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Article

EFFECT OF GLYPHOSATE ON GUINEAGRASS SUBMITTED TO DIFFERENT SOIL WATER POTENTIAL

Efeito do Glyphosate em Capim-Colonião Submetido a Diferentes Potenciais Hídricos do Solo

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ABSTRACT - The action of herbicides on weeds that develop under water deficit can be compromised, because the routes of penetration of hydrophilic herbicides are reduced due to the lower hydration of the cuticle in these plants. Moreover, hydrophobic compounds found in the epicuticular wax coating of plants under water stress, hinder the penetration of hydrophilic compounds. This study evaluated the control efficiency of glyphosate on guineagrass plants when submitted to different water deficits. The study was conducted in a greenhouse, and treatments were composed of guineagrass plants submitted to three soil water conditions [low water deficit (13%), intermediate water deficit (10%) and high water restriction (8%)], three doses of glyphosate (0.0, 270.0 and 540.0 g ha^{-1}) and two phenological stages of plant development (4-6 leaves and 1-3 tillers). The water management started when plants presented two developed leaves. Visual evaluations were performed 7, 14, 21 and 35 days after the application of the herbicide; the morpho-physiological parameters of the specific leaf area, stomatal conductance and the difference between the environment temperature and the leaf temperature on the day of the herbicide application were also analyzed at the end of the study, as well as the dry matter of shoot and root. With the increase of the water restriction, there was a decrease in the analyzed morpho-physiological parameters, as well as in the dry matter accumulation of the shoot and roots of the studied plants. Plant control was more efficient when a 540 g ha^{-1} dose of glyphosate was applied, and when they were controlled at their vegetative stage of 1-3 tiller, and with a water management of 13%. It is possible to state that guineagrass under water restriction have less control efficacy when treated with glyphosate.

Keywords: herbicide, water deficit, weed, *Panicum maximum*.

RESUMO - A ação de herbicidas sobre plantas daninhas que se desenvolvem sob déficit hídrico pode ser comprometida, pois as rotas de penetração de herbicidas hidrofílicos são reduzidas em razão da menor hidratação da cutícula nessas plantas. Além disso, compostos hidrofóbicos presentes na camada de cera epicuticular em plantas estressadas hidricamente dificultam sobremaneira a penetração de compostos hidrofílicos. Avaliou-se neste estudo a eficiência de controle do herbicida glyphosate em plantas de capim-colonião quando submetidas a distintos déficits hídricos. O estudo foi conduzido em casa de vegetação, sendo os tratamentos compostos por plantas de capim-colonião submetidas a três condições hídricas do solo [baixo déficit hídrico (13%), déficit hídrico intermediário (10%) e alta restrição hídrica (8%)], três doses do herbicida glyphosate (0,0, 270,0 e 540,0 g e.a. ha^{-1}) e dois estádios fenológicos de desenvolvimento da planta (4-6 folhas e 1-3 perfilhos). O manejo hídrico teve

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início quando as plantas apresentaram duas folhas desenvolvidas. Foram realizadas avaliações visuais de controle aos 7, 14, 21 e 35 dias após a aplicação do herbicida; analisaram-se ainda os parâmetros morfofisiológicos área foliar específica, condutância estomática e a diferença de temperatura do ambiente com a temperatura foliar no dia da aplicação do herbicida, bem como a matéria seca da parte aérea e da raiz ao final do estudo. Com o aumento da restrição hídrica, houve decréscimo nos parâmetros morfofisiológicos analisados, bem como no acúmulo de matéria seca da parte aérea e das raízes das plantas estudadas. O controle das plantas foi mais eficiente quando ocorreu a aplicação da dose de 540 g ha^{-1} de glyphosate, quando elas foram controladas no estádio vegetativo de 1-3 perfilhos, e no manejo hídrico de 13%. Pode-se afirmar que plantas de capim-colonião sob restrição hídrica têm menor eficácia de controle quando tratadas com glyphosate.

Palavras-chave: herbicida, déficit hídrico, planta daninha, *Panicum maximum*.

INTRODUCTION

Weeds may negatively affect agricultural production, due to the direct interference they cause when in competition for nutrients, water, light, space, and also due to the allelopathic compounds they release (Gomes Jr and Christoffoleti, 2008).

Thus, as for any plant species, whether cultivated or not, weeds are exposed to different environment conditions. Some factors, such as air temperature, can cause damages to plants within minutes, and others, such as the amount of water found in the soil, can take up to days to appear. On the other hand, mineral deficiencies may last months before plants reflect their need for mineral replacement (Wang et al., 2003; Hu and Schmidhalter, 2005).

When submitted to water deficit, plants develop morphological and/or physiological mechanisms to reduce water loss by transpiration, through stomatal closure, leaf area reduction or trichome increase. Other mechanisms are the senescence of older leaves and also the increase of epicuticular wax accumulation, which maintains the hydration of the tissues that are still alive, without reducing the photosynthetic rate (Muller et al., 2011; Zhou et al., 2015; Gonçalves et al., 2017).

The development of plants under environmental stresses, especially high temperatures and water restriction, may affect the absorption of herbicides. This is due to a thickening of the cuticle, which contributes to the evaporation of spray droplets and the volatilization of the applied products. Pereira et al. (2010, 2012) found reductions of approximately 17% and 20% of herbicide efficacy in the control of *Brachiaria decumbens* and *B. plantaginea*, respectively, when plants developed in a soil with water potential of -1.5 MPa.

In another work, the application of glyphosate in the control of *Ligustrum sinense* plants, which developed under low soil moisture, had its efficacy reduced. This may be related to the physiological and morphological behavior of plants due to water restriction (Harrington and Miller, 2005).

Guineagrass (*Panicum maximum* Jacq.) is an aggressive weed that can interfere with the development and productivity of crops where it occurs, such as maize, citrus fruit, coffee and sugarcane. It presents high adaptation to the most varied edaphoclimatic conditions, creates clumps and has a strong and vigorous root system, propagating in a vegetative form and through seed (Kissmann and Groth, 1997). It occurs in agricultural areas due to the expansion of crops to degraded pastures because the species is very aggressive and difficult to control. In the chemical management of guineagrass plants, glyphosate is one of the herbicide options for an effective control of this plant.

Glyphosate is applied during post-emergence and its absorption is basically through the leaves. Its translocation occurs through the symplast all the way to its site of action, where the inhibition of the enzyme 5-enolpyruvyl-chiquimate-3-phosphate synthase (EPSPs) occurs. Thus, the synthesis of three essential amino acids (tryptophan, phenylalanine and tyrosine) is inhibited (Dill, 2005). This herbicide is one of the most indicated in controlling guineagrass, but its effectiveness can be compromised depending on the development stage or condition under which the plant developed (Durigan, 1992).

The development of weed species that are considered aggressive in environments with the influence of abiotic factors, such as water restriction, can modify their morphology and physiology, as well as affect the effectiveness of herbicides used to control them, due to their adaptation to the environment (Pereira et al., 2010; Ali et al., 2017).

Considering the reported issues, this work aimed at studying the control through glyphosate of *P. maximum* plants submitted to different levels of soil moisture.

MATERIAL AND METHODS

The study was installed and conducted under greenhouse conditions from April to May 2015, with an average temperature of 26 ± 5 °C and relative humidity (RH%) of 82 ± 10%.

The experimental design was completely randomized, with treatments arranged in a 3x3x2 triple factorial arrangement, with three soil water conditions [low water deficit (13%), intermediate water deficit (10%) and high water restriction (8%)], three doses of glyphosate (0.0, 270.0 and 540.0 g a.e. ha^{-1}) and two vegetative stages for control purposes (4-6 leaves and 1-3 tillers), with four replications; each pot constituted an experimental unit. The highest dose of glyphosate used in this study is recommended by the manufacturer of the product to control this species, and the used commercial product was Roundup Original (360 g a.e. L^{-1}). The application of the various herbicide doses occurred when the plants reached the development stages of 4-6 leaves and 1-3 tillers.

For each experimental unit, polyethylene pots with a volume capacity of 2.5 L were used, and they were filled with soil classified as Red-Yellow Latosol (Embrapa, 2013) with 18.9% clay, 3.6% silt and 77.5% sand. Soil fertilization was carried out based on the chemical analysis (Table 1).

In order to obtain the soil water retention curve, the Richards pressure plate (Klar, 1984) was used, where four minimum potential soil water values (Ψs) were established: -0.01, -0.03, -0.07 and -1.5 MPa (14%, 13%, 10% and 8%, respectively); the value that represents the maximum capacity of water retention in this soil corresponds to 14%. The other potentials (13%, 10% and 8%) are the water management used as treatments. The relation between water potentials and percentage of soil moisture is described in Table 2.

Through a daily weighing of each pot, when observing that the weight reached the defined water potential for each treatment (13%, 10% or 8%), the replacement of evapotranspired water was carried out, until reaching the soil maximum water potential (14%).

The used species was guineagrass (*P. maximum*), at the density of 10 seeds per pot. After the emergence, before the full development of the first leaf, thinning was performed, leaving only one plant per pot. The soil was maintained at field capacity until the development stage of two

Table 1 **-** Chemical analysis of the soil used in the experiment

pH	M.O.	P_{resin}	H+Al	K	Ca	Mg	SB	CEC	V
($CaCl_2$)	(g dm^{-3})	(mg dm^{-3})	(mmol$_c$ dm^{-3})						(%)
4.9	10.0	4.0	22	0.3	2	3	5.3	27	29

Table 2 **-** Relation between water potentials (MPa) and contents (%) of the soil used in the study

Retained water (dm^3 dm^{-3})						
Tension (MPa)						
Saturated	-0.01	-0.03	-0.05	-0.07	-0.5	-1.5
39%	14%	13%	11%	10%	9%	8%

fully expanded leaves. Subsequently, the water management of each treatment was started, continuing until the end of the study. The application of the different herbicide doses occurred when plants reached the predefined development stage (4-6 leaves and 1-3 tillers).

To apply the herbicide, a CO_2 pressurized backpack sprayer was used, maintained at a constant pressure of 200 kPa, equipped with a bar with Teejet XR 11002VS nozzles, spaced 0.5 m apart, at a height of 0.5 m from the target and with a consumption of 200 L ha^{-1}. The environmental conditions during the application of the experiments with plants at the 4-6 leaf and 1-3 tillers stage were: relative humidity of 73 and 80%, temperature of 23 and 25.6 ^{o}C and wind speed of 3 and 5 km h^{-1}, respectively.

In order to verify the morpho-anatomical changes, the leaf area of the plants from each water management was measured before applying each experiment, with the help of a LI-COR® Area Meter (LI-COR®). Afterwards, the leaves were taken to a forced air circulation oven at 65 ^{o}C until reaching constant weight. With the leaf area values and their respective dry matter, it was possible to determine the specific leaf area (*SLA*), through the formula:

$$SLA = \frac{La}{ldm}$$

where: *La* = leaf area of each experimental unit; and *ldm* = leaf dry matter of this unit.

Also, before the application, the evaluation of physiological characteristics such as stomatal conductance (*Sc*) and leaf temperature were carried out with the help of a Leaf Porometer Model SC-1 (Decagon Devices).

Guineagrass plant control was visually evaluated 7, 14, 21 and 35 days after application (DAA), through a percentage scale of grades, in which 0% represents the total absence of injuries and 100% represents the death of the plant (SBCPD, 1995). At the end of each experiment (35 DAA), the shoot and root system of plants were collected, washed and later maintained in a forced air circulation oven at 65 ^{o}C, until reaching constant weight, to determine the dry matter (g).

Results about the control and dry matter of guineagrass plants were submitted to analysis of variance by F test, and the means were compared by the Student's t test (p>0.05). The physiological parameters, such as specific leaf area, relation between room temperature and leaf temperature and stomatal conductance, were analyzed through the confidence interval at a confidence coefficient of 95% for the means (μ); to do so, the following formula was used:

$$lC(\mu)_{95\%} = \hat{\mu} \pm t\frac{s}{\sqrt{n}}$$

where: t = fixed t value; s = standard deviation; and n = number of samples.

All statistical analyses were carried out with the help of the statistical software AgroEstat (Barbosa and Maldonado Jr, 2015).

RESULTS AND DISCUSSION

The specific leaf area (*SLA*) of guineagrass plants increased significantly with the increase of water availability for their development, both at the development stage of 4-6 leaves and at the stage of 1-3 tillers (Figure 1). Plants submitted to greater water availability (13%) presented significant differences from the other water conditions at both studied development stages. By the analysis of the confidence interval, there was no significant difference under conditions of higher water restriction (10% and 8%); this shows a negative correlation between the species and the water deficit. In other words, under both water conditions, plants had a smaller leaf area, but with an increase in the leaf dry matter per area unit (Figure 1). This may have occurred due to the increase in leaf thickness under these development conditions, as observed in this study, in addition to the increase of the amounts of components found in the cell wall, such as lignin (Poorter et al., 2009; Pacheco et al., 2011).

SLA is highly related to several physiological and chemical parameters, that is, when high levels of *SLA* are found, leaves may have a high concentration of cytoplasmic components, such as proteins, minerals and organic acids. Moreover, high concentrations of foliar nitrogen and

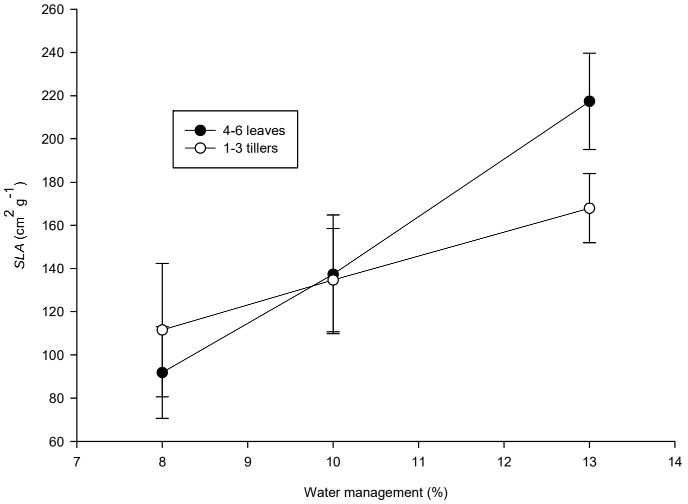

Figure 1 - Specific Leaf Area (*SLA*) of *Panicum maximum* at the stages of 4-6 leaves and 1-3 tillers at day 0 after application, submitted to different soil water managements.

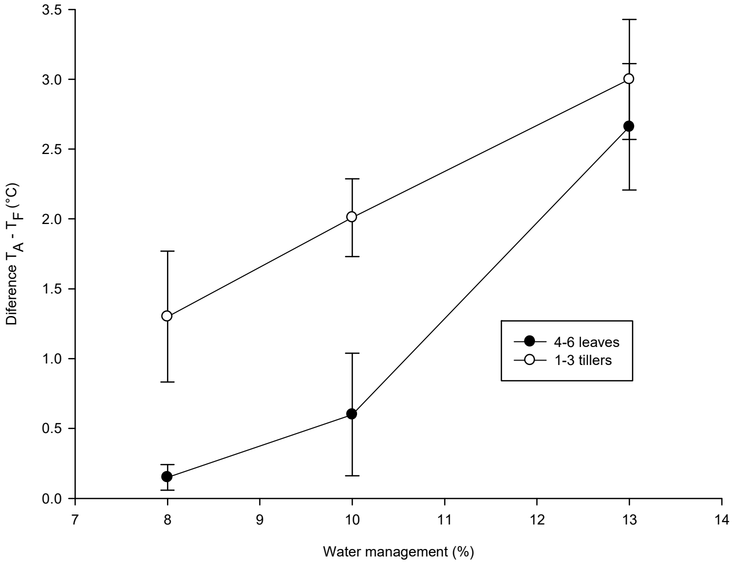

Figure 2 - Difference between room (T_A) and leaf (T_F) temperature of *Panicum maximum* at the development stages of 4-6 leaves and 1-3 tillers, at 0 days after application, submitted to different soil water management.

high photosynthetic activity may occur due to the high concentration of Rubisco enzyme (Reich et al., 2003; Poorter et al., 2009), which influenced the accumulation of dry matter in plants (Figure 1).

The relation between leaf temperature and room temperature can be used as an indicator of the water status of plants. In this case, when the plant is in an environment with water availability, leaves are cooled through transpiration, which functions as a protection mechanism at high temperatures (Krasensky and Jonak, 2012). However, in environments where water is limited to plant development, there is decreased transpiration, which leads to increased leaf temperature (Wang and Gartung, 2010).

In this study, there was an increase in the temperature difference between the environment and the leaf, with the increase of water availability at both development stages of guineagrass (Figure 2). At the development stage of 4-6 leaves, the temperature difference in the 8% and 10% water availabilities was similar, but different from the 13% condition. However, at the development stage of 1-3 tillers, this temperature difference was not affected by the water condition to which plants were submitted. Plants at the initial development stage presented greater difference among the adopted water management, compared to the difference observed at the most advanced stage, the 1-3 tiller one (Figure 2).

The high temperatures observed on guineagrass leaves at the different stages are related to the lower transpiration and photosynthetic rate of the initial development, mainly under the greatest water restriction in the soil - this was proven by the stomatal conductance (*Sc*) observed in this study (Figure 3).

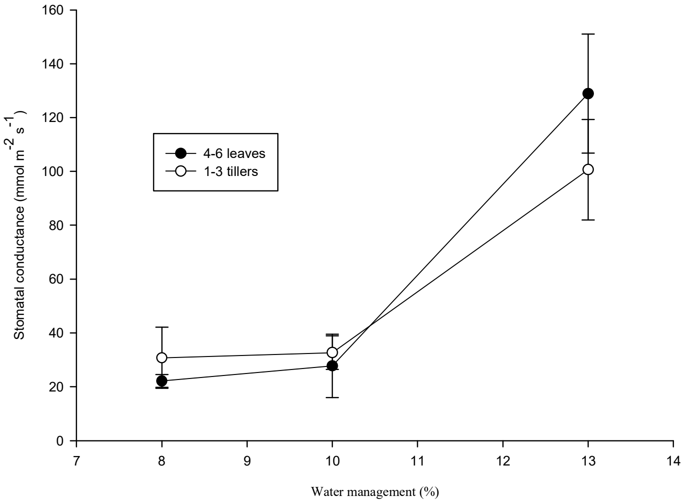

Figure 3 - Stomatal conductance (*Sc*) of *Panicum maximum* at the development stages of 4-6 leaves and 1-3 tillers at 0 day after application, submitted to different soil water managements.

The *Sc* in guinegrass plants at both development stages, submitted to the 8% and 10% water managements, was similar, according to the confidence interval analysis of data at each stage. However, significant decreases were observed, approximately 79% and 83% of the 10% and 8% managements, respectively, in relation to the 13% management, at the 4-6 leaf development stage. There were also significant reductions of 68% and 70% in the 10% and 8% managements, respectively, in relation to the 13% management, at the development stage of 1-3 tiller (Figure 3).

Stomatal conductance is directly related to transpiration and photosynthetic rate, because in this study, the *Sc* presented a significant increase with the availability of water, that is, the increase of the stomatal conductance implies the opening of stomata to capture atmospheric CO_2, which causes water losses. This was observed when there was water availability to the plant, and defines an intrinsic relation between stomatal opening and water issue (Melkonian et al., 2004). When there is no water availability for the plant, there is a reduction in the *Sc*, significantly reducing the photosynthetic activity due to the lower uptake of CO_2 by the assimilatory organs (Damour et al., 2010).

The *Sc* of the most developed guinegrass plants presented lower values under optimal development conditions (13% water management), in relation to the same management at the 4-6 leaf stage. This proves that there is a decrease in stomatal opening for gas exchange, as a mechanism to reduce water loss through transpiration (Kadioglu et al., 2012). Water deficit stimulates the distribution and accumulation of abscisic acid (ABA) in the different tissues of plants, and this accumulation in the apoplast of guard cells reduces the stomatal conductance of the plant (Ali et al., 2017).

Based on the analysis of variance, the isolated factors analyzed in the control of guinegrass were significant at all times, at the different vegetative stages, except for 14 days after application (DAA), where there was no control difference for the species. In the double-factor analysis, control in the interaction between stage and glyphosate doses was significant only at 7, 21 and 35 DAA. In the interaction between vegetative stage and water management, it was significant only at 14 DAA, and in the interaction between water management and the different doses of glyphosate, during all evaluated periods, there was a significant difference in the control of guinegrass. There was no significance in the triple factor analysis during any evaluation period.

In the interaction between development stage and doses of glyphosate at 7 DAA, it was observed that, when glyphosate was applied during the initial development of guineagrass plants

(4-6 leaves), doses of 540 and 270 g ha^{-1} provided the same control in the evaluated period. However, when the application occurred at a later development stage (1-3 tiller), a higher dose provided better control over this species. In the interaction between water management and glyphosate dose at 7 DAA, in plants that developed with low water restriction, glyphosate doses of 540 and 270 g ha^{-1} provided similar control. However, when the plant was submitted to some water deficit (10% or 8%), only the highest dose of glyphosate provided the best control (Table 3).

Table 3 **-** Mean values of the control percentage of *Panicum maximum* plants, 7 days after the application of different doses of glyphosate, depending on the development stage at the time of application and on the water management to which plants were submitted. Jaboticabal - São Paulo, 2015

Stage	Dose			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F$_{Dose}$
4 - 6 leaves	0.0 aB	17.75 bA	19.75 bA	9.22 **
1 - 3 tillers	0.0 aC	37.25 aB	56.08 aA	63.57 **
F$_{Stage}$	-	14.84 **	51.51 **	
Water management	**Dose**			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F$_{Dose}$
13%	0.0 aB	45.50 aA	39.62 aA	31.86 **
10%	0.0 aC	15.37 bB	37.25 aA	18.23 **
8%	0.0 aC	21.62 bB	36.87 aA	17.86 **
F$_{Management}$	-	13.15 **	0.12 ^{ns}	

Means followed by the same letter, lowercase in the column and uppercase on the line, do not differ from one another by the t test ($p>0.05$). (LSD$_{ExD}$ = 10.1) (LSD$_{MxD}$ = 12.4). * significant at 5% probability; ** significant at 1% probability; ^{ns} non-significant.

At 14 DAA, in the interaction between water management and different glyphosate doses, control decreased with the application of 270 g ha^{-1} on plants submitted to moderate and high water restrictions. On the other hand, in the interaction between water management and herbicide application at the various vegetative stages, control was lower when the herbicide was applied at the development stage of 4-6 leaves submitted to a more severe water restriction. However, within the water management factor, control was lower when plants developed under a moderate hydric condition at the vegetative stage of 1-3 tillers (Table 4). Generally speaking, when plants are submitted to periods of water deficit, they tend to decrease their translocation, and this may decrease herbicide efficacy (Skelton et al., 2016), as observed at the early stages of development.

At 21 DAA, it was observed that a higher dose of glyphosate, regardless of the vegetative stage, provided the best control of guineagrass plants. At the herbicide dose of 270 g ha^{-1}, control was affected by the vegetative stage, and it was lower when the spraying occurred at the 4-6 leaf stage (Table 5). In the same period, when analyzing control within the dose of 540 g ha^{-1}, regardless of the water management to which the plant was submitted, the control of guineagrass was excellent (>99%). At the 270 g ha^{-1} dose, under low and high water deficit conditions, it was possible to observe the best control of guineagrass (Table 5). This is probably due to the fact that the herbicide stimulates a rapid senescence of the oldest leaves in the management with high water restriction, since plants, when submitted to severe water deficits, have defense mechanisms, such as the senescence of the oldest leaves. However, the management with good water availability for plants allows a better translocation of the herbicide (Wingler and Roitsch, 2008).

At 35 DAA, guinegrass control through a 270 g ha^{-1} dose of glyphosate was lower when the application was carried out at the vegetative stage of 4-6 leaves. As for the different water managements, the highest dose provided excellent control, regardless of the water management under which the plant developed. However, when plants developed under moderate water restrictions and with the application of a reduced glyphosate dose (270 g ha^{-1}), control was lower (Table 6).

Table 4 **-** Mean values of the control percentage of *Panicum maximum* plants, 14 days after the application of different doses of glyphosate, depending on the development stage at the time of the application and on the water management to which plants were submitted. Jaboticabal - São Paulo. 2015

Dose	Water Management			
	13%	10%	8%	$F_{Management}$
0 g ha^{-1}	0.0 bA	0.0 cA	0.0 cA	-
270 g ha^{-1}	76.87 aA	32.75 bB	43.8 bB	17.76 **
540 g ha^{-1}	77.75 aA	78.37 aA	73.5 aA	0.24 ^{ns}
F_{Dose}	67.07 **	52.16 **	46.01 **	
Stage	**Water Management**			
	13%	10%	8%	$F_{Management}$
4 - 6 leaves	52.66 aA	45.83 aAB	35.41 aB	3.81 *
1 - 3 tillers	50.41 aA	28.25 bB	42.75 aA	6.4 **
F_{Stage}	0.13 ^{ns}	7.81 **	1.36 ^{ns}	

Means followed by the same letter, lowercase in the column and uppercase on the line, do not differ from one another by the t test ($p>0.05$). (LSD_{ExM} = 12.6) (LSD_{MxD} = 15.4). * significant at 5% probability; ** significant at 1% probability; ^{ns} non-significant.

Table 5 **-** Mean values of the control percentage of *Panicum maximum* plants, 21 days after the application of different doses of glyphosate, depending on the development stage at the time of the application and on the water management to which plants were submitted. Jaboticabal - São Paulo. 2015

Stage	Dose			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F_{Dose}
4 - 6 leaves	0.0 aC	70.83 bB	100.0 aA	441.32 **
1 - 3 tillers	0.0 aC	85.83 aB	98.91 aA	481.78 **
F_{Stage}	-	18.77 **	0.10 ^{ns}	
Water Management	**Dose**			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F_{Dose}
13%	0.0 aC	84.87 aB	99.75 aA	8.21 **
10%	0.0 aC	62.12 bB	99.12 aA	50.77 **
8%	0.0 aC	88.0 aB	99.5 aA	4.9 *
$F_{Management}$	-	22.19 **	0.01 ^{ns}	

Means followed by the same letter, lowercase in the column and uppercase on the line, do not differ from one another by the t test ($p>0.05$). (LSD_{ExD} = 6.9) (LSD_{MxD} = 8.5). * significant at 5% probability; ** significant at 1% probability; ^{ns} non-significant.

Table 6 **-** Mean values of the control percentage of *Panicum maximum* plants, 35 days after the application of different doses of glyphosate, depending on the development stage at the time of the application and on the water management to which plants were submitted. Jaboticabal - São Paulo. 2015

Stage	Dose			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F_{Dose}
4 - 6 leaves	0.0 aC	84.75 bB	100.0 aA	1305.9 **
1 - 3 tillers	0.0 aB	98.0 aA	100.0 aA	1470.3 **
F_{Stage}	-	39.49 **	-	
Water Management	**Dose**			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F_{Dose}
13%	0.0 aC	94.37 aB	100.0 aA	946.8 **
10%	0.0 aC	84.37 bB	100.0 aA	868.0 **
8%	0.0 aB	95.37 aA	100.0 aA	955.7 **
$F_{Management}$	-	11.1 **	-	

Means followed by the same letter, lowercase in the column and uppercase on the line, do not differ from one another by the t test ($p>0.05$). (LSD_{ExD} = 4.2) (LSD_{MxD} = 5.2). * significant at 5% probability; ** significant at 1% probability; ^{ns} non-significant.

In a study about *B. plantaginea* submitted to water deficit and with the spraying of fluazifop-p-butyl and sethoxydim, it was observed that, under an 8% water potential in the soil, control efficiency was also affected. This occurred regardless of the herbicide dose and of the phenological stage of the studied plants (Pereira et al., 2010).

At 21 and 35 DAA, with the application of a 540 g ha^{-1} dose of glyphosate, regardless of the water management to which guineagrass plants were submitted, no difference in control was observed; from 21 DAA on, it was possible to observe a total control of plants.

The fact that weed control is lower, as in this case, shows that the level of stress to which plants are submitted decreases the capacity of metabolizing the herbicide molecules, and this results in less control and in a reduction of the herbicide dose (Pereira et al., 2012).

The lowest control observed on guineagrass cultivated in substrates with water restrictions and that received the lowest dose of glyphosate can be attributed to possible defense mechanisms of the plants. These phenomena would be a greater accumulation of cuticle on the leaf surface, lower photosynthetic rates and the leaf area. This hinders the absorption and translocation of the herbicide by plants (Harrington and Miller, 2005; Kadioglu et al., 2012). Therefore, attention should be paid to the herbicide application technology, in order to avoid the application of subdoses, as there may be control failures with the occurrence of water deficit in the soil.

The accumulation of dry matter in the shoot and roots of guineagrass plants submitted to different water potentials of soil and to the application of different glyphosate doses at the development stages of 4-6 leaves and 1-3 tillers were significant in all analyzed variables. Interactions were also significant, except for the accumulation of shoot dry matter in the interaction between vegetative stage and water management. The greatest accumulation of shoot and root dry matter occurred at the stages of 1-3 tillers and 4-6 leaves, respectively. In the water management, both for shoot and roots, dry matter was higher when there was greater water availability for the development of guineagrass plants. As for the different herbicide doses, regardless of the applied one, there was a reduction in the dry matter accumulation of shoot and roots.

The accumulation of dry matter in the shoot of plants that were controlled at both initial and late stages of development was higher when the herbicide was not applied. On the other hand, when the application of glyphosate occurred, the greatest accumulation of dry matter in the shoot occurred when spraying was performed at the 1-3 tiller stage (Table 7). In the unfolding of the interaction between water management and glyphosate doses, the greatest dry matter accumulation in the shoot was observed in plants that developed at the maximum water potential of soil (Table 7).

When analyzing the dry matter accumulation in the roots of guineagrass, it was observed that, regardless of the vegetative stage of the plant at the time of glyphosate application, the

Table 7 **-** Dry matter accumulation of the shoot (g) of *Panicum maximum* 35 days after the application of different doses of glyphosate, according to the water management to which plants were submitted and of the vegetative stage at the time of application. Jaboticabal - São Paulo. 2015

Stage	Dose			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F$_{\text{Dose}}$
4 - 6 leaves	5.35 aA	0.72 bB	0.56 bB	341.7 **
1 - 3 tillers	5.27 aA	1.52 aB	1.10 aB	243.62 **
F$_{\text{Stage}}$	0.15$^{\text{ns}}$	14.64 **	6.74 *	
Water Management	**Dose**			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F$_{\text{Dose}}$
13%	9.32 aA	1.67 aB	1.36 aB	624.88 **
10%	4.36 bA	1.12 bB	0.62 bB	126.76 **
8%	2.26 cA	0.56 cB	0.51 bB	126.76 **
F$_{\text{Management}}$	403.72 **	9.72 **	6.5 **	

Means followed by the same letter, lowercase in the column and uppercase on the line, do not differ from one another by the t test (p>0.05). (LSD$_{\text{ExD}}$ = 0.41) (LSD$_{\text{MxD}}$ = 0.51). * significant at 5% probability; ** significant at 1% probability; $^{\text{ns}}$ non-significant.

water management with the lowest restriction provided the greatest accumulations of dry matter in the root system. When any water restriction occurred, there were 60% and 71% reductions in the 10% and 8% managements, respectively, at the development stage of 4-6 leaves. However, at the 1-3 tiller stage, the dry matter reduction of the 10% and 8% water managements was 40% and 75%, respectively, compared to the 13% management (Table 8).

Table 8 **-** Dry matter accumulation of the root (g) of *Panicum maximum* 35 days after the application of different doses of glyphosate, according to the water management to which plants were submitted and to the vegetative stage at the time of application. Jaboticabal - São Paulo. 2015

Stage	Dose			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F $_{Dose}$
4 - 6 leaves	2.91 aA	0.37 aB	0.28 aB	873.55 **
1 - 3 tillers	2.39 bA	0.24 bB	0.20 aB	613.8 **
F $_{Stage}$	53.41 **	5.54 *	0.33 ^{ns}	
Water Management	Dose			
	0 g ha^{-1}	270 g ha^{-1}	540 g ha^{-1}	F $_{Dose}$
13%	4.64 aA	0.38 aB	0.45 aB	1551.35 **
10%	2.20 bA	0.27 abB	0.17 bB	339.39 **
8%	1.12 cA	0.20 bB	0.16 bB	76.39 **
F $_{Management}$	848.79 **	2.15 ^{ns}	6.86 **	
Stage	Water management			
	13%	10%	8%	F $_{Management}$
4 - 6 leaves	2.11 aA	0.85 aB	0.60 aC	253.47 **
1 - 3 tillers	1.54 bA	0.91 aB	0.38 bC	131.57 **
F $_{Stage}$	62.81 **	0.65 ^{ns}	9.72 **	

Means followed by the same letter, lowercase in the column and uppercase on the line, do not differ from one another by the t test ($p>0.05$). (LSD$_{ExD}$ = 0.14) (LSD$_{MxD}$ = 0.17) (LSD$_{ExM}$ = 0.14). * significant at 5% probability; ** significant at 1% probability; ^{ns} non-significant.

In the interaction between development stage and applied glyphosate dose, regardless of the vegetative stage at which the plant was at the time of the application, the 0 g ha^{-1} dose of the herbicide provided greater dry matter accumulation in the root system of guineagrass plants. However, when analyzing the vegetative stages, it was observed that the greatest accumulation occurred when the application of glyphosate occurred at the 4-6 leaf stage (Table 8). The development of the root system of guineagrass was higher without the application of the herbicide and directly proportional to the water restriction, that is, the lower the water availability to the plant, the lower its root development (Table 8).

The different water conditions, either due to excess or deficit, to which plants are submitted can have negative impacts on their growth and development. Studies have demonstrated that there is communication between roots and shoot by chemical and molecular signals, which act directly on stomata dynamics under conditions of soil water deficit (Shabala et al., 2016).

A water deficit increases the concentration of abscisic acid (ABA) in the various plant tissues, which is why some changes in the morpho-physiological characteristics may occur. When ABA accumulation originates from the roots, shoot development and root system maintenance are affected (Tuberosa, 2012; Ali et al., 2017). It is worth highlighting that under field conditions, with severe water restrictions, glyphosate subdoses may be ineffective in controlling guineagrass plants, and this would bring losses to the productive system.

With the increase of the water restriction, there was a decrease in the morpho-physiological components of guineagrass plants, such as specific leaf area, stomatal conductance and the difference between room and leaf temperatures. Controlling these plants was more effective when the application of the 540 g ha^{-1} glyphosate dose occurred, and when they were controlled at the 1-3 tiller vegetative stage, in a water management without water restriction, that is, plants that develop under water restriction may have its control affected.

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