

EFFECTS OF WEED MANAGEMENT AND PLANT ARRANGEMENTS ON YIELD INDEX OF SWEET SORGHUM

EFEITO DO MANEJO DE PLANTAS DANINHAS E ARRANJO DE PLANTAS NOS ÍNDICES DE PRODUTIVIDADE DO SORGO SACARINO

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ABSTRACT: Sweet sorghum is currently an important alternative for ethanol production in sugar cane off-season. In this study was to evaluate the effects of plant arrangements and the application of atrazine and S-metolachlor on growth and productivity of sweet sorghum. An experiment was conducted in randomized block design and, arranged in split plots with four repetitions. Plots consisted of spacing (0.25 m, 0.45 m 0.45-0.90 m) and sub-plots of weed control methods - atrazine (2000 g ha⁻¹), atrazine + S-metolachlor (2000 + 720 g ha⁻¹), atrazine + S-metolachlor (2000 + 960 g ha⁻¹), atrazine + S-metolachlor (2000 + 1200 g ha⁻¹), atrazine + S-metolachlor (2000 + 1440 g ha⁻¹). Besides that, manual hoeing control was added. The intoxication of sorghum plants and weed control was evaluated at 7, 14 e 28 days after herbicides application (DAA). Plant height, stem diameter, total fresh matter, juice mass and total soluble solids (°Brix) were evaluated at 120 days after crop emergence (DAE). There was no interaction between the factors spacings and control method for variables total matter fresh (TMF), height (H), stem diameter (D), juice mass (JM), and Brix. Application of the mixture (atrazine + S-metolachlor) in the highest doses reduced total fresh matter and °Brix. The spacing of 0.25 m provided the highest productivity of fresh matter, juice mass and increased the °Brix. The application of mixture (atrazine + S-metolachlor) controlled 90% of the weeds at 28 days after application. The increasing in doses of S-metolachlor elevates the intoxication in sorghum plants. The mixture (atrazine + S-metolachlor) has a potential for use in weed control in sweet sorghum, but at doses below 960 g ha⁻¹ of S-metolachlor.

KEYWORDS: *Sorghum bicolor*. S-metolachlor. Atrazine. Biofuel.

INTRODUCTION

Sweet sorghum (*Sorghum bicolor* (L.) Moench.) is an alternative in ethanol production, especially in areas during sugarcane off-season (MAY et al., 2016). Short cycle (90 to 120 days), ease of mechanization and high levels of fermentable sugars present in the stems are advantages of the sweet sorghum compare to others plants (RATNAVATHI et al., 2010).

The initial slow development of sorghum aggravates its susceptibility to weed interference on the first 30 days after emergence (SILVA et al., 2014). The lack of herbicides selective to sorghum has hampered the weeds control, mainly the grasses species. In Brazil, only atrazine is available to the application at pre and post-emergence in sorghum crops. However, this herbicide controls a small number of grasses species (MISHRA et al., 2015).

The association of atrazine with other herbicide molecules, such as mesotrione (WALSH et al., 2012) tembotrione (THEODORO et al., 2018;

BOLLMAN et al., 2009) and nicosulfuron (PEREIRA et al., 2019; SILVA et al., 2019; WILLIAMS et al., 2010) has been used to increase the range weed control in maize. The herbicide S-metolachlor, when applied after maize emergence can control grasses that are in the initial germination process (ARCHANGELO et al., 2002). However, it is necessary to evaluate the effects of S-metolachlor application on the yield and in fermentable sugars accumulation of sweet sorghum plants.

The narrow spacing between rows can reduce weed community interference (SILVA et al., 2014; BRAZ et al., 2019). However, changes in the distance between rows can increase the competition intraspecific and affect the growth and development of sorghum. Studies have shown that the reducing of the spacing increased the fresh matter production of sweet sorghum (ALMODARES et al., 2013). However, others studies found a linear relationship between the solid soluble content (Brix) of the juice and row spacing for sweet sorghum: Increasing 1cm

in spacing, the Brix of the juice was elevated in 0.011 (ALBUQUERQUE et al., 2012).

The objective of this study was to evaluate the effects of the plant spacing and post-emergence application of atrazine + S-metolachlor on the growth and yield of sweet sorghum.

MATERIAL AND METHODS

The experiment was conducted from November 2013 to March 2014 in the experimental field Prof. Diogo Alves de Melo, in Viçosa (MG) (20°46'05" latitude and 45°52'09" longitude, at 650 m of altitude). The climate of the region is humid subtropical, according to the Köppen-Geiger classification (Climate-Data, 2019). The average annual temperature was 21°C and average annual rainfall of 1,200 mm (Figure 1).

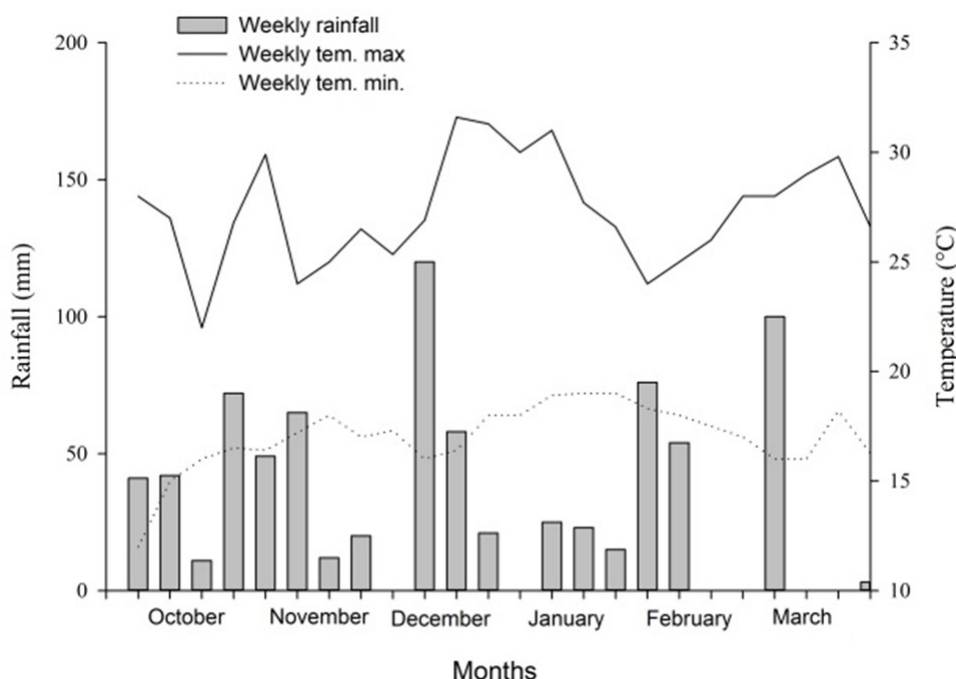


Figure 1. Rainfall and maximum and minimum air temperature during November 1 to March 31, 2014. Viçosa, MG.

Soil was classified as Ultisols (EMBRAPA, 2012) (Table 1). Sorghum plants were fertilized with 300 kg ha⁻¹ of the formulation 8-28-16 (N-P-K) applied directly on the planting rows. Top dressing fertilization was 300 kg ha⁻¹ of urea applied at 20 days after emergence.

Experimental design was a randomized completely block design with four replicates. Treatments were arranged in a split-plot design. Plots consisted of spacing 0.25, 0.45, and 0.45-0.90 m, according described by MAY et al. (2012). Sub-plots was the weed control methods: atrazine (2000 g ha⁻¹), atrazine + S-metolachlor (2000 + 720 g ha⁻¹), atrazine + S-metolachlor (2000 + 960 g ha⁻¹), atrazine + S-metolachlor (2000 + 1200 g ha⁻¹), atrazine + S-metolachlor (2000 + 1440 g ha⁻¹). Besides, manual hoeing control was added.

Sweet sorghum cultivar BRS 506 was sown at 140,000 seeds ha⁻¹, and after emergence the population obtained was 120,000 plants ha⁻¹ for all row spacings stipulated. The useful area all of the

plots was 4.5 m² (1.5 x 3 m). The production per hectare of fresh matter and juice mass were estimated to considering the average obtained from useful areas (4.5 m²).

Herbicide application was carried out 11 days after sorghum emergence (DAE), between the stages V1 and V2 of sweet sorghum development (SMITH; FREDERIKSEN 2000), with a CO₂-pressurized backpack sprayer at constant pressure of 2.5 kgf cm⁻², TT 110.02 spray nozzles, spaced at 50 cm, at a height of 50 cm from soil and spray volume of 120 L ha⁻¹. The application was performed from 07:00 to 09:00 hours, at a temperature of 21.8 °C, relative humidity of 80% and average wind speed of 6 km h⁻¹.

Sorghum plants were irrigated whenever necessary, maintaining the humidity of soil at field capacity. Insecticide deltamethrin at the dose of 5 g ha⁻¹ was applied to control *Spodoptera frugiperda*. The application of the insecticide was performed 40

days after emergence, when 20 % of the plants had visual symptoms of attack by the pest.

Weed species observed in experimental area before herbicide application were: *Cyperus esculentus*, *Oxalis latifolia*, *Avena strigosa*, *Digitaria horizontalis*, *Eleusine indica*, *Urochloa plantaginea*, *Raphanus raphanistrum*, *Commelina benghalensis*, *Eragrostis pilosa*, *Setaria geniculata*, *Siegesbeckia orientalis*, *Stemodia trifoliata*, *Nicandra physaloides*, *Emilia sonchifolia* and *Coronopus didymus*. Weed control was evaluated at 7, 14 and 28 days after herbicide application (DAA). Scale control grading based on values from 0 to 100%, which 0 corresponded to absence of weed control and 100% to total control (SBCPD, 1995). Besides that, on the same dates, visual intoxication of the sorghum plants was measured by using a similar scale.

Sweet sorghum plants were harvested at 120 days after emergence (DAE). The plants harvested were weighed on a digital scale for determination of total fresh matter. Ten plants in each plot were sampled for assessments of plant height (distance from the soil surface to the apex of the panicle) and stem diameter (60 cm from the soil). Moreover, the leaves and panicles of the sampled plants were removed, and the stems were crushed with a shredder.

A sample of 0.5 kg of shredded stem was used in juice extraction, with a hydraulic press at constant pressure of 250 kgf cm⁻², for one minute. Juice mass was determined, and an aliquot of 80 µL was collected for determination of total soluble solids in a refractometer.

The data were submitted to analysis of variance by the F-test at 5% probability. When significant, the means of the treatments were compared by Tukey's test at 5% probability. The effect of increasing rates of the atrazine + S-metolachlor mixture on the variables of weed control and sweet sorghum intoxication was submitted to regression analysis.

RESULTS AND DISCUSSION

There was no interaction between the factors spacings and control method for variables total matter fresh (TMF), height (H), stem diameter (D), juice mass (JM), and Brix. Therefore, the deployment of interaction was not performed for any variable. The competition with weeds reduced the total fresh matter, height and juice mass production (Table 1). The solid soluble content of sorghum in the plot without weeding was similar to treatments where weeded control was carried out.

The content of soluble solids in the sorghum plants affects the synthesis of ethanol, and those with high °Brix can generate greater production of ethanol (HAN et al., 2012). However, the lower mass juice per hectare in plots without weed control will result in lower ethanol production per hectare. Thus, it is necessary to control weeds in sorghum crops to obtain maximum efficiency in ethanol production. The application of atrazine + S-metolachlor reduced °Brix; however, the total fresh matter was reduced by 14% at doses up to 1200 a.i. ha⁻¹ of S-metolachlor (Table 1).

Plants have various mechanisms to protect against biotic and abiotic stresses (KATEROVA et al., 2010). Presence of S-metolachlor causes oxidative damage in cells by membrane lipid peroxidation in sorghum plants (GRONWALD et al., 1987), as well as rice (*Oryza sativa*) and rapeseed (*Brassica napus*) plants (LIU et al., 2012; VERCAMPT et al., 2016). In response to this stress, sorghum plants increase the activity of glutathione-S-transferase (GST), changing the state of glutathione (GSH) to redox for detoxication their cells through forming conjugated GSH-S-metolachlor (GRONWALD et al., 1987; VERCAMPT et al., 2016). However, this mechanism is governed by the energy consumption, obtained through breaks in ATP molecules (VERCAMPT et al., 2016), and soluble solids stored in the tissues of sorghum plants may have been used as energy source to ATP production, reducing °Brix in plants where the S-metolachlor was applied.

The lower spacing of sorghum plants increased total fresh matter (Table 2), without affecting others factors, such as juice mass, total soluble solid content, plant height, and stem diameter. The adjustment of plant spacing can elevate the yield of a crop per area. However, planting in high densities intensifies the intraspecific competition, and it reduces yield crop due to the limitation of the growth resources, such as water and nutrients (MAY et al., 2016).

Sorghum BRS 506 cultivated at spacings 0.25 plants m² showed high yield without affecting others productivity parameters; therefore, this spacing can be recommended to farmers. Others studies evaluate the spacing effect on yield sweet sorghum BRS 506 in different seeding, and both season and off-season crop the spacing rows 0.5 m between plants resulted in the highest total fresh matter (FERNANDES et al., 2014).

The intercalated spacing 0.45-0.45-0.90 promoted reduction of total fresh matter (MFT) and juice mass (JM) compared to the other spacings

(Table 2). The use of this intercalated spacing is to allow mechanized harvesting of sorghum using conventional sugarcane harvesting machines (MAY et al., 2013). However, productivity was affected by the intercalated spacing. This fact may be a result of lower efficiency in the use of solar radiation, water, and nutrients. Narrower spacings can provide better

control of weeds due to faster canopy closure, reduce erosion, the cover of the soil surface, and improve planting quality through the slower rotational speed of seed distribution systems (MAY et al., 2016). Therefore, the wider spacing is not a good alternative since the productive indexes of fresh matter and juice weight are reduced.

Table 1. Total fresh matter (TFM), plant height (H) and stem diameter (D), juice mass (JM) and total soluble solid content (°Brix) of sweet sorghum submitted to the weeds control methods.

Control method	TFM (Mg ha ⁻¹)	H (m)	D (mm)	JM (Mg ha ⁻¹)	°Brix (%)
Weeded control	100.25 a	3.43 a	20.89 a	67.45 a	12.40 a
Control without weeding	81.10 c	3.18 b	20.80 a	54.35 b	13.04 a
Atrazine	100.57 a	3.47 a	21.09 a	69.24 a	11.73 a
¹ Atrazine + S-metolachlor	88.82 ab	3.44 a	21.20 a	61.34 a	10.30 ab
² Atrazine + S-metolachlor	92.12 ab	3.44 a	21.45 a	64.34 a	9.92 bc
³ Atrazine + S-metolachlor	86.79 b	3.38 a	20.41 a	60.42 a	10.11 ab
⁴ Atrazine + S-metolachlor	87.68 b	3.38 a	21.17 a	60.66 a	10.75 ab
DMS	4.02	0.09	1.53	2.65	1.12

Means followed by * differ from the control treatment weeded by Tukey test at 5% probability. ¹ 2000 + 720 g a.i ha⁻¹; ² 2000 + 960 g a.i ha⁻¹; ³ 2000 + 1200 g a.i ha⁻¹; ⁴ 2000 + 1440 g a.i ha⁻¹. LSD= least significant difference.

Table 2. Total fresh matter (TFM), plant height (H), stem diameter (D), juice mass (JM) and total soluble solid content (°Brix) of sweet sorghum at different row spacing.

Spacing (m)	TFM (Mg ha ⁻¹)	H (m)	D (mm)	JM (Mg ha ⁻¹)	°Brix (%)
0.25	104.38 a	3.45 a	20.77 a	70.93 a	11.8 a
0.45	90.21 b	3.31 a	20.79 a	62.88 ab	10.2 a
0.45-0.45-0.90	78.54 b	3.39 a	21.44 a	53.92 b	11.2 a
LSD	3.82	0.09	1.53	9.65	0.82

Means followed by the same letter in the column do not differ by Tukey test at 5% probability. LSD= least significant difference.

The application of atrazine + S-metolachlor intoxicated sweet sorghum plants even at lower doses, and a linear increase of intoxication occurred due to the increasing doses of S-metolachlor at 7, 14, and 28 DAA (Figure 2). The high initial intoxication of sorghum plants, at doses up to 960 g ha⁻¹ showed that this species is susceptible to S-metolachlor, and high doses can cause damages in cells and tissues, reducing yield sorghum crops. However, sorghum plants endured applications this herbicide at doses lower than 960 g ha⁻¹ with intoxication symptoms of 12%.

Sorghum, as well as sugar beet plants, can absorb a lesser amount of the herbicide due to more

significant development of the hypocotyl tissues (ZEMOLIN et al., 2014) and S-metolachlor applications on sorghum plants in stage V2 can increase the tolerance of these species to the herbicide. Additionally, the sorghum plants can degrade the herbicide via oxidation or the glutathione-S-transferase (GST) (SLABA et al., 2015), reducing the toxicity of these plants at 28 DAA. Corn plants that absorbed 0.025 mg kg⁻¹ S-metolachlor were able to degrade 80% of this herbicide in 10 days (CAO et al., 2008).

The increasing of S-metolachlor doses elevated weed control percentage at 7, 14 and 28 days after herbicide application (DAA). The

application of atrazine alone at the rate of 2000 g ha⁻¹ promoted a weed control below 80 % at 28 DAA (Figure 3).

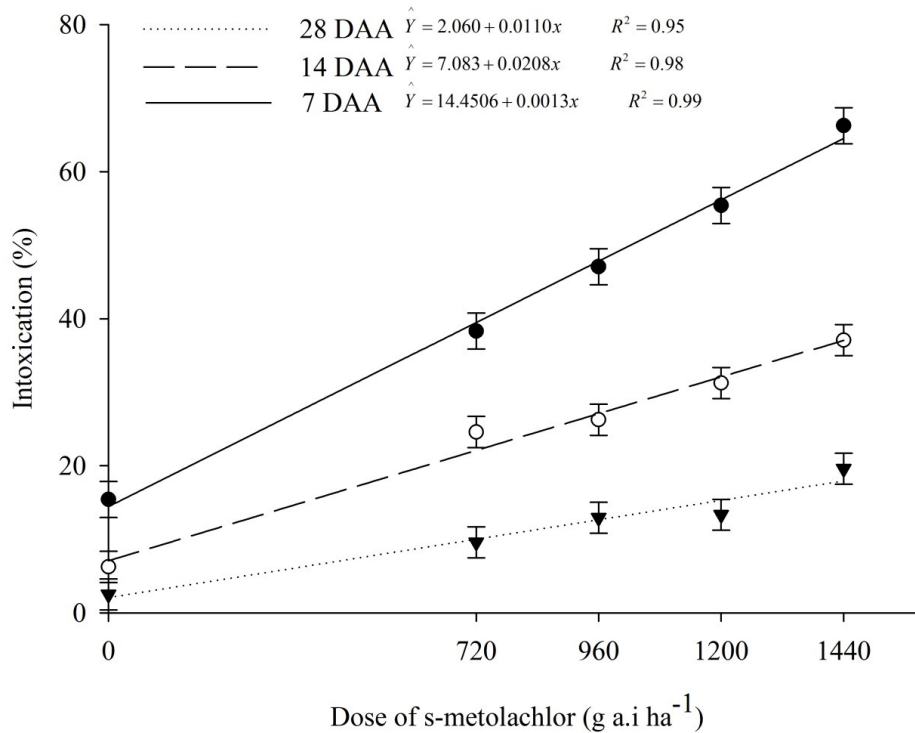


Figure 2. Intoxication (%) of sweet sorghum plants (BRS 506) at 7, 14 and 28 days after the application of different rates of the atrazine + S-metolachlor mixture (2000 g ha⁻¹).

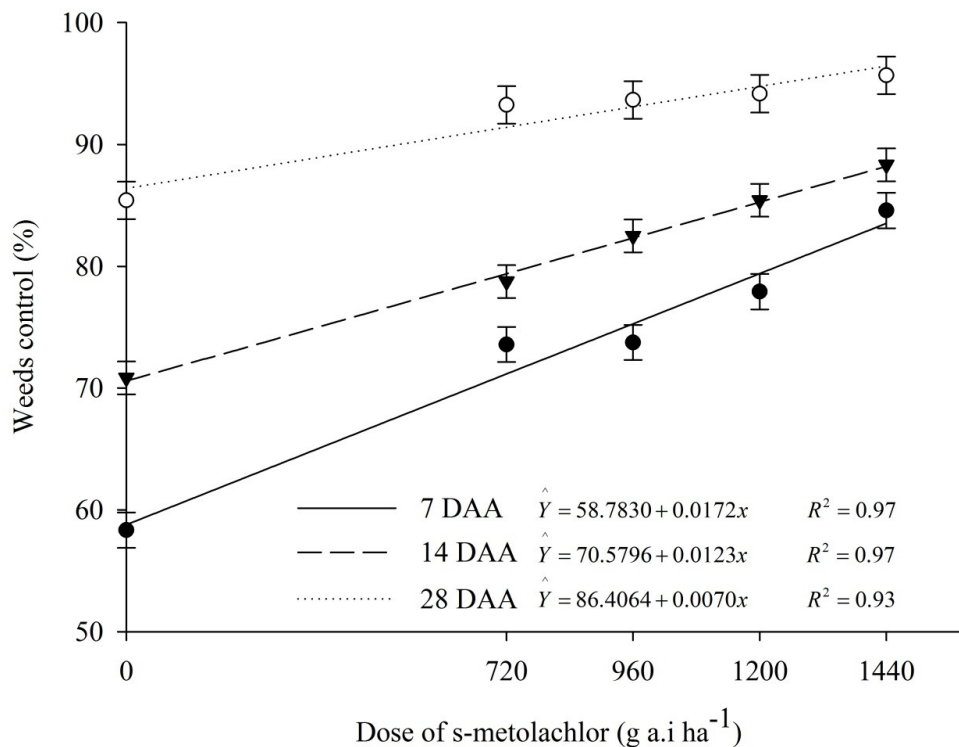


Figure 3. Percentage of weed control in sweet sorghum crops (BRS 506) at 7, 14 and 28 days.

Atrazine was effective to control weeds species, such as *R. raphanistrum*, *C. benghalensis*, *S. orientalis*, *S. trifoliata*, *N. physaloides*, *E. sonchifolia*, and *C. didymus*. However, this herbicide did not efficient to control *D. horizontalis*, *E. indica*, and *U. plantaginea*, resulting in control percentage below 80% (BAHLER et al., 1984; RODRIGUES et al., 2014). The association with S-metolachlor provided the control of the species tolerant to atrazine, increasing weed control percentage at values above 90% even at lower doses. Atrazine application in areas with high weed diversity, principally where there are grass species, do not provide satisfactory control of weeds; thus, it is essential to use other herbicides with the different mode of action. Besides that, the herbicide association can avoid the appearance of weed resistant populations (RIAR et al., 2013; JIMÉNEZ et al., 2013).

Weed control and intoxication of sweet sorghum are increased by increasing the dose of S-metolachlor in the mixture with atrazine. The growth of sorghum is negatively affected by the application of the atrazine + S-metolachlor mixture, mainly at doses 1200 and 1440 g ha⁻¹ of S-metolachlor. The combination of atrazine and S-metolachlor adversely affects the ° Brix, and the magnitude of these effects depends on the dose of S-metolachlor. The 0.25 m spacing promotes a higher fresh matter and total soluble solids value in the sweet sorghum.

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RESUMO: O objetivo desse trabalho foi avaliar os efeitos de arranjos de plantas e dos herbicidas atrazine e S-metolachlor sobre o crescimento e a produtividade do sorgo sacarino. O experimento foi realizado no delineamento em blocos casualizados, com quatro repetições. Os tratamentos foram dispostos em esquema de parcelas subdivididas. Nas parcelas avaliaram-se os espaçamentos entrelinhas (0,25 m, 0,45 m e 0,45-0,45-0,90 m) e nas subparcelas os métodos de controle das plantas daninhas: atrazine (2000 g ha⁻¹), atrazine + S-metolachlor (2000 + 720 g ha⁻¹), atrazine + S-metolachlor (2000 + 960 g ha⁻¹), atrazine + S-metolachlor (2000 + 1200 g ha⁻¹), atrazine + S-metolachlor (2000 + 1440 g ha⁻¹), capina manual e ausência de controle. Aos 7, 14 e 28 dias após a aplicação dos herbicidas foi avaliado a intoxicação das plantas de sorgo e o nível de controle de plantas daninhas na cultura. Aos 120 dias após a emergência da cultura avaliou-se altura de plantas, diâmetro de colmo, massa fresca total, massa de caldo e o teor de sólidos solúveis totais (Brix). Não houve interação entre os fatores espaçamentos e o método de controle para as variáveis massa fresca total (TMF), altura (H), diâmetro do caule (D), peso do suco (JM) e Brix. O controle das plantas daninhas e a intoxicação visual do sorgo aumentaram linearmente com o incremento das doses do S-metolachlor. O crescimento da cultura e os teores de Brix foram reduzidos pela aplicação da associação entre atrazine + S-metolachlor. A escolha do espaçamento de entrelinha influenciou nos componentes de rendimento da cultura. Conclui-se que, o espaçamento de 0,25 m de entrelinhas proporcionou maior produtividade de matéria fresca e de Brix do caldo. A associação entre atrazine e S-metolachlor tem potencial para o uso no controle de plantas daninhas em sorgo sacarino, em doses abaixo de 960 g ha⁻¹ de S-metolachlor.

PALAVRAS-CHAVE: *Sorghum bicolor*. S-metolachlor. Atrazine. Biofuel.

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