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Article

SUSCEPTIBILITY OF PERENNIAL TROPICAL FORAGE PLANTS TO GLYPHOSATE HERBICIDE IN INTEGRATED CROP-LIVESTOCK FARMING SYSTEMS

Suscetibilidade de Forrageiras Tropicais Perenes ao Herbicida Glyphosate em Sistemas Integrados de Produção Agropecuária

MACHADO, L.A.Z.[1]*
COMUNELLO, É.[1]
CECATO, U.[2]
CONCENÇO, G.[3]

ABSTRACT - The purpose of this study was to evaluate forage plant susceptibility in *Urochloa* ssp. and *Megathyrsus maximus* with two glyphosate herbicide doses, to increase the efficiency of integrated crop-livestock farming systems. A randomized block design was adopted, in a split-plot arrangement, with six replications. In the main plots, the following treatments were established: *Urochloa ruziziensis*, *U. decumbens*, *U. brizantha* cvs. Xaraés, BRS Piatã and BRS Paiaguás, *Megathyrsus maximus* cvs. Aruana and BRS Tamani; in the subplots, there were doses of glyphosate herbicide; 0.72 and 1.44 kg a.e. ha^{-1}. The estimated control percentage was consisted of a grading scale from zero (fully living tiller) to 100 (fully dead tillers), assigned 7; 14; 21 and 28 days after herbicide application. The 0.72 kg a.e. ha^{-1} glyphosate dose was not effective for forage control, but it was possible to identify the most susceptible genotypes, such as *U. ruziziensis* and BRS Paiaguás. The 1.44 kg a.e. ha^{-1} dose was satisfactory in controlling (³80%) the grasses *U. ruziziensis*, *U. brizantha* cv. BRS Paiaguás and *M. maximum* cv. Aruana at 17, 18 and 18 days of desiccation intervals, respectively. In conclusion, the susceptibility of forage plants to herbicide glyphosate varies among species and cultivars. *U. ruziziensis*, BRS Paiaguás and Aruana grasses are desiccated with reduced herbicide doses and short desiccation intervals, and can contribute to the diversification of the forage used in integrated crop-livestock farming systems.

Keywords: *Brachiaria*, desiccation, *Megathyrsus*, *Panicum*, *Urochloa*.

RESUMO - O objetivo deste estudo foi avaliar a suscetibilidade das forrageiras ***Urochloa*** *ssp. e* ***Megathyrsus maximus*** *a duas doses de herbicida glyphosate, visando facilitar o estabelecimento de culturas nos sistemas integrados de produção agropecuária. O delineamento adotado foi o de blocos casualizados com parcelas subdivididas em faixa e seis repetições. Os tratamentos nas parcelas principais foram constituídos das forrageiras:* ***Urochloa ruziziensis***, ***U. decumbens***, ***U. brizantha*** *cvs. Xaraés, BRS Piatã e BRS Paiaguás,* ***Megathyrsus maximus*** *cvs. Aruana e BRS Tamani e, nas subparcelas, doses de herbicida glyphosate: 0,72 e 1,44 kg e.a.* ha^{-1}*. A estimativa da porcentagem de controle constituiu-se na atribuição de notas na escala de zero (perfilhos totalmente vivos) a 100 (perfilhos totalmente mortos), realizada aos 7, 14, 21 e 28 dias após a aplicação do herbicida. A dose de 0,72 kg e.a.* ha^{-1} *não foi eficiente para o controle das forrageiras, mas foi possível identificar os genótipos mais suscetíveis, como* ***U. ruziziensis*** *e BRS Piatã. A dose de 1,44 kg e.a.* ha^{-1} *foi satisfatória para o controle (³80%) de* ***U. ruziziensis***, ***U.brizantha*** *cv. BRS Paiaguás e* ***M. maximum*** *cv. Aruana, aos 17, 18 e 18 dias de*

*** Corresponding author:**
<luis.zago@embrapa.br>

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[1] Embrapa Agropecuária Oeste, Dourados-MS, Brasil; [2] Universidade Estadual de Maringá, Maringá-PR, Brasil; [3] Embrapa Clima Temperado, Pelotas-RS, Brasil.

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intervalo de dessecação, respectivamente. Conclui-se que a suscetibilidade das forrageiras ao herbicida glyphosate varia entre espécies e cultivares. Os capins ***U. ruziziensis****, BRS Paiaguás e Aruana são dessecados com reduzida dose de herbicida, apresentam curto intervalo de dessecação e podem contribuir para a diversificação das forrageiras utilizadas nos sistemas integrados de produção agropecuária.*

Palavras-chave: *Brachiaria*, dessecação, *Megathyrsus*, *Panicum*, *Urochloa*.

INTRODUÇÃO

Integrated crop-livestock farming systems (ICLS) provide various technical and economic gains for rural producers and contribute to the improvement of the environment. In these systems, pastures have functions that go beyond animal production, such as providing environmental services, for instance (Carvalho et al., 2009). Its cultivation results in straw and root residues that are fundamental for physical improvement, increasing the content of organic matter and the water availability in the soil; it also contributes to weed control (Christoffoleti et al., 2008; Machado and Assis, 2010; Seidel et al., 2014; Silva et al., 2014).

Until the last decade, temporary pastures were formed by annual species, grown during the off-season of summer crops; then, they were replaced by perennial fodder plants. They present advantages in relation to the annual ones due to their longer growth cycle, being more productive during the dry season, as well as inhibiting the emergence of weeds (Timossi et al., 2007). Although these forage plants generally require a higher dose of herbicide and their senescence is slower and may delay sowing the next crop, *Urochloa ruziziensis* is an exception among them, due to its easy desiccation, which is why this species has returned into the market and is widely used in grazing and as a covering in succession crops.

Perennial forage plants are controlled with the use of systemic herbicides (Costa et al., 2013), such as glyphosate and sulfosate; the herbicide dose and the time required for control are variable among forage species and weeds (Carvalho et al., 2011; Silva et al., 2013, Ceccon and Concenço, 2014). The desiccation interval, which is the period between herbicide application and sowing of the new crop, ranges from 7 to 21 days, and the glyphosate dose ranges from 0.72 to 1.44 kg a.e. ha^{-1} (Jakelaitis et al., 2005; Nunes et al., 2009; Costa et al., 2013; Nepomuceno et al., 2012). Susceptibility to glyphosate may be inter- and intraspecies (Brighenti et al., 2011; Machado and Valle, 2011).

Herbicide doses have economic and environmental implications, and the time required to control forage plants makes it possible to anticipate the sowing of the sucessive crop (Silva et al., 2013) or to delay the use of pastures. Among perennial forage plants, *U. ruziziensis* and Aruana grass are more susceptible to the herbicide glyphosate, and Guinea grass and gamba grass are the most tolerant (Machado et al., 2011).

There are some divergences between the available results on the susceptibility of forage plants to glyphosate, probably due to the field condition during applications, since in some experiments plants were evaluated under successive cuts and, in others, they were evaluated in free growth, resulting in different biomass quantities to be checked (Ferreira et al., 2010; Machado and Assis, 2010; Nascente and Crusciol, 2012). There are also divergences between researches and producers, since forage plants are desiccated with some level of stress even during the dry season, aiming at the anticipation of soybean sowing; this is growing trend in the Midwest region (Machado et al., 2011).

For recently launched forage plants, it is necessary to know their potential for succession, rotation or consortium with annual crops; with this, it will be possible to place them in the different integrated crop-livestock farming systems.

The purpose of this study was to evaluate the susceptibility of the forage species *Urochloa* spp. and *Megathyrsus maximus* at two doses of glyphosate, in order to help the establishment of crops in integrated crop-livestock farming systems.

MATERIALS AND METHODS

The used design was in randomized blocks, with plots subdivided into strips and eight replications, in the 2012/13 harvest. In the main plot, the following forage plants were evaluated: 1) *Megathyrsus maximus* cv. Aruana; 2) *M. maximus* cv. BRS Tamani (lineage PM45); 3) *Urochloa brizantha* cv. Xaraés; 4) *U. brizantha* cv. BRS Piatã; 5) *U. brizantha* cv. BRS Paiaguás (lineage B6); 6) *U. decumbens*; and 7) *U. ruziziensis*. In the subplots, the glyphosate doses 0.72 and 1.44 kg a.e. ha^{-1} were established.

The experiment was conducted in no-tillage, in a Dystroferric Red Latosol; before sowing, it had the following chemical characteristics: pH in water, 5.3; pH in $CaCl_2$, 4.5; Al^3, Ca^{2+}, Mg^{2+}, H + Al and K^+ contents of 0.6, 3.2, 0.7, 8.9 and 0.7 $cmol_c$ dm^{-3}, respectively; P (Mehlich-1), 44.2 mg dm^{-3}; effective CTC, 5.2 $cmol_c$ dm^{-3}; V, 34.1%; and OM, 33.9 g kg^{-1}. On 10/6/2011, 3 Mg ha^{-1} of dolomitic limestone with 70% PRNT were applied on the surface.

Soybean sowing was carried out on 10/28/2011 with a SHM (Semeato) sower, with a density of 32 to 35 viable soybean seeds per square meter. At the time of sowing, 200 kg ha^{-1} of NPK 5-30-15 fertilizer were applied on the rows. Plots measured 6.0 x 6.0 m, and inter-row spacing was 0.6 m. Plants were sown with a 21 day gap after the emergence of soybean, with a self-propelled Wintersteiger plot seeder, which distributed forage seeds in the soybean inter-rows at approximately 4 cm depth. For genotypes *Urochloa* spp. and *Megathyrsus*, seeding densities of 60 and 300 viable pure seeds per square meter were used, respectively. Soon after this operation, weeds were controlled by applying 1.08 kg ha^{-1} of glyphosate; 0.5% of mineral oil was added to the spraying mixture. From that moment on, no herbicides were used in the experiment.

Soybean was harvested on 03/03/2012, and forage plants were evaluated through successive cuts until the end of the dry season, from May to September 2012; three samplings were performed. Rainfalls were not significant in the period from July to September, and there were no frosts (Figure 1).

Forage plants sprouted in the period from 09/12 to 17/10/2012, when 0.72 and 1.44 kg ha^{-1} doses of glyphosate were applied, with a spraying mixture flow rate of 140 L ha^{-1}, to which 0.5% of mineral oil was added. The doses were applied in strips along the blocks, in half of the plot, at 3 x 6 m for each dose. The used commercial glyphosate formulation contained 480 g L^{-1} of N-(phosphonomethyl) glycine isopropylamide salt, corresponding to 360 h L^{-1} of

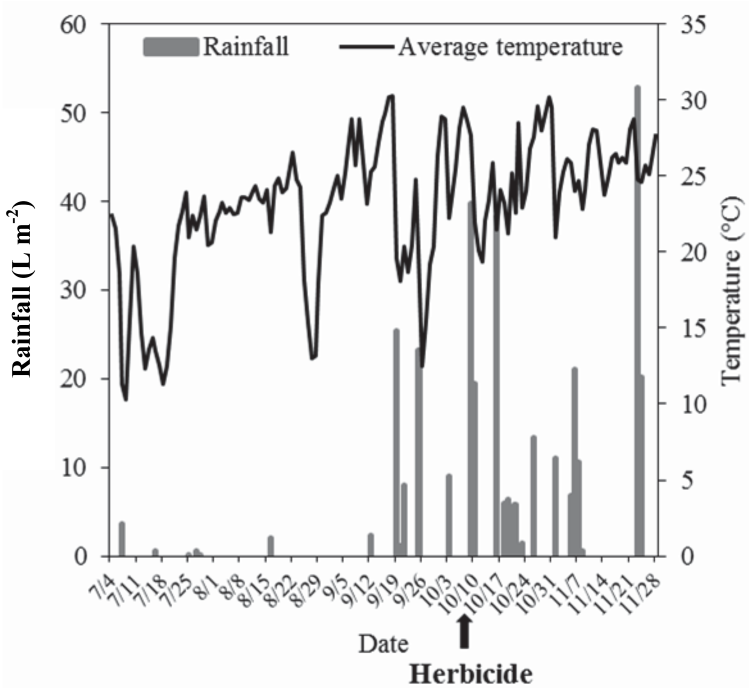

Figure 1 - Rainfall and average daily temperature results in the period from 07/04 to 11/28/2012.

N-(phosphonomethyl) glycine isopropylamide salt. The application of the herbicide was carried out on 10/17/2012, between 8 and 9 AM; at that moment, the average air temperature was 22.1 °C, the relative air humidity was 85%, and the wind speed was 1.44 m s^{-1}.

The evaluation about the control percentage of forage plants was performed with visual estimates, 7 (10/24/2012), 14 (10/31/2012), 21 (11/7/2012) and 28 (11/14/2012) days after the application (DAA) of the herbicide. This estimate consisted in assigning grades from zero (all living tillers) to 100 (all dead tiller) by a trained evaluator. A control rate equal to or higher than 80% was considered efficient (Carvalho et al., 2002). As a reference, there was a plot where the herbicide was not applied. Twenty-eight days after the application of the herbicide, biomass samples were collected to estimate availability and dry matter content. Samples were collected from an area of 1.2 m^2 per plot (0.6 x 2 m), and plants were cut close to the ground, using a sickle. In the laboratory, samples were weighed and placed in a forced air oven at 60 °C until reaching constant weight and were weighed again.

Results were submitted to analysis of variance and to a better fitting polynomial regression model, with the help of the SigmaPlot 11.0 software. The variables total dry matter, dry matter content and control percentage at 28 days were submitted to T test.

RESULTS AND DISCUSSION

The 0.72 kg a.e. ha^{-1} dose of glyphosate was not effective in controlling *U. ruziziensis* (Figure 2; Table 1). Control was satisfactory (≥80%) only at the 1.44 kg a.e. ha^{-1} dose, reached at 14 DAA. For *U. ruziziensis*, Costa et al. (2013) had control efficiency above 80% at 14 days after the application (DAA) of 0.72 and 1.44 kg a.e. ha^{-1} of glyphosate, confirming the results found in this study only for higher doses. It is also in agreement with the results obtained by Nepomuceno et al. (2012), who had satisfactory control of this species between 10 and 20 days after the application of glyphosate.

The applied doses were not efficient in controlling *U. decumbens*, although there was a reasonable sensitivity of this forage plant to glyphosate (Figure 2). For this species, Jakelaitis et al. (2005) obtained satisfactory control 21 days after the application of 0.72 kg a.e. ha^{-1} of glyphosate or sulfosate. According to Nunes et al. (2009), for this forage species, herbicide application should be performed 7 to 14 days before sowing soybean plants. The results found by these authors differ from those in this study, since this species was not satisfactorily controlled.

BRS Tamani, Xaraés and BRS Piatã grasses showed similar behavior (Figures 2 and 3). The applied doses were not enough to control these forage plants, even 28 days after the application of the highest herbicide dose; at the lowest dose, these forage plants resumed their growth at 21 DAA.

Machado et al. (2011) reported higher control efficiencies than in the present study for Xaraés grass, from 76 to 96%, at 21 DAA of 1.08 kg a.e. ha^{-1} of glyphosate. According to these authors, the highest efficiency was obtained where more rainfalls occurred; where water deficit occurred after herbicide application, the control percentage was 38%. Therefore, divergent results from those found in this study may be related to environmental conditions.

The results obtained in this study are in agreement with Machado and Valle (2011), who evaluated Xaraés, BRS Piatã and BRS Paiaguás (B6) grass for three years, and found control percentages from 24 to 76, from 49 to 88 and from 71 to 96, respectively, when 1.08 kg a.e. ha^{-1} of glyphosate were applied.

For BRS Tamani grass, the results obtained in this study differ from those found by Machado et al. (2012), who found 92 and 100% control, respectively, 29 days after the application of 0.72 and 1.44 kg a.e. ha^{-1} of glyphosate. Even if both results were obtained in the same region and with a similar methodology, the environmental conditions were probably different. In this study, there were practically no rainfalls in the August and September (Figure 1); later, plants had a month to recover from water stress and cut; this condition may not have been enough.

Cultivars BRS Paiaguás and Aruana showed great sensitivity to glyphosate, especially at the highest dose, when 80% control was reached at 18 DAA (Figures 2 and 3). The lowest herbicide dose caused considerable damages to BRS Paiaguás grass, but was not enough to control it.

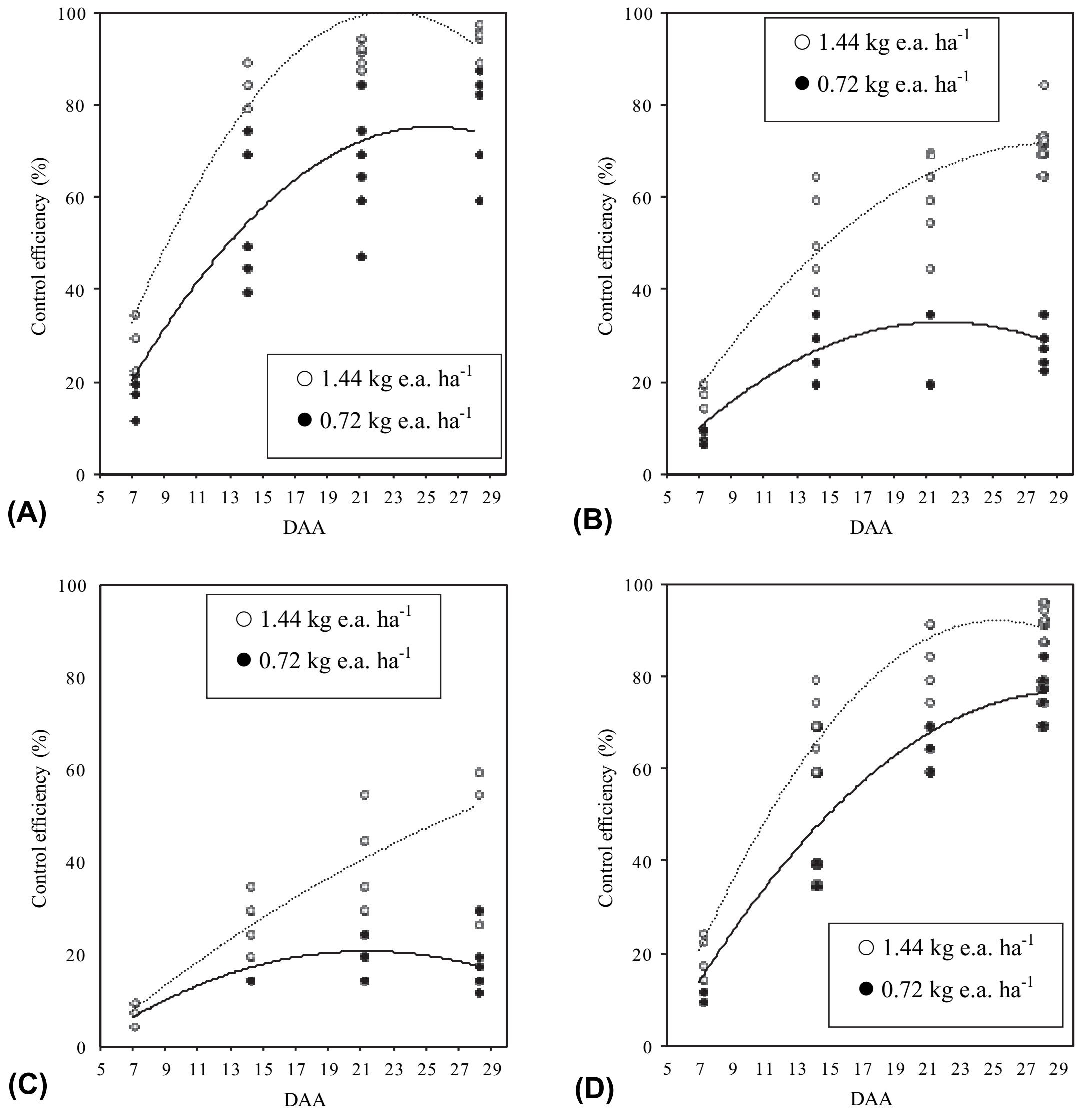

Figure 2 - Control percentage of *Urochloa ruziziensis* (A), *U. decumbens* (B), *U. brizantha* cvs. Xaraés (C) and BRS Paiaguás (D) plants in response to two glyphosate doses, 7, 14, 21 and 28 days after application (DAA), in 2012.

Table 1 - Regression equations and R^2 of the control percentage of forage plants submitted to two glyphosate doses, 7, 14, 21 and 28 days after application, in 2012

Forage plant	Dose	Equation	R^2
U. ruziziensis	0.72	$y=-29.3333+8.2262x-0.1616x^2$	0.785
	1.44	$y=-39.9583+12.2988x-0.2696x^2$	0.944
U. decumbens	0.72	$y=-16.6071+4.5133x-0.1028x^2$	0.703
	1.44	$y = -0.1108x^2 + 6.4082x - 20.786$	0.890
U. brizantha cv. Xaraés	0.72	$y=-11.1667+2.9786x-0.0697x^2$	0.620
	1.44	$y=-8.8333+2.3881x$	0.796
U. brizantha cv. BRS Piatã	0.72	$y=-11.1667+2.9786x-0.0697x^2$	0.62
	1.44	$y=-13.1250+3.2036x-0.0315x^2$	0.796
U. brizantha cv. BRS Paiaguás	0.72	$y=-31.0714+7.2694x-0.1224x^2$	0.885
	1.44	$y=-44.6071+10.8112x-0.2136x^2$	0.942
M. maximus cv. Aruana	0.72	$y=-15.1250+4.4964x-0.0740x^2$	0.641
	1.44	$y=-42.0000+11.0452x-0.233x^2$	0.874
M. maximus cv. BRS Tamani	0.72	$y=-8.5417+2.5774x-0.0638x^2$	0.604
	1.44	$y=-0.5417+0.8488x+0.0383x^2$	0.818

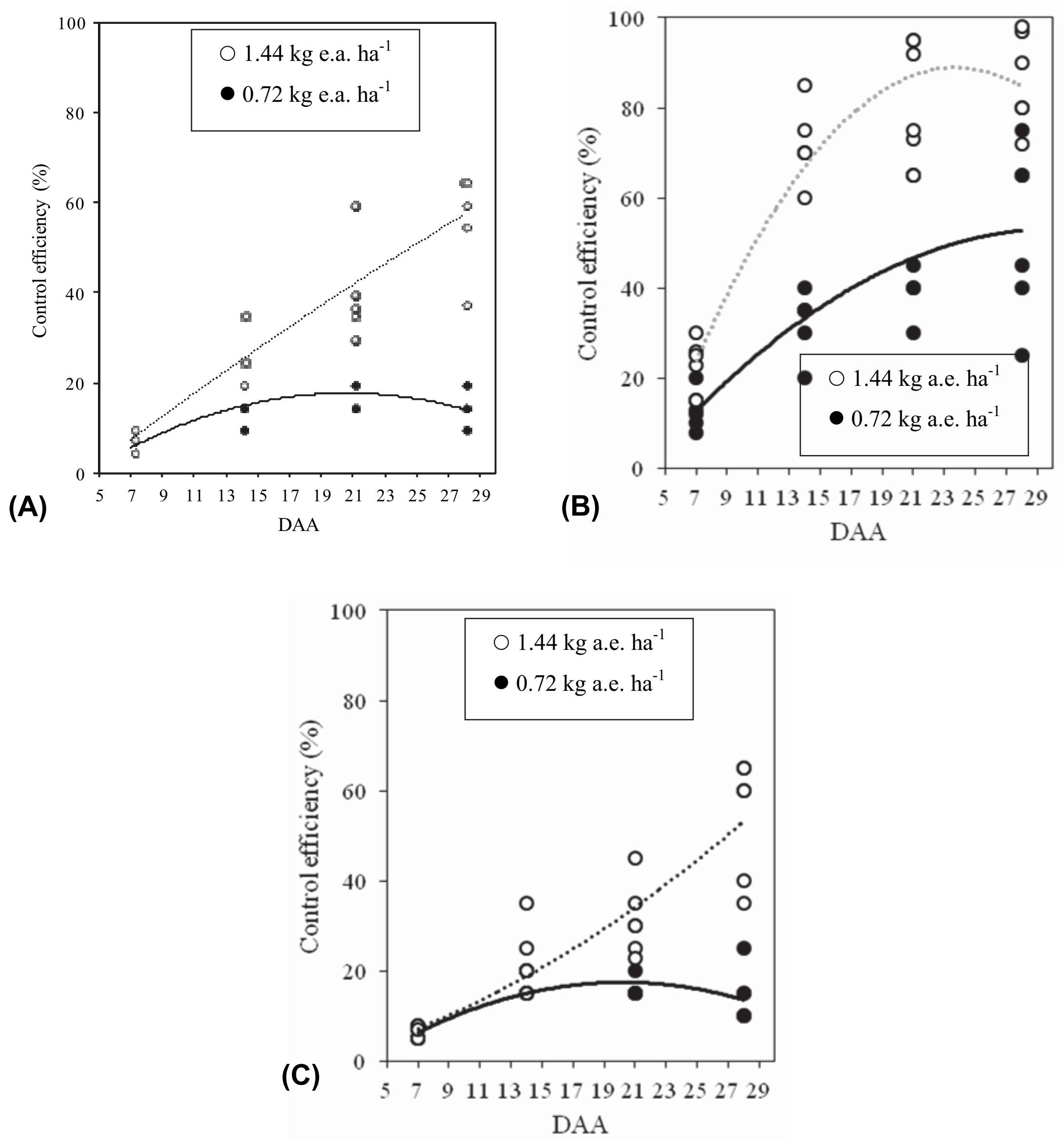

Figure 3 - Control percentage of *U. brizantha* cv. Piatã (A), *M. maximus* cvs. Aruana (B) and BRS Tamani (C) plants in response to two glyphosate doses, 7, 14, 21 and 28 days after application (DAA), in 2012.

As for Aruana grass, Correia and Perussi (2015) obtained satisfactory control 16 days after the application of 1.44 kg a.e. ha^{-1} or sequential with 1.08 kg a.e. ha^{-1}, confirming the results found in this study.

After 28 DAA of glyphosate application, forage plants presented between 1,209 and 2,692 kg ha^{-1} of dry biomass in the shoot (Table 2). This mass corresponded to the forage residue below the cutting height (20 cm), to the regrowth occurred between 09/12 and 10/17/2012 and, in forage plants showing low control efficiency, to the growth occurred after the application of the herbicide.

The highest herbicide dose resulted in higher dry matter percentages for the forage species *U. ruziziensis* and BRS Paiaguás (Table 2), at both doses, due to the loss of water from plants in response to herbicide application. For the 1.44 kg a.e. ha^{-1} dose, the forage species *U. ruziziensis*, BRS Paiaguás and Aruana had a higher control percentage. The most tolerant forage species towards glyphosate were BRS Piatã, BRS Tamani and Xaraés. Even after 28 days from the application of 1.44 kg a.e. ha^{-1} of this herbicide, no satisfactory control percentage was reached for the successive sowing of a crop. *U. decumbens* showed intermediate susceptibility to glyphosate.

A different trend from the one found in this study was verified by Ferreira et al. (2010) 13 days after the application of 1.44 kg a.e. ha^{-1} of glyphosate. These authors obtained 81% control

Table 2 - Shoot biomass, dry matter content and control percentage of seven forage plants, 28 days after the application of 0.72 and 1.44 kg a.e. ha^{-1} of glyphosate, evaluated on 11/14/2012

Forage plant	Shoot biomass		Dry matter percentage		Control percentage	
	0.72	1.44	0.72	1.44	0.72	1.44
	(kg ha^{-1})			(%)		
U. ruziziensis	1,277 d	1,209 d	61.1 a B	83.5 a A	76.0 a B	95.5 a A
U. decumbens	1,760 cd	1,691 bcd	42.9 bc B	64.5 b A	28.5 c B	73.2 b A
U. brizantha cv. Xaraés	2,687 a	2,230 ab	37.9 c B	56.3 bc A	14.2 d B	58.0 c A
U. brizantha cv. BRS Piatã	2,530 ab	2,692 a	41.8 bc B	52.3 c A	18.3 cd B	52.8 c A
U. brizantha cv. BRS Paiaguás	2,031 abc	1,978 bc	68.1 a B	76.0 a A	77.5 a B	93.7 a A
M. maximus cv. Aruana	1,962 bc	1,534 cd	49.0 b A	65.4 b A	52.5 b B	86.2 a A
M. maximus cv. BRS Tamani	2,542 ab	2,297 ab	33.7 bc A	48.4 c A	14.2 d B	54.2 c A

Means followed by the same lowercase letter in the column or by the same capital letter in the line, within the same variable, do not differ significantly ($p \leq 0.05$) by T test.

efficiency for Piatã grass and 51% for *U. decumbens*. Probably, the result difference is related to the used methodology. While the mentioned authors desiccated forage plants that were in free growth during the dry season, with accumulated dry biomass in the shoot exceeding 10 Mg ha^{-1}, in this study there were less than 3 Mg ha^{-1}, since plants were evaluated under successive cuts. This amount of straw referred to the plant base left after the samplings (up to 20 cm above the ground) and the regrowth occurred at the beginning of the rainy season, from 09/12 to 09/17/2012.

For *U. brizantha*, *U. decumbens* and *U. ruziziensis*, Brighenti et al. (2011) obtained higher control efficiency than the one in this study, when they cultivated these forage plants in a greenhouse; on the other hand, in the field experiment, results were lower. The environment in a greenhouse is very different from that of the countryside, mainly due to the lack of water stress. In the field experiment, the authors cultivated forage plants during the summer and evaluated their control in the fall, unlike the present study, in which plants were submitted to water stress and were controlled at the beginning of the rainy season, reproducing the reality of ICLS's.

The susceptibility reaction to glyphosate may be more pronounced in some forage plants depending on the environmental conditions. Massai grass was susceptible to glyphosate herbicide in a favorable rainfall condition (Machado and Assis, 2010; Machado et al., 2012; Ceccon and Concenço, 2014), but it was tolerant to it in a water deficit condition, after the application of the herbicide; this was observed with 10 other genotypes (Machado et al., 2009).

According to Silva et al. (2013), plants with lower desiccation intervals make it possible to anticipate crop sowing, in succession to fodder crops. Instead of anticipating sowing, it is also possible, in integrated farming systems, to delay the removal of the animals for pasture desiccation, which is desired, since at the end of the dry season there is low forage availability.

The use of forage plants as cover crops is very important in production systems, because it provides control and increases weed biodiversity, avoiding their specialization and the emergence of glyphosate-resistant plants (Timossi et al., 2007; Christoffoleti et al., 2008).

Further studies are necessary to reduce the time interval between herbicide application and sowing of subsequent crops, thus improving control efficiency, either with the use of herbicides and adjuvants or by identifying the most susceptible forage plants. The use of herbicide-susceptible forage species may result in reduced feedstock use, providing environmental and economic gains.

It is possible to conclude that the susceptibility of forage plants to the herbicide glyphosate varies between species and cultivars. *U. ruziziensis*, BRS Paiaguás and Aruana grasses are desiccated with reduced herbicide doses, they have a short desiccation interval and can contribute to the diversification of the fodder plants used in integrated crop-livestock farming systems, with a lower impact on the environment.

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