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Monitoring and baseline of glyphosate-resistant sourgrass in the main soybean growing regions of Brazil

Monitoramento e baseline da resistência de capim-amargoso ao herbicida glifosato nas principais regiões produtoras de soja no Brasil

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ABSTRACT

Frequent application of glyphosate for consecutive years has enhanced the selection pressure on sourgrass (*Digitaria insularis*) populations, which resulted in the development of glyphosate-resistant biotypes. Therefore, this work was developed with the objective of monitoring sourgrass resistance to glyphosate, develop a baseline of sourgrass susceptibility to this molecule and, consequently, identify the discriminatory dose between resistant and susceptible populations. This work was divided into three steps. The first step consisted of identifying and sorting sourgrass resistant and susceptible biotypes among 30 samples. In the second step, glyphosate baseline was elaborated considering exclusively the glyphosate-susceptible biotypes, which allowed the definition of a discriminatory dose. At the end, the third step, monitoring of glyphosate-resistant biotypes was achieved, considering five growing seasons (2016 – 2020) and 809 samples of sourgrass populations, collected throughout 12 states of Brazil. Glyphosate baseline was elaborated to sourgrass and ideal discriminatory rate was identified as 960 g ha^{-1}. Glyphosate-resistant populations of sourgrass were found in all soybean growing regions sampled. Among 809 populations, 25.96% were considered resistant to glyphosate. The states with the highest frequency of glyphosate-resistant populations were Rio Grande do Sul, Mato Grosso do Sul, Bahia, Mato Grosso and Paraná.

KEYWORDS: *Digitaria insularis;* discriminatory dose; mapping; dispersal; susceptibility.

RESUMO

Este trabalho foi desenvolvido com o objetivo de monitorar a resistência de capim-amargoso ao herbicida glyphosate desenvolver uma baseline de suscetibilidade da espécie e, por consequência, identificar a dose discriminatória de glifosato entre populações resistentes e suscetíveis de capim-amargoso. Todo o trabalho foi dividido em três fases. A primeira fase consistiu da análise de 30 amostras de capim-amargoso, identificando-as e classificando-as em resistentes ou suscetíveis. Na segunda fase, foi elaborada uma baseline para suscetibilidade do capim-amargoso ao herbicida glyphosate, o que permitiu a definição de uma dose discriminatória. Ao final, na terceira fase, obteve-se o monitoramento dos biótipos de capim-amargoso quanto à resistência, considerando-se cinco safras (2016 – 2020) e 809 amostras de capim-amargoso, oriundas de 12 estados brasileiros. Assim sendo, a baseline de suscetibilidade de capim-amargoso ao glyphosate foi estimada, cuja dose discriminatória ideal foi de 960 g ha-1. Populações de capim-amargoso resistentes ao glyphosate foram encontradas em todas as regiões produtoras de soja amostradas. Dentre 809 populações, 25,96% foram consideradas resistentes ao glyphosate. Os estados com maior frequência de populações resistentes foram: Rio Grande do Sul, Mato Grosso do Sul, Bahia, Mato Grosso e Paraná.

PALAVRAS-CHAVE: *Digitaria insularis;* dose discriminatória; mapeamento; dispersão; susceptibilidade.

INTRODUCTION

Glyphosate is the most important herbicide used globally for weed desiccation in no-tolerant crop areas and in perennial crops. Its high adoption is a consequence mainly of its broad spectrum of control and low cost (GALLI & MONTEZUMA 2005, DUKE & POWLES 2008). However, intense adoption of glyphosate promotes high selection pressure on weed populations, which may result in the detection of glyphosate-resistant biotypes (HEAP & DUKE 2018); a phenomenon that was observed in all regions of the world where glyphosate was used intensively (HEAP 2022).

Weed resistance to glyphosate was initially considered unlikely to evolve in nature, based on facts that intentional selection for tolerance to this herbicide, using whole plants or tissue culture, was not successful and mutants generated in laboratory with highly resistant EPSPs had undesirable enzymatic kinetics (BRADSHAW et al. 1997). This seemed to be true, since after 15 years of using glyphosate no cases of resistance had been detected. However, intensive application of glyphosate, mainly after introducing tolerant transgenic crops to this molecule (Roundup Ready - RR), enhanced selection pressure on weed communities, resulting in the evolution of glyphosate-resistant populations from eleven weed species in Brazil (HEAP 2022).

The number of species with glyphosate-resistant biotypes is not so expressive; however, the area where they may be found is expected to increase continuously due to the high number of applications achieved in perennial crops and in transgenic crops tolerant to this molecule (DUKE & POWLES 2008). In Brazil, frequent glyphosate application over several years has generated high selection pressure on sourgrass (*Digitaria insularis*) populations identified in some Brazilian states.

There are several different methods for detecting herbicide-resistant weeds (BECKIE et al. 2000). Field or greenhouse experiments, like dose-response curves using the whole plant, are the most common and precise; however, they depend on upon time and space if a huge number of samples are available. Glyphosate has a great variation in its recommendation dose, due to plants' phenological stage and different weed species (RODRIGUES & ALMEIDA 2018). Therefore, the knowledge of the species standard susceptible curve (baseline) and the discriminatory dose between resistant and susceptible biotypes is an excellent alternative for easier and fast identification of further samples of the same species.

In countries like the United States of America, where weed resistance to herbicides is widespread in large areas and present in many species, research and resources are allocated for mapping and monitoring areas with the presence of herbicide-resistant populations. This monitoring and mapping plan allows the detection of resistance at low frequencies, which helps direct proactive management of resistant populations. It is an important way of providing an early warning system to address the problem of herbicide resistance (ADEGAS et al. 2017). In Brazil, monitoring and mapping herbicide weed resistance has not been completely developed, making works like this important in the country.

Therefore, this work was developed to develop a baseline of sourgrass susceptibility to glyphosate and, consequently, identify the discriminatory dose between resistant and susceptible populations. With discriminatory dose, 809 sourgrass populations were evaluated and classified, which allowed monitoring dispersal of glyphosate resistance in sourgrass populations throughout five growing seasons in Brazil.

MATERIAL AND METHODS

This work was all developed in a greenhouse and it was divided into three steps. Among 30 samples of sourgrass populations, the first step consisted of identifying and sorting sourgrass resistant and susceptible biotypes. In the second step, the glyphosate baseline was elaborated considering exclusively the glyphosate-susceptible biotypes, which allowed the definition of a discriminatory dose for glyphosate. At the end, the third step, monitoring of glyphosate-resistant biotypes was achieved, considering five growing seasons and 809 samples of sourgrass populations, collected throughout 12 states of Brazil.

First step – Dose-response curves for 30 populations of sourgrass

Thirty populations of sougrass were evaluated, being collected in the main soybean growing regions of Brazil, in the states of Goiás, Minas Gerais, Mato Grosso e Paraná (Table 1 and Figure 1). In each area, seeds of at least 20 plants were collected, in physiological maturity. Geographical coordinates were also collected for all the sampling spots (data not presented).

In this experiment, seeds of sourgrass populations were distributed to 2.0 L plastic boxes, filled with proportion of commercial substrate (*Pinus* bark, turf and vermiculite) and vermiculite, 3:1 v/v. At the phenological stage of two definitive leaves, seedlings were transplanted to 1L-pots, filled with the same mixture of substrate and vermiculite, where they remained up to the end of the trials, in the medium density of three plants per pot, without water deficiency.

Table 1. Samples of sourgrass populations, state of collection and geographic coordinates adopted for evaluating glyphosate susceptibility.

State	Geographic Coordinates	
	Latitude	Longitude
GO	-17,78278	-50,96056
GO	-17,80556	-50,90278
GO	-17,31278	-50,51139
GO	-17,32028	-50,56889
GO	-17,31139	-50,60750
GO	-17,28167	-50,61056
GO	-17,29694	-50,66806
GO	-17,27250	-50,61139
MG	-18,17750	-49,88389
MG	-18,28222	-49,61278
MG	-17,48250	-49,41194
MT	-13,82778	-59,09417
MT	-15,06917	-53,65778
MT	-16,38583	-55,16472
MT	-13,68583	-55,52889
MT	-14,06250	-56,49250
MT	-12,02028	-55,69667
MT	-14,03389	-58,00333
MT	-11,61278	-55,48111
MT	-11,98306	-55,95361
MT	-13,20583	-55,27222
MT	-11,91694	-55,49833
MT	-12,33222	-55,98806
MT	-13,85556	-56,74861
MT	-13,02972	-56,06444
MT	-13,34250	-56,44556
MT	-14,05639	-52,36778
MT	-13,22278	-51,94944
PR	-24,60722	-53,40667
PR	-23,15694	-50,34278

Figure 1. Geographical distribution of sourgrass biotypes adopted for evaluating glyphosate susceptibility.

Glyphosate-susceptibility of sourgrass populations was measured by dose-response curves. Treatments were organized in completely randomized blocks, with six treatments (rates) and four replications. Following glyphosate rates were adopted (g ha^{-1} of equivalent acid): 7,680, 3,840, 960, 240, 120 and herbicide absence. Glyphosate applications were performed on plants on plants with 2-3 tillers. For that, a CO2 pressurized backpack sprayer was used, connected to a boom with two TeeJet XR 110.02 nozzles, positioned 0.50 m over the targets, and distributed 200 L ha^{-1} of spray solution.

Percent control and dry mass were evaluated 28 days after application (DAA). For percent control evaluation, score zero was considered for plants without herbicidal symptoms and 100% for dead plants. Mass of dry matter was reached by collecting all remaining plant structures in the pots and then drying that in an oven at 70ºC for 72 hours. Mass of dry matter was corrected to percent values by comparing mass measured in herbicidal treatments with check plots without herbicide, which were considered 100%.

Data analysis was performed by applying F test on variance analysis followed by non-linear regressions. Dose-response curves were fitted to log-logistic models. Percent control was fitted to the model proposed by STREIBIG (1988) (Equation 1).

$$y = \frac{a}{\left[1+\left(\frac{x}{b}\right)^{c}\right]} \quad (1)$$

Where: *y* = percent control; *x* = rate of the herbicide; and *a*, *b* and *c* = parameters of the curve, once *a* is the difference between the maximum and minimum points of the curve (amplitude), *b* is the rate that promotes 50% of variable response and *c* is the slope of the curve.

For mass of dry matter, it was adopted the log-logistic model proposed by SEEFELDT et al. (1995) (Equation 2).

$$y = a + \frac{b}{\left[1+\left(\frac{x}{c}\right)^{d}\right]} \quad (2)$$

Where: *y* = mass measurement; *x* = rate of the herbicide; and *a*, *b*, *c* and *d* = parameters of the curve, once *a* is the lower limit of the curve, *b* is the difference between the maximum and minimum points of the curve (amplitude), *c* is the rate that promotes 50% of variable response and *d* is the slope of the curve.

Log-logistic models have some advantages once one parameter of the equation is the estimative of C_{50} (control by 50%) or GR_{50} (growth reduction by 50%) (CHRISTOFFOLETI 2002). Although one parameter of the log-logistic model is an estimative of C_{50} or GR_{50}, its mathematical calculation was also performed using the inverse equation, according to the discussion proposed by CARVALHO et al. (2005). After rate-response curves were elaborated, accumulated response patterns of C_{50} and GR_{50} were evaluated for all populations, as well as the factor of resistance (F = R/S). Identifying resistant and susceptible samples allowed the elaboration of sourgrass susceptibility baseline for glyphosate.

Second step – Elaborating glyphosate-susceptible baseline to *Digitaria insularis*

In this step, among 30 initial samples, only glyphosate-susceptible populations were considered, according to evaluations performed in the first step. Response patterns for C_{80} and GR_{80} were also calculated for susceptible populations by inverse equation (CARVALHO et al. 2005). Its confidence interval was obtained using Equation 3.

$$\hat{m} \mp to\frac{s}{\sqrt{r}} \quad (3)$$

Where $\hat{m}$ = estimated mean or repetitions; t_o = value found in the table of ‘t’ test; *s* = standard deviations and r = number of repetitions.

Third step – Monitoring dispersal and glyphosate-resistance for *Digitaria insularis*

From several soybean growing regions of Brazil, 809 samples of sourgrass populations were collected throughout the seasons of 2016 (132 samples), 2017 (210 samples), 2018 (160 samples), 2019 (110 samples) and 2020 (197 samples). These samples were obtained from Brazilian states of Bahia, Goiás, Maranhão, Minas Gerais, Mato Grosso, Mato Grosso do Sul, Pará, Paraná, Rio Grande do Sul, Santa Catarina, São Paulo and Tocantins. Samples were collected between the months of January and March of each season, in areas where a lack of control was observed after glyphosate application.

At least 50 plants were sampled in each area, obtaining a composed sample of at least 1,000 seeds (BURGOS et al. 2013). Seeds were stored in paper bags and identified according to geographic coordinates, municipalities and state. For installing the experiment, seeds were distributed to plastic trays, filled with 1L of commercial substrate. At the beginning of tillering, plants were transplanted to 200 mL plastic pots also filled with commercial substrate, where they remained up to the end of the trails, at the density of three plants per pot.

The experimental design was completely randomized blocks with four repetitions. The discriminatory rate adopted was obtained in the previous step of this research. Classifying populations by using a single dose may be useful if this dose is enough to allow the survivance of resistant samples and the death of susceptible plants (BECKIE et al. 2000, BURGOS 2015).

Herbicide application was performed on plants with 2-3 tillers. The technology of application was the same adopted in the first step of this research, as well as evaluation methods. At 28 DAA, populations were classified as resistant (R), segregant (r) or susceptible (S), based on the methodology used by LÓPEZ-OVEJERO et al. (2017), presented in Table 1. Using geographical coordinates of each sample and evaluation results, maps were elaborated with spatial distribution of spots, using software QGIS 2.14.12. Spots of each sourgrass sample were colored in the maps according to the classification of susceptibility (Table 2), after 28 DAA evaluations. The frequency of glyphosate-resistant populations was calculated for each state, as well as, percent of susceptibility.

Table 2. Criteria, classification and color of sourgrass population samples in Brazil.

Criteria	Classification	Color
Control of all repetitions > 80%	S - Susceptible	White
One or two repetitions with control < 80%	r - Segregant	Yellow
Three or more repetitions with control < 80%	R - Resistant	Red

Adapted from López-Ovejero et al. (2017).

RESULTS AND DISCUSSION

Dose-response curves for 30 initial populations of sourgrass

Among 30 initial populations of sourgrass, 14 were considered susceptible to glyphosate, with C_{50} and GR_{50} means of 447.3 and 486.8 g ha^{-1}, respectively. Other 16 populations were considered resistant, with C_{50} or GR_{50} always above 1,000 g ha^{-1} of glyphosate (Tables 3 and 4). These values are in accordance with scientific literature in which C_{50} or GR_{50} of susceptible populations are usually found between 150 and 700 g ha^{-1} of glyphosate (CORREIA et al. 2010, GONÇALVES NETTO et al. 2015, ANDRADE et al. 2019, CANEDO et al. 2019).

Table 3. Log-logistic[1] parameters, coefficient of determination (R^2) and control by 50% (C_{50}), estimated on percent control, for 30 populations of sourgrass (*Digitaria insularis*) submitted to glyphosate applications.

Population	Percent control			R^2	C_{50}
	A	b	C		
1	99.312	264.576	-5.119	0.999	265.293
2	99.163	340.559	-1.556	0.998	344.276
3	100.141	389.275	-2.036	1.000	388.736
4	102.711	405.173	-1.648	0.977	392.399
5	102.407	436.427	-1.904	0.977	425.780
6	101.390	433.041	-2.537	0.994	428.384
7	99.990	454.931	-1.922	0.996	454.980
8	100.110	466.645	-2.708	0.995	466.266
9	101.499	482.228	-1.697	0.995	473.910
10	101.876	498.128	-1.779	0.995	487.924
11	99.881	505.204	-3.460	0.994	505.552
12	102.106	520.404	-2.184	0.982	510.665
13	102.603	552.691	-1.696	0.991	536.400
14	100.431	583.593	-3.381	0.989	582.112
15	105.486	1125.886	-1.348	0.988	1042.227
16	103.810	1127.821	-1.251	0.998	1063.528
17	109.511	1321.738	-0.978	0.997	1106.084
18	102.303	1148.426	-1.870	0.995	1121.108
19	104.535	1268.268	-1.416	0.991	1192.814
20	100.928	1233.104	-1.886	0.998	1221.137

21	111.520	1538.858	-0.940	0.994	1234.131
22	104.526	1435.546	-1.050	0.998	1321.799
23	101.101	1336.996	-1.932	0.999	1322.015
24	101.151	1425.584	-1.904	0.997	1408.648
25	107.742	1940.374	-1.286	0.997	1734.926
26	115.406	2738.982	-0.861	0.983	2004.739
27	100.444	2275.451	-2.019	0.998	2265.504
28	107.623	2630.095	-1.520	0.993	2395.661
29	103.967	2541.170	-1.355	0.999	2401.925
30	108.972	3290.100	-1.134	0.996	2844.511

[1]Log-logistic model: $y = a/(1+(x/b)^c)$.

Table 4. Log-logistic[1] parameters, coefficient of determination (R^2) and growth reduction by 50% (GR_{50}), estimated on dry mass, for 30 populations of sourgrass (*Digitaria insularis*) submitted to glyphosate applications.

Population	Mass of dry matter				R^2	GR_{50}
	a	b	C	d		
1	-0.194	100.178	276.801	2.885	1.000	276.399
2	0.651	99.789	352.407	1.644	0.996	357.131
3	-1.149	100.474	408.148	1.884	0.997	400.359
4	-1.118	100.499	474.662	2.053	0.999	466.734
5	-1.685	98.882	505.083	2.085	0.987	483.546
6	-0.005	99.344	486.749	2.177	0.997	483.758
7	-1.890	99.625	510.436	1.878	0.989	488.241
8	-2.152	101.134	513.608	1.727	0.995	495.292
9	-1.572	96.349	529.157	2.655	0.983	501.728
10	0.143	97.320	523.772	3.019	0.996	515.310
11	-0.690	99.036	553.370	2.276	0.997	541.973
12	-2.622	101.220	613.421	1.176	0.991	573.293
13	-0.743	99.379	611.483	2.545	0.999	601.377
14	-0.662	100.225	635.913	2.179	1.000	629.544
15	-4.729	103.746	1147.488	1.331	0.996	1056.303
16	-3.267	100.450	1171.152	1.439	0.991	1076.456
17	-1.272	99.653	1144.790	2.083	0.999	1113.346
18	-2.750	103.476	1178.856	1.532	0.983	1149.131
19	-5.558	106.501	1268.680	1.172	0.997	1178.140
20	-3.586	104.298	1250.224	1.070	0.997	1187.443
21	-3.330	103.622	1257.752	1.101	0.999	1192.495
22	0.112	98.650	1246.337	2.251	0.999	1233.764
23	-4.325	103.577	1364.062	1.472	0.995	1276.222
24	-3.936	104.795	1332.098	1.398	0.998	1277.290
25	-5.395	105.915	1814.606	1.083	0.993	1666.601
26	-2.373	101.990	1798.209	1.401	0.999	1730.153
27	-0.211	97.320	2027.357	2.270	0.997	1971.201
28	-6.423	106.726	2349.026	1.100	0.994	2116.290
29	-4.162	104.433	2396.542	1.909	0.997	2304.795
30	-5.432	102.732	2881.148	1.300	0.997	2550.089

[1]Log-logistic model: $y = a + b/(1+(x/c)^d)$.

With 16 resistant biotypes, means of C_{50} and GR_{50} might also be generated (1605.05 and 1504.98 g ha^{-1}), which allowed the calculation of F (factor of resistant). For percent control, F was about 3.58, and for dry mass it was about 3.09. The factor of resistance is an index that varies according to the biotypes, time of continuous herbicide selection in the areas and weed species (DUKE & POWLES 2008). For sourgrass

(*Digitaria insularis*), factors of resistance are usually considered low, between 5.6 (CARVALHO 2011) and 8.0 (CHRISTOFFOLETI et al. 2009).

Elaborating glyphosate-susceptible baseline to *Digitaria insularis*

For 14 glyphosate-susceptible populations of sourgrass, it was also calculated the mean of C_{80} (857.39 g ha^{-1} ± 81.85) and GR_{80} (941.16 g ha^{-1} ± 127,35) (Figure 2). Data was perfectly fitted to log-logistic models, with the coefficient of determination always above 99% (Table 5). Values of C_{80} and CR_{80} were calculated once they are the minimum level of efficacy required by current legislation (CARVALHO et al. 2005).

If adjust of percent control (Table 3), mass of dry matter (Table 4), baseline (Figure 2) and commercial recommendation (RODRIGUES & ALMEIDA 2018) are concomitantly considered, it becomes evident that 960 g ha^{-1} of glyphosate is the ideal discriminatory dose for sourgrass populations. Frequently, this dose is considered efficient for controlling glyphosate-susceptible biotypes and insufficient to control resistant biotypes (CORREIA et al. 2010).

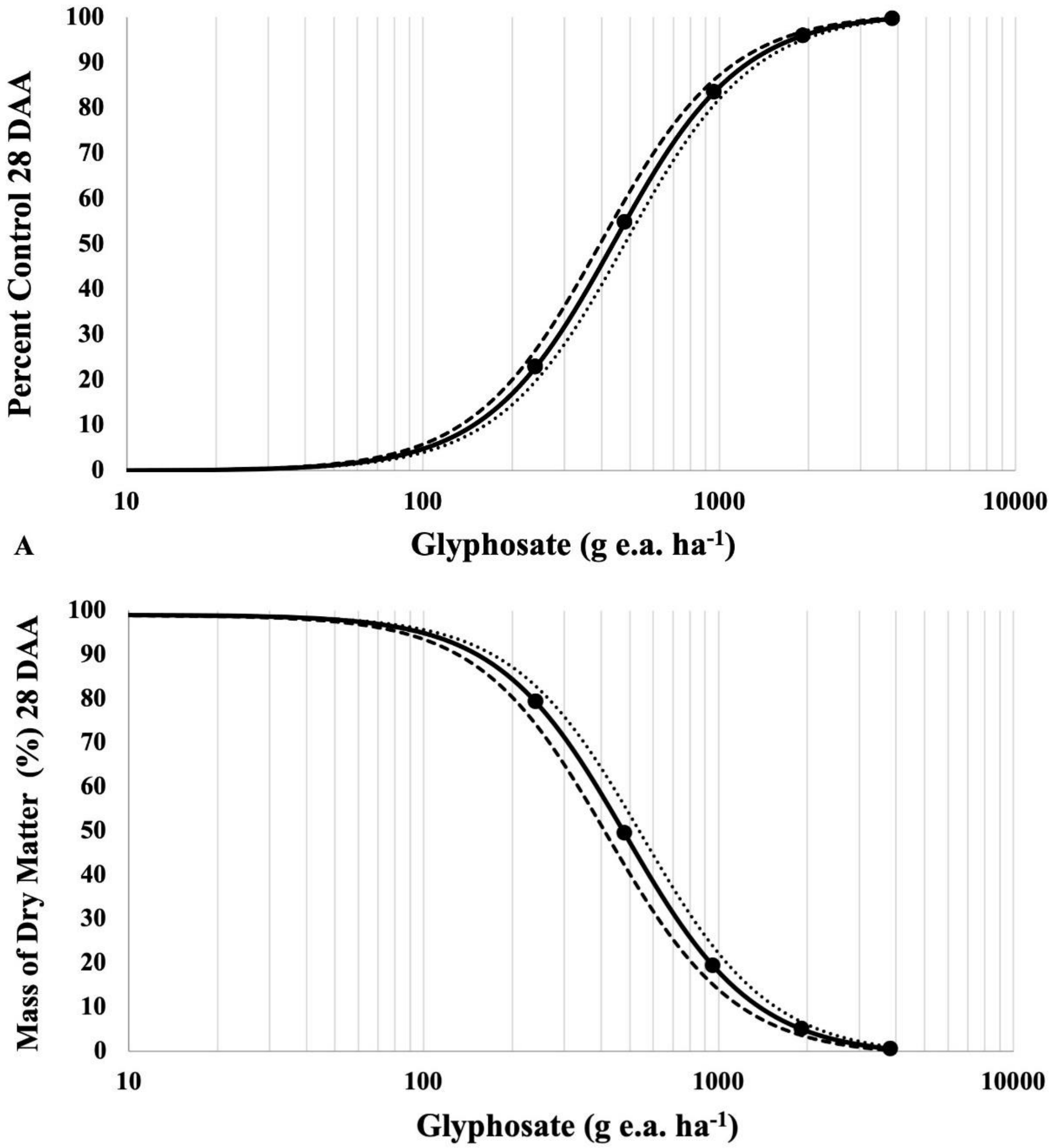

Figure 2. Means of percent control (A) and mass of dry matter (B) for 14 glyphosate-susceptible populations of sourgrass, submitted to different rates of glyphosate and evaluated at 28 days after application (DAA). Santa Bárbara D'Oeste - SP. 2022.

Table 5. Log-logistic[1] parameters, coefficient of determination (R^2), lethal doses (C_{80}), growth reduction (GR_{80}) and standard error for 14 glyphosate-susceptible populations of sourgrass (*Digitaria insularis*) submitted to glyphosate applications.

Variable	Parameter				R^2	C_{80} or GR_{80}	Standard Error
	a	b	c	d			
Control	100.95	440.95	-2.01	---	0.998	857.39	± 81.85
Dry mass	-1.08	100.11	485.11	1.99	0.998	941.16	± 127.35

[1] Log-logistic models; Control: $y = a/(1+(x/b)^c)$; Dry mass: $y = a + b/(1+(x/c)^d)$.

Monitoring dispersal and glyphosate resistance for *Digitaria insularis*

Following previous steps, 960 g ha^{-1} of glyphosate was considered the ideal discriminatory dose for resistant or susceptible populations throughout five years of evaluations. This way, among 809 populations of sourgrass, 74.04% were considered susceptible (S), 7.78% were evaluated as segregant (r) and 18.18% were identified as resistant (R). At least one glyphosate-resistant population was found in all Brazilian states (Figure 3). Accumulated r + R populations resulted in 25,96%, which may be considered a low frequency, after many years of glyphosate adoption.

Similar results were found by LÓPEZ-OVEJERO et al. (2017). These authors found glyphosate-resistant populations in all regions of Brazil. In this case, 2,593 biotypes were evaluated, sampled in 14 Brazilian states between 2012 and 2015. Among these samples, 26% were considered resistant to glyphosate.

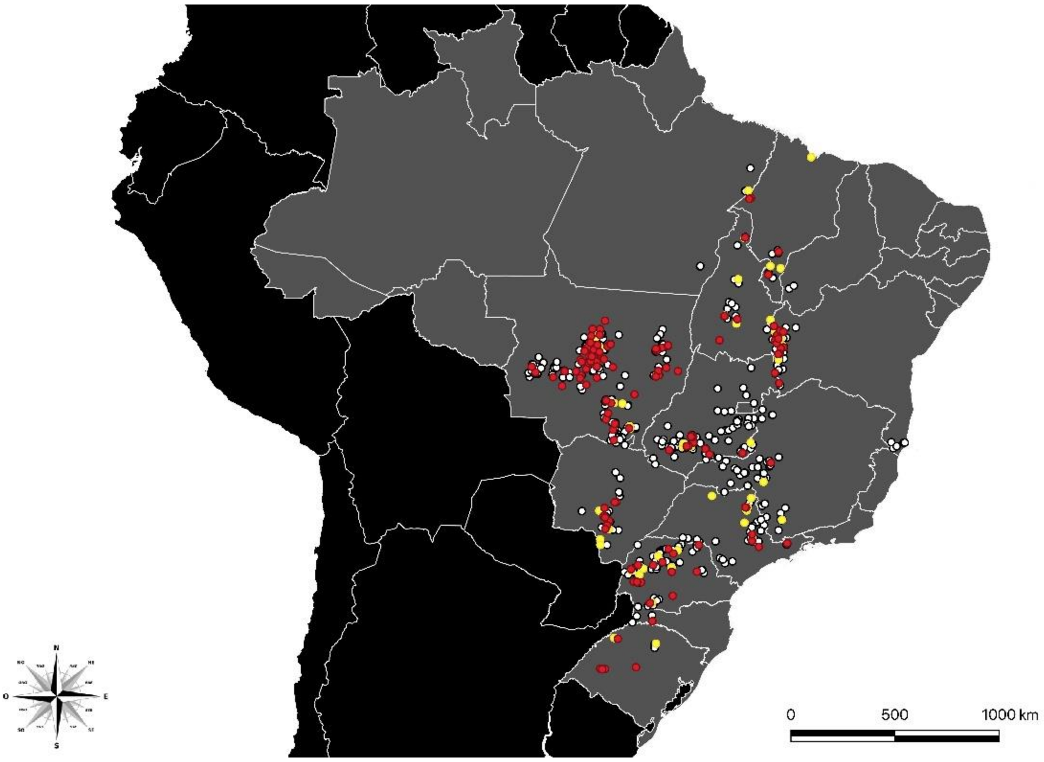

Figure 3. Dispersal of glyphosate-resistant (red), segregant (yellow) or susceptible (white) populations of sourgrass in Brazil, between the agricultural seasons of 2016 and 2020.

Mato Grosso was the state most represented by samples, with 252 populations (29,76%) (Table 6). Minas Gerais, Pará, Santa Catarina and Tocantins were the states with the lowest frequency of glyphosate-resistant populations. On the other side, the states with the highest frequency of glyphosate-resistant populations were Rio Grande do Sul, Mato Grosso do Sul, Bahia, Mato Grosso and Paraná (Table 6). Expansion of glyphosate-resistant transgenic crops (RR) to Central areas of Brazil, mainly soybean and maize crops, might have contributed to a strong selection of resistant biotypes. Glyphosate selection pressure is intense in RR crops, which may result in resistant biotypes of weeds (YANNICCARI et al. 2016).

Table 6. Number (Nº) and frequency (%) of glyphosate-resistant populations (R + r)[1] of sourgrass in Brazilian states, between seasons of 2016 and 2020.

State	Glifosato (960)		
	Nº	∑(R+r)	%
Bahia	69	25	36.23
Goiás	110	17	15.45
Maranhão	47	13	27.65
Minas Gerais	57	3	5.26
Mato Grosso do Sul	43	19	44.18
Mato Grosso	252	75	29.76
Pará	7	1	14.28
Paraná	84	25	29.76
Rio Grande do Sul	11	9	81.81
Santa Catarina	5	1	20.00
São Paulo	87	13	14.94
Tocantins	37	9	24.32
Total	809	210	25.95

[1](R + r = Resistant + Segregant).

The first case of a glyphosate-resistant population of sourgrass was reported in 2006, from Paraguay; after that, some other reports were done, including ACCase-EPSPs multiple resistance (HEAP 2022). This species has some characteristics that contribute to its infestation in agricultural areas, such as developing rhizomes and clumps, perennial cycle, C4 photosynthetic metabolism, and hairy seeds, which are easily dispersed by wind currents (PRESOTO et al. 2020, TAKANO et al. 2018, LORENZI 2014).

Besides wind dispersal of seeds, the movement of agricultural machines such as grain harvesters and seeders may also be responsible for the gene flow and, consequently, resistance dispersion (GONÇALVES NETTO et al. 2021). In this specific case of sourgrass, two main causes may be correlated to the fast dispersal of glyphosate-resistant populations. The first is related to the flow of rented machinery for harvesting grains, while the second is due to the local selection exerted by the repeated use of the same mechanism of action (TAKANO et al. 2018).

CONCLUSION

Glyphosate baseline was elaborated to sourgrass, and the discriminatory rate was identified as 960 g ha^{-1}.

Glyphosate-resistant populations of sourgrass were identified in all soybean growing regions sampled.

Among 809 populations, 25,96% were considered resistant to glyphosate.

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