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Periods of sourgrass interference in the soybean[1]

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ABSTRACT - Sourgrass (*Digitaria insularis*) is one of the principal weeds in Brazil, and there are reports of its being glyphosate-resistant. The aim of this study was to determine the coexistence period of the TMG7063 IPRO soybean cultivar with a weed community predominated by *D. Insularis*, with no negative interference on final production (period prior to interference - PPI), as well as to determine the period for which the crop must remain free of such interference (total period of interference prevention) in Brazil. The coexistence and control periods under study were 15, 30, 45, 60, 75, 90, 105, and 120 days after sowing (DAS) the soybean, with the experiment arranged in a randomized block design with four replications. At the end of each coexistence period and at the end of the control-period experiment (single collection), there was an increase in weed density, dry matter, and the relative importance of *D. insularis* as the coexistence period increased. The number of pods was reduced from 87 (from 120 DAS in the control) to 49 (from 75 DAS for coexistence), and maximum yield was reduced from 5,551.3 kg ha^{-1} (from 120 DAS in the control) to 3,998.6 kg ha^{-1} (from 60 DAS for coexistence) due to coexistence with the weed community. The PPI was estimated at nine DAS, with losses of 5.0%. It can be concluded that a weed community predominated by *D. insularis* reduces soybean yield by up to 59.3%. The 'TMG 7063 IPRO' soybean can coexist with a weed community predominated by *D. insularis* for up to nine days after sowing and tolerate a loss in yield of up to 5%.

Key words: *Digitaria insularis* (L.) Fedde. *Glycine max* (L.) Merrill. Weeds. Coexistence. PPI.

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INTRODUCTION

Soybean is cultivated at a highly technical level throughout all its stages of operation, which have, nevertheless, undergone several changes in such areas as management techniques (for example, direct sowing), besides the changes resulting from the introduction of transgenic cultivars. This has led to changes in the weed flora, particularly in soybean cultivars resistant to glyphosate (Roundup Ready®) and glufosinate-ammonium (Liberty Link®). The adoption of these cultivars has altered the use of post-emergent herbicides and led to changes in the composition of the weed flora (VENCILL *et al*., 2012).

Among the weeds that are difficult to control, sourgrass (*Digitaria insularis* (L.) Fedde) is becoming increasingly important in soybean crops in Brazil (LOPEZ OVEJERO *et al*., 2017), especially due its aggressive characteristics, such as reproduction from both seeds and rhizomes, clumpy formation, slow initial growth, and subsequent exponential dry matter accumulation (MACHADO *et al*., 2006). It is found in areas of no-tillage, in degraded pastures, at roadsides, and in vacant lots (MACHADO *et al*., 2008), and is reported to be glyphosate-resistant in various regions of Brazil (CARVALHO *et al*., 2011; LOPEZ OVEJERO *et al*., 2017).

Seeds from glyphosate-resistant plants have a higher rate of germination, which occurs at higher temperature ranges (between 15 ºC and 30 ºC) (MARTINS; BARROSO; ALVES, 2017; MONDO *et al*., 2010), higher water deficit, and greater sowing depths than seeds of susceptible plants (MARTINS; BARROSO; ALVES, 2017). Plants originating from rhizomes have a higher number of stomata per mm^2 and a thicker epidermis, albeit with no difference for rhizome starch accumulation (MACHADO *et al*., 2008).

The increasing occurrence of herbicide-resistant weeds following the adoption of transgenic soybean cultivars, a result of their inefficient control, can result in a potential loss in crop yield (SOLTANI *et al*., 2017). In the specific case of *D. insularis*, despite it being one of the principal weeds to affect the soybean crop, there is still a lack of field studies that determine the degree of interference it exerts and its periods of interference, if any.

The following periods of interference were defined by Pitelli and Durigan (1984): the period prior to interference (PPI), total period of interference prevention (TPIP), and critical period of weed control (CPWC). These periods are determined by means of regression curves that correlate crop yield to periods with the presence and absence of weeds.

Given the above, we raised the hypothesis *that D. Insularis* has a negative effect on growth and yield in the soybean, and that this interference might depend on the coexistence period. The aim of this study, therefore, was to determine: a) The interference of *D. insularis* in the TMG7063 IPRO soybean cultivar; b) the period for which the 'TMG7063 IPRO' soybean sown under no-tillage can coexist with a weed community predominated by *D. Insularis* from rhizomes (clumps), with no negative interference on final production (PPI); and c) the period that the crop might remain free of such interference (TPIP) in the region of Jaboticabal in the state of São Paulo, Brazil.

MATERIAL AND METHODS

This study comprised one experiment, installed and conducted in an area (21º15'22" S, 48º18'58" W, altitude 595 m) cultivated with soybean during the first season and maize during the off-season, in the 2019/2020 crop year. According to the Köppen climate classification, the climate is type Aw, with rainfall mainly during the summer. The experiment was conducted in an area with a history of predominantly *D. Insularis* infestation from rhizomes.

The soil in the experimental area is classified as a Eutrophic Red Latosol, with slightly wavy topography and good drainage (EMBRAPA, 2018). Chemical analysis of a soil sample (0-20 cm) showed a pH of 5.7, with 13 g dm^{-3} organic matter, 41 mg dm^{-3} P, and 2.3, 24, and 8 $mmol_c$ dm^{-3} K, Ca, and Mg, respectively, resulting in a base saturation (V%) of 61. When planting, 300 kg ha^{-1} 04:28:08 NPK formula were applied. Climate conditions during the experiment are shown in Figure 1.

The experiment was set up on October 31, 2019, under a no-tillage system in five rows using a fertilizer spreader (Frankhouser). The area was dried out before the soybean was sown together with glyphosate (Zap QI 620® - 2.0 L ha^{-1} c.p.) and cletodim (Cletodim Nortox® - 1.00 L ha^{-1} c.p.). The 'TMG 7063 IPRO' soybean cultivar was used, which has an indeterminate growth habit, an average cycle of approximately 114-135 days, and is moderately resistant to lodging, with a recommended population (stand) of approximately 222,222 plants ha^{-1} depending on the time of sowing (10 plants m^{-1}) (TROPICAL MELHORAMENTO & GENÉTICA, 2021).

The seeds were treated industrially with fipronil insecticide (Fipronil® - 200 mL of c.p.) and carbendazim and thiram (Derosal Plus® - 200 mL) per 100 kg of seeds. Fifteen seeds were distributed per meter at a spacing of 0.45 m between rows. The seeds were treated with *Bradyrhizobium japonicum* liquid inoculant (Atmo® - 100 mL 50 kg^{-1} seeds, bacterial concentration - 5 x 109 CFU mL^{-1}). Preventive phytosanitary treatment was carried out using the thiamethoxam and lambda-cyhalothrin insecticide (Engeo Pleno® - 250 mL ha^{-1} of c.p.) and the azoxystrobin and cyproconazole (Monaris®

- 300 mL ha^{-1} of c.p.), and pyraclostrobin and epoxiconazole (Opera® - 500 mL ha^{-1} of c.p.) fungicides.

The treatments consisted of models to determine the critical period of interference prevention. The following two interference models were used: (a) initially weedy-check (coexistence periods) and (b) initially weed-free (control periods). The models for the coexistence periods were used to determine the period prior to interference (PPI), during which the plots were maintained with weeds and soybean (coexistence) from emergence to the different development periods (15, 30, 45, 60, 75, 90, 105, and 120 (harvest) days after sowing). Following this period, the clumps of *D. Insularis* and the other weeds in the plots were removed manually, and the plots kept clean until the end of the cycle. The model for the control period was used to determine the total period of interference prevention (TPIP), in which the plots were kept without weeds from sowing the soybean to the different development periods (15, 30, 45, 60, 75, 90, 105, and 120 (harvest) days after sowing). Following these periods, *D. insularis* and other weeds that emerged in the area were allowed to grow freely.

A randomized-block experimental design was used in a 2 x 8 factorial scheme, with the factors comprising the two interference models (coexistence and control) and the eight periods, to give 16 treatments (Table 1), with four replications. Each plot consisted of seven rows of soybean seeds, 6 m in length and spaced 0.45 m apart, totaling 18.9 m^2. The five central rows were used as the working area for sampling and evaluation, disregarding 0.5 m at each edge, to give a total of 11.25 m^2.

A phytosociological survey was carried out at the end of each coexistence period between the weeds and the soybean crop. Weeds found in two sample areas of 0.25 m^2 (a total of 0.5 m^2 per plot) were randomly selected from the working area of each plot. The shoots of all plants in the sample area were cut close to the ground, removed from the plots, and identified using specialized literature (KISSMAN; GROTH, 1999; LORENZI, 2014). Once separated by species, they were counted and dried in a forced air circulation oven at 70 °C for 96 hours to determine the dry matter, and weighed on a 0.01-g precision balance. In this way, weed density and the dry matter of each species in the community were determined, allowing a phytosociological analysis to be carried out. The relative importance (RI) was then calculated; this comprises an index that includes three other indices: relative frequency, relative density, and

Figure 1 - Climate conditions during the experiment with the ‘TMG 7063 IPRO’ soybean. Rainfall (mm), relative humidity (%), maximum temperature (°C), and minimum temperature (°C), 2019/2020

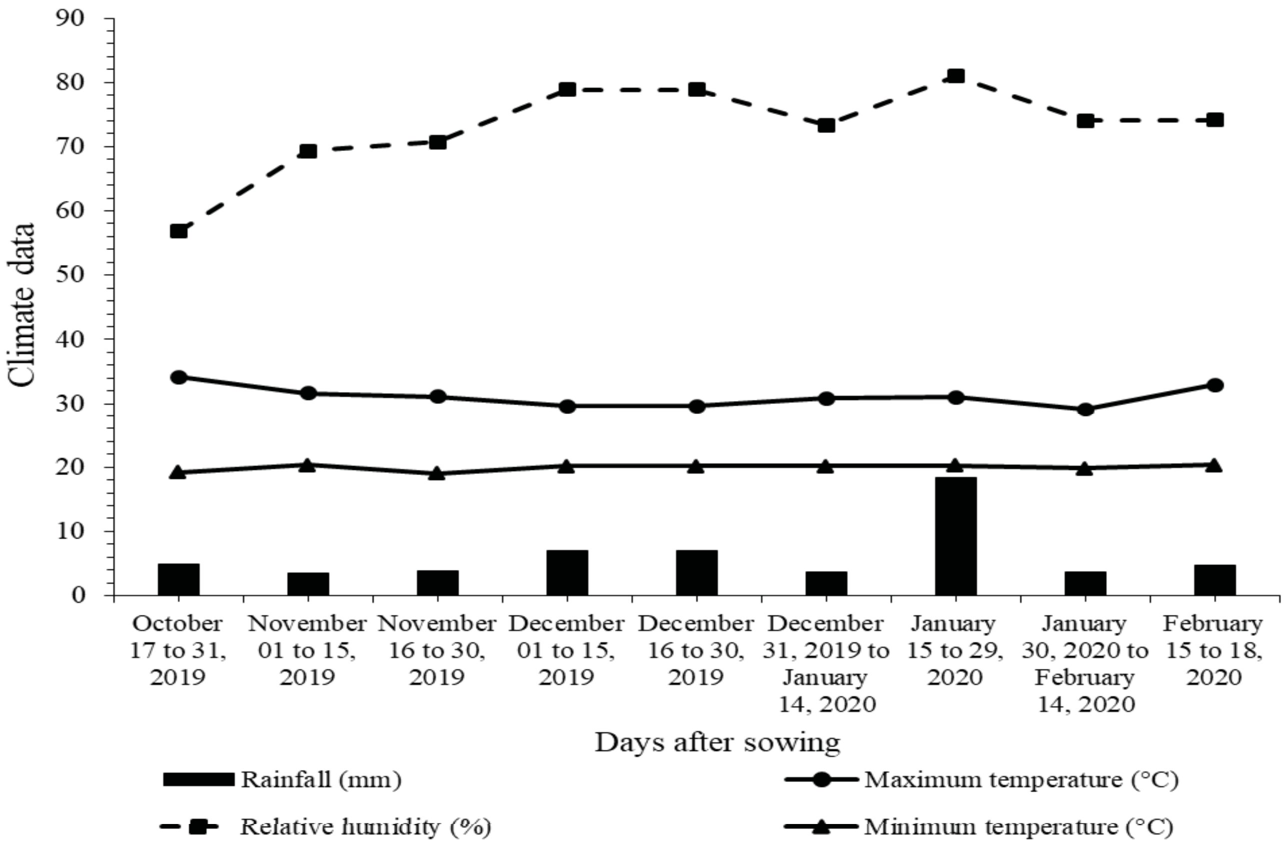


Table 1 - Experimental treatments to determine interference periods in the 'TMG 7063 IPRO' soybean, 2019/2020

Coexistence periods	Control periods
0 - 15	0 - 15
0 - 30	0 - 30
0 - 45	0 - 45
0 - 60	0 - 60
0 - 75	0 - 75
0 - 90	0 - 90
0 - 105	0 - 105
0 - 120	0 - 120

relative dominance, which together form the importance value index (IVI) of each species. The latter index is divided by the IVI of each species and multiplied by 100, resulting in the RI (MUELLER-DOMBOIS; ELLENBERG, 1974). The Shannon-Weaver index (H') and the equitability index (E') were also calculated (PINTO-COELHO, 2000).

To determine soybean yield, the five central rows of each plot were harvested when the grain moisture content neared 13%. The pods were threshed mechanically using a Nogueira thresher, and any harvested grains were weighed on a 0.01-g precision balance. The yield data were extrapolated to the hectare and analyzed separately for each model (initial periods of coexistence or weed control). Yield results were submitted to regression analysis using the Boltzmann sigmoidal model, as per Kuva *et al*. (2001).

$$Y = A_2 + \left[\left\{A_1 - A_2\right\} / \left\{1 + e^{((x-zo)dz)}\right\}\right] \quad (1)$$

Based on the regression equations, periods of weed interference were determined for an arbitrary tolerance level of 5.0%, and a 10.0% reduction in yield compared to the weed-free control treatment. The OriginPro® v8.5 software (Origin Lab® Corporation, Northampton, MA, USA) was used for the regression analysis.

Ten soybean plants per plot were evaluated for height (m) and number of pods. The data were subjected to analysis of variance and when significant, the mean values were compared using Tukey's test at 5% probability.

RESULTS AND DISCUSSION

Only six weed species from six families were identified (Table 2) in the phytosociological survey. During the coexistence periods, only two species were identified among the six: *D. Insularis* and *Acanthospermum hispidum*, while the six species were all present during the control periods. The low diversity of weed species in the area can be explained by the previous type of management (no-tillage with glyphosate), and by the aggressiveness of the species, which became more dominant in the area throughout their development, while the other species were suppressed or died (RADOSEVICH; HOLT; GHERSA, 1997), with *D. Insularis* highlighted as possibly already glyphosate-resistant.

Analyzing weed density in response to the coexistence periods, the first peak (4.00 plants m^{-2}) was seen 30 days after sowing (DAS), decreasing at 45 and 60 DAS (3.50 and 2.75 plants m^{-2}, respectively), with a new peak at 75 DAS, to reach the maximum value of 4.75 plants m^{-2}. The density of the weed community went down again in the next evaluation and then remained stable until the end of the experiment (Figure 2), resulting in an average of 3.5 plants m^{-2} over the experimental period. The plots of the control periods showed two peaks in emergence, at 45 and 105 DAS, with 3.25 and 3.00 plants m^{-2}, respectively. The maximum number of individuals was seen at 45 DAS; there was generally a reduction in density before and after each peak. According to Ross and Lembi (2008), more than one peak in germination may occur during the crop cycle due to the asynchronous germination of the seeds.

Shoot dry matter accumulation in the weeds was exponential during the coexistence periods (Figure 3), corroborating the results of Machado *et al*. (2006) for *D. insularis* in an experiment with plants originating from rhizomes; during the control periods, this value was minimal, reaching a maximum of approximately 61 g m^{-2} at 75 DAS. Dry matter accumulation was low, as the weed species that infested the area present slow initial growth and may have been suppressed by the rapid formation of the soybean canopy (GAZZIERO *et al*., 2019). In addition, most of the weeds found in the area reproduce by seed (LORENZI, 2014), with the low rainfall and temperature (Figure 1) during the experiment thereby contributing to low germination and poor plant establishment.

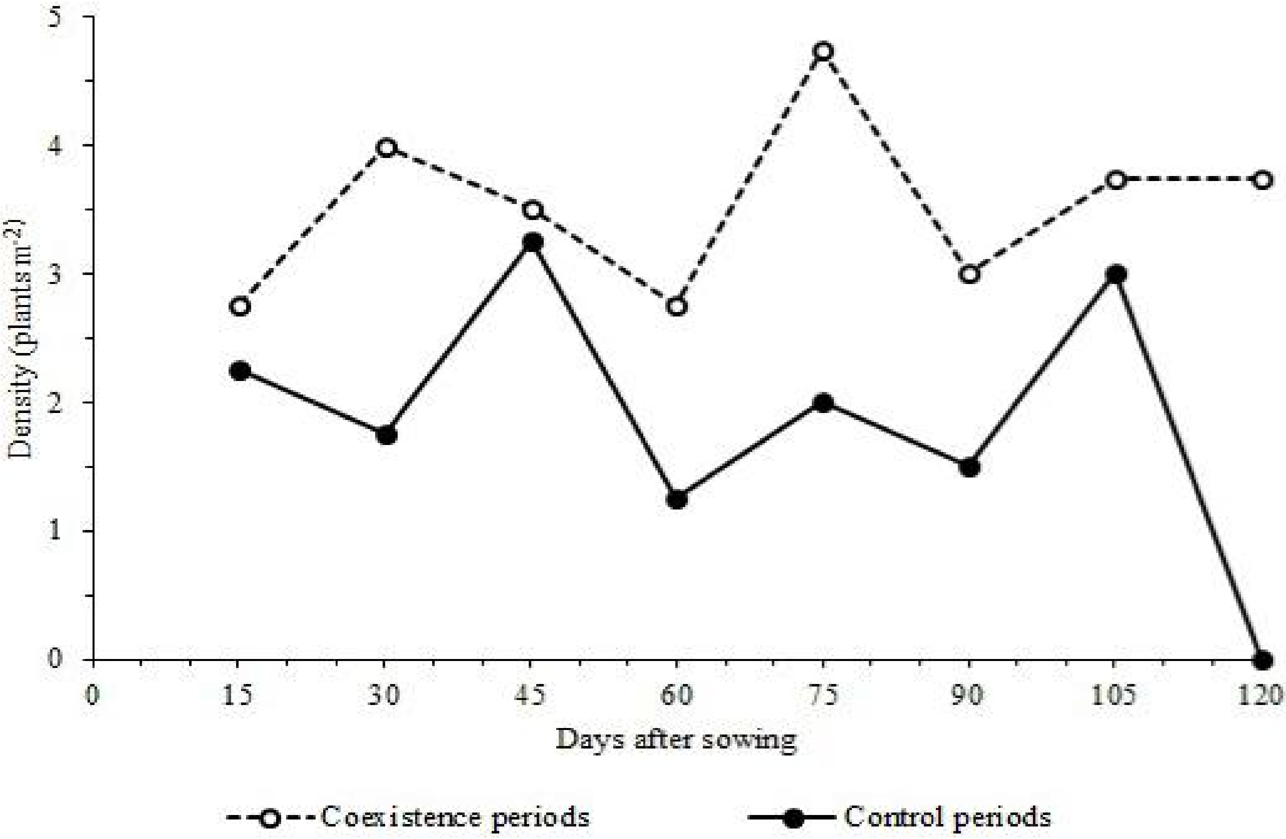
The most prominent weed during the coexistence periods was *D. insularis* (DIGIN) (Figure 4), this being the only species found in the plots in the evaluations at 15, 30, 45, 60, 90, and 105 DAS; in the other evaluations, DIGIN achieved an RI of 94.45 and 93.51 at 75 and 120 DAS, respectively. For the control periods (Figure 4), the RI of the other weeds (Others) was 100 in each of the evaluations, except at 45 DAS (92.79), when *D. insularis* was 7.21. *D. insularis* may have been suppressed by the other infesting species, as it shows slow initial growth up to 45 days, especially under shaded or low light conditions (MACHADO *et al*., 2006), but also by the type of management, since the plants were cut. This result shows that adopting a control measure up to 15 DAS allows the crop to control the weed community.

Table 2 - List of weed species in the 'TMG 7063 IPRO' soybean, 2019/2020

Family	Species	Code*	Common name in Portuguese
Amaranthaceae	Alternanthera tenella Colla	ALRTE	Apaga-fogo
Commelinaceae	Commelina benghalensis L.	COMBE	Trapoeraba
Convolvulaceae	Ipomoeasp.	-	Corda-de-viola
Fabaceae	Indogofera hirsuta L.	INDHI	Anilera
Poaceae	Digitaria insularis L.	DIGIN	Capim-amargoso
Asteraceae	AcanthosperumhispidumDC.	ACNHI	Carrapicho-de-carneiro

*International Weed Society international code

Figure 2 - Density of the weed community based on the coexistence and control periods in the 'TMG 7063 IPRO' soybean, 2019/2020



The diversity index (H') and the equitability (E') index for each coexistence period within each period of evaluation (Table 3) were null, which shows the predominance of *D. insularis* in the area, except for the evaluations at 75 and 120 DAS, with 0.35 for H' and E' and 0.29 (H') and 0.41 (E'), respectively. During the control periods, the diversity and equitability indices varied little in the evaluations, so it can be said that the area did not undergo any major changes (DAJOZ, 2005).

There was no significant difference in plant height or 1000-seed weight in the soybean for the periods of weed interference (Table 4); this corroborates the results of Gazziero *et al*. (2019) for soybean under the interference of *D. insularis* regrowth.

The number of pods per plant (NPP) shown in Table 4 was reduced by 44% from 75 DAS for the coexistence periods and the control periods, and by 31%

Figure 3 - Shoot dry matter of the weed community in the 'TMG 7063 IPRO' soybean under different coexistence and control periods, 2019/2020

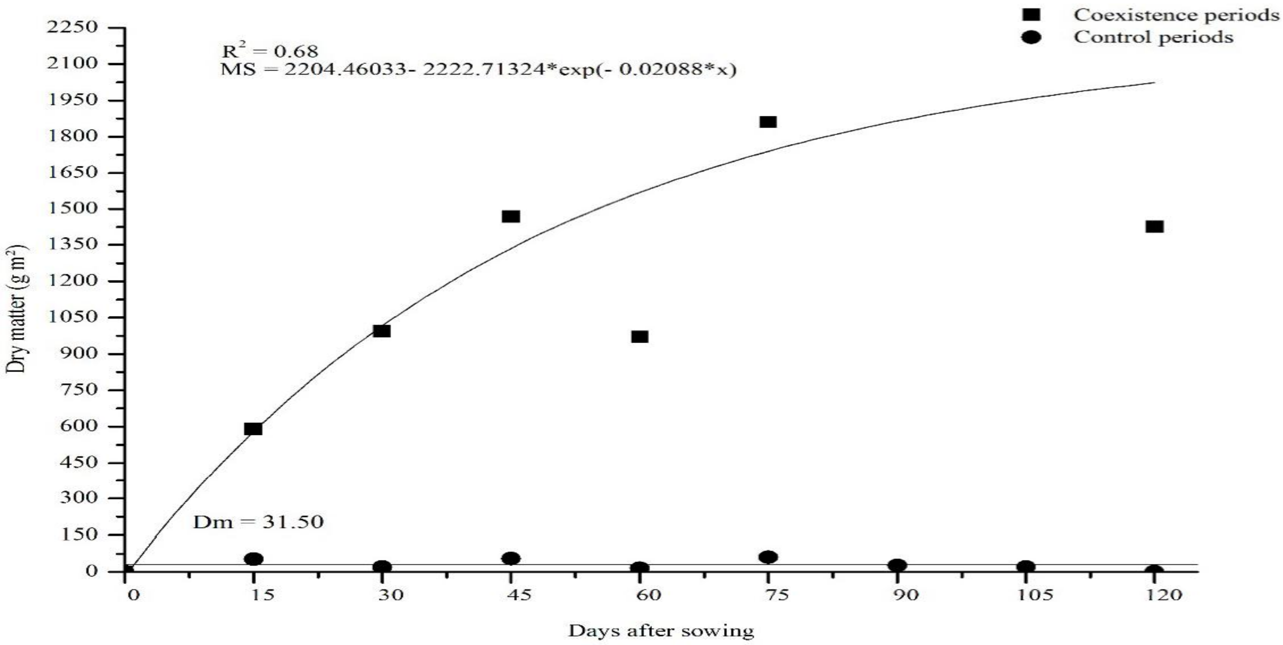
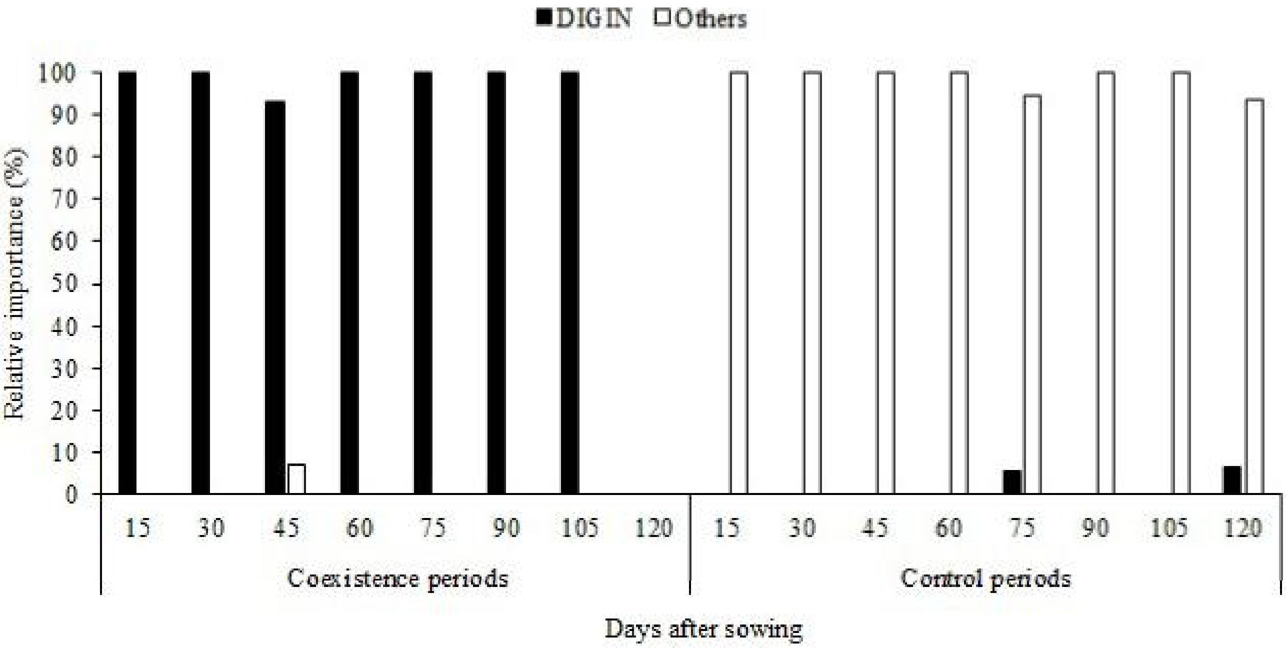


Figure 4 - Relative importance of sourgrass (DIGIN) and other weeds (Others) under different coexistence and control periods in the 'TMG 7063 IPRO' soybean, 2019/2020



from 60 DAS onwards. This result corroborates that of Tavares *et al*. (2012) of 29% for the Pioneer 98Y11 cultivar, and of 49% for the Pioneer 98C81 cultivar coexisting with weeds.

The results for soybean yield (Table 4) showed an average reduction of 28% for the coexistence periods from 60 DAS onwards compared to the control period of 120 DAS. The values for the upper limit of the period prior to interference (PPI) were estimated, with a tolerable reduction of 5.0% and 10.0% in soybean yield. It was therefore possible to determine the PPI at 9 and 37 DAS (Figure 5). A similar result was found by Zandoná *et al*. (2018) for three sowing periods in soybean in competition with weeds at 14, 15, and 5 days after crop emergence,

Table 3 - Shannon-Wiener index (H') and Equitability index (E') of the weeds as a function of the periods of evaluation in the 'TMG 7063 IPRO' soybean, 2019/2020

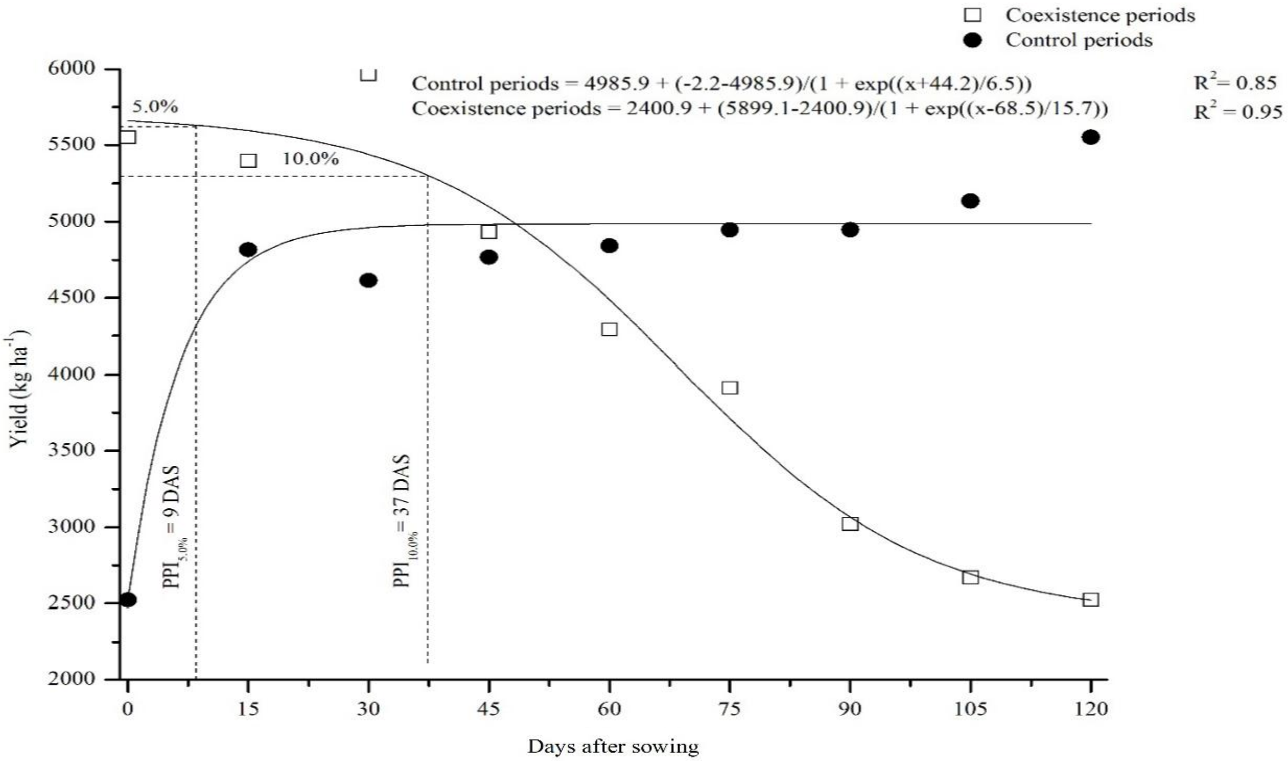
DAS	Coexistence period		Control period	
	H'	E'	H'	E'
15	0.00	0.00	1.21	0.61
30	0.00	0.00	0.60	0.60
45	0.00	0.00	1.41	0.55
60	0.00	0.00	0.67	0.67
75	0.35	0.35	0.90	0.57
90	0.00	0.00	1.01	0.64
105	0.00	0.00	0.72	0.45
120	0.29	0.41	0.00	0.00

DAS: Days after sowing; diversity coefficients: H'—Shannon-Weaver, E'—Equitability

Table 4 - Effect of the coexistence periods and weed control on plant height, number of pods per plant, and 1000-seed weight in the 'TMG 7063 IPRO' soybean during the periods of evaluation, 2019/2020

Treatme nt DAS	PH (m)	NPP	W1000S (g)	Y (kg ha^{-1})
Coexistence periods				
0 - 15	1.1 a	76 ab	172.0 a	5397.3 ab
0 - 30	1.1 a	72 abc	174.6 a	5966.1 a
0 - 45	1.0 a	78 ab	173.1 a	4932.1 ab
0 - 60	1.1 a	75 ab	184.7 a	3998.6 bcd
0 - 75	1.1 a	49 e	188.6 a	3913.1 bcd
0 - 90	1.1 a	52 cde	175.3 a	3020.7 cd
0 - 105	1.1 a	50 de	171.4 a	2670.7 d
0 - 120	1.1 a	52 cde	170.9 a	2523.0 d
Control periods				
0 - 15	1.2 a	71 abc	175.6 a	4816.9 abc
0 - 30	1.2 a	70 abcde	174.8 a	4612.8 abc
0 - 45	1.2 a	68 abcde	167.8 a	4766.7 abc
0 - 60	1.1 a	60 bcde	166.9 a	4842.1 abc
0 - 75	1.2 a	60 bcde	171.6 a	4945.9 ab
0 - 90	1.1 a	70 abcd	174.4 a	4948.8 ab
0 - 105	1.2 a	70 abcd	172.5 a	5134.1 ab
0 - 120	1.2 a	87 a	186.2 a	5551.3 ab
F treatment	1.26^{NS}	7.57**	1.98*	7.81**
F block	5.64**	1.65^{NS}	0.72^{NS}	4.19*
DMS (5%)	0.21	21.01	22.73	1858.36
CV (%)	7.27	12.36	5.01	16.10

Figure 5 - Yield of the ‘TMG 7063 IPRO’ soybean under different periods of weed interference with estimates of the period prior to interference (PPI), 2019/2020



respectively. Analyzing the equation, the yield decreased from 5,899 to 5,604 and 5,309 kg ha^{-1}, respectively, during the determined PPI. However, when the extremes are compared, i.e. the total weed-free period and total weedy-check period, the yield of the ‘TMG 7063 IPRO’ soybean decreased by 59.3% (2,401 kg ha^{-1}), clearly demonstrating the need to control a weed community consisting almost exclusively of *D. insularis*. These results are similar to those of Gazziero *et al*. (2019), who found a high reduction in soybean yield, ranging from 500 to 1,400 kg ha^{-1}, resulting from the low plant density of *D. Insularis* from clump regrowth.

CONCLUSIONS

1. A weed community with the predominance of *D. insularis* reduces yield in the ‘TMG 7063 IPRO’ soybean by up to 57.5% by reducing the number of pods per plant, without affecting the 1000-seed weight or plant height;
2. The ‘TMG 7063 IPRO’ soybean can coexist with an infesting community with a predominance of *D. insularis* for up to nine days after sowing, tolerating a loss in yield of up to 5%.

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