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Control period and economic threshold level of glyphosate tolerant weeds in 2.4-D resistant soybean.

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Abstract

Weed densities, species, costs of control, crop value and interference periods should be considered for weed management. With this regard, three experiments were carried out to evaluate weed control periods and weed density in a new soybean cultivar. In ths first trial, control efficacy was measured by visual phytotoxicity of four weed species *I. hederifolia*, *E. heterophylla*, *Conyza* spp. and *R. brasiliensis* using four different herbicides with two doses each: glyphosate (720 and 1,440 g ea ha^{-1}), 2.4-D (670 and 1,340 g ea ha^{-1}), glufosinate (400 and 600 g ea ha^{-1}) and glyphosate + 2.4-D (410 + 390 and 820 + 780 g ea ha^{-1}). Herbicides were sprayed in an entirely randomized 4x8+1 factorial scheme with six repetitions. In the second experiment, 2,4-D-resistant soybean growth was measured under increasing densities of the same weeds (21 plants m² *vs* 21, 42, 84, 168 and 336 plants m²). This experiment was conducted under entirely randomized design with 25 treatments with four repetitions. Critical level of damage and economic threshold level of each weed species in soybean were measured using non-linear regressions. In a third experiment, weed with soybean were submitted to increasing periods of control and coexistence (7, 14, 21, 28, 35, 49 and 70 days after soybean emergence, plus two control treatments). Glufosinate and glyphosate+2.4-D (820 + 780 g ea ha^{-1}) showed greater weed control than glyphosate alone (720 g ea ha^{-1}). The yield loss of 0.85, 2.12, 5.71 and 34.24% were found for each weed of *E. heterophylla, I. hederifolia*, *R. brasiliensis* and *Conyza* spp., coexisting with soybean. There was a soybean grain yield loss of 50% in the weedy treatment. Soybean weed management should occur between 18thand 48th days after its emergence. Economic threshold level on soybean yield suggested is below one plant of *Conyza spp*. and *R. brasiliensis* per m^{-2}. The use of glufosinate and glyphosate+2,4-D provides a greater flexibility of herbicide use for farmers.

Keywords: Brazil pusley, hairy fleabane, herbicide, morning glory, wild poinsettia.
Abbreviations: CLD_Critical Level of Damage; CPIP_Critical Period of Interference Prevention; ETL_Economic Thresold Level; PPI_Period Prior to Interference; REI_Relative Importance Index; TPIP_Total Period of Interference Prevention.

Introduction

Soybean may be the most important crop for human and animal nutrition, with 36.2 million hectares planted in Brazil and 341 million tons produced worldwide (CONAB, 2020). Among the barriers to higher soybean yield, the presence of herbicide tolerant and resistant weeds, increases production costs and interferes with crop development, leading to yield losses (Varah et al., 2019). The best decision making for weed control and reduced herbicide usage is derived from the determination of the levels of interference of each species together with the control efficacy data of different herbicides, added to the production costs of the crop (Das et al., 2010; Galon et al., 2019; Zhang et al., 2016). Weed interference can be estimated using the Critical Level of Damage (CLD), represented by the percentage of crop yield interference caused by one individual of a given species. In soybean, CDL, of *Conyza* spp. or *Richardia brasiliensis* can range from 0.97% to 2.0% (Diesel et al., 2016). Another species, such as *Ipomoea* spp. and *Euphorbia heterophylla*, can reduce soybean yield about 45% and 22%, respectively (Piccinini et al. 2018; Rizzardi et al., 2004).

The Economic Threshold Level (ETL) of weeds is corresponded to the density of the species, in which the control cost equals the crop yield loss. It is calculated based on weed interference, herbicide cost and efficacy and crop value (Kalsing e Vidal, 2010; Das et al. 2010; Galon et al., 2007; Tironi et al., 2016). This calculation helps in adoption of management strategies, besides mitigating the misuse of herbicides (Agostinetto et al., 2019; Hazra et al., 2011). Another important aspect for the success in weed management is the definition of the moment when the control should occur (Swanton et al., 2015). Three periods are important such as total period of interference prevention (TPIP), period prior to interference (PPI) and critical period of interference prevention (CPIP). The study of these periods determines the period, in which the methods of weed control are most effective (Tursun et al., 2016).

Furthermore, the adoption of biotechnological tools, such as 2,4-D herbicide-tolerant soybean cultivars, allows the rotation of the glyphosate, decreasing the selection pressure within production systems. ENLIST E3™ soybean is a new technology that promotes soybean post-emergence tolerance to the application of 2,4-D, becoming an important alternative for the management of weeds such as *Conyza* and *E. heterophylla*, both resistant to glyphosate (Simpson et al., 2017; Robinson et al., 2015; Wright et al., 2010). No information about weed interference or weed control periods exists in worldwide literature for this cultivar.

Therefore, this study aimed to calculate CLD and ETL of *I. hederifolia*, *Conyza* spp., *E. heterophylla* and *R. brasiliensis*, using 2.4-D, glyphosate, glufosinate and glyphosate + 2.4-D herbicides and to determine the periods of interference of a weed community in the 2.4-D resistant soybean.

Results and discussion

Glyphosate tolerant weed chemical control options

There were both visual (phytotoxicity level) and physical (dry mass) differences in weed control treatments. In relation to phytotoxicity, there was a significant interaction between herbicides and weed species, while dry mass differed only among herbicides (Table 1). Treatment with glyphosate (1,440 g ea ha^{-1}) and glufosinate (400 and 600 g ea ha^{-1}) proved to be effective in controlling all weed species. At the lowest rate of glyphosate (720 g ea ha^{-1}), control of *R. brasiliensis* and *E. heterophylla* was not effective. Similar results were found in both species, where low glyphosate doses were inefficient (Carvalho et al., 2003; Takano et al., 2013). For *Richardia brasiliensis* the most effective treatments were the application of the highest doses of glyphosate and 2.4-D, glufosinate at both doses and the glyphosate + 2.4-D mixture (410 + 390 g and ha^{-1}) while *E. heterophylla* showed to be controlled by the same herbicides but needed higher doses of glyphosate + 2.4-D (820 + 780 g and ha^{-1}). Comparison of glufosinate with 2.4-D, glufosinate showed that the mean weed control degree was higher. In its lowest dose (400 g ea ha^{-1}), its control was above 90% for all weed species. In all studied species, Glyphosate + 2.4-D (410 + 390 g ea ha^{-1}) showed higher control (80%) even at higher doses of glyphosate alone. This fact is important, especially in the current scenario, where the resistance of *E. heterophylla* to glyphosate was recently found in Brazil (Table 3). The use of 2.4-D as an option for broadleaf weed control is highlighted in other studies, where reported synergistic effect of this molecule mixed with glyphosate (Carvalho 2003; Takano et al., 2013; Osipe et al., 2017; Kozlowski, 2001).

Regarding to the dry mass of weed plants, all herbicides differed from the treatment without herbicide application. 2.4-D (1,209 g ea ha^{-1}), glufosinate and glyphosate + 2.4-D (820 + 780 g ea ha^{-1}) showed greater weed suppression capacity than glyphosate (720 g ea ha^{-1}). Glufosinate showed better control than 2.4-D, controlling all species more than 90%. Similar data was found by Castro (2019), with 100% control of *E. heterophylla* and *Ipomoea* spp. using 300 and 150 g ea ha^{-1} of glufosinate, respectively.

Critical damage level and economic threshold level

In terms of weed interference on soybean, major reductions were found even at low densities, being *Conyza* spp. the specie that causes the higher damage at lower densities, while *Ipomoea hederifolia* caused the smallest damage (Figure 1). The critical level of damage, which is represented by the percentage of crop yield interference by each individual of a given weed species were 0.85, 2.12, 5.71 and 34.24% respectively for *I. hederifolia, E. heterophylla, R. brasiliensis* and *Conyza* spp. These findings are important contribution to the field of weed management. The resistance to glyphosate is common *Conyza* spp. in plant coexisting with soybean during all crop cycle.

The economic threshold level (ETL) (Figure 2) shows that the weed control should give priority to suppress *Conyza* spp. > *Richardia brasiliensis* > *Ipomoea hederifolia* > *Euphorbia heterophylla,* considering a scale of greater to lower importance of these weed species.

Under the studied circumstances and considering soybean yield loss due to weed interference caused by *Conyza* spp. and *R. brasiliensis*, is it possible to infer that ETL was always below one weed plant per m^{-2}. This indicates that the control of the species must be carried out independent of its density per square meter. Plants of *Conyza* spp. and *R. brasiliensis* cannot growth with soybean crop. In this case, the choice of herbicide for management will depend on its effectiveness.

Conyza spp. has a worldwide resistance to glyphosate. Therefore its control with the use of cover crops or pre-emergence herbicides before soybean establishment before or early after soybean sowing to suppress this weed is of great importance. If it remains on field beyond soybean yield loss, there will be an increase of this weed specie in the next crop seasons due to its seed production. *Chenopodium album* also presents this behavior in soybean (Fischer et al., 2004). At these cases, authors argue that weed not only competes in resources with crop, but also presents high chances of allelopathy (Shabbir and Javaid, 2010). For example, *Conyza* spp. is proved to reduce soybean root development by 20%, affecting nutrient and water absorption (Rockenbach and Rizzardi, 2019).

The Economic Threshold Level (ETL) for *I. hederifolia,* considered that all the herbicides were effective for its control, aiming the choice of herbicide conditioned to the density of plants per area in a range of zero to one plant m^{-2} and also to the price of the herbicide. In this case, the tolerated ELD of 0.3 plant m^{-2} for the cheapest herbicide (glyphosate 720 gea ha^{-1}) and up to 1.2 plant m^{-2} when the herbicide chosen was glufosinate at a dose of 600 g ea ha^{-1} and/or glyphosate + 2.4-D at a dose of 820 + 780 g ea ha^{-1} is required.

Regarding to *E. heterophylla* herbicide control efficacy, the study points out four effective options: Glyphosate at dose 1,440 g ea ha^{-1} can be used as long as the population does not exceed 1.5 plant m², and when this threshold is exceeded, glufosinate appear as an efficient alternatives to be used in a plant population up to 2.3 or 3.14 plants m² (at doses of 400 and 600 g and ha^{-1}, respectively).

Combination of glyphosate + 2.4-D at doses of 820 + 780 g ea ha^{-1} allows the presence of *I. hederifolia*, as an effective control for all plants present in the area as suggest by Trezzi et al. (2005).

Table 1. Significance values for isolated factors and interaction between weed species and herbicides applied for visual control (%) and weed dry mass (g).

Factors	Visual control (%)	Drymass (g)
Species	<0.0001	0.0952
Herbicide	<0.0001	<0.0001
Species x Herbicide	<0.0001	0.4181
CV*	9.18	38.70

*Coefficient of variation. Values below than 0,005 are significantly different by 5% Tukey's test. Values below 0,001 are significant different by 1% Tukey test.

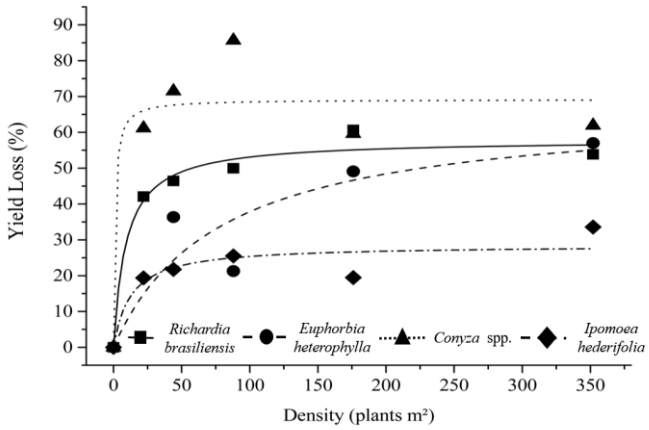

Fig 1. Soybean yield loss (YL) in coexistence with increasing densities of weeds: *R. brasiliensis* (■YL=(57,94x)/(9,13+x), R^2=0,97), *E. heterophylla* (●YL== (61,17x)/(77,54+x), R^2=0,76), *Conyza* spp. (▲YL=(69,18x)/(1,02+x), R^2=0,86) and *I. hederifolia* (♦YL=(28,49x)/(12,38+x), R^2=0,81).

Table 2. Herbicides phytotoxic levels (%) on weed species at twenty-one days after its application.

Treatments	Dose g ea ha^{-1}	Species* *Conyza* spp.		*Richardia brasiliensis*		*Ipomoea hederifolia*		*Euphorbia heterophylla*	
Glyphosate	720	100	Aa	16	Ce	96	Aa	45	Bd
Glyphosate	1,440	100	Aa	88	Aab	99	Aa	99	Aa
2.4-D	806	90	Aa	60	Bd	89	Aa	68	Bc
2.4-D	1,209	97	Aa	80	Bbc	97	Aa	76	Bc
Glufosinate	400	100	Aa	94	Aab	99	Aa	91	Aab
Glufosinate	600	100	Aa	99	Aab	99	Aa	97	Aa
Glyphosate + 2.4-D	410+390	100	Aa	82	Bbc	100	Aa	80	Bbc
Glyphosate + 2.4-D	820+780	100	Aa	72	Bcd	100	Aa	93	Aab

*Means in the same row followed by distinct capital letters and in the column followed by differ lowercase letters differ by Tukey test (p≤0.05).

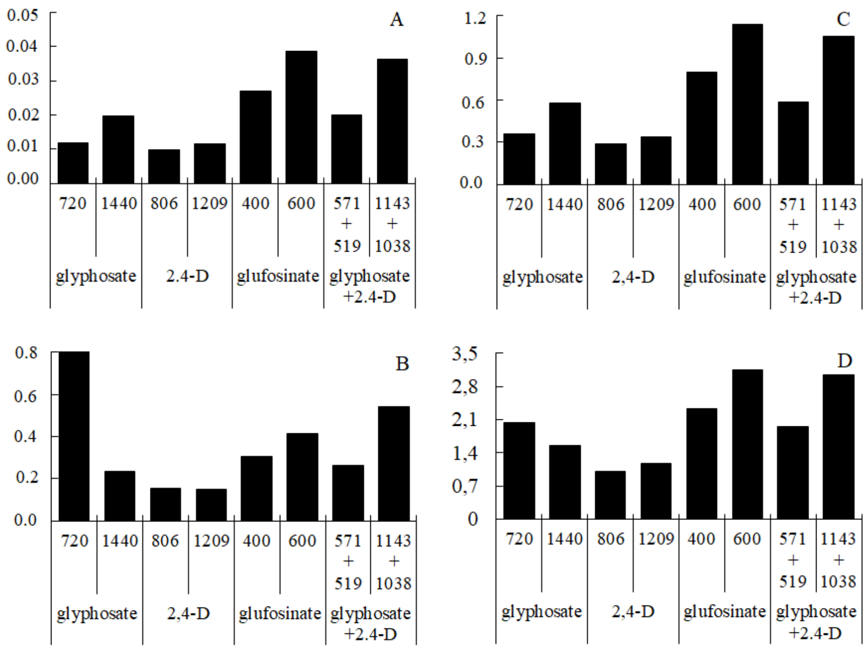

Fig 2. Economic Threshold Level from different weed species (A: *Conyza* spp, B: *R. brasiliensis*, C: *I. hederifolia* and D: *E. heterophylla*) in relation to different herbicides and its doses, considering application costs in \$ 2.62 and soybean value in \$ 0.22 kg of grain.

Table 3. Mean dry mass (g) of *Conyza*spp, *Richardia brasiliensis*, *Ipomoea hederifolia* and *Euphorbia heterophylla*, at twenty-one days after herbicide application.

Treatments	Dose g ea ha^{-1}	Drymass (g)*	
Control	-	0.28	a
Glyphosate	720	0.19	b
Glyphosate	1,440	0.15	bc
2.4-D	806	0.14	bc
2.4-D	1,209	0.13	c
Glufosinate	400	0.11	c
Glufosinate	600	0.11	c
Glyphosate + 2.4-D	410 + 390	0.14	bc
Glyphosate + 2.4-D	820 + 780	0.13	c

*Means in the column followed by differ lowercase letters differ by Tukey test (p≤0.05).

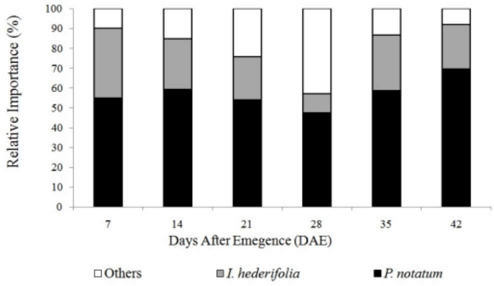

Fig 3. Relative Importance (%) of the different weed species coexisting with soybean crop at the field experiment area along different assessment periods (days after soybean emergence).

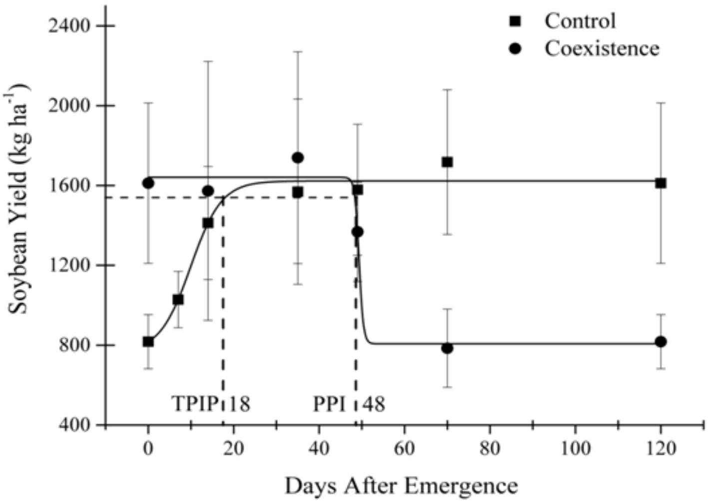

Fig 4. Soybean yield loss (kg ha^{-1}) in coexistence periods between soybean grow with ((Y=(765.93-1,622.75)/(1+exp(x-9.95)/3.61)), R^2=0.98) and without weed interference ((Y=(1,552.48-806.82)/(1+exp(x-49.64/0.57)), R^2=0.92).

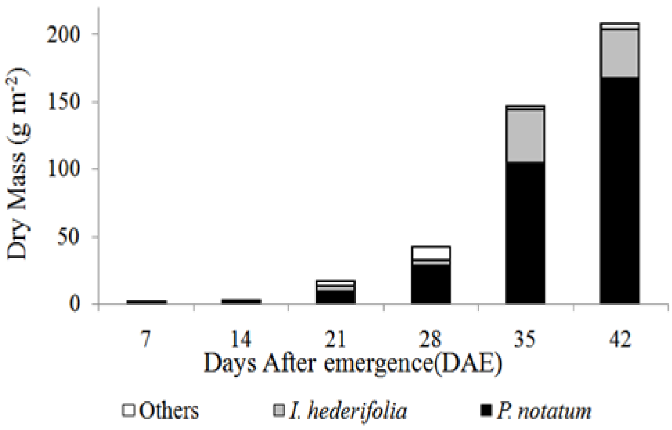

Fig 5. Dry mass accumulated (g m^{-2}) by weeds present in the experimental area at different days after soybean emergence.

Economic threshold level of *Conyza* spp. in soybean crop reported by Trezzi et al. (2013), indicate that even low plant densities (four plants m^{-2}) is enough to cause economic damage to the soybean crop. In this study, four plants were found to cause great damage and a critical level noticed on Fig 2 is below one plant m^{-2}. It is worth remembering that these levels can be altered if the plants come to show resistance to the used herbicides. Furthermore, soybean yield loss can reach easily 35% in cases of high *Conyza* plant population (average of 13.3 plants m^{-2}) as reported by Trezzi et al. (2013). Furthermore, this control prevents new seeds from being produced and spread in the field, since a plant can produce more than 150,000 seeds that will inherit the resistance characteristic and can remain viable in the soil up to three years (Wu et al., 2007).

Weed interference periods

Weed species present in the field experiment was composed of four major species, such as *Paspalum notatum* the most important one once maintained its Relative Importance Index (REI) above 45% during the entire soybean crop cycle and a eudicotyledonou specie (*I. hederifolia*) that had its Relative Importance Index (REI) above 9% during the crop cycle.

These relative values were obtained mainly due to high density of *P. notatum* and high dry mass accumulation of *I. hederifolia* especially 45 days after the soybean crop emergence. Other species such as turnip (*Raphanu sraphanistrum*) and nutsedge (*Cyperus rotundus*) were identified coexisting with the crop until 42 days after its emergence.

There was a grain yield loss of 50% between the treatment without weed interference (weed controlled) and with its presence along the whole soybean cycle (weed not controlled) (Figure 4).

The regression Y=(1,552.48-806.82)/(1+exp(x-49.64/0.57)) indicates a yield threshold of 1,552.48 kg ha^{-1} achieved at 18 days after soybean emergence (TPIP). The weeds that emerged after this period did not cause significant yield damage. For coexistence treatments the regression calculated a yield threshold of 1,622.75 kg ha^{-1} obtained at 48 days after soybean emergence (PPI), which is the period that the crop supported coexistence with the weeds. Period before interference (PPI) reported in the literature goes from 10 to 50 days after soybean emergence (Silva et al., 2009). A great number of biotic and abiotic factors that results in different levels of interference and competition may explain these differences on PBI reported among experiments.

Comparison of PPI and TPIP results showed a longer period of PPI, meaning that the used soybean cultivar proved to be very competitive in relation to the weed population during its first's stages of growth. Likewise, Silva et al. (2012), reported a similar situation in a study with sunflower (*Helianthus annuus*). A possible explanation for this competitiveness might be due to the undetermined growth habit of the cultivar, which ensures plasticity and ability to adapt various spatial arrangements. With regard to weeds growth, we showed low dry mass accumulation up to 14 days after the soybean emergence (Figure 5). This result may be explained by the rainfall shortage that occurred at this period and a small weed seedbank of problematic species such as those previously reported in the work. Therefore, it is recommended to control weeds between any of the given periods, between 18th and 48th days after crop emergence.

Materials and methods

Plant materials and site description

Three experiments were carried out to identify the control effectiveness of different herbicides on different weeds as well interference and interference periods of them in a glyphosate, glufosinate and 2,4-D tolerant soybean cultivar. The application of 2,4-D in soy post-emergence is possible due to the genes that translate aryloxyalkanoato-dioxigenase-type enzymes (AADs) and catalyze the degradation of 2,4-D, transforming the herbicide molecule into non-toxic metabolites to the plant. Currently this technology, called Enlist (Scott, 2014; Wright, 2010).

First experiment was carried out under semi-controlled conditions (irrigation control) at the Federal University of Paraná - UFPR (25° 24' 42.40" S; 49° 14' 54.00 "O), Curitiba, Paraná-Brazil, at an altitude of 935m above sea level and a Cfb climate according to Köppen classification, characterized without a defined dry season, cool summers and moderate winter with minimum annual average temperature between 17°C and 18°C. Average annual rainfall varies between 1,400 and 1,600 mm.

The Interference periods experiment was carried out at field condition at Colombo, Paraná-Brazil in the 2018/2019 growing season (25° 21' 10.90" S; 49° 08' 42.00" O), on a haplic gleisoil. Soybean ENLIST E3™ (same cultivar used at the 1st experiment) was sown at a density of 13 seeds per linear meter and 0.45 m inter-row spacing, targeting an initial population of 288,886 plants per hectare. Final stand included 244,000 plants per hectare. As a base fertilizer, we used 350 kg ha^{-1} of 04-20-20 (N-P_2O_5-K_2O) chemical fertilizer.

Weed control efficacy

Control efficacy of four weed species, *I. hederifolia*, *E. heterophylla*, *Conyza* spp. and *R. brasiliensis* was evaluated using four different herbicides with two doses each: glyphosate (Glizmax Prime, 480 g ea L^{-1}, Dow AgroSciences, São Paulo, Brazil), at doses of 720 and 1,440 g ea ha^{-1}, 2.4-D (DMA 806BR, 670 g eaL^{-1}, Dow AgroSciences, São Paulo, Brazil) at doses of 670 and 1,340 g ea ha^{-1}, glufosinate (Finale, 200 g ea L^{-1}, BASF, São Paulo, Brazil) at doses of 400 and 600 g ea ha^{-1} and glyphosate + 2.4-D (EnlistDuoColex-D, 205 + 195 g ea L^{-1}, Dow AgroSciences, São Paulo, Brazil) at doses of 410 + 390 and 820 + 780 g ea ha^{-1}, in addition to a control without herbicide application.

Experiment was carried out in an entirely randomized 4x8+1 factorial scheme composed of four species, eight herbicide treatments above cited and two control treatment (without herbicide application) with six repetitions. Each weed species was sown directly in two-liter pots. Soil chemical traits were: pH ($CaCl_2$) 4.8;P-Mehlich 7.0 mg dm^{-3}; Ca, Mg, K and Al 8.4, 4.9, 0.12 and 0.1 $cmol_c dm^{-3}$, respectively; H+Al, and CECpH7 were 8.4 and 21.62 $cmol_c dm^{-3}$; and base saturation (V%) of 61%. No fertilizer was applied due to good soil chemical condition.

After germination, plants were thinned to the density of one plant per pot. At four to six leaves stage, herbicides were sprayed with a CO_2-pressurized backpack sprayer equipped with an application bar of one meter with two spray tips (AIXR110.015 TeeJet Technologies, Wheaton, IL) calibrated

to deliver 200 L ha^{-1} maintained at constant pressure (3 kPa). Temperature at the time of application was 27 ºC and relative humidity of 39%. The amount of herbicide to be applied was calculated considering the concentration of active ingredient of the herbicide trademarks.
The assessment of herbicide phytotoxicity on weeds species were carried out at seven, 14 and 21 days after its application (DAA) assigning percentage grades from 0% to absence of phytotoxicity and 100% to the death of plants. Symptoms included chlorosis, leaf necrosis, and stunted growth. Weed plants biomass were harvested 21 days after herbicide application and dried in an oven with forced air at 60 °C for 72 hours to determinate the dry matter yield of each replication. ANOVA and Tukey's test was done at 5% probability with the AgroEstat program.

Critical and economic damage level

This experiment was carried out at the same place as the prior experiment aiming to evaluate the interference effect of the same species used in the previous experiment on ENLIST E3™ soybean, adopting increasing densities of the weeds (Oliveira et al., 2018). Soybean was sown in an eight-liter pots at a density of 21 plants m² together with each weed species at densities of 21, 42, 84, 168 and 336 plants m². The control plot was represented as soybean without the presence of weeds. This experiment was conducted under entirely randomized design with 25 treatments (five densities of each of the four weeds species and one control), with four repetitions.
Soybeans and weeds grown together up to 120 days after sowing (DAS), when the weeds had their aerial part cut close to the soil and oven-dried with forced air circulation at 60°C until constant dry mass weight. Soybeans pods of each plant were harvested and trimmed, and yield corrected to 13% moisture. Based on these data, the relative loss of yield in each treatment was calculated.
The data were submitted to analysis of variance, when significant were evaluated by the regression analysis to calculate the critical level of damage (CLD) of each weed specie in soybean, using non-linear regression of the rectangular hyperbole type proposed by Cousens (1985) adapted according to Eq. (1):

$$YL = \frac{(axX_0)}{(b+X_0)} \qquad (1)$$

In which: *YL r*epresents yield loss (%), *X*o value of the variable *a*, a, the maximum asymptote value and b, the value of weed infestation level, which is equivalent to 50% of the maximum asymptote value. The CLD was then obtained by the ratio of parameters *a* and *b* in the equation, representing the impact of each plant on soybean crop yield.
To calculate the economic threshold level (ETL), we used the CLD estimates from equation one, and also the adapted equation proposed by Lindquist and Kropff (1996), following Eq (2):

$$ETL = [\frac{CC}{(PxYx\frac{CLD}{100}x\frac{H}{100})}] \qquad (2)$$

In which: *ETL* represents the economic threshold level (number of weed plants per square meter), *CC* the control cost (herbicide + application cost in dollars), P the price of soybean (dollars per kg of grain), Y the maximum yield of soybean in the experiment (kg ha^{-1}), *CLD* the critical level of damage and H the efficacy of each herbicide (%) (Piasecki and Rizzardi, 2017).
To determine weed cost of control, the mean price of each treatment along the last ten years (from 2009 to 2019) was considered, using a reference data from the Center for Advanced Studies in Applied Economics (CEPEA, 2019). The cost of the application was set to \$ 3.07 ha^{-1} considering one dollar equals to R\$ 5.34 (Oliveira and Dalchiavon, 2019). Control effectiveness was determined in the first experiment (control effectiveness) and the price paid for soybean was of \$ 0.22 kg of grains (equivalent to \$ 13.29 for a bag of 60 kg, which was the main value paid at the local where experiment was established) (CONAB, 2020).

Interference periods

Each experimental unit (plots) was composed of five soybean rows three meters long each, totaling 6.75 m², where, the 0.5 m of the plots ends were excluded. Experiment was laid out as a random block design with four repetitions in a 2x7+2 factorial scheme, being factor A related to the beginning or end period of weed control and Factor B to seven coexistence periods between soybean and weed control, which happened at seven, 14, 21, 28, 35, 49 and 70 days after soybean emergence (70% at minimum), plus two control treatments (one soybean plant was kept with the presence of weeds during its entire cycle (120 days and other soybean without weed interference). Weeds were removed through manual weeding.
At the end of each coexistence period, the present species were identified, quantified and dried to obtain its dry mass. A square metal of 50x50 cm (0.25m²) were randomly released at two places in each plot. After counting, the plants were removed (cut rent to the soil), stored in paper bags and oven-dried at 60^{o}C until constant weight. These data were used for phytosociological calculations and to determine the relative importance (RI) of the weed species (Mueller-Dombois and Ellemberg, 1974).
Soybean was evaluated by harvesting the plants in the useful plot of each treatment when the grains reached 13% of moisture ($\pm$120 days after emergence). These data were submitted to the Boltzmann non-linear analysis in the Origin 9 program, using Eq. (3) (Beluci et al., 2018):

$$Y = [\frac{(P1-P2)}{\left(1+e^{\frac{X-Xi}{dx}}\right)}] \qquad (3)$$

In which: Y corresponds to the soybean yield (kg ha^{-1}) according to the period of coexistence or weed control, *P1* the maximum yield (kg ha^{-1}) from soybean grown without weeds interference during its entire cycle, *P2* the minimum yield (kg ha^{-1}) obtained by soybean coexisting with weeds during its entire cycle, (*P1-P2*) the yield loss (kg ha^{-1}) caused by the weed community presence, *x* the upper limit of the control or coexistence period (days), *xi* the intermediate value between the maximum and minimum yield (days) and *dxa* the rate of yield loss (kg ha^{-1} day^{-1}) by coexistence between weeds and soybean.
The period prior to interference (PPI), total period of interference prevention (TPIP), critical period of interference prevention (CPIP) were determined considering the arbitrary level of 5% soybean yield loss, expressed in kg ha^{-1}, value relative to the average cost of weeds control (Galon et al., 2019).

Conclusions

Among data, glufosinate and glyphosate + 2.4-D (820 + 780 g ea ha^{-1}) showed greater weed control capacity then glyphosate (720 g ea ha^{-1}). Soybean crop yield loss of 0.85, 2.12, 5.71 and 34.24% was found for each plant of *E. heterophylla. I. hederifolia*, *R. brasiliensis* and *Conyza* spp., respectively. There was a soybean grain yield loss of 50% at the treatment with weed interference along its whole cycle. Soybean weed management should occur between 18^{th} and 48^{th} days after its emergence. Threshold Economic level on soybean yield is below one plant of *Conyza*spp. and *R. brasiliensis* per m^{-2}. Use of glufosinate and glyphosate + 2,4-D on ENLIST E3™ soybean provides a greater flexibility of herbicide use in relation to the weeds management.

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