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Luminous restriction and chemical control with glyphosate in integrated management of *Urochloa brizantha* L.

Restrição luminosa e controle químico com glyphosate no manejo integrado de *Urochloa brizantha* L.

Restricción de luz y control químico con glifosato en el manejo integrado de *Urochloa brizantha* L.

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Matheus Sales Nogueira e Silva
ORCID: https://orcid.org/0000-0001-7167-6102
Universidade Federal de Minas Gerais, Brazil
E-mail: matheussnogueira@hotmail.com
Leonardo David Tuffi Santos
ORCID: https://orcid.org/0000-0002-9362-778X
Universidade Federal de Minas Gerais, Brazil
E-mail: ltuffi@ica.ufmg.br
Luan Mateus Silva Donato
ORCID: https://orcid.org/0000-0002-3906-2431
Universidade Federal de Minas Gerais, Brazil
E-mail: luandonato@ufmg.br
Guilherme Augusto de Paiva Ferreira
ORCID: https://orcid.org/0000-0001-6266-9963
Universidade Federal de Viçosa, Brazil
E-mail: guilhermepaiva017@gmail.com
Dandara Maria Clara do Rosario Barbosa
ORCID: https://orcid.org/0000-0001-5618-584X
Universidade Federal de Minas Gerais, Brazil
E-mail: dandarabarbosa@hotmail.com
Rodrigo Eduardo Barros
ORCID: https://orcid.org/0000-0003-4785-7725
Universidade Federal de Minas Gerais, Brazil
E-mail: rodrigo.edb@hotmail.com
Matheus Mendes Reis
ORCID: https://orcid.org/0000-0003-2100-2438
Instituto Federal do Norte de Minas Gerais, Brazil
E-mail: matheussmendes@hotmail.com

Abstract
The objective was to evaluate the effect of different light conditions in the cultivation environment on the control of *U. brizantha* by glyphosate. The experimental design was in a plot scheme divided into randomized blocks with five replications. In the plots, environments with light conditions were allocated: full sun, intermittent shading with 3 hours of sun/day, and continuous shading. In the subplots, the herbicide doses: 0, 480, 960, and 1440 g. a. e. glyphosate ha^{-1} applied to *U. brizantha* plants. The control of *U. brizantha* by the herbicide glyphosate was more efficient in shaded environments, either with continuous or intermittent shading, in relation to full sun, indicating that the conditions of light influenced the action of the herbicide. At 35 DAA, control values of *U. brizantha* above 80% were observed from the 765 g. a. e ha^{-1} dose of glyphosate for treatments with shading. Already in conditions of full sun, 65% of control values were reached in the highest dose, which is considered unsatisfactory for the management of this species. *U. brizantha* submitted to light restriction had the content of epicuticular wax, starch, soluble and total sugar reduced; however, the leaf area was larger in these environments compared to full sun. The reserve content, epicuticular wax, and leaf area variables are affected by shading with a direct relationship with the greater control of *U. brizantha* by glyphosate in this cultivation condition.
Keywords: Dose reduction; Epicuticular wax; Herbicide; Morphoanatomy; Shading.

Resumo
Objetivou-se avaliar o efeito do ambiente com distintas intensidades luminosas sobre o controle de *Urochloa brizantha* pelo glyphosate. Foi utilizado o esquema de parcelas subdivididas em blocos casualizados com cinco repetições. Nas parcelas foram alocados ambientes com condições de luminosidade: pleno sol, sombreamento

intermitente com 3 horas de sol/dia e sombreamento contínuo. Já nas subparcelas as doses do herbicida: 0, 480, 960 e 1440 g. e. a ha^{-1} de glyphosate aplicadas sobre as plantas de *U. brizantha*. O controle de *U. brizantha* pelo herbicida glyphosate foi mais eficiente nos ambientes sombreados, seja com sombreamento contínuo ou intermitente, em relação ao pleno sol, indicando que as condições de luminosidade influenciaram na ação do herbicida. Observaram-se, aos 35 DAA, valores de controle de *U. brizantha* acima dos 80% a partir da dose 765 g. e. a. ha^{-1} de glyphosate para os tratamentos com sombreamento. Já em condições de pleno sol foram alcançados valores de 65% de controle na maior dose, o que é considerado insatisfatório para o manejo dessa espécie. *U. brizantha* submetida a restrição luminosa teve o teor de cera epicuticular, amido, açúcar solúvel e açúcar total reduzido, entretanto a área das folhas foi maior nesses ambientes em comparação ao pleno sol. As variáveis teor de reservas, cera epicuticular e área das folhas são afetadas pelo sombreamento e isso influencia diretamente no maior controle de *U. brizantha* pelo glyphosate.
Palavras-chave: Redução de dose; Cera epicuticular; Herbicida; Morfoanatomia; Sombreamento.

Resumen
El objetivo fue evaluar el efecto del ambiente con diferentes intensidades de luz sobre el control de *Urochloa brizantha* por glifosato. Se utilizó un esquema de parcelas divididas en bloques al azar con cinco repeticiones. En las parcelas se asignaron ambientes con condiciones de luminosidad: pleno sol, sombreado intermitente con 3 horas de sol/día y sombreado continuo. En las subparcelas las dosis de herbicida fueron: 0, 480, 960 y 1440 g. y. un ha^{-1} de glifosato aplicado en plantas de *U. brizantha*. El control de *U. brizantha* por el herbicida glifosato fue más eficiente en ambientes sombreados, ya sea con sombreado continuo o intermitente, en relación a pleno sol, indicando que las condiciones de luminosidad influyeron en la acción del herbicida. A los 35 DDA se observaron valores control de *U. brizantha* superiores al 80% a partir de la dosis de 765 g. y. Los. ha-1 de glifosato para tratamientos de sombreado. En condiciones de pleno sol se alcanzaron valores del 65% de control a la dosis más alta, lo que se considera insatisfactorio para el manejo de esta especie. *U. brizantha* sometida a restricción de luz redujo el contenido de cera epicuticular, almidón, azúcar soluble y azúcar total, sin embargo, el área foliar fue mayor en estos ambientes en comparación con pleno sol. Las variables contenido de reserva, cera epicuticular y área foliar se ven afectadas por la sombra y esto influye directamente en el mayor control de *U. brizantha* por parte del glifosato.
Palabras clave: Reducción de dosis; Cera epicuticular; Herbicida; Morfoanatomía. Sombreado.

1. Introduction

Urochloa brizantha L. is a widespread species in the tropics, and its use is associated with its potential application in different agricultural production systems. It is estimated that in Brazil alone, more than 60 million hectares are planted with this species due to the high adaptation to climatic conditions and high productivity of biomass and seeds (Duarte et al., 2019; Santos et al., 2007). With the growth in the last decade of no-tillage and integrated production systems, its use has become even more widespread (Brant et al., 2018). *U. brizantha* also compose integrated production systems such as intercropping in consortium with coffee, fruit, and timber species (Pedrosa et al., 2014; Fidalski et al., 2009; Santos et al., 2017), requiring its control for production of straw either for direct planting or as soil cover.

However, in many areas, *U. brizantha* is found as a weed that is difficult to control, causing economic and environmental damage (Santos et al., 2007; Silva et al., 2016; Lima et al., 2019). Additionally, it occurs as an invader of conservation areas worldwide, becoming a problem for the growth of native species of interest (Freitas et al., 2019).

Products based on glyphosate are among the main herbicides recommended for the control of *U. brizantha* in Brazil (MAPA, 2020). Glyphosate is the most widely used herbicide globally, mainly due to its low cost (Duke and Powles, 2008) and due to the broad spectrum of action, acting against more than 160 weeds (Dill et al., 2010).

The wide use of glyphosate involves its application in agriculture (Tomlin, 2000), as a plant growth regulator and desiccant (FAO / WHO, 2016) and in non-agricultural applications (Dill et al., 2010). With the advent of genetically modified crops, the use of glyphosate in agriculture has expanded (Myers et al., 2016). The global use of glyphosate-based products in agricultural and non-agricultural areas went from 67 million kg in 1995 to 826 million kg in 2014 (Benbrook, 2016), with a continuous increase of about one million tons per year worldwide (Landrigan and Belpoggi, 2018).

The intensive use of glyphosate and its negative impacts on the contamination of human beings (Agostini et al., 2020), water (La Cecilia et al., 2018; Aparicio et al., 2013), soil (Travaglia et al., 2015; Cassigneul et al., 2016) and food (Gélinas et al., 2018; Zoller et al., 2018) are questioned by society. In the literature, weed resistance to glyphosate cases is also of concern (Beckie, 2011; Green, 2012; Shaner et al., 2012). All of these problems are related in part to the quantity of the product used in the applications. An alternative to reduce the negative impacts of using this molecule would be to reduce the doses used or adapt the product's use according to the need and the environment.

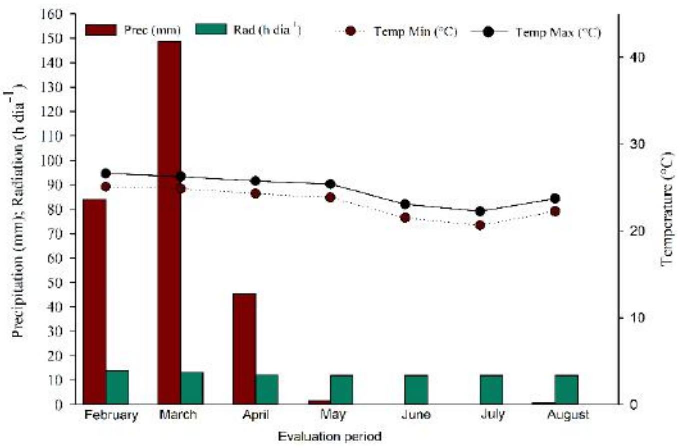
In shading conditions of the environment, changes are found in the plants, such as in the angle of inclination of the leaves (Meng et al., 2014), in the leaf area index (Li et al., 2010), in the deposition of cutin and wax in leaves (Skoss, 1995), photosynthetic rate (Jiang et al., 2011) and dry mass partition (Artru et al., 2018) which can alter its sensitivity to herbicides. In the case of glyphosate, the product's action can be influenced by the barriers against the penetration and absorption of this product in the leaf (Machado et al., 2009) and energy available for the metabolism of the herbicidal molecule (Fernando et al., 2016).

There is still little elucidated in the literature about the change in herbicides' dynamics applied to plants with some light restriction. Also, the recommendation of herbicide doses always takes into account plants in full sun. However, in many crops or growing conditions, weeds have light restrictions, and the literature neglects this. Therefore, this research's objective was to evaluate the effect of different light conditions in the cultivation environment on the control of *U. brizantha* by glyphosate.

2. Methodology

The experiment was carried out under field conditions at the Institute of Agricultural Sciences at UFMG, located at 43° 50'18.31 "W longitude, at 16 ° 40'59.22" S latitude and 650 m altitude. Köppen classifies the climate of the region, as Aw (Tropical with dry winter) (Alvares et al., 2013), the data of precipitation, radiation, and temperature in the city of Montes Claros - MG of the experimental period are shown in Figure 1.

Figure 1 - Precipitation (Prec), hours of radiation per day (Rad), minimum temperature (Temp min), and maximum temperature (Temp max) in the period of conducting the experiment.



Source: Authors.

The soil of the experimental area was classified as Cambisolo Háplico with the following chemical characteristics in the 0-20 cm layer: pH in water: 6.8; P Mehlich (mg dm^{-3}): 2.61; Remaining P (mg L^{-1}): 31.74; K (mg dm^{-3}): 3.48; Ca (cmolc dm^{-3}): 6.1; Mg (cmolc dm^{-3}): 1.7; Al (cmolc dm^{-3}): 0.00; H + Al (cmolc dm^{-3}): 1.3; SB (cmolc dm^{-3}): 7.81; t (cmolc dm^{-3}): 7.81; m (%): 0; T (cmolc dm^{-3}): 9.11. The granulometric characterization showed, respectively: 30, 38 and 32 dag kg^{-1} of sand, silt and clay, being, therefore, of medium texture.

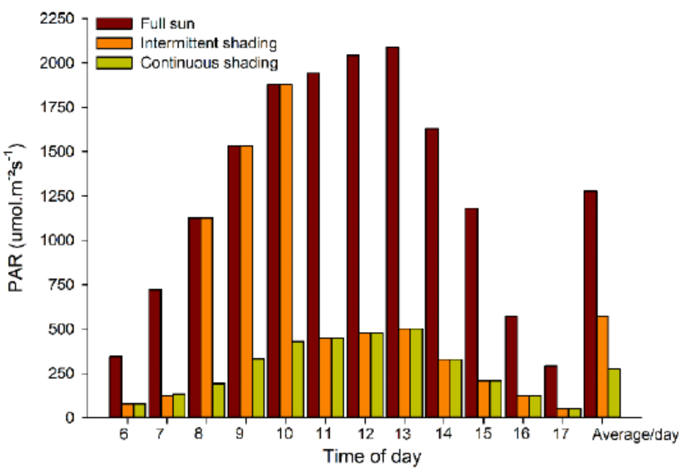
The test was designed in split plots with five repetitions in a randomized block design, totaling 60 experimental units. In the plots, three different environments were allocated according to the luminosity, full sun, intermittent shading with 3 hours of sun daily, and continuous shading. In the subplots, the doses of 0 (control), 480, 960, and 1440 g a. e. ha^{-1} of glyphosate.

The experimental plots had 4x4 meters (16m²) and were demarcated in an open area, without interference from trees and shrubs, with soil previously prepared with a leveling grid. *Urochloa brizantha* cv. Marandu was sown in the plots at a distance of 0.5 meters between lines. The subplots had an area of 2 x 2 meters (4 m^2) with four cultivation lines for evaluation. The fertilization was with 300 Kg ha^{-1} of the fertilizer formulated 4–30–10 (N-P-K) based on the soil analysis. In the absence of precipitation, daily irrigations were carried out to raise the soil moisture to the field capacity. Polyethylene tubes were distributed along with the experimental plots and installation of Top RSB model micro sprinklers, working pressure of 20 mca, and nominal flow of 100 L ha^{-1}.

In the plots with continuous and discontinuous shading, a structure was built to support the use of black polyethylene screens, restricting 70% of the solar radiation, with all sides remaining completely closed. The structures allowed the movement of the shade, which, when closed, remained completely fixed for the treatments with discontinuous shading, to provide direct radiation of 3 hours between 08:00 and 11:00 am.

In the different light conditions, photosynthetically active radiation (PAR) was determined with the Ceptometer device (AccuPar model LP-80, Decagon Devices Inc, Pullman, WA, USA) to characterize the environments (Figure 2). This determination was made to characterize the environments and demonstrate the difference in radiation in each treatment.

Figure 2 - Photosynthetically active radiation in different environments.



Source: Authors.

After planting the *U. brizantha*, which took place in February 2019, four uniform cuts were made in march, april, may and june, to encourage the tillering and the uniformity of the plots. After each cut, the equivalent per plot was applied to 60 kg ha^{-1} of nitrogen in coverage, with agricultural urea (45% N). After the third uniform cut, the plants were air-conditioned in the respective environments for two months until the herbicide application.

The herbicide was applied using a CO_2 sprayer pressurized to CO_2 (Herbicat, Catanduva - SP, Brazil), equipped with a bar with a Teejet AL8002 tip (Teejet Technologies, Louisville - KY, USA) and pressure regulating valve (GP15S model, Enerpac, Menomonee Falls, Wisconsin, USA) constant at 200 kPa, with a volume of 250 L ha^{-1} of application. PVC barriers that separated each of the subplots were used to avoid drift and contamination of the parallel subplots at the time of application. At the time of application, the plants were fully established with an average height of 40 cm.

Visual analysis was performed at 35 DAA to determine the level of control, assigning scores from 0 to 100%, where 0 corresponds to a non-intoxicated plant and 100% to a dead plant according to the methodology described by Alam (1974). The control evaluation was carried out by three duly trained people with experience in this type of evaluation, the values being expressed by the arithmetic mean of the observations. In the same period, the aerial part of the plants' surviving biomass was collected close to the soil. For this sampling, a hollow metal frame in the dimension of 1m² was used. Subsequently, its green mass weight was measured on a precision scale (Shimadzu Corp., Kyoto, Japan). To determine the aerial part's dry mass, approximately 100 grams of the collected material were taken to a forced circulation oven at 65ºC for 72 hours. The dry weight was measured on a precision scale extrapolated to the total value of the sample.

Before the application, leaf samples were collected in the subplots to estimate the leaf area, soluble sugar levels, starch, and epicuticular wax. After drying at 65ºC for 72 hours, the samples were ground in a Willey mill (Marconi Equipment for laboratories, Piracicaba, Brazil) with a 2 mm sieve to perform chemical analysis. The soluble sugar content was determined according to the methodology of McCready et al. (1950) and the quantification of the starch content by the reaction with anthrone solution (Hodge and Hofreiter, 1962; Plummer, 1978).

The epicuticular wax was quantified by exposing the leaf blades of *U. brizantha* in a test tube of known weight with about 30 ml of dichloromethane for 90 seconds, shaking lightly to not to overflow the cell content. After removing the wax from the leaves, the dichloromethane solution plus wax was taken to a water bath; after the evaporation of the liquid, the amount of wax was measured on a precision scale. The leaf area was estimated using two leaves per m² representative of the subplot collected in the middle third of the plants.

The data were considered normal by the Shapiro - Wilk test when performing the analysis of variance. The regression equations were adjusted for the intoxication and dry mass of the remaining aerial biomass, considering the environments and herbicide doses. For the content of soluble sugar, starch, epicuticular wax, and leaf area, the Tukey test ($p \leq 0.05$) was performed considering the different cultivation environments. The variables were correlated through multiple Pearson correlation analysis. Statistical analyzes were performed using the R Studio version 3.3.1 statistical program (R CORE TEAM, 2020).

3. Results

The glyphosate herbicide was more efficient in the control of *U. brizantha* in shaded environments, either with continuous or intermittent shading, in relation to full sun, indicating that the light conditions influenced the herbicide action. Ambient light conditions and glyphosate doses showed interaction for *U. brizantha* control variable ($P \leq 0.05$). At 35 days after application of the herbicide (DAA), control values of *U. brizantha* above 80% were observed in the 765 g ha^{-1} dose of glyphosate in continuous shading and the 1.075 g ha^{-1} dose in intermittent shading. In full sun conditions, 65% control values were achieved at the highest dose tested (Figure 3A). To obtain 80% control in the *U. brizantha* in full sun conditions, it is necessary to apply a dose of 1,663 g ha^{-1}.

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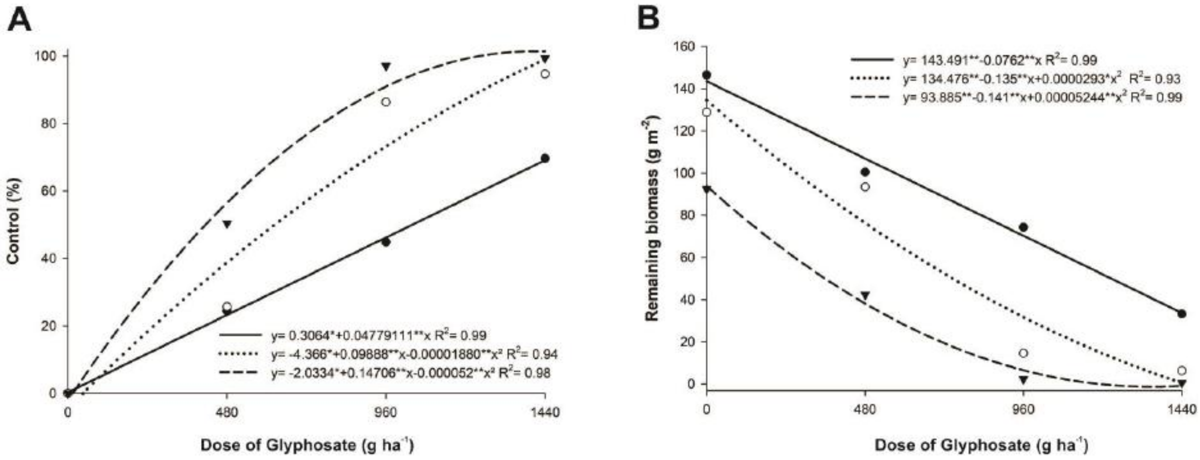
Figure 3 - Percentage of control (A) and remaining dry biomass (g m^{-2}) (B) of *U. brizantha* under different light conditions and glyphosate doses, at 35 days after herbicide application.



(●; —) full sun, (○; ····) intermittent shading and (▼; ----) continuous shading. ** significant at 1% and * significant at 5% by t test. Source: Authors.

In shaded and full sun environments, quadratic and linear equations were adjusted, respectively, for the control of *U. brizantha* as a function of glyphosate doses. The tested doses reached maximum intoxication in environments with light restriction, which was not observed when cultivated in full sun (Figure 3A).

The light restriction and the increase in the glyphosate doses reduced the remaining dry mass of the aerial part of *U. brizantha* at 35 DAA, with an interaction between the light conditions and the glyphosate doses ($P \leq 0.05$) (Figure 3B). On shading, *U. brizantha* had a greater reduction in the remaining dry mass after applying glyphosate and a higher percentage of control (Figure 3).

In continuous and intermittent shading, the remaining biomass reduced 99.4% and 95%, respectively, from the control for the highest tested dose, while in full sun, the reduction was 77.3%. Full sun at a dose of 1,440 g ha^{-1} showed 33.17 g m^{-2} of dry mass, while at a dose of 1,663 g ha^{-1}, where it is estimated that it would have 80% control, the remaining biomass was 16 g m^{-2}. In intermittent shading, 23 g m^{-2} of remaining biomass was observed at a dose of 1,075 g ha^{-1}. In intermittent shading, 23 g m^{-2} of remaining biomass was observed at a dose of 1,075 g ha^{-1}. Meanwhile, *U. Brizantha* grown in continuous shading remaining biomass was 16 g m^{-2} in a dose 765 g ha^{-1}. The remaining biomass of *U. brizantha* followed the same pattern as the control percentage, with reductions in shaded environments from the dose 765 g ha^{-1}. However, even in the full sun, the percentage of control was not satisfactory (Figure 3A) at the highest tested dose, the remaining biomass showed a 77% reduction in this treatment compared to the zero dose.

The shading of *U. brizantha* influenced its dry mass of the aerial part. However, when exposed to 3 hours of direct light a day, its productivity was similar (P> 0.05) to full sun. Continuous shading reduced the dry mass of the shoot by 36.8% compared to full sun. Therefore, the shading of 70% presents an interesting result to assist in controlling *U. brizantha* by glyphosate (Table 1). Also, it can be observed that in full sun, there was satisfactory production of dry mass, indicating the good development of the plants.

Table 1 - Remaining dry mass of the aerial part of *U. brizantha* at 35 DAA without herbicide application under different light conditions.

Cultivation environment	Remaining dry mass (g m^{-2})
Full sun	146.45 a
Intermittent shading	128.77 a
Continuous shading	92.48 b
CV 1 (%):	27.5
CV 2 (%):	21.4

Means followed by the same letter in the column do not differ by the Tukey test at 5% probability. CV 1: coefficient of variation in environments; CV 2: coefficient of variation in the doses. Source: Authors.

The light conditions of the growing environment influenced (P≤0.05) the starch levels, soluble sugars, and total leaf sugars in the aerial part of *U. brizantha*. The plants of *U. brizantha* accumulated lower reserves in environments with light restriction compared to plants grown in full sun (Table 2).

Table 2 - Starch content, soluble sugars, and total sugars of *U. brizantha* under different light conditions.

Cultivation environment	Starch (%)	Soluble sugars (%)	Total sugars (%)
Full sun	8.98a	10.05a	19.03a
Intermittent shading	4.23b	8.59a	12.83b
Continuous shading	4.37b	6.43b	10.81c
CV (%)	16.79	13.77	4.78

Averages followed by the same letter in the column do not differ by the Tukey test at 5% probability. Source: Authors.

Plants grown in full sun had a higher content of starch and total sugars (P> 0.05) (Table 02). Plants grown in full sun and intermittent shading showed higher soluble sugar contents than plants grown in continuous shading (Table 02).

The plants of *U. brizantha* maintained in light restriction showed greater leaf area. When shaded, the leaf area of *U. brizantha* reaches 42% greater than that of plants without light restriction (Table 3).

Table 3 - Leaf area and amount of epicuticular wax of *U. brizantha* under different light conditions.

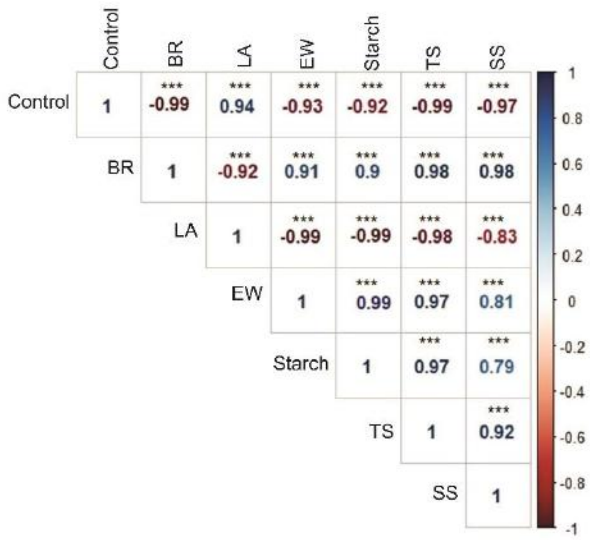
Cultivation environment	Leaf area (cm^2)	Epicuticular wax (mg cm^{-2})
Full sun	30.42b	0.480a
Intermittent shading	51.67a	0.039b
Continuous shading	52.53a	0.036b
CV (%)	11.05	15.59

Averages followed by the same letter in the column do not differ by the Tukey test at 5% probability. Source: Authors.

U. brizantha maintained in full sun showed higher epicuticular wax content (Table 3). The shading reduced by up to 92.5% the amount of *U. brizantha* epicuticular wax compared to non-shaded plants.

The control of *U. brizantha* at 35 DAA had a negative correlation above -0.9 with the variables of remaining biomass, starch content, soluble sugar, total sugar, and epicuticular wax (Figure 4). Thus, with a lower content of reserves and epicuticular wax, the control of *U. brizantha* by glyphosate is greater, observed in treatments with light restriction. Following the same pattern, the biomass remaining after applying the herbicide reduces as the control of the plants by glyphosate increases.

Figure 4 - Pearson's correlation between each variable analyzed in the study.



*** Correlations are significant by the t-test at 0.001; BR: biomass remaining after glyphosate application; LA: leaf area; EW: epicuticular wax; TS: Total sugar; SS: Soluble sugar. Red letters indicate negative correlation and blue letters positive correlation. Source: Authors.

The leaf area of *U. brizantha* had a correlation of 0.94 with the control at 35 DAA (Figure 4). Thus, by increasing the leaf area, *U. brizantha* becomes more sensitive to glyphosate; this fact was observed in plants subjected to light restrictions in this experiment.

The reserve content and remaining biomass were positively correlated with values above 0.8 (Figure 4). The leaf area had a negative correlation above -0.8 with all variables of reserve content and remaining biomass (Figure 4).

4. Discussion

The 65% control observed in plants in full sun, with the application of the manufacturer's dose recommended, is considered unsatisfactory for the management of the species (Silva et al., 2013). The restriction of luminosity in the cultivation environment of *U. brizantha*, whether with continuous or intermittent shading with 3 hours of direct light, increases the efficiency of the species control by glyphosate (Figure 3). The changes in the accumulation of carbohydrates (Table 2) and the morphological and anatomical characteristics (Table 3) of *U. brizantha* are directly related to the lower sensitivity of the species to glyphosate in environments with light restriction (Figure 4).

The higher sensitivity of *U. brizantha* and *Meghatirsus maximus* to glyphosate in an environment with 50% light restriction, compared to plants kept in full sun, was reported Brant et al. (2018). The higher sensitivity to glyphosate by weeds grown in shaded environments, compared to plants kept in full sun, was also observed for *Commelina benghalensis* (Santos et al., 2015), *Macroptilium atropurpureum* (Costa et al., 2020), *Cyperus rotundus* (Santos et al., 2015), *Merremia cissoides* (Ferreira et al., 2022a), and for *Euphorbia heterophylla* (Ferreira et al., 2022b) corroborating what was found in the present study.

This research study innovates in relation to Brant et al. (2018) for testing intermittent shading in simulation of what happens in field conditions with shading by other larger species. Studies on the response of plants to light restriction use the shade of trees in cultivation environments (Santos et al., 2017), or artificial shading with sombrite (Parissi and Koukoura, 2009; Martins et al., 2014, Costa et al., 2020, Santos et al., 2015, Brant et al. 2018, Ferreira et al., 2022a). However, these two types of light restriction differ in light incidence since, in natural conditions, there is an alternation between direct and diffuse radiation that affects the understory, which does not occur in artificial shading. In this sense, when beams of direct radiation stimulate a shaded plant, it needs some time to respond to the light stimulus, increasing its photosynthesis (Salisbury et al., 1992). It is also worth mentioning that the present study was carried out in field conditions, and a more intense shading of 70% was used, similar to what happens in the forest and fruit plantation understory (Schmidt et al., 2017), while Brant et al. (2018) used 50% light restriction.

The greater control observed in shading treatments can be related to plants' morphological and chemical characteristics in these environments that use their protection sources to adapt to the new environment (Costa et al., 2018). With changes in dry mass, leaf area, amount of reserves, and amount of epicuticular wax, the herbicide's action dynamics are altered (Brant et al., 2018; Costa et al., 2018; Tuffi Santos et al., 2015). These factors can increase the exposure of plants to glyphosate; besides, with less reserve, they tend to decrease their ability to recover after intoxication (Silva & Silva, 2007; Santos et al., 2015).

In the present study, the content of epicuticular wax, starch, soluble sugar, and total sugar showed a strong inverse correlation with *U. brizantha* intoxication. On the other hand, the larger the leaf area, the greater the control (Figure 4). The shading provided a reduction in the reserve and epicuticular wax content, in addition to an increase in the leaf area, with which plants in these environments became more sensitive to glyphosate. The smaller amount of wax and the larger leaf area increases the plants' exposure to glyphosate, increasing its interception and absorption (Costa et al., 2018). The reduction of the amount of reserves in *U. brizantha* cultivated in shaded environments can increase the lack of essential amino acids caused by glyphosate, thereby increasing control efficiency.

The reduction in the remaining dry mass of *U. brizantha* after applying the herbicide in continuous shading is related to the lesser capacity of the plant to accumulate photoassimilates. With 70% light restriction, plants have less electron capture by the antenna complex, consequently lower electron transport rate and less energy for the formation of soluble sugars, starch, and various enzymes (Taiz et al., 2017). On the other hand, this response can be attributed to the role of glyphosate in inhibiting the shikimate route, and this route is responsible for about 20% of the carbon assimilated in the plant when photoassimilation is inhibited, thus reducing the accumulation of energy, which can potentiate intoxication in plants with less total carbohydrate content (Silva and Silva, 2007; Taiz et al., 2017). Additionally, glyphosate inhibits the formation of the amino acids phenylalanine, tyrosine, and tryptophan in sensitive plants (Almeida et al., 2019), which can affect the functioning of different metabolic routes. Some perennial plants such as *U. brizantha*, because they accumulate reserves mainly in rhizomes, may not be completely killed by glyphosate due to their ability to use their reserves to supply the deficiencies caused by the herbicide, as was observed in plants under full sun. However, this lack of nutrients may not be supplied in shaded plants with less reserves and, consequently, are killed by the herbicide even in lower doses.

Plants with light restriction tend to have a larger area of their leaves to enhance light capture. With this, the probability of intercepting the herbicide by these plants is greater, in relation to full sun, with positive reflexes on control (Tuffi Santos et al., 2015; Costa et al., 2018).

Costa et al. 2018 attribute the greater sensitivity to the glyphosate of *Macroptilium atropurpureum* grown in the shade to the morphoanatomical characteristics favorable to the penetration and translocation of the herbicide. Also, shaded plants tend to accumulate more nitrate, which can be an aggravating factor in glyphosate poisoning since this herbicide potentiates the accumulation of this compound in plants, causing toxicity (Bellaloui et al., 2006).

The penetration of the herbicide in the plant is an important factor for its efficiency; without adequate penetration, the herbicide cannot be transported to the cells of the parenchyma and be translocated to the site of action (Silva and Silva; 2007). *U. brizantha* and other plants in full sun tend to protect themselves from water loss by depositing wax on the leaf surface (Taiz et al., 2017). This protective compound is generally nonpolar and tends to repel water and some herbicides such as glyphosate, which are polar (Viana et al., 2010). Thus, the penetration of the herbicide in leaves with higher epicuticular wax content is less efficient (Costa et al., 2018). However, the deposition of wax in plants in shaded environments is less, facilitating the herbicide's penetration and action (Procópio et al., 2003; Gomes et al., 2017).

The *U. brizantha*, being an efficient species in the accumulation of reserves, with several points of growth, perennial, and fast establishment, the control by herbicides has not been efficient if used alone, needing in certain cases of high doses for a satisfactory result. For glyphosate, the minimum recommended dose is 1440 g ha^{-1}; however, in most cases, for efficient control, the dosage exceeds 2000 g ha^{-1} (Silva et al., 2013). For this reason, integrated weed management should be used to provide resource savings and less environmental degradation when it comes to the control of *U. brizantha* and similar species. The light restriction is recurrent in many cultivation systems and often affects weed growth. Therefore, it should be considered in the integrated weed management strategy, as changes in plants may influence glyphosate action, as verified in this work.

5. Conclusion

Urochloa brizantha cultivated in shaded environments presents greater sensitivity to the herbicide, making the species control efficient with 765 g ha^{-1} in continuous shading and 1075 g ha^{-1} in intermittent shading. In full sun, a higher dose than those tested is necessary for the species' efficient control.

Changes in the morphology of plants and a reduction in the accumulation of reserves when subjected to light restriction have a high correlation with the control of *U. brizantha*, which confirms the involvement of these characteristics with the greater efficiency of glyphosate in shaded environments.

The response of weeds grown in shaded environments to glyphosate and other herbicides needs to be studied to contribute to the adequate recommendation of product doses and their sustainable management in different cultivation situations.

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