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# SELECTIVITY OF HERBICIDES APPLIED ALONE AND IN TANK MIXTURES TO SWEET SORGHUM IN POST-EMERGENCE

**Abstract** – The small number of herbicides registered for sorghum (*Sorghum bicolor* (L.) Moench) restricts its cultivation. The aim of this study was to evaluate the selectivity of herbicides applied alone or in tank mixtures to sweet sorghum in post-emergence. Two experiments were conducted in greenhouse, the first with herbicides applied alone and the second with herbicide mixtures. Based on the results of greenhouse experiments, treatments were selected to evaluate selectivity in the field. In the field experiment, the herbicides applied alone and herbicide mixtures did not differentiate from the control without herbicide application regarding to phytotoxicity, fresh mass of the aerial part, percentage of dry mass of the aerial part and Brix of sweet sorghum at 28 days after application. The treatments considered selective were: atrazine (1000 to 2000), bentazon (360 to 720), S-metolachlor (576 to 864), mesotrione (48 to 150), carfentrazone (4 to 8), 2,4-D amine (335 to 670), besides mixtures with [atrazine + S-metolachlor] [601 + 471.2] and [901.5+ 706.8], atrazine + 2,4-D amine (1000 to 2000 + 100.5 to 268), atrazine + tembotrione (1000 + 42 to 63) and atrazine + mesotrione (1000 + 48 to 72) (doses in g a.i. ha$^{-1}$).

**Keywords**: biomass, chemical control, renewable sources, *Sorghum bicolor* L.

# SELETIVIDADE DE HERBICIDAS ISOLADOS E EM MISTURA APLICADOS EM PÓS-EMERGÊNCIA DE SORGO SACARINO

**Resumo -** O reduzido número de herbicidas registrados para a cultura do sorgo (*Sorghum bicolor* (L.) Moench) limita seu cultivo. Objetivou-se avaliar a seletividade de herbicidas isolados e em mistura em tanque aplicados em pós-emergência da cultura do sorgo sacarino. Foram conduzidos dois experimentos em casa-de-vegetação, o primeiro com herbicidas isolados e o segundo com misturas de herbicidas. Diante dos resultados dos experimentos realizados em casa de vegetação, foram selecionados tratamentos para avaliação da seletividade em campo. No experimento em campo, os herbicidas isolados e em mistura não diferiram da testemunha sem aplicação de herbicidas quanto à fitotoxicidade, massa fresca da parte aérea, porcentagem da massa seca da parte aérea e Brix das plantas de sorgo sacarino aos 28 dias após a aplicação. Os tratamentos considerados seletivos foram: atrazine (1000 a 2000), bentazon (360 a 720), S-metolachlor (576 a 864), mesotrione (48 a 150), carfentrazone (4 a 8), 2,4-D amina (335 a 670), além das misturas [atrazine+S-metolachlor] [601 + 471,2] e [901,5 + 706,8], atrazine + 2,4-D amina (1000 a 2000 + 100,5 a 268), atrazine + tembotrione (1000 + 42 a 63) e atrazine + mesotrione (1000 + 48 a 72) (doses em g i.a. ha$^{-1}$).

**Palavras-chave**: biomassa, controle químico, fontes renováveis, *Sorghum bicolor* L.

With the increase in the world population, there is greater demand for the supply of energy from a wide variety of sources. However, the energy matrices of most countries are composed of sources derived from the burning of fossil fuels, which are polluting and non-renewable. For the production of ethanol, sugarcane currently stands out as the main alternative of plant origin, however, it is essential to develop new agricultural crops as options for renewable sources that have bioenergetic potential (Silva et al., 2014).

Sweet sorghum (*Sorghum bicolor* (L.) Moench) is cultivated all over the world, and in Brazil, its main use is as a food source in livestock (Menezes et al., 2014). The crop has a short developmental cycle, tolerance to drought periods, high biomass production and high sugar content in the stalks (Teixeira et al., 1999). In addition, it represents an excellent alternative for bioenergy production as it presents desirable agronomic characteristics for the sugar and alcohol industries, as it allows its use in the sugarcane off-season and its implantation and harvesting is fully mechanized (Albuquerque et al., 2012; Solano et al., 2017).

One of the obstacles to the production of sweet sorghum is weeds. The lack of control over them during the crop development cycle negatively affects the height and diameter of the plants, making them more susceptible to lodging, making harvesting difficult and resulting in productivity losses that can reach 50% (Silva et al ., 2014). A common practice in Brazil for weed control is the adoption of tank mixtures, in order to reduce costs and expand the spectrum of control (Gazziero, 2015). Generally, tank mixtures are carried out in post-emergence of the cultures, however, there are few options of herbicides registered in this modality of application for the control of weeds in the sorghum crop, among them, atrazine and 2,4-D (Correia & Gomes, 2015; Cunha et al., 2016; Rodrigues & Almeida, 2018).

Although the crop is an interesting renewable source alternative for biomass and ethanol production, the scarcity of publications and recommendations on the use of herbicides in post-emergence can lead to incorrect use in agricultural areas, and thus compromise the productivity and quality of the sweet sorghum. Registered herbicides only for the corn crop are frequently applied to the sorghum crop, which can result in phytotoxicity due to the plant's greater sensitivity to certain molecules. Therefore, it is necessary to identify herbicides that are selective for the crop. Based on the above, the objective of this work was to evaluate the selectivity of herbicides applied alone and in tank mixtures in post-emergence of sweet sorghum crop.

## Material and Methods

*Experiment – Greenhouse*

<u>Origin and Production of Plant Material</u>

Two experiments were carried out in a greenhouse at the Irrigation Training Center of the State University of Maringá (CTI/UEM)

(23°23'44.70" S and 51°57'3.23" W, at 510 m height), in Maringá – Paraná, the first with herbicides applied alone and the second with tank mixture herbicides. The period for conducting the experiments was from April to June 2016. The sweet sorghum hybrid used was N31G2091. The soil used had a very clayey texture, consisting of 3.5% coarse sand, 6.8% fine sand, 64.7% clay and 25% silt; pH ($H_2O$) 6.0 and 10.02 cmolc$_c$ dm$^{-3}$ cation-exchange capacity.

### Experimental Design and Treatments

In both experiments, a completely randomized design with four replications was used. For the experiment with the herbicides applied alone, 35 treatments were evaluated: atrazine (2000; 1500 and 1000 g a.i. ha$^{-1}$), bentazon (720; 540 and 360 g a.i. ha$^{-1}$), S-metolachlor (1152; 864 and 576 g a.i. ha$^{-1}$), [atrazine + S-metolachlor] ([1202 + 942.5]; [901.5 + 706.8] and [601 + 471.2] g a.i. ha$^{-1}$), tembotrione (84; 63 and 42 g a.i. ha$^{-1}$), mesotrione (150; 96; 72 and 48 g a.i. ha$^{-1}$), flumioxazin (40; 30 and 20 g a.i. ha$^{-1}$), carfentrazone (8; 6 and 4 g a.i. ha$^{-1}$), 2,4-D amine (670; 502.5 and 335 g a.i. ha$^{-1}$), imazetaphyr (84.8; 63.6 and 42.4 g a.i. ha$^{-1}$), chlorimuron-ethyl (12.5; 9.3 and 6.25 g a.i. ha$^{-1}$) and control without herbicide application.

For the experiment with herbicide mixtures, 23 treatments were evaluated: atrazine + 2,4-D (2000 + 201; 2000 + 100.5; 1500 + 268; 1500 + 201; 1500 + 100.5; 1000 + 268; 1000 + 201 and 1000 + 100.5 g a.i. ha$^{-1}$), atrazine + tembotrione (1500 + 84; 1500 + 63; 1500 + 42;

1000 + 84; 1000 + 63 and 1000 + 42 g a.i. ha$^{-1}$), atrazine + mesotrione (1500 + 150; 1500 + 96; 1500 + 72; 1500 + 48; 1000 + 150; 1000 + 96; 1000 + 72 and 1000 + 48 g a.i. ha$^{-1}$) and control without herbicide application.

Treatments were defined based on recommendations for maize cultivation (Rodrigues & Almeida, 2018) and based on other studies in the literature (Campos et al., 2016; Galon et al., 2016; Machado et al., 2016). The experimental units consisted of pots with a capacity of 3.5 L of soil, with two sweet sorghum plants.

### Application of Treatments

Herbicide applications were carried out with a precision backpack sprayer pressurized with $CO_2$ was used, equipped with a bar containing three flat jet nozzles, model XR 11002, spaced 0.5 m apart and positioned 0.5 m from the surface of the targets. The working pressure used was 40 lb in$^{-2}$, with a displacement speed of 1 m s$^{-1}$, resulting in an application rate equivalent to 150 L ha$^{-1}$. The applications were carried out under appropriate meteorological conditions for spraying, with an air temperature of 28°C, a relative humidity of 60% and an average wind speed of 0.83 m s$^{-1}$. At the time of herbicide applications, the sweet sorghum plants had their second and third leaves fully expanded.

### Assessments

In both experiments, the phytotoxicity of sorghum plants was evaluated at 28 days after

application (DAA), through visual evaluation. In each evaluation, scores were assigned in a percentage scale, where 0 represents the absence of phytotoxicity and 100% the death of the plants (Velini et al., 1995). At 28 DAA, the plants were collected, placed in paper bags and taken to a greenhouse with forced air circulation at 58°C until they reached a constant mass. Then, the samples were weighed to determine the aerial part dry mass (APDM).

### Experiment - Field

#### Origin and Production of Plant Material

The period for conducting the two field experiments (one for herbicides applied alone and the other for tank mixtures) on the Experimental Farm of Iguatemi (FEI/UEM) took place between February and May 2017. The soil in the experimental area was classified as Dystrophic Red Latosol (Santos et al., 2013), sandy, clay loam texture, consisting of 50.8% of coarse sand, 23.7% of fine sand, 20.4% of clay and 5.1% of silt; pH ($H_2O$) 6.0 and 4.82 $cmolc_c$ $dm^{-3}$ cation-exchange capacity. The design used was a randomized block design with six replications for the two experiments. The experimental unit consisted of seven rows of sorghum with spacing of 0.45 m (3.15 m) and 5.0 m in length, totaling 15.75 m².

In the entire experimental area, desiccation with glyphosate (2445 g a.i. $ha^{-1}$) was carried out fifteen days before no-tillage, in an area where soybean had been previously cultivated. Sowing was carried out on 02/22/2017 with a density of 8 seeds per linear meter. The sowing fertilization was carried out using 300 kg $ha^{-1}$ of the 08-20-20 formulation (0.3% Zn). Top dressing was carried out for both experiments on 04/08/2017 using 98 kg $ha^{-1}$ of protected urea. All treatments were weeded on demand during the sweet sorghum cycle in order to eliminate the effect of weed competition on yield, leaving the crop exposed only to the effect of herbicides.

Meteorological data related to the period of conducting experiment were collected at the agrometeorological station of the National Institute of Meteorology (Instituto Nacional de Meteorologia, 2020), and are presented in Figure 1.

#### Experimental Design and Treatments

As a consequence of the results of the experiments conducted in a greenhouse, herbicide treatments were selected for field evaluation, considering the treatments that showed phytotoxicity ≤ 25% in relation to the control without herbicide application and/or APDM ≥ to the control without herbicide application.

From the results obtained with the herbicides applied alone, the following treatments were selected to be evaluated in the field: atrazine (2000; 1500 and 1000 g a.i. $ha^{-1}$), bentazon (720; 540 and 360 g a.i. $ha^{-1}$), S-metolachlor (864 and 576 g a.i. $ha^{-1}$), [atrazine + S-metolachlor] ([901.5 + 706.8] and [601+ 471.2] g a.i. $ha^{-1}$), mesotrione (150; 96 ; 72 and 48 g a.i. $ha^{-1}$), carfentrazone (8; 6 and 4 g a.i. $ha^{-1}$), 2,4-D amine (670; 502.5 and 335 g a.i. $ha^{-1}$) and control without herbicide application.
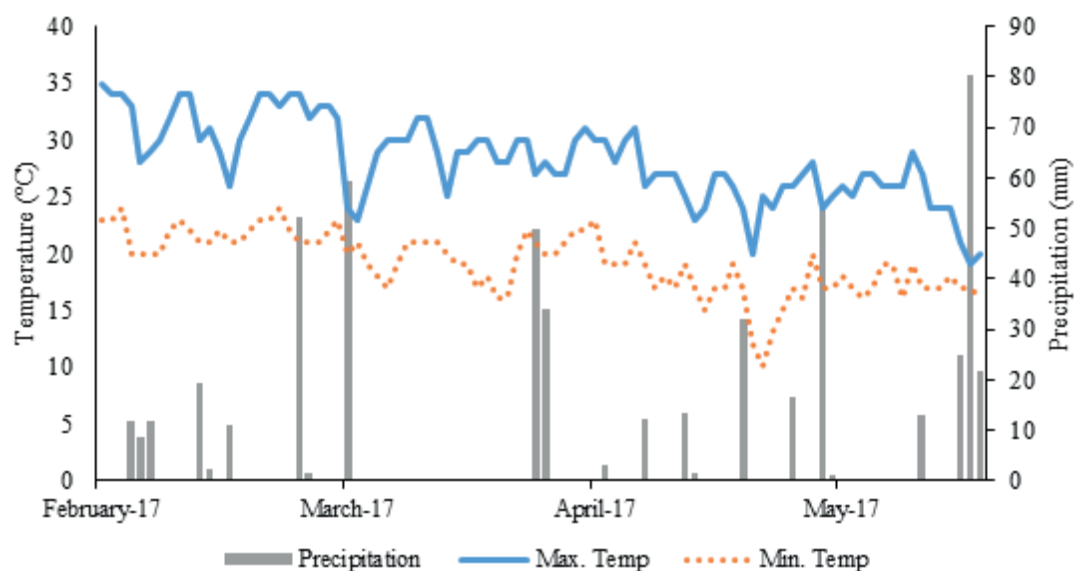
**Figure 1.** Meteorological data during the period of conducting experiment with herbicides applied alone and mixed herbicides in sweet sorghum post-emergence.

From the results obtained with herbicide mixtures, the following treatments were selected: atrazine + 2,4-D amine (2000 + 201; 2000 + 100.5; 1500 + 268; 1500 + 201; 1500 + 100.5; 1000 + 268; 1000 + 201 and 1000 + 100.5 g a.i. ha$^{-1}$), atrazine + tembotrione (1000 + 63 and 1000 + 42 g a.i. ha$^{-1}$), atrazine + mesotrione (1000 + 72 and 1000 + 48 g a.i. ha$^{-1}$) and control without herbicide application.

### Application of Treatments

The herbicide applications were carried out with the a precision backpack sprayer pressurized with $CO_2$ was used, equipped with a bar containing three flat jet nozzles, model ST-IA 135015, spaced 0.5 m apart and positioned 0.5 m from the surface of the targets. The working pressure used was 35 lb in$^{-2}$, with a displacement speed of 1 m s$^{-1}$, resulting in an application rate equivalent to 150 L ha$^{-1}$. The applications were carried out under appropriate meteorological conditions for spraying, with an air temperature of 28°C, a relative humidity of 63% and an average wind speed of 1.66 m s$^{-1}$. At the time of herbicide applications, most of the sweet sorghum plants had their third leaf fully expanded.

### Assessments

In both experiments, the phytotoxicity of sorghum plants at 28 DAA was evaluated, following the methodology already described in the experiment in a greenhouse. Brix evaluations were carried out at 48 DAA, measured at the ends of the fourth node, from top to bottom, from the base of the inflorescence, in three plants of the central lines of the plots.

The harvest of the experiments was carried out on 05/08/2017 (48 DAA), after the

beginning of flowering of the culture, when the Brix, sampled in the control without herbicide application, presented a minimum concentration of 7°Bx. At 48 DAA, the aerial part of the plants present in two meters of the central lines of the plots were collected and weighed to determine the aerial part fresh mass (APFM). Afterwards, the samples were placed in paper bags and taken to an oven with forced air circulation at 58°C until they reached a constant mass. Then, the samples were weighed to determine the APDM.

Statistical Analyses

Data from the greenhouse and field experiments were analyzed for error normality and homogeneity of variances using Shapiro-Wilk and Levene tests, respectively (p ≤ 0.05). After accepting the assumptions, the analysis of variance was performed using the F test. The means were compared using the Scott-Knott cluster test (p ≤ 0.05).

**Results and Discussion**

*Experiment – Greenhouse – Herbicides applied alone*

It was observed that all doses of the herbicides atrazine, bentazon, carfentrazone, 2.4-D amine, and treatments with S-metolachlor (864 and 576 g a.i. ha^{-1}), [atrazine + S-metolachlor] ([901.5+706.8] and [601+471.2] g a.i. ha^{-1}) and mesotrione (150 and 96 g a.i. ha^{-1}) showed maximum levels of phytotoxicity of up to 25% (Table 1). In a study evaluating the selectivity of herbicides applied in post-emergence of grain

sorghum, no phytotoxicity was observed after the application of atrazine (2200 g a.i. ha^{-1}), bentazon (720 g a.i. ha^{-1}), bentazon + atrazine (480 + 880 g a.i. ha^{-1}) and bentazon + pendimethalin (720 + 1000 g a.i. ha^{-1}) (Machado et al., 2016).

More severe symptoms of phytotoxicity were observed in treatments with tembotrione (84, 63 and 42 g a.i. ha^{-1}), imazethapyr (84.8, 63.6 and 42.4 g a.i. ha^{-1}) and chlorimuron-ethyl (12. 5 and 9.3 g a.i. ha^{-1}) which ranged from 81 to 95% of phytotoxicity. In a study conducted by Cunha et al. (2016) to assess the selectivity of tembotrione for the grain sorghum crop, it was observed that the increase in herbicide doses generates greater toxicity in the crop, with maximum values of 74% for the dose of 176.4 g L^{-1}.

In general, APDM in all doses of treatments atrazine, bentazon, S-metolachlor, mesotrione, carfentrazone, 2,4-D amine, atrazine+S-metolachlor ([901.5+706.8] and [601+ 471.2] g a.i. ha^{-1}) presented results that did not differ or were superior to those observed in the control without herbicide. Contrary results showed the treatments with tembotrione, flumioxazin, imazethapyr and chlorimuron-ethyl at all doses, also [atrazine+S-metolachlor] ([1202+942.5] g a.i. ha^{-1}), which presented reductions for this variable in relation to the control without herbicide application. Dan et al. (2010) found a reduction in dry mass in grain sorghum as a function of the increase in the dose of tembotrione and the time of application, in which the lower the sorghum development stage, the greater the damage. In a study aiming to determine the selectivity of post-

**Table 1.** Phytotoxicity (%) and aerial part dry mass (APDM) of *Sorghum bicolor* L. 28 days after application (DAA) of the herbicides applied alone in post-emergence.

| Treatments (g a.i. ha⁻¹) | Phytotoxicity (%) | | APDM (g vase⁻¹) | |
|---|---|---|---|---|
| atrazine (2000)[1] | 15.00 | f | 3.40 | a |
| atrazine (1500)[1] | 16,25 | f | 2,18 | b |
| atrazine (1000)[1] | 8,75 | g | 2,19 | b |
| bentazon (720)[1] | 10,00 | g | 4,84 | a |
| bentazon (540)[1] | 11,25 | g | 2,37 | b |
| bentazon (360)[1] | 7,50 | g | 4,19 | a |
| S-metolachlor (1152) | 28,75 | d | 2,91 | b |
| S-metolachlor (864) | 25,00 | e | 3,61 | a |
| S-metolachlor (576) | 8,75 | g | 2,93 | b |
| [atrazine+S-metolachlor] [1202+942.5][1] | 37,50 | d | 1,38 | c |
| [atrazine+S-metolachlor] [901,5+706.8][1] | 22,50 | e | 2,09 | b |
| [atrazine+S-metolachlor] [601+471.2][1] | 25,00 | e | 2,57 | b |
| tembotrione (84)[1] | 83,75 | b | 0,58 | c |
| tembotrione (63)[1] | 89,25 | a | 0,35 | c |
| tembotrione (42)[1] | 81,25 | b | 0,54 | c |
| mesotrione (150)[1] | 20,00 | e | 2,16 | b |
| mesotrione (96)[1] | 25,00 | e | 2,18 | b |
| mesotrione (72)[1] | 32,50 | d | 2,55 | b |
| mesotrione (48)[1] | 31,25 | d | 3,67 | a |
| flumioxazin (40)[1] | 47,50 | c | 1,35 | c |
| flumioxazin (30)[1] | 48,75 | c | 1,29 | c |
| flumioxazin (20)[1] | 48,75 | c | 1,26 | c |
| carfentrazone (8) | 18,75 | f | 3,36 | a |
| carfentrazone (6) | 21,25 | e | 3,10 | b |
| carfentrazone (4) | 15,00 | f | 2,87 | b |
| 2,4-D amina (670) | 15,00 | f | 3,33 | a |
| 2,4-D amina (502.5) | 16,00 | f | 2,88 | b |
| 2,4-D amina (335) | 15,00 | f | 3,51 | a |
| imazethapyr (84,8) | 95,00 | a | 0,40 | c |
| imazethapyr (63.6) | 88,00 | a | 0,83 | c |
| imazethapyr (42,4) | 81,25 | b | 0,87 | c |
| chlorimuron-ethyl (12.5)[1] | 83,75 | b | 0,99 | c |
| chlorimuron-ethyl (9.3)[1] | 78,75 | b | 0,93 | c |
| chlorimuron-ethyl (6.25)[1] | 33,75 | d | 1,90 | c |
| Testemunha sem herbicida | 0,00 | g | 2,72 | b |
| F | 79,81* | | 6,20* | |
| CV (%) | 17,45 | | 41,83 | |

*Significant by Scott-Knott test ($p \leq 0.05$). Means followed by the same letter do not differ from each other according to the Scott-Knott test ($p \leq 0.05$). [1]Added Assist 0.5% v v-1. CV – coefficient of variation.

emergence herbicides in the culture of sweet sorghum, it was observed that the herbicide tembotrione (100 g a.i. ha$^{-1}$) resulted in lower fresh mass production when compared to the 2,4-D, atrazine herbicides and bentazon (Teixeira et al., 2017). Lower phytotoxicity values (20 to 32%) were observed for the herbicide mesotrione when compared to the herbicide tembotrione (81 to 89%), both belonging to HPPD inhibitors. This result can be explained by a higher metabolic rate of mesotrione (Abit et al., 2009), resulting in less damage to sweet sorghum plants.

*Experiment – Greenhouse – Herbicide mixtures*

The results obtained with the applications of herbicide mixtures are shown in Table 2. Phytotoxicity levels from 0 to 3.75% were observed in sorghum plants caused by the application of atrazine + 2,4-D amine mixtures in all doses evaluated and 0% for the lowest dose of atrazine + mesotrione, not differing from the control without herbicide application. In general, mixtures of atrazine + 2,4-D amine caused lower levels of phytotoxicity in sweet sorghum than mixtures of atrazine with inhibitors of carotenoid synthesis. Atrazine can be degraded by three metabolic pathways, in the case of sorghum crops, degradation occurs by N-dealkylation, which lead to the removal of the alkyl side chains of the herbicide, hindering the absorption and translocation of the herbicide in the plant, besides it is possible that the herbicide is metabolized into non-toxic compounds due to the high presence of benzoxazinones (Shimabukuro, 1968; Jachetta &

Radosevich, 1981; Rodrigues & Almeida, 2018).

In treatments with the highest doses of atrazine + tembotrione or atrazine + mesotrione mixtures, the highest levels of phytotoxicity (>60%) were observed. All treatments with mixtures based on atrazine + mesotrione caused injuries to sweet sorghum plants, except at the dose of 1000 + 48 g a.i. ha$^{-1}$. Other studies have also reported high levels of phytotoxicity in sweet sorghum with the application of a mixture of atrazine + tembotrione (1500 + 100.8 g a.i. ha$^{-1}$), with values above 98% for cultivars BRS 506, BRS 509 and BRS 511 (Galon et al., 2016). However, Campos et al. (2016) observed, under field conditions, that the mixture of atrazine with tembotrione (1500+100.8 g a.i. ha$^{-1}$) did not significantly affect the dry mass accumulation of sweet sorghum cultivars BRS 506, BRS 509 and BRS 511. The treatments that showed lower levels of phytotoxicity were also those that showed results similar or closer to the control in terms of aerial part dry mass.

*Experiment – Field – Herbicides applied alone*

The treatments considered more selective in the greenhouse experiments were evaluated in the field, aiming to determine the effect of herbicides on characteristics related to the production of sorghum biomass for energy generation.

Only for the treatments composed by the herbicides atrazine (2000 g a.i ha$^{-1}$), S-metolachlor (864 g a.i. ha$^{-1}$) and 2,4-D amine (502.5 g a.i. ha$^{-1}$) there was no decrease in the

levels of phytotoxicity from the first (14 DAA) to the second assessment (28 DAA). In the evaluation at 14 DAA, the levels of phytotoxicity of herbicide treatments ranged from 1.33 to 20%. As for the evaluation at 28 DAA, the levels ranged from 0 to 10.83% (Table 3). Treatments with [atrazine+S-metolachlor] ([901.5 + 706.8] and [601 + 471.2] g a.i. ha$^{-1}$), mesotrione (150; 96 and 72 g a.i. ha$^{-1}$), carfentrazone (8, 6 and 4 g a.i. ha$^{-1}$) and 2,4-D amine (670 g a.i. ha$^{-1}$) showed higher levels of phytotoxicity at 14 DAA, however, at 28 DAA, no differences were observed between the herbicide treatments and the control. The application of the mixture of atrazine + S-metolachlor (1500 + 384 g a.i. ha$^{-1}$) in post-emergence caused phytotoxicity below 5% in hybrids ESX5200 and EJX7C5110 at 35 days after emergence (Maciel et al., 2017), similar to the results found for the hybrid N31G2091 used in this study. Although the results are similar, differential tolerance to herbicides may occur due to genetic variations in the hybrids, affecting herbicide absorption, translocation and metabolism (Bunting et al., 2004; Galon et al., 2016).

In the first two weeks after the application of the herbicides, some symptoms of phytotoxicity were observed, however, the sweet sorghum plants showed the capacity to recover from the symptoms after 28 DAA. Similar results were obtained by Archangelo et al. (2002), who observed absence of symptoms of phytotoxicity (chlorosis) in forage sorghum after 28 days of application of the herbicides atrazine, [atrazine + S-metolachlor] and atrazine + vegetable oil at doses close to those used in this work.

For the variables APFM, DP and Brix, no significant effects of the herbicide treatments were observed in relation to the control, demonstrating the selectivity of the treatments evaluated for the crop. Maciel et al. (2017) also did not observe differences between the treatments atrazine + S-metolachlor and atrazine + S-metolachlor + isoxaflutole in pre-emergence, besides the treatment atrazine + S-metolachlor in post-emergence and the control without application in relation to cultural characteristics of sweet sorghum, such as plant height, stem diameter, number of internodes and stand.

*Experiment – Field – Herbicide mixtures*

In the evaluation at 14 DAA, the lowest phytotoxicity values were observed in treatments with the mixture of atrazine + 2,4-D amine, and the lowest dose did not differ from the control without herbicide (Table 4). The atrazine + mesotrione and atrazine + tembotrione mixtures showed phytotoxicity levels ranging from 28 to 43%. The plants showed symptoms of leaf whitening, which is related to the mechanism of action of the herbicides mesotrione and tembotrione, which blocks the enzyme p-hydroxyphenylpyruvate dioxygenase (HPPD), responsible for the carotenoid biosynthesis pathway (Senseman, 2007; Rodrigues & Almeida, 2018). In the case of atrazine + 2,4-D amine mixtures, the maximum level of phytotoxicity was approximately 20%.

**Table 3.** Phytotoxicity at 14 and 28 days after application (DAA), aerial part fresh mass (APFM), aerial part dry mass percentage (APDMP) and Brix of *Sorghum bicolor* L. plants at 48 days after application (DAA) of herbicides applied alone in post-emergence.

| Treatments (g a.i. ha^{-1}) | Phytotoxicity (%) 14 DAA | | 28 DAA | | APFM (t ha^{-1}) | | APDMP (%) | | Brix (ºBx) | |
|---|---|---|---|---|---|---|---|---|---|---|
| atrazine (2000)[1] | 5.00 | b | 5.83 | a | 35,71 | a | 20,10 | a | 10.00 | a |
| atrazine (1500)[1] | 3,33 | b | 2,50 | a | 32,22 | a | 18,85 | a | 8,68 | a |
| atrazine (1000)[1] | 3,16 | b | 0,00 | a | 31,90 | a | 17,82 | a | 9,16 | a |
| bentazon (720)[1] | 2,50 | b | 1,66 | a | 35,76 | a | 17,68 | a | 9,40 | a |
| bentazon (540)[1] | 6,66 | b | 4,16 | a | 34,50 | a | 19,93 | a | 8,82 | a |
| bentazon (360)[1] | 5,00 | b | 1,66 | a | 29,41 | a | 17,54 | a | 8,84 | a |
| S-metolachlor (864) | 1,33 | b | 3,33 | a | 38,07 | a | 23,03 | a | 9,47 | a |
| S-metolachlor (576) | 4,16 | b | 0,83 | a | 34,73 | a | 18,13 | a | 8,69 | a |
| [atrazine+S-metolachlor] [901.5+706,8][1] | 8,83 | a | 4,16 | a | 33,13 | a | 16,34 | a | 9,34 | a |
| [atrazine+S-metolachlor] [601+471.2][1] | 9,16 | a | 5,00 | a | 32,12 | a | 16,59 | a | 9,01 | a |
| mesotrione (150)[1] | 20,00 | a | 10,83 | a | 31,26 | a | 18,71 | a | 8,50 | a |
| mesotrione (96)[1] | 11,66 | a | 10,00 | a | 31,49 | a | 16,86 | a | 8,67 | a |
| mesotrione (72)[1] | 10,83 | a | 2,50 | a | 27,50 | a | 18,12 | a | 8,44 | a |
| mesotrione (48)[1] | 6,16 | b | 4,66 | a | 35,43 | a | 21,13 | a | 9,33 | a |
| carfetrazone (8) | 12,33 | a | 4,66 | a | 30,24 | a | 19,71 | a | 9,86 | a |
| carfetrazone (6) | 8,66 | a | 3,33 | a | 36,75 | a | 18,31 | a | 8,75 | a |
| carfetrazone (4) | 8,83 | a | 8,00 | a | 31,10 | a | 18,77 | a | 8,74 | a |
| 2,4-D amina (670) | 12,50 | a | 4,66 | a | 35,65 | a | 19,28 | a | 9,87 | a |
| 2,4-D amina (502.5) | 5,00 | b | 9,16 | a | 30,19 | a | 19,58 | a | 9,53 | a |
| 2,4-D amina (335) | 7,50 | b | 0,00 | a | 39,32 | a | 19,22 | a | 8,36 | a |
| Testemunha sem herbicida | 0,00 | b | 0,00 | a | 30,70 | a | 19,48 | a | 9,36 | a |
| F | 2,26* | | 1,69* | | 0,65[ns] | | 1,14[ns] | | 0,75[ns] | |
| CV (%) | 97,57 | | 145,42 | | 27,89 | | 18,86 | | 15,28 | |

*Significant by Scott-Knott test (p ≤ 0.05); ns = not significant. Means followed by the same letter do not differ from each other, according to the Scott-Knott test (p ≤ 0.05). [1]Added Assist 0.5% v v[-1]. VC – coeficiente of variation.

**Table 4.** Phytotoxicity at 14 and 28 days after application (DAA), aerial part fresh mass (APFM), aerial part dry mass percentage (APDMP) and Brix of Sorghum bicolor L. plants at 48 days after application (DAA) of herbicide mixtures in post-emergence.

| Treatments (g a.i. ha^{-1}) | Phytotoxicity (%) | | | APFM (t ha^{-1}) | | APDMP (%) | | Brix (ºBx) | |
|---|---|---|---|---|---|---|---|---|---|
| | 14 DAA | | 28 DAA | | | | | | |
| atrazine + 2,4-D amina (2000+201)[1] | 20.17 | c | 5.83 | a | 28.87 | a | 22.41 | a | 10.65 | a |
| atrazine + 2,4-D amina (2000+100.5)[1] | 19,17 | c | 3,33 | a | 30,87 | a | 20,27 | a | 9,72 | a |
| atrazine + 2,4-D amina (1500+268)[1] | 19,67 | c | 5,00 | a | 28,77 | a | 21,78 | a | 9,73 | a |
| atrazine + 2,4-D amina (1500+201)[1] | 14,50 | c | 6,68 | a | 31,73 | a | 19,90 | a | 9,79 | a |
| atrazine + 2,4-D amina (1500+100.5)[1] | 17,50 | c | 7,50 | a | 32,07 | a | 22,74 | a | 9,03 | a |
| atrazine + 2,4-D amina (1000+268)[1] | 17,50 | c | 9,17 | a | 30,96 | a | 18,70 | a | 9,37 | a |
| atrazine + 2,4-D amina (1000+201)[1] | 15,83 | c | 4,17 | a | 30,04 | a | 19,73 | a | 9,55 | a |
| atrazine + 2,4-D amina (1000+100.5)[1] | 7,50 | d | 1,67 | a | 37,45 | a | 22,38 | a | 10,01 | a |
| atrazine+tembotrione (1000+63)[1] | 34,67 | b | 5,50 | a | 31,25 | a | 21,11 | a | 8,22 | a |
| atrazine+tembotrione (1000+42)[1] | 43,33 | a | 12,50 | a | 28,78 | a | 19,81 | a | 9,89 | a |
| atrazine+mesotrione (1000+72)[1] | 32,50 | b | 5,83 | a | 31,30 | a | 20,20 | a | 10,11 | a |
| atrazine+mesotrione (1000+48)[1] | 28,33 | b | 5,83 | a | 29,21 | a | 19,59 | a | 9,79 | a |
| Testemunha sem herbicida | 0,00 | d | 0,00 | a | 32,93 | a | 21,06 | a | 10,00 | a |
| F | 12,11* | | 1,80ns | | 0,71ns | | 1,11ns | | 0,95ns | |
| CV (%) | 45.11 | | 118,48 | | 21,84 | | 15,11 | | 14,57 | |

*Significant by Scott-Knott test (p ≤ 0.05); ns = not significant. Means followed by the same letter do not differ from each other, according to the Scott-Knott test (p ≤ 0.05). [1]Added Assist 0.5% v v[-1]. CV – coefficient of variation.

At 28 DAA, all treatments showed lower phytotoxicity of sweet sorghum plants, showing similar results in relation to the control. The results obtained are similar to those observed in the herbicides applied alone, since there are symptoms of phytotoxicity in the first evaluation, but with later crop recovery.

Maximum levels of 42% of phytotoxicity were observed in the post-emergence application of the mixture of atrazine + tembotrione (1500 + 100.8 g a.i. ha^{-1}) in the sweet sorghum cultivars

BRS 506, 509 and 511 (Campos et al., 2016). The authors found greater symptoms at 7 DAA and a subsequent reduction in injuries with the development of the plants.

Similar to what happened with the experiment with herbicides applied alone, for the other variables (APFM, DP and Brix), the herbicide mixtures applied in post-emergence did not show a negative effect in relation to the control without herbicide.

For both herbicides applied alone and

herbicide mixtures, the fact that the treatments do not affect Brix, which is the main component of productivity and quality of sweet sorghum biomass (sugar/mass) indicates that there are different selective herbicide treatments for application in post-emergence of sweet sorghum. The choice of the producer for the most adequate treatment should take into account the spectrum and density of weed species present and the possible differential tolerance of other cultivars.

## Conclusions

There is initial phytotoxicity in sorghum plants, however, recovery occurs over the days, without interfering with Brix content.

Selective treatments for post-emergence use in sweet sorghum (all doses in g a.i. ha$^{-1}$) are atrazine (1000 to 2000), bentazon (360 to 720), S-metolachlor (576 to 864), mesotrione (48 to 150), carfentrazone (4 to 8), 2,4-D amine (335 to 670), [atrazine+S-metolachlor] [601 + 471.2] and [901.5 + 706.8], atrazine + 2,4-D amine (1000 to 2000 + 100.5 to 268), atrazine + tembotrione (1000 + 42 to 63) and atrazine + mesotrione (1000 + 48 to 72).

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