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Article

Productivity, Control, and Decomposition of Irrigated Forage Species under Glyphosate Doses and Shading

Produtividade, Controle e Decomposição de Forrageiras Irrigadas sob Doses de Glyphosate e Sombreamento

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ABSTRACT - Light intensity available in growing environments may influence the susceptibility of plants to glyphosate and decomposition of their residues. This study aimed to assess the productivity, control, and decomposition of forage straw submitted to glyphosate doses and exposed to full sun and 50% shade. Two experiments were carried out, one for Piatã grass (*Urochloa brizantha* cv. Piatã) and other for Tanzania grass (*Megathyrsus maximus* cv. Tanzania). The experimental design was a randomized block design with strip-plot and four replications. Two growing environments (at full sun and under 50% shade) were installed in strips in the growing area, combined with six doses of glyphosate (0, 360, 720, 1,080, 1,440, and 1,800 g a.e. ha^{-1}) used for forage desiccation. Shade did not change Tanzania grass productivity ($p<0.05$), but it reduced Piatã grass productivity ($p>0.05$), suggesting its low tolerance to light restriction. Tanzania grass is more tolerant to glyphosate when compared to Piatã grass, especially at full sun conditions. In general, the evaluated forages present a high susceptibility to glyphosate as incident radiation is reduced, which allows using lower doses to desiccate them in shaded environments. Straw decomposition of Piatã and Tanzania grasses was slower under shading. In this environment with light restriction, straw is more durable and has a better quality for the no-tillage system.

Keywords: crop-livestock-forest integration system, no-tillage system, post-emergence desiccation, luminous intensity, *Urochloa*, *Megathyrsus*.

*RESUMO - A intensidade luminosa disponível nos ambientes de cultivo pode influenciar a suscetibilidade das plantas ao glyphosate e também a decomposição de seus resíduos. Objetivou-se neste estudo avaliar a produtividade, o controle e a decomposição da palha de forrageiras submetidas a doses do herbicida glyphosate, expostas a pleno sol e sob 50% de sombra. Foram realizados dois ensaios, sendo um para capim-piatã (**Urochloa brizantha** cv. Piatã) e outro para capim-tanzânia (**Megathyrsus maximus** cv. Tanzânia). Os experimentos foram conduzidos em faixas, no delineamento experimental de blocos casualizados com quatro repetições. Foram testados dois ambientes de cultivo, a pleno sol e sob 50% de sombra, alocados em faixas na área de cultivo, combinados com seis doses de glyphosate, 0, 360, 720, 1.080, 1.440 e 1.800 g ha^{-1} de equivalente ácido (e.a.), utilizadas na dessecação das forrageiras. O sombreamento não alterou a produtividade do capim-tanzânia ($p<0,05$), porém reduziu a produtividade do capim-piatã ($p>0,05$), sugerindo baixa tolerância dessa espécie à restrição luminosa. O capim-tanzânia é mais tolerante ao glyphosate em relação ao capim-piatã, sobretudo em condições de pleno sol. De maneira geral, as forrageiras avaliadas apresentam alta*

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suscetibilidade ao glyphosate com a redução da radiação incidente, de modo a permitir a utilização de menores doses para dessecação dessas forrageiras em ambiente sombreado. A decomposição da palhada do capim-piatã e capim-tanzânia foi mais lenta sob sombreamento, possibilitando uma palhada mais duradoura, o que pode favorecer a adoção do sistema de plantio direto na palha.

Palavras-chave: integração lavoura-pecuária-floresta, plantio direto, pós-emergência dessecação, intensidade luminosa, *Urochloa*, *Megathyrsus*.

INTRODUCTION

Integrated production systems have been presented as an alternative to current models of agricultural exploitation, aiming at production diversification through the integration of agricultural, livestock, and forestry components. The increase in biodiversity and the synergistic effect of crop-livestock-forest integration systems (CLFIS) promote, among other benefits, the improvement of soil physical, chemical, and biological attributes. These benefits are enhanced when CLFIS is adopted together with the no-tillage system (NTS) (Macedo, 2009; Vilela et al., 2011; Garnett et al., 2013).

The insertion of tree or shrub plants in integrated production systems causes the other components to reduce quantity and quality of light available in the understory. Thus, the use of plant species tolerant to a reduced solar radiation becomes necessary. According to Martuscello et al. (2009), leaf size, number of leaves per tiller, and a population density of tillers stand out as important structural parameters of a pasture under shading, which are altered aiming at a higher use of incident light. In addition, with no-tillage system adoption, it is necessary to use plants that present potential for formation and maintenance of straw on the soil, promoting an efficient and long-term soil cover (Panachuki et al., 2011; Doneda et al., 2012; Guedes Filho et al., 2013).

The herbicide glyphosate is widely used for desiccating different plant species, including those for straw formation in the no-tillage system (May et al., 2016; Santos et al., 2016; Timossi et al., 2016). Among its characteristics are the low cost, fast degradation, broad spectrum of action, and low toxicity to mammals. However, chemical control with glyphosate may promote changes in plant chemical composition, altering the decomposition rates of the material resulting from desiccation (Costa et al., 2015; Jasper et al., 2015).

Additionally, glyphosate efficiency in controlling weeds in environments with light restriction is potentiated (Santos Júnior et al., 2013; Santos et al., 2015), which allows reducing its use in shaded environments commonly found in agricultural and non-agricultural areas. Currently, glyphosate dose recommendations in the product leaflet do not consider the growing environment, which generalizes field situations, leading to a higher herbicide use.

In this context, the aim of this study was to assess the influence of light availability on productivity, desiccation, and decomposition of forage straw submitted to different glyphosate doses.

MATERIAL AND METHODS

The experiments were conducted in Montes Claros, MG, Brazil, from December 2013 to October 2014. This municipality is located at the geographical coordinates of 16º44’06" S and 43º51’43" W, with an average altitude of 646 m. According to Köppen classification, regional climate is Aw, a savannah tropical climate characterized by the occurrence of a dry winter and a rainy summer. The soil of the experimental area was classified as an Ultisol (Cambissolo Háplico, Brazilian Soil Classification System). The following results were obtained from the soil chemical and physical analyses carried out at a depth of 0-20 cm: pH in water of 6.8, P Mehlich of 2.61 mg dm^{-3}, P-remaining of 31.74 mg L^{-1}, K of 3.48 mg dm^{-3}, Ca of 6.1 $cmol_c$ dm^{-3}, Mg of 1.7 $cmol_c$ dm^{-3}, Al of 0.00 $cmol_c$ dm^{-3}, H+Al of 1.3 $cmol_c$ dm^{-3}, SB of 8.69 $cmol_c$ dm^{-3}, t of 8.69 $cmol_c$ dm^{-3}, T of 10.02 $cmol_c$ dm^{-3}, sand of 30 dag kg^{-1}, silt of 38 dag kg^{-1}, and clay of 32 dag kg^{-1}.

Two experiments were carried out, one for *Urochloa brizantha* cv. Piatã (Syn. *Brachiaria brizantha*) and other for *Megathyrsus maximus* cv. Tanzania (Syn. *Panicum maximum*). Thus, the experiments were assessed separately. The experimental design was a randomized block design with split-plots referring to the growing environments and with four replications. Two growing environments (full sun and 50 ± 4.2% shade) were combined with six glyphosate (Roundup Original®) doses (0, 360, 720, 1,080, 1,440, and 1,800 g a.e. ha^{-1}. Shading was obtained with Sombrite® black polypropylene screens. Light interception in the shaded growing environment was carried out by determining the photosynthetically active radiation by means of 10 observations in each environment by using a linear ceptometer (AccuPAR Linear PAR/LAI ceptometer, Model LP 80, Decagon Devices). A useful area of 4 m^2 (2 x 2 m) was delimited for each plot.

The forage species *Urochloa brizantha* cv. Piatã (Piatã grass) and *Megathyrsus maximus* cv. Tanzania (Tanzania grass) were manually broadcasted using 6 and 4 kg ha^{-1} of viable pure seeds, respectively. Twelve to 15 seedlings m^{-2} were maintained in post-emergence. Soil tillage was previously carried out by means of two harrowing. Planting fertilization consisted of 50 kg ha^{-1} P_2O_5 as single superphosphate broadcasted on the day of forage sowing. Seeds and fertilizers were manually incorporated into the soil with a hoe.

At 50 and 80 days after sowing (DAS), forages were cut at 20 cm from the soil surface by means of a costal brushcutter and subsequent topdressing fertilization with 50 kg ha^{-1} of nitrogen as urea to promote tillering and standardization of the studied species before herbicide application. The material from each cutting was removed from the experimental area.

The irrigation of the experimental area was performed through a micro-sprinkler irrigation system, with a flow capacity of 1.2 m^3 ha^{-1}, using a two-day irrigation shift and three-hour irrigation time. Weeds were mechanically controlled with a hoe.

At 107 DAS and after the last brushing for standardization, biomass production was obtained. A square frame of 0.25 m^2 was used to delimitate the forage collection area and plants were cut close to the soil. The collected forage species were weighed to determine the fresh matter (FM) and then taken to a forced air circulation oven at 65 ^oC until constant weight to determine the dry matter (DM).

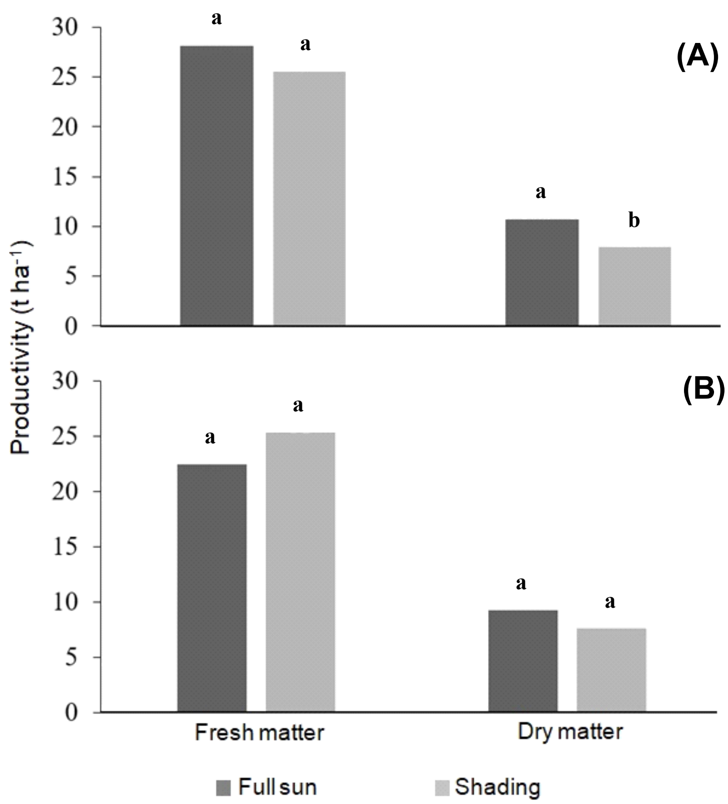
Glyphosate application was carried out at 108 DAS using a costal sprayer with nozzles Teejet 11002 for a pressure of 200 kPa and spray volume of 120 L ha^{-1}. Laminated wood panels were used to avoid spray drift between experimental units. The assessments of forage control were carried out visually by four evaluators at 14 and 28 days after application (DAA). Scores from 0 to 100 were assigned, where 0 represents the absence of intoxication symptoms and 100 the total plant death (Alam, 1974). At the end of the assessments, the simple arithmetic mean of the values of each evaluator was used to obtain the average control at each plot.

At 15 DAA, a single plant representative of each desiccated plot was cut close to the soil to determine plant biomass decomposition. This plant was cut into fragments of 5 cm in length and dried in a forced air circulation oven at 65 ^oC until constant weight. Subsequently, an aliquot proportional to the forage species hectare was weighed (Pariz et al., 2011) and placed in polyethylene litter bags (Young, 1989; Thomas and Asawaka, 1993) with dimensions of 15 x 25 cm. Two litter bags were used per plot. One of the litter bags was left in direct contact with the soil, while the second one was deposited on the straw of the area. The results were expressed by the average of both positions. The value of the decomposed straw of each plot corresponded to the difference between the average obtained from both litter bags before and after incubation, which was carried out for 15, 30, 45, 60, 75, 90, 105, and 120 days in the field.

The data of productivity were submitted to the analysis of variance by the F-test and the means were compared for each environment. The data were submitted to the F-test, regressions were adjusted as a function of glyphosate doses, and the growing environments were compared by the Tukey's test at 5% probability. The statistical analyses were performed by using the software Sisvar version 5.3 (Ferreira, 2010) and the graphs were constructed by means of the software Sigmaplot version 10.0.

RESULTS AND DISCUSSION

No interaction ($p>0.05$) was observed between the factors growing environments and glyphosate doses applied to the forage desiccation on the productivity of Piatã and Tanzania grasses. Fresh matter productivity of Piatã grass was similar between shaded and full sun environments, as also observed for Tanzania grass (Figure 1). However, dry matter productivity of Piatã grass was, on average, 25.4% higher at full sun (p<0.05) when compared to the shaded environment. Tanzania grass productivity was similar among the studied environments (Figure 1).



Means followed by the same letter do not differ between growing environments by the F-test (p<0.05).

Figure 1 - Productivity (t ha^{-1}) of fresh and dry matter of Piatã (A) and Tanzania (B) grasses at full sun and under 50% shade.

The increase in shading level may promote a reduction in the accumulated dry matter production of tropical forages (Sousa et al., 2007; Reis et al., 2013; Bosi et al., 2014). According to Martuscello et al. (2009), dry matter production is important in determining the adaptability of forage species to shade conditions. According to these authors, forage species present different levels of shade tolerance. However, all studied forages drastically reduced the productivity under shade conditions above 50%. Paciullo et al. (2007) observed a marked productivity reduction in *U. Decumbens* when shading was changed from 35 to 65%. Andrade et al. (2004) also observed reductions of 60% in the production of *U. brizantha* cv. Marandu when cultivated under 70% shade.

The difference of results between fresh and dry matter is possibly related to a lower plant transpiration when grown under shading conditions, leading to plants with a lower dry matter content, as reported by Volenec and Nelson (2003). This change in the water content of tissues contributes to masking the differences between the fresh matter productivity of forage species under shaded environment and at full sun.

The reduced dry matter productivity observed for Piatã grass when grown under a shaded environment suggests a low tolerance to the 50% shading level. However, Maia et al. (2014) assessed grass productivity in a crop-livestock integration system under a rainfed condition and observed that Piatã grass was among forages that obtained a greater prominence in quality and productivity, with a value of 7,372 kg ha^{-1} of dry matter in a cut. A slightly higher productivity was achieved in our study, with a value of 7,920 kg ha^{-1} of dry matter under shading.

A reduction in light intensity and red/extreme red wavelengths lead to decreases in tillering of forage plants (Deregibus et al., 1983). Tiller is the basic unit of the forage species, and the tillering capacity represents the pasture production potential. Thus, the reduced dry matter productivity observed in Piatã grass under shaded environment was caused by a decrease in the number of tillers. In addition, in areas with light restriction, as observed by Martuscello et al. (2009), leaves present a higher specific leaf area, leading to the production of lower weight leaves.

The results observed here are in accordance with those found in the literature, which demonstrated a greater adaptation of Tanzania grass to environments with light restriction. Oliveira et al. (2013) observed a higher dry and fresh matter production for Tanzania grass under shading when compared to the full sun, showing a good adaptation of this grass to low light conditions.

Forage species control by glyphosate showed a quadratic pattern in relation to the doses in both growing environments (Figure 2). This behavior is similar to that observed by Santos Júnior et al. (2013) when working with glyphosate doses for controlling purple nutsedge at full sun and under shading. According to Alam (1974) classification, control levels between 80 and 90% are considered as very good and above 90% are considered as excellent. In this sense, at 14 DAA a very good control was observed for Piatã grass under shading, even with the lowest doses. In this period, even with the highest dose, smaller signs of toxicity were observed for Piatã grass at full sun. At 28 DAA, an excellent control was obtained for Piatã grass with the lowest dose (360 g a.e. ha^{-1}) under the shaded environment, but only with a dose of 1,080 g a.e. ha^{-1} an excellent control was observed at full sun (Figure 2).

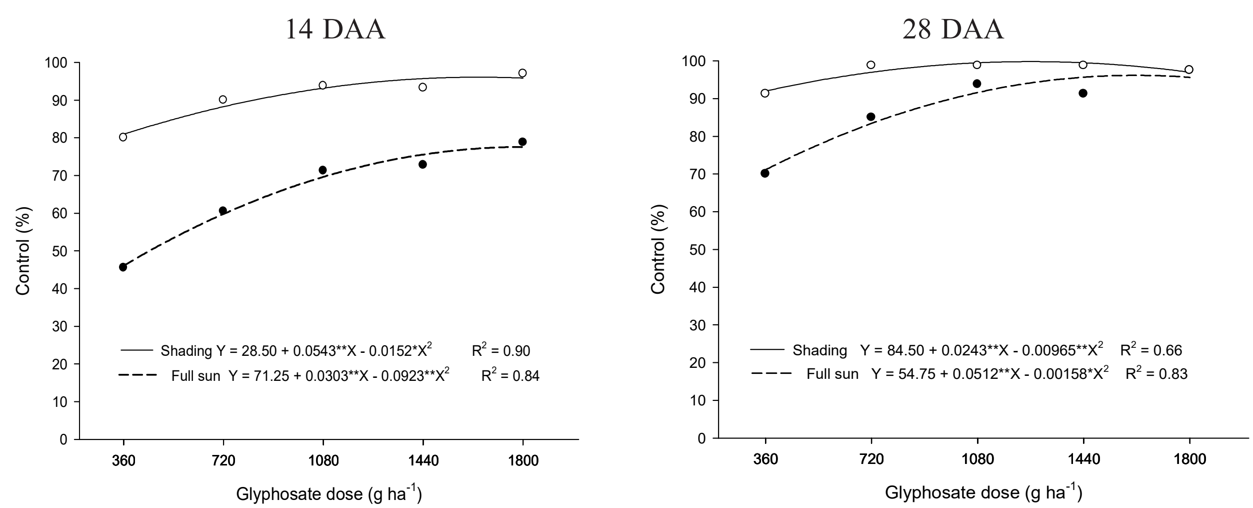


Figure 2 - Control of Piatã grass at 14 and 28 days after glyphosate application at full sun and under shading conditions.

The response pattern of Tanzania grass to glyphosate doses showed a quadratic response (Figure 3), as observed for Piatã grass. However, a higher tolerance was observed for Tanzania grass when compared to Piatã grass. At 14 DAA, a very good control was only observed from the dose of 720 g a.e. ha^{-1} and under the shaded environment, while at full sun only at the highest dose (1,800 g a.e. ha^{-1}) provided the same level of control. The synergistic effect of shading on forage control with glyphosate is also evident at 28 DAA when the dose of 360 g a.e. ha^{-1} allowed an excellent control. On the other hand, at full sun, the same level of control was only possible at the highest dose 1,800 g a.e. ha^{-1} (Figure 3).

The quantitative and qualitative reduction of incident solar radiation promotes physiological and anatomical adaptations in different plant species. These adaptations aim to optimize light capture by plants (Taiz and Zeiger, 2009). In this sense, it is observed the presence of supporting tissues with lower thickness, higher shoot development in detriment to root system, plant etiolation due to increased stem height, development of leaves with a higher specific leaf area, changes related to the leaf to stem ratio, changes related to the tilt angle of plant shoot

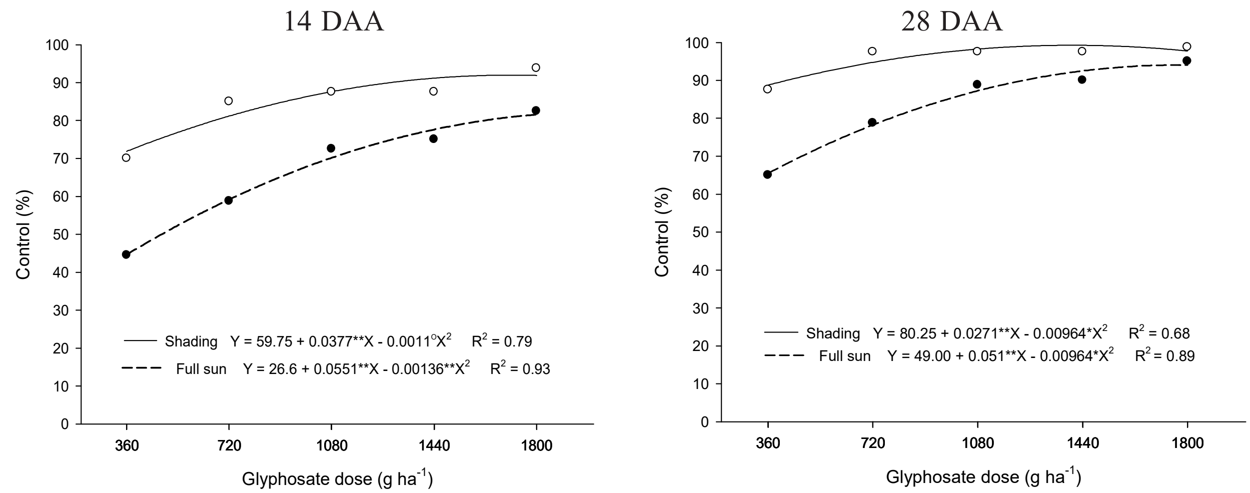


Figure 3 - Control of Tanzania grass at 14 and 28 days after glyphosate application at full sun and under shading conditions.

components, among other adaptive processes (Dias-Filho et al., 2000; Peri et al., 2006; Paciullo et al.,2008; Martuscello et al., 2009; Paciullo et al., 2010; Bosiet al., 2014).

Thus, a higher plant control under shading was possibly due to morphological and anatomical adaptations resulting from a reduction in solar radiation, which allowed a higher interception, absorption, and translocation of the applied product (glyphosate) to the active sites of the mechanism of action, standing out an increase in specific leaf area and a reduction in leaf tissue thickness. Santos Júnior et al. (2013) described this process in a study on the management of purple nutsedge and Benghal dayflower with glyphosate under shaded environments.

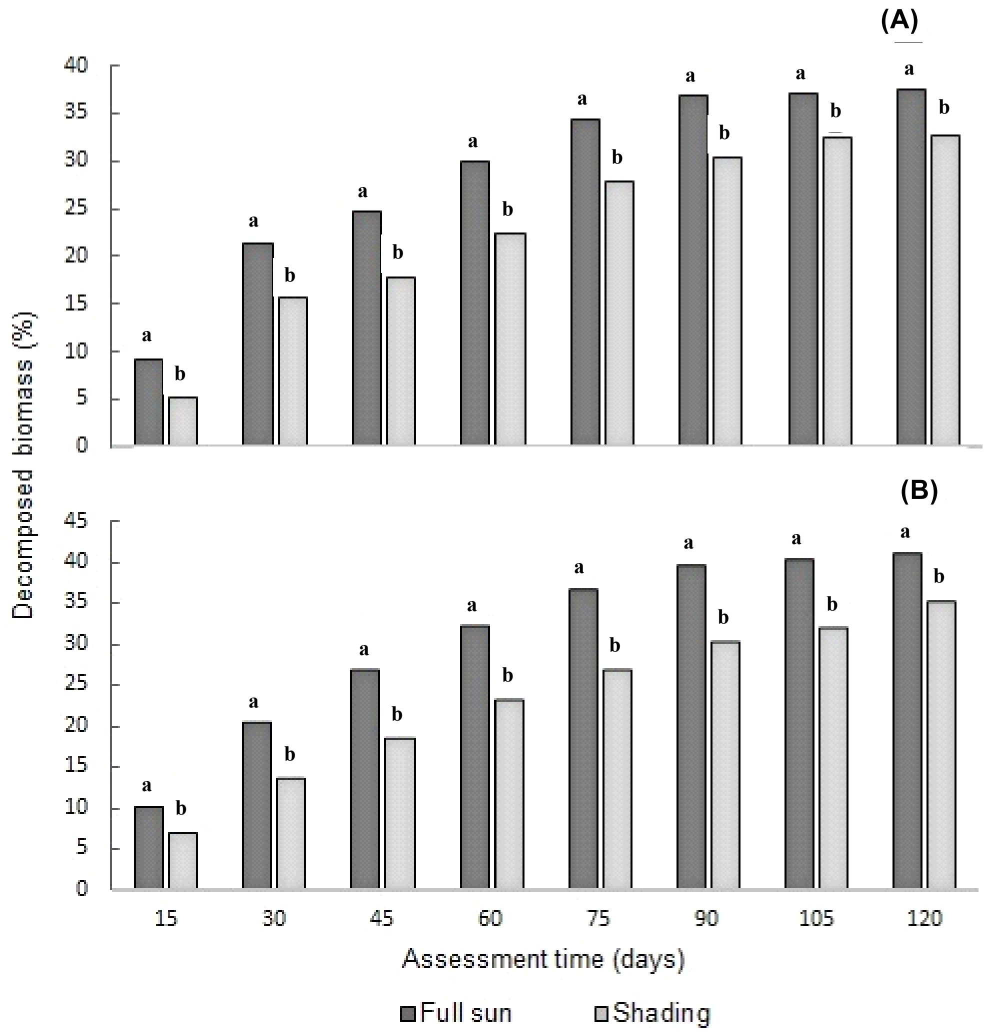
The highest sensitivity to chemical control by shaded plants allows using lower herbicide doses than the current recommendations, which do not consider this variable, with no distinction between plants grown under shading and at full sun (Santos Júnior et al., 2013). Thus, it is suggested the possibility of reducing herbicide doses in integrated production systems, leading to a reduction in costs and the negative consequences of using chemical weed control. In addition, forage desiccation could be performed in CLFIS with about 1/3 to 1/4 of the recommended doses for conventional systems, showing its conservationist character. Thus, it is necessary to conduct and disseminate studies on the survey and verification of management with a better use of the applied resources, as well as an efficient and sustainable use of the natural resources.

The percentage of decomposed biomass was not influenced ($P>0.05$) by glyphosate doses and the interaction environmental × dose. According to Costa et al. (2015), plant residues with a higher C/N ratio have a lower decomposition rate. In this sense, according to Jasper et al. (2015), the use of glyphosate promotes a reduction in lignin and cellulose contents in the plant material, thus reducing the C/N ratio. However, in our study, glyphosate application did not lead to changes in the decomposition process of the remaining straw of plants controlled with this herbicide.

Another important factor associated with decomposition is the relationship between herbicide use and soil microbial biomass since herbicides interfere with the dynamics of edaphic microorganisms, altering decomposition rates. According to Andrighetti et al. (2014), glyphosate may have deleterious effects on bacterial communities. However, as reported in the literature, glyphosate application following the recommended doses does not lead to negative changes in microbial populations (Giesy et al., 2000).

Straw decomposition of Piatã and Tanzania grasses was higher at full sun regardless the assessment time (Figure 4). The highest percentages of biomass decomposed at full sun resulted from a higher temperature associated with favorable moisture conditions (Brighenti et al., 2011). Possibly, these conditions intensified the mineralization process by the edaphic fauna.

Straw permanence for a longer period on the soil surface may contribute to maintaining moisture in the environment, which favors a reduction in thermal amplitude and reduces the



Means followed by the same letter at the same assessment time do not differ from each other by the F-test at 5% probability.

Figure 4 - Decomposed biomass of Piatã (A) and Tanzania (B) grasses assessed at 15, 30, 45, 60, 75, 90, 105, and 120 days after cutting at full sun and under shading.

risk of water shortage, creating a favorable microclimate for plant and animal development. Thus, shaded environments present a greater potential in the conservation of plant residues on the soil surface, which may favor straw formation in integrated production systems that adopt the no-till system.

With this study, we can conclude that a reduction in dry matter productivity observed for Piatã grass suggests a low tolerance to the shading level of 50%. However, Tanzania grass shows potential for pasture formation in areas with a shade level similar to that of our study. Tanzania grass is more tolerant to glyphosate when compared to Piatã grass, especially at full sun. In general, the assessed forage species present a high sensitivity to glyphosate as incident radiation decreases, allowing a significant reduction in the dose required for desiccate them in a shaded environment. Straw decomposition of Piatã and Tanzania grasses is slower under shading, allowing a more durable straw, which may favor the no-tillage system adoption.

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