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Article

Selectivity and Effectiveness of Herbicides in the Grain Sorghum Crop

Seletividade e Eficácia de Herbicidas na Cultura do Sorgo Granífero

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ABSTRACT - Over the years, cultivated areas of sorghum have expanded considerably in Brazil. Chemical weed control has become an obstacle due to the scarcity of herbicides registered for the crop. The aim of this study was to evaluate the efficiency of weed control and selectivity of herbicides applied in pre and post emergence in the crop. Two experiments were conducted. In one of them, the hybrid BRS 310 was used while DKB 550 was used in the other. The experiments were performed in the field in randomized block design, evaluating seven treatments with four replications. The used treatments were: 1. Hand weeding, 2. S-metolachlor (1,440 g a.i. ha^{-1}), 3. S-metolachlor (1,440 g a.i. ha^{-1}) + atrazine (2,000 g a.i. ha^{-1}), 4. atrazine (2,000 g a.i. ha^{-1}), 5. atrazine (3,000 g a.i. ha^{-1}), 6. atrazine (2,000 g a.i. ha^{-1}) + mineral oil (0.25%), and 7. atrazine (2,000 g a.i. ha^{-1}) + mineral oil (0.5%). It was verified that post-emergence atrazine was efficient in the weed control and selective to the sorghum crop, not affecting productivity, except in mixture with mineral oil (0.5%). S-metolachlor cannot be recommended in pre-emergence for the tested cultivars because it is not selective, reducing plants and productivity.

Keywords: *Sorghum bicolor*, phytotoxicity, chemical control, weed management, productivity.

RESUMO - Como o decorrer dos anos, as áreas cultivadas de sorgo no Brasil expandiram de forma considerável. O controle químico de plantas daninhas se tornou um entrave devido à escassez de herbicidas registrados para a cultura. Objetivou-se com este trabalho avaliar a eficiência no controle de plantas daninhas e seletividade de herbicidas aplicados em pré e pós-emergência na cultura. Foram conduzidos dois experimentos. Em um deles utilizou-se o híbrido BRS 310 e, no outro, DKB 550. Os experimentos foram realizados em campo, no delineamento em blocos casualizados, avaliando-se sete tratamentos com quatro repetições. Os tratamentos utilizados foram: 1. capina manual; 2. S-metolachlor (1.440 g i.a. ha^{-1}); 3. S-metolachlor (1.440 g i.a. ha^{-1}) + atrazine (2.000 g i.a. ha^{-1}); 4. atrazine (2.000 g i.a. ha^{-1}); 5. atrazine (3.000 g i.a. ha^{-1}); 6. atrazine (2.000 g i.a. ha^{-1}) + óleo mineral (0,25%); e 7. atrazine (2.000 g i.a. ha^{-1}) + óleo mineral (0,5%). Verificou-se que a atrazine em pós-emergência foi eficiente no controle de plantas daninhas e seletiva à cultura do sorgo, não afetando a produtividade, exceto em mistura com óleo mineral (0,5%), e que o S-metolachlor não pode ser recomendado em pré-emergência para os cultivares testados, pelo fato de não ser seletivo, promovendo a redução de plantas e produtividade.

Palavras-chave: *Sorghum bicolor*, fitotoxicidade, controle químico, manejo de plantas daninhas, produtividade.

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INTRODUCTION

Sorghum (*Sorgum bicolor*) is one of the most versatile and efficient species, both from a photosynthetic point of view and by its rusticity, making it an option for growing under adverse climatic conditions to the maize cultivation (Dan et al., 2010). Its recognized versatility extends from the use of its grains as human food and feed, ration production and even the numerous applications of its forage in ruminant nutrition, being more used in Brazil (Ribas, 2009; Menezes et al., 2014).

In the early development stages, sorghum plants are relatively small, fragile and has slow growth (Silva et al., 2014). Competition with weed at this stage is quite critical, and if control measures are not taken in the first few weeks after the emergence of sorghum plants, grain yield can be reduced by around 35-70% (Rodrigues et al., 2010)

The chemical control of weeds in the crop is limited by the low amount of registered herbicides, being only atrazine, simazine and 2,4-D (Correia and Gomes, 2015; AGROFIT, 2018). Studies on the effects and efficacy of herbicides on sorghum are fundamental to increase alternatives for weed control (Machado et al., 2016).

Atrazine is indicated mainly in the control of dicotyledon, showing low control spectrum on grasses. Due to the low control spectrum on grasses, it is common to find sorghum crops completely infested by this group of plants, even after the application of the herbicide in pre- or post-emergence. The addition of vegetable or mineral oil to the herbicide improves the efficiency when applied in the initial post-emergence, before the tillering of grasses. However, the herbicide package insert should be checked if there is such a recommendation, whether it does not exist, it is not indicated, since it may potentiate the herbicide effect, intoxicating the crop (Silva et al., 2007).

The main problems associated with the use of herbicides are the emergence of resistant species and consequently there is a growing demand for new compounds that have action mechanisms different from the herbicides in use. Some products, such as metolachlor and alachlor, belonging to the group of acetanilide, which are recommended for maize, are being used in sorghum by producers due to the affinity between both crops, and being tested in research study for the crop (Takano et al., 2016).

Herbicides belonging to this chemical group are paired in pre-emergence to control annual grasses (Peterson et al., 2001). The herbicide S-metolachlor is widely used in pre-planting in the corn crop, with graminicide, mainly to control of *Commelia benghalensis* L.

One of the major obstacles to the expansion of sorghum cultivation has been the difficulty in weed management, due to the sensitivity of this crop to graminicide herbicides marketed in Brazil. The use of safeners has been developed for use of alachlor and Smetolachlor in grain sorghum. In order to increase the tolerance of the cultivated species, without affecting the sensitivity of weeds (Alterman and Jones, 2003). However, when these experiments were carried out, these products were not being marketed in Brazil.

Thus, it is important to conduct research to find new selective herbicide solutions for the crop. Another factor to consider is the degree of tolerance of each hybrid of sorghum to herbicides and also the dose of product, which presents selectivity to the sorghum, besides being sufficient to control weeds.

Based on the above, the aim was to evaluate the efficiency of different herbicides in weed control and their selectivity, when applied in pre- and post-emergence in the grain sorghum crop.

MATERIAL AND METHODS

Two experiments were conducted at the Experimental Station of the Universidade Federal de Lavras (UFLA), Muquém Farm, located in Lavras (44°58' W longitude and 21°12' S latitude, 951 m altitude), Minas Gerais State, Brazil. The hybrid DKB 550 was used in one of the experiments and the hybrid BRS 310 was used in the other, chosen due to the high productive potential and the resistance to the main diseases (resistance to cercosporiosis and moderate resistance to anthracnose, helmintosporiosis and rust).

The soil was a Red-Yellow Latosol of clayey texture (Embrapa, 2006), showing the following chemical analysis: pH ($CaCl_2$) 5.8; O.M. 2.62 $dag.kg^{-1}$; P 9.93 mg dm^{-3}; K 80.62 mg dm^{-3}; S 18.89 mg dm^{-3}; Ca^{2+} 2.46 $cmol_c$ dm^{-3}; Mg^{2+} 0.45 $cmol_c$ dm^{-3}; Al^{3+} 0.5 $cmol_c$ dm^{-3}; H + Al 3.31 $cmol_c$ dm^{-3}; SB 3.12 $cmol_c$ dm^{-3}; T 6.43 $cmol_c$ dm^{-3}. Before sowing, three tons per hectare of limestone was applied in the area in order to correct toxic aluminum and increase soil saturation, as recommended for the crop (Sousa and Lobato, 2004).

The sowing of hybrids occurred in November 28, 2016, with a final population of 233,000 plants ha^{-1} (DKB 550) and 200,000 plants ha^{-1} (BRS 310). The fertilization was based on the soil analysis and recommendations for soils of the Cerrado, with 350 kg ha^{-1} of formulated fertilizer NPK 08-28-16 (Sousa and Lobato, 2004). Were applied 100 kg ha^{-1} of N in total area, 60 days after seeding.

The daily averages of temperature and relative humidity, as well as the occurrence of rainfall, were recorded by the bioclimatology sector of the Federal University of Lavras (UFLA). Table 1 shows the measures and monthly totals.

Table 1 **-** Monthly averages of temperature, relative humidity and rainfall

Month	Total rainfall (mm)	TAVG[(1)] (ºC)	RH AVG[(2)] (%)
November/16	190.2	27.4	75.7
December/16	145.0	29.5	71.9
January/17	157.9	30.3	72.8
February/17	64.1	29.9	69.6
March/17	158.6	29.4	70.0

[(1)] Monthly average air temperature; [(2)] Monthly air relative humidity.

The used experimental design was the randomized complete block design with four replications. The experimental plot consisted of five rows of crop, 5 m length and spaced 0.6 m between rows, totaling 15 m^2. The two central lines were evaluated, corresponding to 6.0 m^2 of useful area.

The herbicides were applied with a backpack sprayer pressurized with CO_2 equipped with four tongue-type nozzles TT110015, spaced 0.5 m apart. The used application volume was 200 L ha^{-1}, working compression of 200 kPa. The treatments applied in pre-emergence occurred on the day of sowing and the treatments applied in the post-emergence occurred when the sorghum plants were in phenological stage 1 (visible on the third ligule). The detailed description of treatments, as well as the used commercial products are listed in Table 2.

Table 2 **-** Characteristics of products used in the experiment

Herbicide		Dose (g ha^{-1} a.i.[(1)])
Common name	Trade name	
1. Control - hand weeding	-	-
2. S-metolachlor	Dual Gold®	1,440
3. S-metolachlor + atrazine	Dual Gold® + Gesaprim®	1,440 + 2,000
4. Atrazine	Gesaprim®	2,000
5. Atrazine	Gesaprim®	3,000
6. Atrazine + oil[(2)]	Gesaprim®+ Assist®	2,000 + 4.8
7. Atrazine + oil[(3)]	Gesaprim®+ Assist®	2,000 + 9.6

[(1)] a.i. = active ingredient; [(2)] Mineral oil - Assist® (0.25% v.v); [(3)] Mineral oil - Assist® (0.50% v.v).

The evaluated characters were: weed control (WC), phytotoxicity (PTO), plant height at flowering (HGT), final stand (STD), 100 grain weight (GW), and productivity (PRO).

Weed control evaluations and species identification were performed at 0, 7 and 21 days after application (DAA) of treatments. For these evaluations, two squares with an area of 0.25 m^2 in each plot were used randomly. Thus, the density of individuals in the present population, number of plants per m^2 and evaluation of weed development stages, were measures taken before to the application of treatments.

In order to obtain control percentages at 7 and 21 DAA, we compared the number of weeds per m^2 with 0 DAA for all plots.

Phytotoxicity evaluations were based on the assignment of grades according to plant intoxication by visual identification of sorghum crop damage performed at 7 and 21 DAA of herbicides application. The grades represented the average of four replicates and were assigned based on the grading scale of the European Weed Research Council (EWRC), according to Melhorança (1984): 1: no damage; 2: small changes (discoloration, deformation) visible in some plants; 3: small changes (discoloration, deformation) visible in several plants; 4: strong discoloration (yellowing) or reasonable deformation, without, however, occurring necrosis (tissue death); 5: necrosis (burning) of some leaves, especially in the margins, accompanied by deformation in leaves and shoots; 6: more than 50% of leaves and shoots showing necrosis (deformation); 7: more than 80% of leaves and shoots destroyed; 8: extremely serious damage, leaving only small green areas on the plants; 9: plant death.

Moreover, the possible effects of plant intoxication sorghum growth were determined by measuring plant height, which occurred 115 days after emergence (physiological maturation). For this purpose, the height in the base of the stem was taken until the insertion of the flag leaf in five plants per plot, taken at random.

Productivity was achieved by harvesting the two central lines of the plots, where the panicles were threshed by hand in order to separate the seeds from each plot, which were weighed. At that moment, each sample had its moisture measured in order to correct the total grain mass per plot to 13% moisture. From each plot, a 100 grain sample was taken at random from the harvested volume, weighed and had its moisture corrected to 13%.

At the end of the crop cycle, the plant stand was evaluated, counting the number of plants in the four central lines from each plot.

For statistical analysis, the counting data and percentage were transformed into square root (x + 0.5) to meet ANOVA premises. The data were analyzed statistically by applying the F test on the ANOVA, followed by the Scoot-Knott test for comparison of the variables. The 5% significance level was adopted. The constant averages in the tables are from the original data, without transformation.

RESULTS AND DISCUSSION

Among the weeds present in the area, a clear dominance of *Richardia brasiliensis, Cenchrus echinatus* and *Ipomoea triloba* was observed in both experiments, and the other weeds found in the total area are presented in Table 3. These results were similar to those performed by Karam et al., (2014) which found high frequency of these three species *R. brasiliensis, C. echinatus* and *Ipomoea* spp., for the maize and soybean producing regions in the states of Minas Gerais and Goiás, Brazil.

Weed control data are shown in Table 4. In the experimental area of the hybrid BRS 310, at seven days after application, there were significant differences ($p<0.05$) between the treatments. However, the difference was not detected by means test. In turn, at 21 days after application, there were significant differences between treatments ($p<0.05$). Herbicides with atrazine, whether or not mixed with oil, showed the same control efficiency as the control treatment (weeding).

In the experimental area of the hybrid DKB 550, at seven days after application, there were not significant differences ($p<0.05$) between treatments, there were only significant differences

Table 3 **-** Percentage of weeds in the total area at zero days after the control

Weed	Family	Bayer Code	BRS 310	DKB 550
			(%)	
Commelia benghalensis L.	Commelinaceae	(COMBE)	8.58	15.17
Cenchrus echinatus	Poaceae	(CCHEC)	27.54	31.88
Eleusine indica	Eleusine indica	(ELEIN)	-	1.54
Monocotyledons			36.12	48.59
Alternanthera tenella	Amaranthaceae	(ALRTE)	1.58	3.09
Melampodium perfoliatum	Asteraceae	(MEMPE)	0.23	3.08
Richaedia brasiliensis	Rubiaceae	(RCHBR)	39.50	22.88
Galinsoga parviflora	Asteraceae	(GASPA)	0.23	5.91
Ipomoea triloba	Convolvulaceae	(IPOTR)	14.45	5.14
Bidens pilosa	Asteraceae	(BIDPI)	7.90	11.31
Eudicotyledons			63.89	51.41
Total			100	100

Table 4 **-** Weed control percentage in BRS 310 and DKB 550 grain sorghum, at 7 and 21 days after application of different treatments

Treatment	Dose (g a.i. ha^{-1})	Weed Control (%)			
		BRS 310		DKB 550	
		7 DAA	21 DAA	7 DAA	21 DAA
S-metolachlor	1,440	5.00 a	0.00 b	31.62 a	4.41 b
S-metolachlor + atrazine	1,440 + 2,000	41.25 a	41.25 a	26.67 a	29.58 b
Atrazine	2,000	64.75 a	58.41 a	34.22 a	20.29 b
Atrazine	3,000	73.17 a	53.88 a	41.12 a	42.74 b
Atrazine + oil(1)	2,000 + 4.8	61.60 a	69.46 a	32.84 a	28.17 b
Atrazine + oil(2)	2,000 + 9.6	68.10 a	62.41 a	32.99 a	18.55 b
Control - weeding	-	100.00 a	100.00 a	100.00 a	100.00 a
Overall average		59.12	55.06	42.78	34.82
CV (%)		47.68	45.81	57.38	62.65
p-value	-	0.0380*	0.0094*	0.1955ns	0.0267*

(1) Mineral oil - Assist® (0.25% v.v); (2) Mineral oil - Assist® (0.50% v.v); * Significant at 5% probability. Averages followed by same letter in the column did not differ statistically among themselves by Scott-Knott test at 5% probability.

at 21 DAA ($p<0.05$). All treatments with herbicides differed statistically from the control treatment (weeding), presenting low percentages of weed control at 21 days after application (Table 4).

According to Rodrigues and Almeida (2011), atrazine is effective mainly in the weed control of broad leaves and some grasses. Corroborating with the present study, where 51 to 64% of experimental areas showed high infestation by weeds of broad leaves (Table 3), with a higher effect of this herbicide, evidencing the higher percentages of control. In the BRS 310 experiment, there was a grater infestation of eudicotiledones weed which showed the highest control rates due to the use of atrazine. However, for the DKB 550 experiment there was greater infestation of monocotyledons weed, resulting in less control by atrazine (Tables 3 and 4).

Several grass species are tolerant to atrazine, according to Silva et al. (2007), one of the plausible explanations for this increase in grass tolerance is related to the lower absorption through leaf tissues or to the existence of compounds, such as benzoxazinones, capable of providing reactions like hydroxylation, dealkylation and even conjugation, reducing the herbicide activity. In contrast, the application of S-metolachlor in pre-emergence shows satisfactory control for *C. echinatus* and *C. benghalensis* (Rodrigues and Almeida, 2011; Lopes Ovejero et al., 2013). Corroborating with Brighenti et al. (1998), where they observed high control levels of *C. benghalensis* in the use of 2,400 g a.i. ha^{-1} of S-metolachlor in maize. However, in the present study, the lower doses of S-metolachlor (1,440 g a.i. ha^{-1}) and the greater infestation by broad leaves in the areas (Table 3) evidenced the low level of weed control (Table 4).

There were significant differences among treatments for plant stand ($p<0.05$) in both experiments, however, there were no significant differences for plant height (Table 5).

Table 5 - Plant height (HGT) and final stand (STD) of the different treatments applied in BRS 310 and DKB 550 sorghum plants

Treatment	Dose (g a.i. ha^{-1})	BRS 310		DKB 550	
		HGT (m)	STD	HGT (m)	STD
S-Metalochlor	1,440	1.26 a	62501.3 b	1.33 a	71252.4 b
S-Metalochlor + Atrazine	1,440 + 2,000	1.29 a	34792.4 c	1.35 a	78543.2 b
Atrazine	2,000	1.28 a	118752.4 a	1.37 a	122294.1 a
Atrazine	3,000	1.25 a	114169.0 a	1.30 a	99377.0 a
Atrazine + oil(1)	2,000 + 0.25%	1.35 a	125835.9 a	1.33 a	98543.6 a
Atrazine + oil(2)	2,000 + 0.50%	1.30 a	117085.7 a	1.32 a	121877.4 a
Control - weeding	-	1.24 a	114585.7 a	1.36 a	109168.9 a
Overall average		1.28	98246.01	1.34	100150.81
CV (%)		12.30	10.93	6.52	12.63
p-value		0.3362^{ns}	< 0.0001*	0.3224^{ns}	0.0441*

(1) Mineral oil - Assist® (0.25% v.v); (2) Mineral oil - Assist® (0.50% v.v); * Significant at 5% probability; ns - Not significant. Averages followed by same letter in the column did not differ statistically among themselves by Scott-Knott test at 5%.

The observation of the plant stand shows that all the treatments with atrazine did not influence this characteristic, being equally to the control treatment (weeding). Nevertheless, the treatments with S-metalochlor influenced in the crop survival, with 45% reduction in the stand for treatment with S-metolachlor (1,440 g a.i. ha^{-1}) and 69% for the treatment with S-metolachlor + atrazine (1,440 g + 2,000 g a.i. ha^{-1}) for hybrid BRS 310. For the hybrid DKB 550, the reductions were 35% and 28% for the respective treatments. These data corroborate with those showed by Martins et al. (2006), 63% and 83% reduction for the herbicides metolachlor + atrazine and metolachlor, respectively. As well as observed by Galon et al. (2016) in which the herbicide S-metolachlor (1,440 g a.i. ha^{-1}) when applied solely in pre-emergence or ready-mix with atrazine (1,500 g a.i. ha^{-1}) promoted morphological changes in sweet sorghum cultivars BRS 509, BRS 506 and BRS 511, causing tissue swelling and young stem curling, leading to reduced growth and failure in the final stand of the crop.

There were significant differences among the treatments for phytotoxicity at 7 ($p<0.05$) and 21 DAA ($p<0.05$) in both experiments (Figure 1).

When comparing the two commercial sorghum hybrids submitted to herbicide application (Figure 1), it was observed that, at 7 and 21 DAA, both hybrids BRS 310 and DKB 550 showed phytotoxicity indexes higher than 5 (severe) for the herbicide atrazine (2,000 g a.i. ha^{-1}) + 0.50% oil, indicating sensitivity of hybrids to the highest oil percentage. However, it did not affect the plant population, equally to the control treatment (Table 5). However, Martins et al. (2006) observed in their studies that the isolated application of atrazine was selective for the crop as well as the application with oil in the two tested formulations (0.25% and 0.5%). In turn, the same authors worked with sorghum cultivar A-6304, showing the importance of evaluations for current cultivars. In saccharin sorghum, low phytotoxicity levels were observed for cultivars BRS 509, BRS 506, BRS 511, when applied atrazine (1,500 g a.i. ha^{-1}) solely in pre-emergence (Galon et al., 2016).

By analyzing phytotoxification symptoms during evaluations, for the herbicides atrazine (2,000 g a.i. ha^{-1}), atrazine (3,000 g a.i. ha^{-1}), and atrazine (2,000 g a.i. ha^{-1}) + 0.25% oil, phytotoxification indexes lower than 3 (medium) were observed for hybrid DKB 550. In relation to the hybrid BRS 310 regarding only the herbicide atrazine (2,000 g a.i. ha^{-1}) + 0.25% oil, the symptoms observed in the evaluation performed at 21 DAA were almost the same as in the first evaluation, with indices higher than 3 (medium).

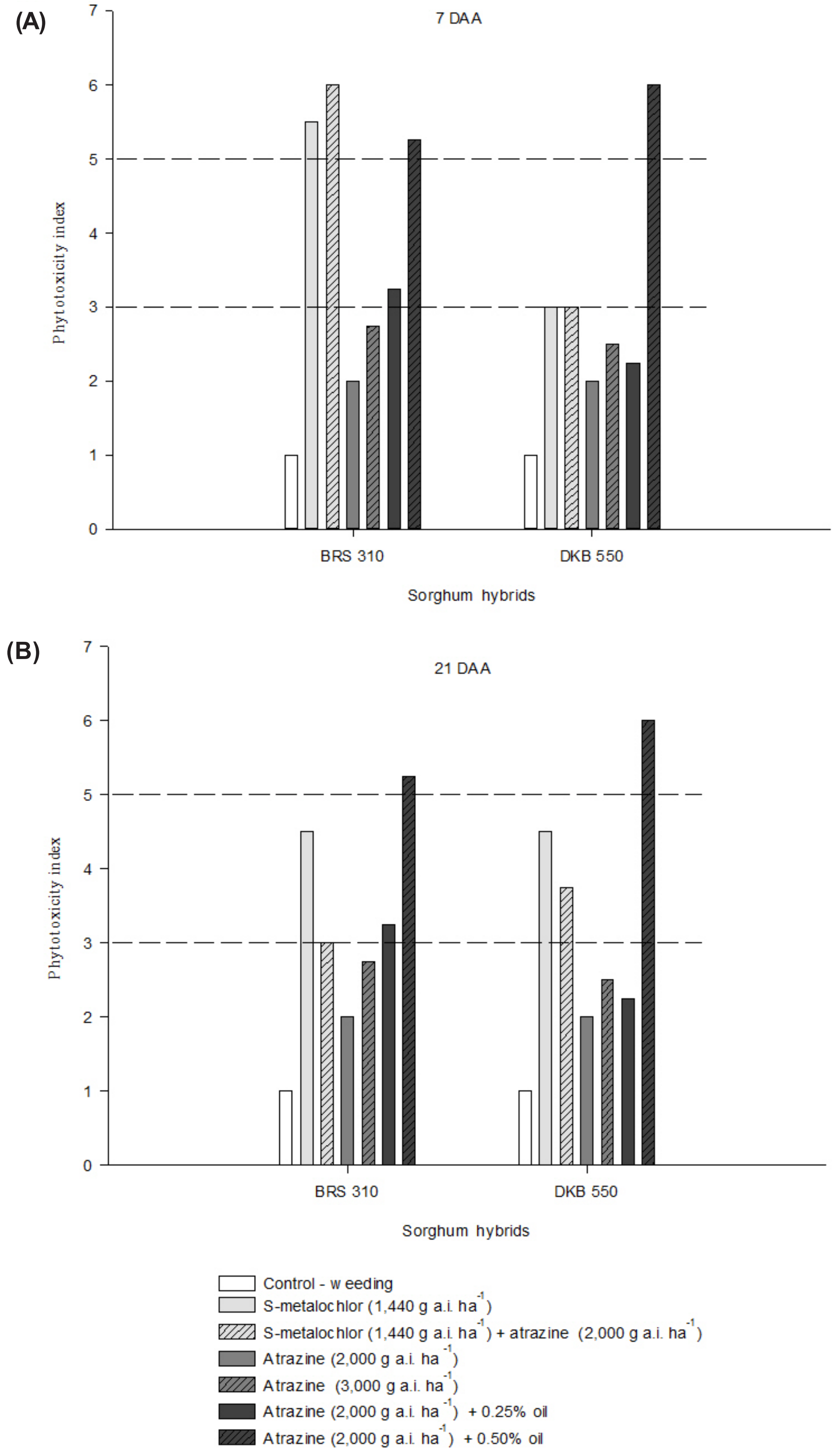

Figure 1 - Phytotoxicity index at: (A) 7, and (B) 21 days after application of the herbicides in different sorghum hybrids, BRS 310 and DKB 550.

For the herbicides S-metolachlor isolated or associated with atrazine, the effects were also accentuated at 7 DAA for hybrid BRS 310, showing recovery in the evaluations performed at 21 DAA, with indexes varying from 3 to 5 (medium to severe). However, for the hybrid DKB 550, there was an advance in the phytotoxification in the final evaluation, for the same herbicides, where the difference was significant by the reduction of the plant stand in comparison to the other treatments, denoting the mortality effect of sorghum plants in both experiments, as observed by Martins et al. (2006).

These results indicate that the permanence or disappearance of phytotoxication symptoms of hybrids may be related to the greater or lesser sensitivity degree of these when submitted to the studied herbicides. Such differences may even affect grain yield.

There were significant differences among treatments of 100 grain weight ($p<0.05$) for the hybrid BRS 310 (Table 6), where the plants obtained the highest 100 grain weight in the plots with control atrazine + oil (2,000 g a.i. a^{-1} + 0.50%). Although the action mechanism of the herbicides atrazine, simazine, metolachlor and alachlor is by inhibition of photosynthesis (Rodrigues and Almeida, 2011), the phytotoxicity effect on the remaining plants was not intense enough to significantly affect the reserve accumulation of the formed seeds. There was not significant differences ($p>0.05$) among treatments in the experiment DKB 550 for the 100 grain weight (Table 6).

Table 6 - Productivity and 100 grain weight (GW) of BRS 310 and DKB 550 grain sorghum plants, depending on the different treatments

Treatment	Dose (g a.i. ha^{-1})	BRS 310		DKB 550	
		GW[(3)] (g)	PRO[(4)] (kg ha^{-1})	GW (g)	PRO (kg ha^{-1})
S-metolachlor	1,440	1.99 b	2657.6 b	2.19 a	4404.50 b
S-metolachlor + atrazine	1,440 + 2,000	2.12 b	2647.9 b	2.30 a	3542.00 b
Atrazine	2,000	2.11 b	5763.8 a	2.16 a	5158.88 a
Atrazine	3,000	2.11 b	5081.9 a	2.20 a	4183.55 b
Atrazine + oil[(1)]	2,000 + 0.25%	2.07 b	5564.4 a	2.24 a	6045.61 a
Atrazine + oil[(2)]	2,000 + 0.50%	2.39 a	5931.7 a	2.15 a	4473.35 a
Control - weeding	-	1.95 b	5418.7 a	2.14 a	5542.51 a
Overall average		2.11	4723.73	2.20	4764.34
CV (%)		6.56	19.08	5.03	20.26
p-value		0.0090*	0.0010*	0.4594[ns]	0.0262*

(1) Mineral oil - Assist® (0.25% v.v); (2) Mineral oil - Assist® (0.50% v.v); (3) GW - 100 grain weight; (4) PRO - Productivity; * Significant at 5% probability; ns - Not significant. Averages followed by same letter in the column did not differ statistically among themselves by Scott-Knott test at 5%.

There were significant differences among treatments for productivity ($p<0.05$) in both experiments (Table 6). The grain yield of the hybrid BRS 310 was reduced by approximately 50% with the applications of S-metolachlor isolated or associated with atrazine when compared to the control treatment. In the case of the hybrid DKB 550, grain yield was also reduced by the application of these two treatments, and by the application of the higher atrazine dose (3,000 g a.i. ha^{-1}). However, the percentage reduction in productivity was lower, ranging from 21% (S-metolachlor) to 36% (S-metolachlor + atrazine). This shows that every hybrid has a different sensitivity for different herbicides. The other treatments did not affect productivity (Table 6). Corroborating with the results found by Martins et al. (2006), which observed a decrease of 43% and 77% of grain yield in treatments of atrazine + metolachlor and metolachlor, respectively.

Regarding atrazine, sorghum has a tolerance mechanism that hinders the absorption and translocation of this herbicide in the plant or by the high levels of benzoxazinones, an enzymatic complex responsible for the metabolization of atrazine in non-toxic compounds (Rodrigues and Almeida, 2011). The application of atrazine in isolation was selective for both hybrids at the lowest dose (2,000 g a.i. ha^{-1}), without affecting productivity. This result corroborates with those obtained by Galon et al. (2016) with sorghum cultivars in the application of atrazine (1,500 g a.i. ha^{-1}). However, the higher atrazine dose (3,000 g a.i. ha^{-1}) caused reductions in productivity for the hybrid DKB 550 (Table 6).

Corroborating with the results obtained in the present study, high intoxication of sorghum plants was reported in the literature, with reduction in stand and consequently productivity by the application of S-metolachlor in the pre-emergence (Martins et al., 2006; Reis et al., 2014). S-metolachlor acts at the beginning of plant development, being absorbed in the coleoptile region of grasses and hypocotyl of dicotyledons (Silva et al., 2007). In these regions, the cells are underdeveloped and did not show wax in cuticle. It is observed that sorghum plants at the beginning of development, after emergence, become more tolerant to S-metolachlor due to its toxic action occurring during the emergence process of seedlings. However, even at lower concentrations (1,440 g a.i. ha^{-1}), S-metolachlor can be absorbed by the shoot of sorghum plants, causing intoxication and reducing growth and yield, as observed in this study and by Machado et al. (2016) at a dose of 768 g a.i. ha^{-1} or also higher doses of the product (2,520 g a.i. ha^{-1}), as observed by Martins et al. (2006).

In the USA, the recommendation for S-metolachlor in the sorghum crop is performed with the use of safener in the seed treatment. The adoption of this practice is able to reduce crop intoxication, and no damages are observed for the final plant development (Geier et al., 2009; Thompson et al., 2016).

Thus, the application of atrazine in post-emergence at the dose of 2,000 g a.i. ha^{-1} did not affect sorghum yield, being selective to the crop. However, atrazine at the dose of 3,000 g a.i. ha^{-1} reduced the yield of sorghum DKB 550. The mixture of atrazine (2,000 g a.i. ha^{-1}) with oil caused phytotoxicity, but did not affect the yield of hybrids. However, the use of S-metolachlor in pre-emergence associated or not with atrazine reduces the stand, causes phytotoxicity and reduces yield of the tested cultivars.

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