone + clomazone	19.09 a	26.74
glyphosate + sulfentrazone + S-metolachlor	19.78 a	26.96
glyphosate + flumioxazin + clomazone	16.31 a	27.10
glyphosate + flumioxazin + S-metolachlor	17.02 a	28.30
Treatment (Calculated F)	6.84**	1.21 ^{ns}
Block (Calculated F)	1.30^{ns}	2.59 ^{ns}
CV (%)	17.89	3.05
Overall average	17.26	27.14

** significant at the 1% probability level by F-test; ns - not significant. Means followed by same lowercase in column do not differ from each other by the Scott Knott's test at the 5% probability level.

‘Santa Helena’ (‘Fécula Branca’), demonstrating high crop selectivity.

As all treatments used in this study showed to be efficient in weed control, in addition to be highly selective in cassava cv. ‘Santa Helena’, it is up to producers to use their discretion in selecting the most advantageous tank mixture, aiming at reducing costs without reducing efficiency. The average root yield achieved in the treatments was

18.40 t ha^{-1}, while with no weed control, root yields decreased by 68.5%. Such reduction represents $ 5,670 Brazilian reais in losses per hectare, considering $ 450 Brazilian reais t^{-1} of roots (CEPEA, 2018).

CONCLUSIONS

In the first experiment, the sequential herbicide application exhibited high selectivity in cassava cv. ‘Santa Helena’ as well as an effective control of weed plants, especially with the following treatments: sulfentrazone (500 g ha^{-1}), sulfentrazone/[clomazone + clethodim] (500/[1125 + 120] g ha^{-1}), sulfentrazone/mesotrione (500/240 g ha^{-1}), [sulfentrazone + S-metolachlor]/[clomazone + clethodim] ([500 + 1920]/[1125 + 120] g ha^{-1}) and [sulfentrazone + S-metolachlor]/mesotrione ([500 + 1920]/240 g ha^{-1}).

In the second experiment, all treatments were highly selective in cassava cv. ‘Santa Helena’ and extremely efficient in the control of weeds, showing that the mixture of glyphosate with pre-emergent herbicides can be an excellent alternative for the suppression of weeds already emerged, avoiding the need for another soil breaking-up operation before planting the cassava cuttings.

Therefore, tank-mixed herbicide applications, sequential applications and the use of glyphosate mixed with pre-emergent herbicides are excellent strategies for weed management in cassava cv. ‘Santa Helena’ crop.

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