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Article

Effects of 2,4-D Herbicide on Species of the *Digitaria* Genus

*Efeitos do Herbicida 2,4-D em Espécies do Gênero **Digitaria***

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ABSTRACT - The objective of this work was to evaluate the effects of the 2,4-D herbicide on the growth and development of *Digitaria insularis* and *Digitaria horizontalis* plants under different climatic conditions. Two greenhouse experiments were conducted in a completely randomized design, with 11 treatments (rates of the herbicide) and four replications. Rate-response curves were determined for the 2,4-D rates of 0, 50.37, 100.75, 201.5, 403, 806, 1,612, 3,224, 6,448, 12,896, and 25,792 g a.i. ha^{-1}. The plants presented growth stimulus with low rates of 2,4-D in the autumn-winter period, but this stimulus was not found in the spring-summer period. The plants subjected to application of high rates of 2,4-D had significantly lower growth and development than the control, regardless of the climatic conditions. Therefore, auxin herbicides must be used with caution, mainly in periods of low temperatures, because any problems related to the application technology – which may cause the contact of plants with low rates of this herbicide – will promote the growth of plants of these species, hindering the control and favoring the dispersion of these plants.

Keywords: synthetic auxin, *Digitaria insularis, Digitaria horizontalis*, hormesis.

*RESUMO - O objetivo dos experimentos foi avaliar os efeitos promovidos pelo herbicida 2,4-D no crescimento e desenvolvimento de **Digitaria insularis** e **Digitaria horizontalis** em condições climáticas distintas. Realizaram-se dois experimentos em casa de vegetação no delineamento inteiramente casualizado com 11 tratamentos (doses do herbicida) e quatro repetições. Para isso, foram conduzidas curvas de dose-resposta nas doses de 0; 50,37; 100,75; 201,5; 403; 806; 1.612; 3.224; 6.448; 12.896 and 25.792 g a.i. ha^{-1}. Verificou-se que no período de outono/inverno as espécies apresentaram estímulo de crescimento com baixas doses de 2,4-D, enquanto na primavera/verão esse estímulo não foi observado. Doses mais elevadas do herbicida reduziram significativamente o crescimento e desenvolvimento das espécies, independentemente da condição climática avaliada. Dessa forma, o uso de herbicidas auxínicos precisa ser feito com cautela, especialmente em períodos com temperaturas mais baixas, pois quaisquer eventuais problemas relacionados à tecnologia de aplicação, que possibilitem o contato das plantas com baixas doses destes herbicidas, promoverão estímulo de crescimento dessas espécies e, assim, dificultarão o controle e favorecerão o aumento da dispersão dessas plantas.*

Palavras-chave: auxina sintética, *Digitaria insularis*, *Digitaria horizontalis*, hormese.

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INTRODUCTION

Sourgrass (*Digitaria insularis* (L.) Mez ex Ekman) is a perennial, highly-competitive grass that can reduce maize and soybean yields in more than 32 and 44%, respectively (Gazziero et al., 2012; Gemelli et al., 2013). It is nowadays one of the main weed species in Brazil, mainly due to its high dispersion capacity, control difficulties, and increasing cases of resistance to herbicides (Barroso et al., 2015; López-Ovejero et al., 2017; Takano et al., 2018).

Jamaican crabgrass (*Digitaria horizontalis* Willd) is also a perennial grass with high infestation potential and has been considered one of the most aggressive weed species in modern agriculture (Silva et al., 2018). In general, Jamaican crabgrass is known in Brazil as a complex of three species (*Digitaria horizontalis* Willd, *D. ciliaris* (Retz.) Koeler, and *D. nuda* Schumach) that infests crops, is difficult to control, and is an important weed species in sugarcane crops (Tropaldi et al., 2018).

The 2,4-D herbicide is a syntactic auxin used to control eudicotyledonous weeds in pastures and to kill weeds in no-till system, especially those that are resistant to glyphosate. However, this herbicide has hormonal action when not properly applied, even at low rates, presenting high potential of damage to sensitive crops to its active ingredient (Goggin et al., 2016) and promoting growth stimulus a process named hormesis (Calabrese and Mattson, 2017).

Hormesis in crop plants, such as soybean, eucalyptus, pines, maize, coffee, and citric fruit plants, has been studied for some time (Velini et al., 2008). However, few studies consider this effect on weeds, such as sourgrass and Jamaican crabgrass, which are important weeds for agriculture because they are difficult to control and cause economic impact by decreasing the crop profit. Thus, considering that 2,4-D is a synthetic auxin and has hormonal action, the hypothesis of this work was that the contact of low rates of this herbicide with these weeds as occur when it is not properly applied due to the incorrect use of application technologies or lack of maintenance of agricultural sprayers causes damages to crops due to growth and development stimulus.

The possible growth stimulus due to low rates of 2,4-D may be related to the effects of auxin on cell elongation. This process is dependent on the action of enzymes such as hydrolases, pectinases, cellulases, and hemicellulases (Taiz and Zeiger, 2004). Considering that all enzymes have an optimal activity temperature, the enzyme activity probably decreases and, consequently, the auxin production will be lower in *D. insularis* and *D. horizontalis* plants grown at low temperatures. Under these conditions, low rates of 2,4-D could supply this auxin demand and allow the growth of these species. However, under high temperature conditions, this effect would not be noticed due to the normal auxin concentrations in these plants.

In this context, the objective of this work was to evaluate the hormesis effects of the 2,4-D herbicide on the growth and development of *Digitaria insularis* and *Digitaria horizontalis* plants during the autumn-winter and spring-summer periods.

MATERIAL AND METHODS

Two greenhouse experiments were conducted in a completely randomized design, with 11 treatments (rates of 2,4-D herbicide) and four replications. The plant species used were *Digitaria insularis* and *Digitaria horizontalis*. The experiments were carried out in 2018 and 2019, in different periods: the first experiment in the autumn-winter (June to August 2018), and the second in the spring-summer (November 2018 to January 2019) (Figure 1). The height of the plants was evaluated at 7 and 21 days after application (DAA) of 2,4-D, and their shoot dry weight (SDW) was evaluated at 21 DAA.

The experimental units consisted of 0.35 liter pots filled with a commercial substrate (Carolina II®), in which seeds of each species were planted at depth of 1 cm. This substrate was composed of sphagnum peat, expanded vermiculite, roasted rice husk, dolomitic limestone, agricultural gypsum, and NPK traces; it presented electrical conductivity of 0.7±0.3 mS cm^{-1}, pH of 5.5, density of 155 kg m^{-3}, and 55% water retention capacity.

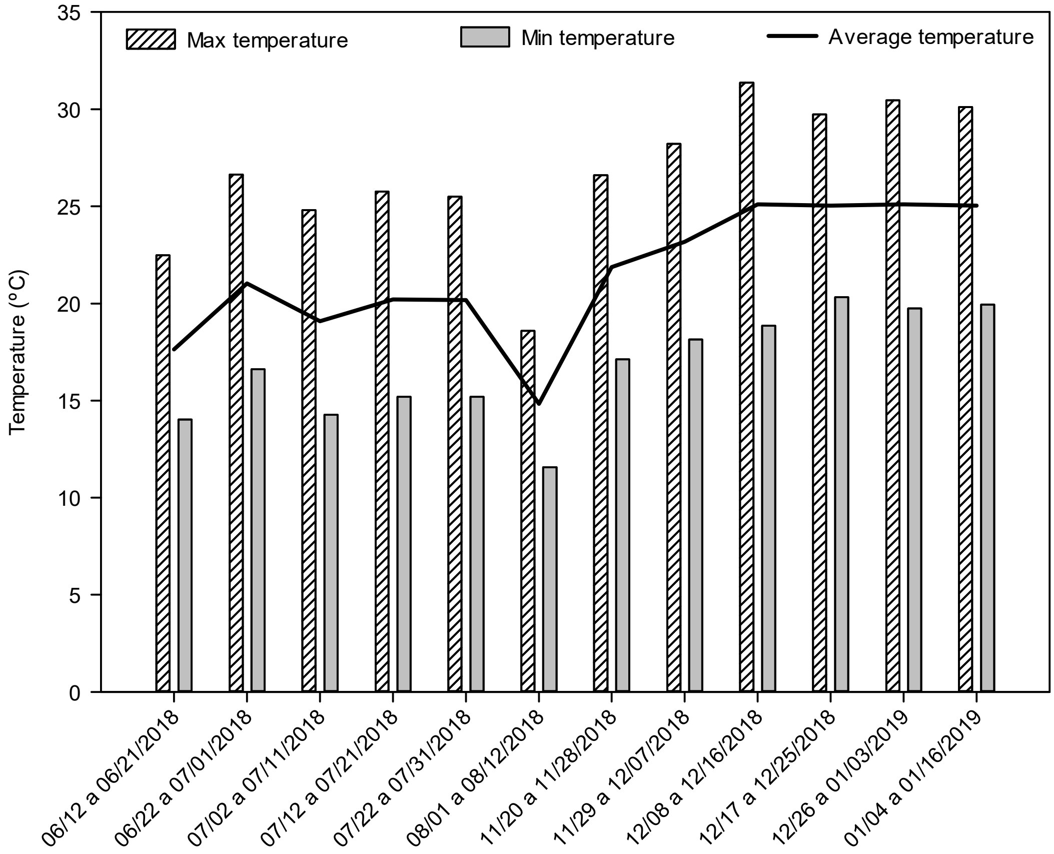


Figure 1 - Maximum, minimum, and average temperatures in the periods in which the experiments were conducted.

The seedlings were thinned after germination, keeping four plants of each species per pot. The experimental units were kept in metal trays containing a water layer of 5 cm until the application of the treatments. Thus, all plants were under the same water supply and light conditions.

The herbicide was applied when the plants had four to six tillers, using a stationary sprayer with a 2 meter spray boom that runs for 6 meters assisted by an electric motor with speed modulation control. The spray boom had four XR110.02VS flat nozzles (Teejet®, Wheaton, USA) spaced 0.5 m apart and positioned at 0.5 m high from the soil containers. The equipment was set to work at a pressure of 196.13 kPa and speed of 3.6 km h^{-1}, generating a solution application volume of 200 L ha^{-1}. The 2,4-D herbicide (dimethylamine salt; DMA® 806 BR, 806 g a.i. L^{-1}) was used at rates of 0, 50.37, 100.75, 201.50, 403, 806, 1,612, 3,224, 6,448, 12,896, and 25,792 g a.i. ha^{-1}. The air temperatures and air relative humidities at the time of application were, respectively, 19 °C and 69% (Experiment 1) and 27 °C and 70% (Experiment 2).

The aerial part of the plants was cut, packed in paper bags, and dried in a forced-air circulation oven at 65 °C until constant weight to evaluate the SDW. The biomasses were weighted in a precision balance (0.0001 g). The SDW was converted to percentage in relation to the SDW of the control.

The data were subjected to analysis of variance and the means were compared by the t test ($p \leq 0.05$). The non-linear regression models of Brain and Coussens (1989) and Streibig (1980) were used to describe the rate-response curves with or without hormesis, according to equations 1 and 2:

Brain and Coussens (1989) model, BC.5 – with hormesis

$$f(x) = c + \frac{d - c + fx}{1 + exp\,(b(log(x) - log(e)))} \quad \text{(eq. 1)}$$

Streibig (1980) model, LL.4 – without hormesis

$$f(x) = c + \frac{d - c}{1 + exp\ (b(log(x) - log(e)))} \quad \text{(eq. 2)}$$

where the parameters *c* and *d* are the lower and upper limits of the curve; and *b* is the relative slope over *e*, which is the logarithm of the inflection point. The models used differ only for the *f* coefficient, which multiplies the *x* variable and allows the determination of the reduction in the sum of squares of the residues.

The best model for fitting the data was defined by calculating the difference between the sum of mean squares of the regression of the models, considering the inclusion of the *f* parameter in equation 1. The difference between the sum of squares of the residues of the models was tested for $p \leq 0.05$ and $p \leq 0.01$, using the F calculated as follow:

$$f = \frac{Ss\ equation\ 2 - Ss\ equation\ 1}{MSR}$$

where *Ss* is the sum of squares and *MSR* is the mean square of the residue.

When F was significant, the hypothesis f = 0 was rejected, accepting the occurrence of growth stimulus, and opting for the use of the logistic model with the additional factor *f* (BC.5), as described by Velini et al. (2008). When F was not significant, the hypothesis *f* = 0 was accepted, concluding that there was no growth stimulus when using low rates of 2,4-D; and then, a third model was used to fit the data, as shown in equation 3:

Streibig (1988) log-logistic model, LL.3

$$y = \frac{a}{1 + \left(\frac{x}{x0}\right) b} \quad \text{(eq. 3)}$$

where *y* is the plant height or SDW; *x* is the herbicide rate; *a* is the asymptote between the maximum point and minimum point of the variable; *x*0 is the herbicide rate that results in 50% of the response of the variable; and *b* is the curve slope.

RESULTS AND DISCUSSION

The plant height of the *Digitaria insularis* and *Digitaria horizontalis* plants at 7 and 21 days after application (DAA) of 2,4-D as a function of the rates used, the coefficients of determination (R^2), and the parameters of the logistic model fitted to the data are described in Table 1. The comparison between the treatments with different 2,4-D rates indicated significant differences at 7 and 21 DAA for both species. The parameters evaluated presented adequate fit, with R^2 of 0.83 and 0.95 for *D. insularis* and 0.96 and 0.93 for *D. horizontalis* at 7 and 21 DAA, respectively.

The rate-response curves of plants of both species due to the treatments with the 2,4-D herbicide are shown in Figure 2. The highest plant heights were found with the rate of 100.75 g a.i. ha^{-1} for sourgrass, and with the rates of 50.375 and 100.75 g a.i. ha^{-1} for the Jamaican crabgrass at 7 and 21 DAA, respectively.

The 2,4-D rates of 50, 100.75, 375, and 403 g a.i. ha^{-1} resulted in higher plant height for *D. insularis* plants grown in the autumn-winter period, at 7 and 21 DAA, when compared to the control (0 g a.i. ha^{-1}), but the greater growth stimulus was found when using the rate of 100.75 g a.i. ha^{-1} (Figure 2). This rate resulted in *D. insularis* plants with heights 16.66% higher than the control at 7 DAA; and 39.15% higher than the control at 21 DAA (Table 1).

The 2,4-D rate of 50.375 g a.i. ha^{-1} resulted in the greatest growth stimulus in *D. horizontalis* plants grown in the autumn-winter period, which presented heights 14.03% higher when compared to the control at 7 DAA. The 2,4-D rate of 100.75 g a.i. ha^{-1} resulted in plant with heights 13.15% higher when compared to the control at 21 DAA (Table 1 and Figure 2). These data corroborate those found in the literature, which report maximum growth stimulus for herbicides of 20 to 30% when compared to the control in controlled conditions (Belz et al., 2011).

Table 1 **-** Height of *Digitaria insularis* and *Digitaria horizontalis* plants grown in the autumn-winter period, at 7 and 21 days after application of 2,4-D (DAA)

2,4-D (g a.i. ha^{-1})	Plant height (cm)			
	7 DAA	21 DAA	7 DAA	21 DAA
	D. insularis		*D. horizontalis*	
0	7.50	12.13	21.38	28.50
50.375	8.50	15.88	24.38	30.50
100.75	8.75	16.88	23.50	32.25
201.5	8.50	16.25	23.00	30.75
403	7.50	16.50	23.00	25.00
806	7.00	9.50	21.25	23.75
1612	7.00	8.38	17.25	23.00
3224	6.88	6.88	17.13	18.75
6448	6.75	6.50	15.75	19.25
12896	5.75	5.50	15.75	22.00
25792	5.12	4.25	12.50	17.50
CV (%)	16.18	16.09	16.18	17.81
F value:				
Rates	3.75**	31.75**	2.97*	5.59**
Hypothesis f ≠ 0	1250.36**	1014.30**	456.57**	322.53**
Regression	7.82**	75.72**	7.12**	13.03**
Model	BC.5	BC.5	BC.5	BC.5
R^2	0.83	0.95	0.96	0.93
Constants	g=19.14	g=245.70	g=111.30	g=171.22
	b=7.52	b=12.09	b=21.48	b=28.26
	k=0.95	k=1.82	k=1.15	k=1.83
	d=-0.58	d=0.06	d=0.21	d=0.08
	f=20.6	f=4.61	f=3.10	f=19.06

** = significant at $p \leq 0.01$ and * = significant at $p \leq 0.05$. BC.5 = Brain and Cousens (1989) model. CV = coefficient of variation.

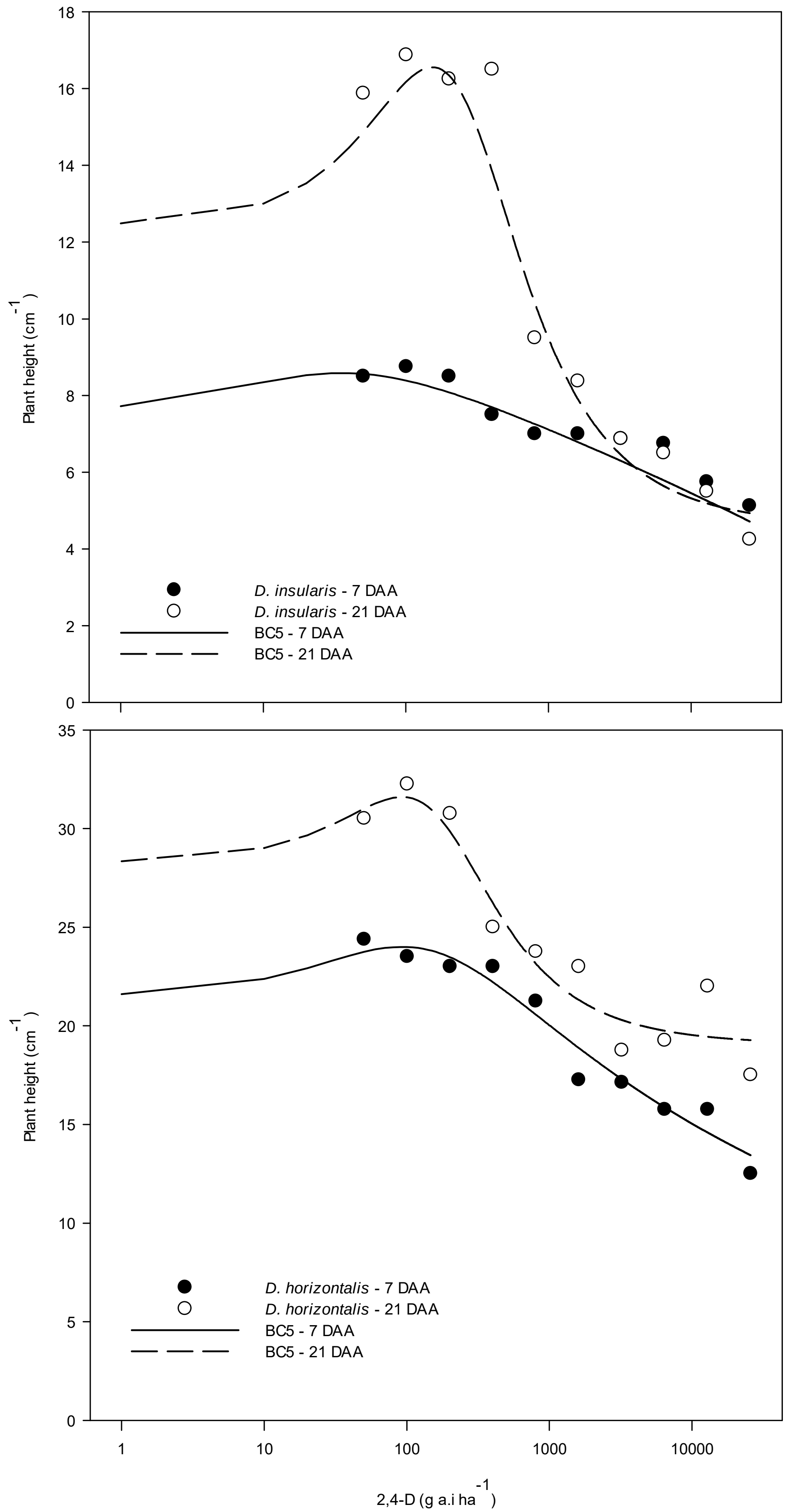
However, growth stimulus at 21 DAA was found only with 2,4-D rates between 50.385 and 201.5 g a.i. ha^{-1} for *D. horizontalis*, whereas this stimulus was found with 2,4-D rates of up to 403 g a.i. ha^{-1} for *D. insularis* (Table 1). According to Carvalho et al. (2013), the range of rates that results in growth stimulus and the amplitude of responses vary between species, as also found in the experiment 1 of the present study.

The plants in the experiment 2, which were grown in the spring-summer period, presented no growth stimulus due to the 2,4-D herbicide when compared to the control. The means of plant height found for *D. insularis* and *D. horizontalis* at 7 and 21 DAA as a function of the 2,4-D rates, the R^2, and the parameters of the logistic model fitted to the data are shown in Table 2.

The hypothesis f = 0 was accepted, i.e., there was no hormesis for the low rates of the herbicide. Therefore, the non-linear regression model LL.3 was used (Figure 3). The R^2 presented good fit of the evaluated parameters for both species 0.87 and 0.93 for *D. insularis*, and 0.72 and 0.73 for *D. horizontalis* (Figure 3). According to the rate-response curves of both species to the 2,4-D herbicide, the highest plant heights of sourgrass and Jamaican crabgrass were found for plants without herbicide application.

This was probably due to the variations in the plants that occur when they are subjected to stress conditions (Belz et al., 2011), such as variations in temperature. The assumption that all factors affecting plant growth can affect the stimulus response to a phytotoxin was reinforced in the last few years, since most environmental factors are important to plant growth (Belz and Duke, 2014). In addition, Carvalho et al. (2013) reported that the stimulus response to an herbicide may be connected to factors that can affect plant growth, such as species, biotype or cultivar, physiological status, plant density, environmental conditions, and type of formulation used and the time that the plants are exposed to it.

Moreover, when the environmental conditions allow the plant to develop up to its genetically-fixed growth potential or under extreme conditions that prevent the plant growth, the occurrence of hormesis is improbable (Belz et al., 2011). This was found in the present study, in which the



BC.5 = Brain and Cousens (1989) model. The graphics are in logarithmical scale.

Figure 2 - Plant height curves for *Digitaria insularis* and *Digitaria horizontalis* plants grown in the autumn-winter period, at 7 and 21 days after application of 2,4-D (DAA).

Table 2 - Height of *Digitaria insularis* and *Digitaria horizontalis* plants grown in the spring-summer period, at 7 and 21 days after application of 2,4-D (DAA)

2,4-D (g a.i. ha^{-1})	Plant height (cm)			
	7 DAA	21 DAA	7 DAA	21 DAA
	D. insularis		*D. horizontalis*	
0	17.42	21.33	32.83	35.50
50.375	15.08	19.17	29.83	32.58
100.75	13.67	16.92	29.08	34.00
201.5	11.17	13.50	29.08	30.98
403	12.58	13.42	28.42	30.08
806	10.46	10.67	25.33	30.75
1612	6.75	10.25	25.08	24.25
3224	7.46	5.83	21.42	24.92
6448	8.66	5.64	22.41	25.66
12896	4.55	3.25	20.16	20.66
25792	3.55	1.83	15.91	18.66
CV (%)	22.79	17.59	19.16	21.66
F value:				
Rates	14.58**	44.34**	4.27**	3.30**
Hypothesis f ≠ 0	626.12^{ns}	913.28^{ns}	196.56^{ns}	440.42^{ns}
Regression	69.15**	147.30**	22.96**	23.46**
Model	LL.3	LL.3	LL.3	LL.3
R^2	0.87	0.93	0.72	0.73
Constants	a=17.54	a=21.47	a=32.71	a=35.73
	b=0.43	b=0.60	b=0.38	b=0.38
	X0=1651.95	X0=860.87	X0=30973.58	X0=33453.04

** significant at $p \leq 0.01$, * significant at $p \leq 0.05$, and ^{ns} not significant. LL.3 = Streibig (1988) equation. CV = coefficient of variation.

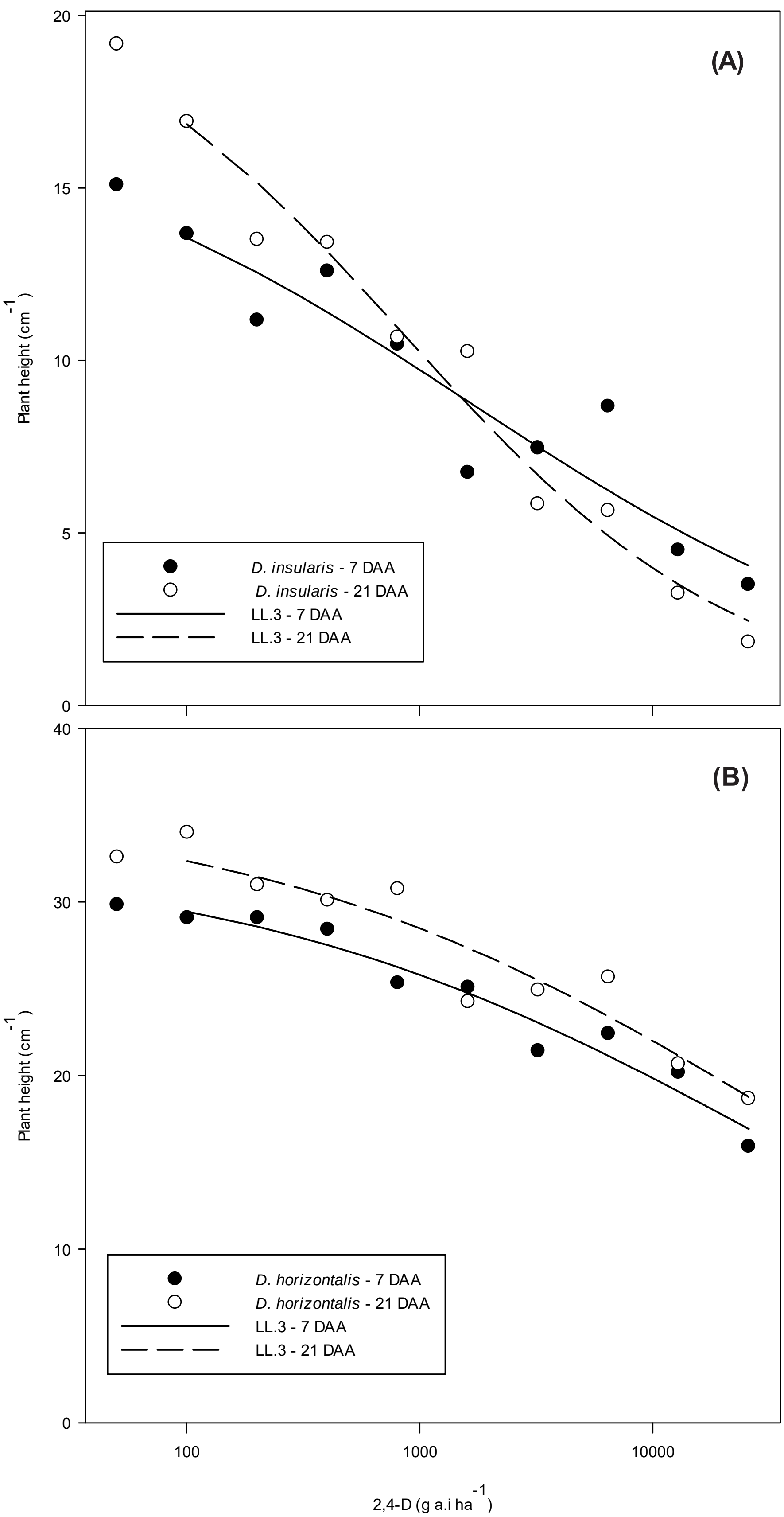
plants presented no growth stimulus when grown in the spring-summer period (Table 2 and Figure 3). An example that illustrates this is the dependence on temperature for the effect of growth stimulators, such as PCIB (2-(p-chlorophenoxy)-2-methylpropionic acid) and parthenin, as shown by Belz et al. (2011) in germination bioassays. According to these authors, the environmental condition for a pronounced hormesis caused by the PCIB on lettuce roots was found in a temperature regime of 15/10 °C (day/night), whereas at a higher temperature 36/25 °C (day/night), this hormesis did not occur.

This can also occur for 2,4-D herbicide. According to the hypothesis of acid growth, auxin increases the H^+ flux and, consequently, decreases the apoplast pH. This activates expansins, which breaks the cross-link (hydrogen bonds) between microfibrils of cellulose and hemicelluloses. Subsequently, hydrolase, pectinase, cellulase, and hemicellulase enzymes are activated and will loosen the cell wall, increasing its extensiveness and promoting cell elongation (Taiz and Zeiger, 2004). However, all enzymes have an optimal activity temperature and, in general, as in chemical reactions, the enzyme activity decreases as the temperature is decreased.

Therefore, under low temperature conditions, the activity of expansins, hydrolases, pectinases, cellulases, and hemicellulases can decrease, consequently, decreasing the production of auxin in the plants. Under this condition, low rates of 2,4-D could supply the plants' demand for auxin and enable cell elongation, increasing their growth and development, as observed for the *D. insularis* and *D. horizontalis*. This effect of the herbicide was not found in the spring-summer period probably due to normal production of auxin in these plants; however, further experiments are needed to confirm this result.

According to Duke et al. (2006), the use of low rates of some herbicides, such as glyphosate, can inhibit preferentially the synthesis of lignin, making the cell walls more elastic and remain in this state for a long time during the plant development. This can result in a higher longitudinal growth of the plants, as observed in the experiment in the autumn-winter period.

The accumulated shoot dry weight (SDW) of the plants showed that the growth stimulus occurred only when plants were grown in the autumn-winter period. The logistic model with the additional factor for the parameter evaluated was significant; thus, the hypothesis f = 0 was rejected and it was assumed that hormesis occurred at low rates of 2,4-D (Table 3).



LL.3 = Streibig (1988) equation. The graphics are in logarithmical scale.

Figure 3 **-** Plant height curves for *Digitaria insularis* and *Digitaria horizontalis* plants grown in the spring-summer period, at 7 and 21 days after application of 2,4-D (DAA).

Table 3 **-** Shoot dry weight of *Digitaria insularis* and *Digitaria horizontalis* plants at 7 and 21 days after application of 2,4-D (DAA)

2,4-D (g a.i. ha^{-1})	Shoot dry weight (%)			
	D. insularis – E1	*D. horizontalis* – E1	*D. insularis* – E2	*D. horizontalis* – E2
0	100.00	100.00	100.00	100.00
50.375	100.99	119.66	56.38	96.93
100.75	107.56	113.51	61.79	95.19
201.5	98.36	112.63	46.49	95.59
403	85.63	110.32	51.57	86.93
806	57.86	96.95	42.05	85.71
1612	46.74	81.86	31.11	82.27
3224	29.94	96.87	22.07	76.29
6448	20.53	81.21	23.64	68.91
12896	15.85	73.54	18.88	57.55
25792	10.94	53.03	5.52	42.52
CV (%)	26.82	18.68	26.96	26.72
F value:				
Rates	21.67**	5.27**	21.41**	2.82*
Hypothesis f ≠ 0	118.03**	1305.79**	-6.69^{ns}	617.52^{ns}
Regression	53.97**	11.97**	83.45**	36.56*
Model	BC.5	BC.5	LL.3	LL.3
R^2	1.00	0.91	0.89	0.80
Constants	g=329.52	g=26.81	a=99.01	a=98.56
	b=98.86	b=101.62	b=0.39	b=0.64
	k=1.47	k=0.82	X0=231.17	X0=20012.95
	d=0.23	d=-1.05	-	-
	f=1.56	f=154.20	-	-

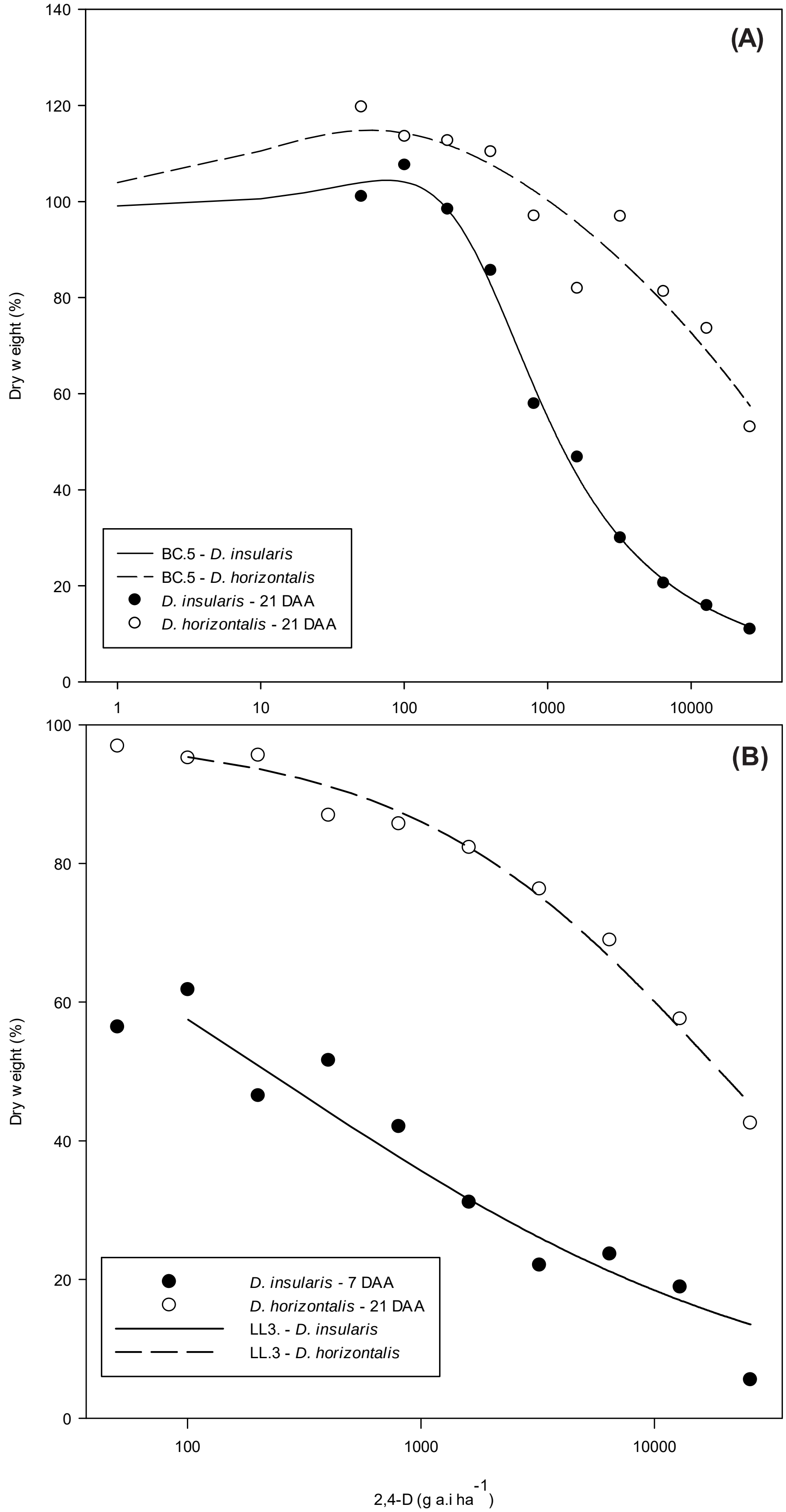
** significant at $p \leq 0.01$, * significant at $p \leq 0.05$, and ^{ns} not significant. E1 = Experiment 1 (autumn-winter period). E2 = Experiment 2 (spring-summer period). LL.3 = Streibig (1988) equation. CV = coefficient of variation.

The greatest growth stimulus for *D. insularis* plants was found with the 2,4-D rate of 100.75 g a.i. ha^{-1}, presenting plants with 7.56% higher SDW when compared to the control. The greatest growth stimulus for *D. horizontalis* plants was found with the 2,4-D rate of 50.375 g a.i. ha^{-1}, presenting plants with 19.66% higher SDW when compared to the control. The growth stimulus was greater for *D. horizontalis* than for *D. insularis* not only due to its higher percentage, but due to the range of herbicide rates causing the stimulus in the Jamaican crabgrass, which was up to 403 g a.i. ha^{-1}, whereas for the sourgrass, the hormesis effect occurred only with the 2,4-D rates of 50.375 and 100.75 g a.i. ha^{-1} (Table 3 and Figure 4).

Velini et al. (2008) found higher biomass when evaluating the effects of low rates of glyphosate in soybean and maize crops, with significant higher total and shoot dry weights for conventional soybean with glyphosate rates of 1.8 to 18 g a.e. ha^{-1}; they found similar results for maize, but with rates of 1.8 and 36 g a.e. ha^{-1}. When the hormesis effect is pronounced, it is induced by the environmental conditions in which plants grown when favorable, they promote changes in cells and organisms under stress conditions and low herbicide rates (Calabrese, 2014; Calabrese and Mattson, 2017). Therefore, the increase in SDW does not mean that the plant is allocating resources in this part, but in the whole plant (Carvalho et al., 2013).

The results of growth stimulus found for sourgrass and Jamaican crabgrass are important due to the occurrence of problems during the application of 2,4-D on crops. Theoretically, the growth stimulus effect can appear involuntarily due to spray drift, errors during application, absorption of low rates of herbicide by the soil (mainly after degradation or immobilization processes), contact between leaves of treated and non-treated plants, and low amount of herbicide drops reaching the target because of the protection by higher plants (Velini et al., 2010).

The 2,4-D herbicide is widely used and has a hormonal effect that can be highly toxic to plants, even at low rates, causing losses in crops, such as coffee (Voltolini et al., 2015) and peanuts (Leon et al., 2014). This denotes the need for caution regarding the application of this herbicide, maintenance of sprayers, and ideal conditions for application.



BC.5 = Brain and Cousens (1989) model. LL.3 = Streibig (1988) equation. The graphics are in logarithmical scale.

Figure 4 - Shoot dry weight curves for *Digitaria insularis* and *Digitaria horizontalis* plants grown in the autumn-winter (A) and spring-summer (B) periods, at 7 and 21 days after application of 2,4-D (DAA).

The concerning about losses due to spray drift of 2,4-D has increased due to the release of cultivars tolerant to this herbicide and the consequent increase of its use. Therefore, researches are needed to develop adequate technologies to reduce the harmful effect of spray drift of 2,4-D, such as anti-drift hydraulic nozzles with air induction (Alves et al., 2018), use of adjuvants (Oliveira et al., 2015), and new formulations of 2,4-D as the choline salt of the Enlist™ technology (Enlist, 2019).

Another concerning is about herbicide application to improve the crop quality. The use of glyphosate can increase the saccharose contents in sugarcane (McDonald et al., 2000), and herbicides inhibitors of protoporphyrinogen oxidase (Protox) can improve plant defense against pathogens and diseases (Nelson et al., 2002). Moreover, low herbicide rates can increase crop yield; according to Carvalho et al. (2013), low rates of glyphosate in coffee crops increased in 18% the stem diameter, 31% the leaf dry weight, and 27% the total dry matter of the plants.

Therefore, the commercial exploitation of low rates of 2,4-D needs to be carried out with caution, mainly in the autumn-winter period, since, as found in the present study, low rates of 2,4-D promoted growth stimulus in two of the most important weeds found in crops in Brazil. This can result in an increase in the dispersion of these species, since these plants are difficult to control when they are at advanced development stages. Thus, the dispersion of sourgrass and Jamaican crabgrass in agricultural areas can increase and, consequently, hinder the control of resistance of these species to herbicides.

In addition, the technology for application of herbicides needs to be considered when spraying 2,4-D, since the spray drift of this herbicide can cause the phytotoxicity problems already known, and can promote growth stimulus in sourgrass and Jamaican crabgrass due to the lower rates that can reach these plants during the application. Therefore, operational issues must also be considered to avoid oscillations of the spray boom during the spraying, since mistakes like this can cause heterogeneous distribution of the spray solution in the area and, thus, some plants can receive lower rates of the herbicide and have their growth increased.

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REFERENCES

Alves GS, Kruger GR, Cunha JPAR. Spray drift and droplet spectrum from dicamba sprayed alone or mixed with adjuvants using air-induction nozzles. Pesq Agropec Bras. 2018;53:693-702.

Barroso AAM, Galeano E, Albrecht AJP, Dos Reis FC, Victoria Filho R. Does sourgrass leaf anatomy influence glyphosate resistance? Comun Sci. 2015;6:445-53.

Brain P, Cousens R. An equation to describe dose responses where there is stimulation of growth at low doses. Weed Res. 1989;29:93-6.

Belz RG, Duke SO. Herbicides and plant hormesis. Pest Manage Sci. 2014;70:698-707.

Belz RG, Cedergreen N, Duke SO. Herbicide hormesis–can it be useful in crop production? Weed Res. 2011;51:321-32.

Calabrese EJ, Mattson MP. How does hormesis impact biology, toxicology, and medicine? NPJ Aging Mech Dis. 2017;13:1-8.

Calabrese EJ. Hormesis: from mainstream to therapy. J Cell Comm Signal. 2014;4:289-91.

Carvalho LB, Alves PLCA, Duke SO. Hormesis with glyphosate depends on coffee growth stage. An Acad Bras Cienc. 2013;85:813-22.

Duke SO, Cedergreen N, Velini ED, Belz RG. Hormesis: Is it an important factor in herbicide use and allelopathy? Outlooks Pest Manage. 2006;17:29-33.

Enlist. [acesso em 15 Fev. 2019]. Disponível em: https://www.enlist.com/en.html.

Gazziero DLP, Voll E, Fornarolli D, Vargas L, Adegas FS. Efeitos da convivência do capim-amargoso na produtividade da soja. In: 28º.Anais do Congresso Brasileiro da Ciência das Plantas Daninhas. Campo Grande: 2012. p.345-50.

Gemelli A, Oliveira Junior RS, Constantin J, Braz GBP, Jumes TMC, Gheno EA, et al. Estratégias para o controle de capim-amargoso (*Digitaria insularis*) resistente ao glyphosate na cultura milho safrinha. Rev Bras Herb. 2013;12:162-70.

Goggin DE, Cawthray GR, Powles SB. 2,4-D resistance in wild radish: reduced herbicide translocation via inhibition of cellular transport. J Exp Bot. 2016;67:3223-35.

Leon RG, Ferrell JA, Brecke BJ. Impact of exposure to 2,4-D and dicamba on peanut injury and yield. Weed Technol. 2014;28:465-70.

López-Ovejero RF, Takano HK, Nicolai M, Ferreira A, Melo MSC, Cavenaghi AL, et al. Frequency and dispersal of glyphosate-resistant sourgrass (*Digitaria insularis*) populations across brazilian agricultural production areas. Weed Sci. 2017;65:285-94.

McDonald LM, Morgan T, Kingston G. Chemical ripeners: na opportunity for the Australian sugar industry. In: Proceedings of the 2000 Conference of the Australian Society of Sugar Cane Technologists held at Bundaberg. Queensland: 2000. p.290-5.

Nelson KA, Renner KA, Hannerschmidt R. Effects of protoporphyrinogen oxidase inhibitors on soybean (*Glycine max* L.) response, *Sclerotinia sclerotiorum* disease development, and phytoalexin production by soybean. Weed Technol. 2002;16:353-9.

Oliveira RB, Antuniassi UR, Gandolfo MA. Spray adjuvant characteristics affecting agricultural spraying drift. Eng Agric. 2015;35:109-16.

Silva A, Albuquerque DA, Anchieta AAJ, Alves JMA, Rocha JMR, Medeiros PRD, et al. Caracterização de plantas daninhas em área rotacionada de milho and feijão-caupi em plantio direto. Sci Agropec. 2018;9:113-21.

Streibig JC. Herbicide bioassay. Weed Res. 1988;28:479-84.

Streibig JC. Models for curve-fitting herbicide dose response data. Acta Agric Scand. 1980;30:59-64.

Taiz L, Zeiger E. Fisiologia vegetal. 3ª.ed. Porto Alegre: Artmed; 2004.719p.

Takano HK, Oliveira Junior RS, Constantin J, Mangolim CA, Machado MFPS, Bevilaqua MRR. Spread of glyphosate resistant sourgrass (*Digitaria insularis*): Independent selections or merely propagule dissemination? Weed Biol Manage. 2018;18:50-60.

Tropaldi L, Brito IPFS, Dias RC, Araldi R, Carbonari CA, Velini ED. Eficácia de herbicidas inibidores da síntese de carotenoides no controle de espécies de capim-colchão. Rev Cienc Agr. 2018;41:171-80.

Velini ED, Trindade MLB, Barberis LRM, Duke SO. Growth regulation and other secondary effects of herbicides. Weed Sci. 2010;58:351-4.

Velini ED, Alves E, Godoy MC, Meschede DK, Souza RT, Duke SO. Glyphosate applied at low doses can stimulate plant growth. Pest Manage Sci. 2008;64:489-96.

Voltolini GB, Castanheira DT, Gonçalves AH, Silva LG, Nascimento TLC, Netto PM. Ação do herbicida 2,4-D sobre o crescimento de mudas de cafeeiro. In: 9º Simpósio de Pesquisa dos Cafés do Brasil. 2015.