

PRE-EMERGENT HERBICIDE APPLICATION PERFORMED AFTER CROP SOWING FAVORS PIGWEED (*AMARANTHUS* SPP.) AND WHITE-EYE (*RICHARDIA BRASILIENSIS*) CONTROL IN SOYBEANS

A APLICAÇÃO DE HERBICIDAS PRÉ-EMERGENTES NA MODALIDADE PLANTE-E-APLIQUE FAVORECE O CONTROLE DE CARURU E POAIA-BRANCA NA CULTURA DA SOJA

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The use of pre-emergent herbicides offers a promising alternative for proper management of difficult-to-control weed species in soybeans, such as white-eye (*Richardia brasiliensis* Gomes), a glyphosate-tolerant species, and weeds in the *Amaranthus* genus (commonly referred to as pigweeds). Here, we aimed at determining whether weed control efficacy and crop selectivity are altered when pre-emergent herbicide applications take place either prior to, or right after crop sowing. To this end, field trials were conducted employing 10 pre-emergent herbicide treatments (plus an untreated control as well as an untreated, weed-free treatment), replicated four times and sprayed either before, or right after soybean sowing. Results indicate that the actual timing of pre-emergent herbicide spraying relative to soybean sowing significantly changed the weed control efficiency set forth by most herbicide active ingredients tested, with no change to their selectivity to crop plants whatsoever. Some herbicides (e.g. diclosulam, mesotrione, flumioxazin, and a flumioxazin + imazethapyr mixture), however, were equally effective for controlling white-eye and pigweeds regardless of application timing. Moreover, the only herbicide treatments allowing for satisfactory (>70%) control of all target weed species (white-eye, pigweeds, and black oats, *Avena strigosa* Schreb.) were flumioxazin and a flumioxazin + imazethapyr mixture. Spraying performed after sowing resulted in average yield gains of over 600 kg ha⁻¹ relative to pre-sowing applications, possibly owing to better control of broadleaves. Altogether, this information is useful to soybean producers, as it does not lead to an increase in overall costs; instead, it only affects the timing of entry into the area for pre-emergent herbicide application.

RESUMO

A utilização de herbicidas pré-emergentes oferece alternativa promissora para o manejo de populações de plantas daninhas de difícil controle na cultura da soja, como aquelas apresentando tolerância ao herbicida glifosato como a poaia-branca (*Richardia brasiliensis*). Neste trabalho, objetivamos analisar avaliar possíveis diferenças na eficiência de controle e seletividade à soja quando pré-emergentes são aplicados anteriormente, ou logo após a semeadura da cultura. Para tal, conduziu-se experimento de campo empregando 10 herbicidas pré-emergentes (além de testemunhas sem controle e capinadas), com 4 repetições e aplicando-se os tratamentos antes ou após a semeadura da soja. Resultados indicam que o momento de aplicação de herbicidas pré-emergentes em relação à semeadura da soja alterou significativamente a eficiência de controle de alguns ingredientes ativos sobre plantas daninhas, porém não afetou a seletividade destes. Contudo, os herbicidas diclosulam, mesotrione, flumioxazina, e a mistura flumioxazina + imazethapyr foram igualmente eficientes para o controle de poaia-branca e caruru, independentemente do momento de aplicação. Os únicos tratamentos com herbicidas que propiciaram controle satisfatório (>70%) de todas as espécies avaliadas (poaia-branca, caruru e aveia-preta, *Avena strigosa* Schreb.) foram flumioxazina, e a mistura flumioxazin + imazethapyr. Aplicações em plante-e-aplique resultaram em ganhos produtivos médios de mais de 600 kg ha⁻¹ em relação ao aplique-e-plante, possivelmente devido ao controle superior de plantas daninhas latifoliadas. Em conjunto, estas informações são úteis ao sojicultor, visto que não acarretam elevação no custo de manejo, somente afetando o momento de entrada na área para aplicação dos pré-emergentes.

1. Introduction

The use of pre-emergent herbicides is key to ensure cost-effective, sustainable weed management in soybean fields, especially in a scenario at which glyphosate usage skyrocketed, as did the number of glyphosate-resistant weed populations in Brazil and worldwide (LOPEZ-OVEJERO et al. 2013; HEAP, 2020). Such is related to the fact that the number of glyphosate applications per year increased significantly in the past 18 years, whereas the actual number of herbicidal modes of action used per year saw a sharp decrease, leading to a greater selection pressure on glyphosate and favoring the evolution of glyphosate-resistant weed populations. In this scenario, the use of pre-emergent herbicides should be seen as a means for solving issues related to the long-term, frequent usage of a single herbicidal mechanism of action (PETERSON et al. 2018). In the United States of America alone, in the wake of resistance to glyphosate, pre-emergent herbicide usage increased from 25% to 70% of the country's acreage (PETERSON et al. 2018), a similar trend noticed in Parana state, a major soybean growing area in Brazil (Penckowski, personal communication).

Pre-emergent herbicides, as suggested, are sprayed onto the soil surface prior to the emergence of either crop or weed seedlings, affecting key processes during seed germination such as cell division, amino acid biosynthesis, and many more (PEDROSO; AVILA NETO, 2018). Such molecules allow crops to develop in a weed-free environment for a certain number of days or even weeks due to their residual activity in the soils (NUNES et al. 2018). For this reason, the actual herbicide rates are sometimes adjusted according to the soil texture and organic matter content (PEDROSO; AVILA NETO 2018). Moreover, some pre-emergent herbicides display herbicidal modes of action which are not available for use as a post treatment, allowing for an effective rotation of modes of action, which, in turn, can effectively delay or prevent the evolution of herbicide resistance in weed populations (NUNES et al. 2018). However, various factors must be taken into account when planning pre-emergent herbicide applications, as misuse can lead to severe crop phytotoxicity or even affect the subsequent crop species in the area due to herbicide residues in the soil – a phenomenon known as carry-over (WALSH et al. 2015; SOUSA et al. 2018).

Weed interference is widely regarded as a major biotic stress impacting crop yields and food production around the globe. In Brazilian soybean (*Glycine max* (L.) Merr.) fields, weed infestations can decrease crop yields by as much as 46% (NEPOMUCENO et al. 2007) or more, depending on the actual weed density, flora and weed control tools used. Among troublesome weed species commonly found in soybean fields in Brazil are pigweeds (*Amaranthus* spp.) and white-eye (*Richardia brasiliensis* Gomes), prolific broadleaves with similar seed germination timing as the crop (SANTOS et al. 2016; ZANDONA et al. 2017).

Pre-emergent herbicide applications for improved

control of such weed species is key to ensure sustainable, elevated soybean yields. The *Amaranthus* genus is comprised of 11 species; to date, several cases of herbicide-resistance have been reported in the genus, including a newly reported case of glyphosate resistance in Brazil (HEAP, 2020). On the other hand, white-eye is naturally tolerant to glyphosate, and tends to reach high infestation levels in glyphosate-only weed management programs (OSIPE et al. 2017). Combined, such worrisome facts corroborate with the incorporation of herbicides with soil activity (pre-emergent molecules) to weed management programs in soybeans, as these offer distinct herbicidal modes of action and allow for rotation of control measures. Furthermore, the greater diversity of herbicide modes of action aid in the management of volunteer crops, whose management is often complicated due to tolerance to herbicides (such as glyphosate and ammonium-glufosinate), or even the presence of large soil seedbanks (LOPEZ-OVEJERO et al. 2016). The latter holds true for black oats (*Avena strigosa* Schreb), a grass species (Poaceae) which is commonly used as winter cover cropping in Southern Brazil. Since this crop is not usually harvested, seeds go to the soil seedbank and can interfere with subsequent summer crops.

Knowledge regarding the correct timing for pre-emergent herbicide applications is key to ensure that the desired level of weed control is achieved. In Brazil, two separate systems are commonly used in soybeans – these differ in the actual timing of herbicide spraying. In the plant-then-spray system, as suggested, spraying is done right after crop sowing and before weed and crop emergence. Naturally, the second one is known as spray-then-plant system and consist of herbicide spraying performed prior to crop sowing. Although somewhat similar at first glance, these systems present major changes to the soil surface-straw interface due to planting operations (straw cutting, grain drilling and subsequent seed coverage), especially under direct seeding systems (PEDROSO; AVILA NETO 2018). These, in turn, can potentially alter activity and selectivity of pre-emergent herbicides, as these must remain in the top few centimeters of the soil to ensure proper control (known as the weed seed germination active zone). Therefore, the present work aimed at assessing whether the actual timing of pre-emergent herbicide spraying (prior to soybean sowing, or right after it) affected parameters such as crop phytotoxicity and yields, as well as efficacy of control of pigweed, white-eye, and black oat, such that weed management can be improved in Brazilian soybean fields.

2. Material and Methods

Field trials were conducted in the 2017/18 growing season. Field trials were conducted in the 2017/2018 growing season in Itaara (Rio Grande do Sul State), Brazil (Lat. 29°35'09.2"S, Long. 53°49'02.1"W; Elev. 441m). Soils in the experimental area were classified as Neosol (SISTEMA BRASILEIRO DE CLASSIFICAÇÃO DE

SOLOS, 2018), and soil analysis indicated average soil organic matter and clay percentages of 4.1 and 10.0, respectively. Soybean cv. “BMX Potencia RR” sowing was performed onto black oat (*A. strigosa*) straw (Figure 1), 20

days after spraying of glyphosate (Roundup Original DI®) at 1,500 g e.a. ha⁻¹ to ensure proper weed control and soybean growing conditions.



Figure 1. Overall appearance of the experimental field at crop sowing day. The photo on the left side was taken right after herbicide spraying at the spray-then-plant system (and immediately prior to soybean seeding), whereas the photo on the right side was shot immediately after herbicide spraying at the plant-then-spray system.

Experiments were arranged following a bi-factorial scheme consisting of multiple combinations between factor A (main plots), which comprised 12 different vegetation management strategies (Table 1); and factor B (sub-plots), herbicide application timing - either prior to crop sowing, or right after it. The former included 10 pre-emergent herbicide treatments, as well as an untreated (weedy) control and an untreated weed-free check treatment, whose plots were hoed throughout the trial. Out of 10 herbicides, two are not

currently registered for use in Brazilian soybean fields: Only© (a mixture of imazapic + imazethapyr), and Callisto® (mesotrione); their use allow for information to be collected regarding possible selectivity to soybean plants, as well as weed control efficacy. Callisto® was sprayed at a similar rate relative to its registered label rate for use as a post-emergence treatment in maize, whereas Only® was sprayed at an actual higher rate than used in tolerant crops in order to allow for the study of residual activity.

Table 1. List of treatments (Factor A) employed in this study.

Treatments	Trade name	Rate (l or kg ha ⁻¹)	Rate (g a.i. ha ⁻¹)
Untreated control	-	-	-
Diclosulam ^{1,2}	Spider 840 WG	0.04	33.6
Flumioxazin ³	Flumyazin 500 WP	0.12	60.0
Flumioxazin ³ + imazethapyr ²	Zethamaxx	0.60	60.0 + 127.2
Sulfentrazone ³	Boral 500 SC	0.40	200
Clomazone ⁴	Gamit	2.50	1,250.0
S-Metolachlor ⁵	Dual Gold	2.00	1,920.0
Pendimethalin ⁶	Herbadox	2.50	1,250.0
Trifluralin ⁶	Permerlin 600 EC	3.00	1,800.0
Imazapic ² + imazethapyr ²	Only	1.33	33.2 + 99.8
Mesotrione ⁷	Callisto	0.40	192.0
Untreated weed-free checks	-	-	-

¹Herbicide active ingredient; ²Acetolactato synthase (ALS-AHAS) inhibitor; ³Protoporphyrinogen IX oxidase (PROTOX or PPO) inhibitor; ⁴Deoxyxylulose 5-phosphate (DXP) synthase inhibitor; ⁵Inhibition of very long chain fatty acids (VLCFA) biosynthesis; ⁶Inhibition of microtubule assembly; ⁷4-Hydroxyphenylpyruvate dioxygenase (4-HPPD) inhibitor.

Experimental units consisted of 30 m² plots repeated four times, at which 15 m² (sub-plots) were sprayed as a spray-then-plant system (i.e. prior to soybean sowing; Figure 1), and the remaining area was sprayed right after crop sowing (plant-then-spray system). Treatments were applied using a CO₂-pressurized backpack sprayer equipped with an XR 110.02 flat-fan nozzle calibrated to deliver 150 L ha⁻¹ at 210 kPa.

Efficacy of control of white-eye, two pigweed species (*Amaranthus deflexus* L. and *A. spinosus* L., in similar densities) and volunteer black oats was assessed 39 days after herbicide spraying to allow for differences in pre-emergence residual activity to be evaluated. Visual control ratings followed a percentage scale, at which 0% indicates lack control or any herbicide-induced symptoms, whereas 100% indicates plant death (FRANS, 1972). Phytotoxicity to soybeans was determined by taking stand counts and plant height 40 days after herbicide spraying, and by assessing crop yields; these were expressed in plants m⁻², cm, and kg ha⁻¹, respectively. Crop stand counts were performed on 5 m-long sections within each plot, and plant height determined by manually measuring 10 randomly selected plants per plot.

Following testing of assumptions, data were subject to ANOVA (p≤0.05) and means compared using Tukey HSD test (p≤0.05), when appropriate. Data analysis was performed on R studio (R CORE TEAM, 2020) using the ExpDes.pt package (FERREIRA; CAVALCANTI; NOGUEIRA, 2014).

3. Results and Discussion

Results indicated no significant differences in crop stand counts (p≤0.05) among treatments. Regardless of actual herbicide application timing (before or after crop seeding) or herbicide treatment, soybean stand counts averaged 15.5 plants m⁻² (data not shown), suggesting that pre-emergent herbicide treatments did not impact soybean plant growth negatively. Furthermore, there was no significant interaction among factors A (herbicide treatments) and B (timing of application) for the variable plant height (Table 2), indicating similar responses regardless of actual herbicide spraying timing. The only herbicide found to decrease soybean plant heights was mesotrione, whose values were significantly lower than those recorded in clomazone-treated plots. However, such heights values were still statistically similar to all other treatments, including plots which were kept weed-free via hoeing. This can be explained by the fact that mesotrione is not registered for use as a pre-emergent herbicide in soybeans, suggesting it might lack enough selectivity to this crop to allow for its use. Plant stature is an important trait which dictates the overall outcome of weed-crop competition, as smaller plants might be more easily shaded by large weed plants, affecting light energy capture and photosynthetic activity (SCHAEDLER et al. 2015).

Table 2. Plant height (m) and productivity (kg ha⁻¹) recorded for soybean cv. BMX Potencia RR.

Application timing	Height (cm)	Productivity (kg ha ⁻¹)
Plant-then-spray ¹	81.86 ^{ns}	2,615.75a
Spray-then-plant ²	82.55	2,008.91b
Herbicide		
Untreated control	85.50ab ³	1,796.96c
Diclosulam	78.90ab	2,238.83bc
Flumioxazin	79.37ab	2,323.30ab
Flumioxazin + imazethapyr	82.50ab	2,383.33ab
Sulfentrazone	80.85ab	2,273.96ab
Clomazone	86.00a	2,467.90ab
S-Metolachlor	82.50ab	2,714.91a
Pendimethalin	84.92ab	2,467.54ab
Trifluralin	80.40ab	2,354.75ab
Imazapic + imazethapyr	84.32ab	2,230.43bc
Mesotrione	77.37B	2,070.48bc
Untreated weed-free checks	83.72ab	2,405.83ab
CV (%) - Application timing	2.65	7.13
CV (%) - Herbicides	6.09	11.81

¹Herbicide treatments were sprayed after soybean sowing; ²Herbicide treatments were sprayed before crop sowing;

³Significantly different means according to Tukey's HSD test (p≤0.05) are indicated by different letters within a column; ^{ns}No significant difference among means according to Tukey's HSD test (p≤0.05).

Average soybean productivity in untreated weed-free checks was increased by 610 kg ha⁻¹ in comparison to untreated control plots (Table 2). Moreover, there was a 600 kg ha⁻¹ average yield increase when herbicides were sprayed after crop sowing (plant-then-spray system) relative to spraying taking place prior to seeding (spray-then-plant), regardless of actual herbicides used. Such fact is likely related to better broadleaf weed control (Tables 3 and 4) achieved by the former, and to the lack of soil movement taking place after spraying. Weeds in the *Amaranthus* and *Richardia* genera are commonly found in Brazilian soybean fields (ZANDONA et al. 2017) which can cause severe soybean yield losses (GUGLIELMINI; VERDÚ; SATORRE, 2017).

Altogether, results from soybean plant height, stand counts and productivity combined suggest that selectivity of pre-emergent herbicides to soybean was not altered by timing of application. Therefore, improvements on weed control efficacy, if any, are key to decide whether to spray pre-emergent herbicides before or after crop sowing. An analysis of weed control efficacy indicated a significant interaction between herbicide treatments and timing of application. Overall, pigweed (*Amaranthus* spp.) control

levels achieved via applications of either diclosulam, flumioxazin, flumioxazin + imazethapyr, sulfentrazone, imazapic + imazethapyr, or mesotrione did not differ from the untreated weed-free checks regardless of application timing, indicating flexibility and efficacy for pigweed control (Table 3). Interestingly, control levels achieved with applications of either clomazone, s-metolachlor, or pendimethalin were significantly higher when spraying took place after crop sowing (plant-then-spray). At such application timing, control set forth by applications of either clomazone, mesotrione, diclosulam, flumioxazin, sulfentrazone, or a flumioxazin + imazethapyr mixture did not differ from untreated weed-free checks, indicating excellent control levels. However, the mitotic inhibitors trifluralin and pendimethalin performed poorly relative to other herbicide treatments. The use of pre-emergent herbicides has been shown to be a good strategy for *Amaranthus* spp. suppression, as an overall reduction of *Amaranthus rudis* seed germination was noticed when pre-emergent herbicides were incorporated into the weed management program (LEGLEITER; BRADLEY; MASSEY, 2009).

Table 3. Pigweed (*Amaranthus* spp.) control percentages recorded at 39 days after herbicide spraying.

Treatments	Application timing	
	Plant-then-spray ¹	Spray-then-plant ²
Untreated control	0.00 ^{ns,d} ³	0.00c
Diclosulam	90.00 ^{ns,ab}	95.00a
Flumioxazin	100.00 ^{ns,a}	95.00a
Flumioxazin + imazethapyr	100.00 ^{ns,a}	100.00a
Sulfentrazone	95.00 ^{ns,a}	90.00a
Clomazone	85.00 Aab ⁴	61.25Bab
S-Metolachlor	78.75 Aab	36.25Bbc
Pendimethalin	52.50 Abc	15.00Bc
Trifluralin	23.75 ^{ns,cd}	35.00bc
Imazapic + imazethapyr	90.00 ^{ns,ab}	68.75ab
Mesotrione	98.75 ^{ns,a}	100.00a
Untreated weed-free checks	100.00 ^{ns,a}	100.00a
CV (%)	7.62	23.55

¹Herbicide treatments were sprayed after soybean sowing; ²Herbicide treatments were sprayed before crop sowing; ³Significantly different means according to Tukey's HSD test (p≤0.05) are indicated by different lowercase letters within a column; ^{ns}no significant difference among means within a row, according to Tukey's HSD test (p≤0.05); ⁴Significantly different means according to Tukey's HSD test (p≤0.05) are indicated by different uppercase letters within a row.

Similarly to pigweed control (Table 3), control levels of white-eye control (Table 4), a troublesome glyphosate-tolerant species, differed across herbicides and application timing. Sulfentrazone, a PROTOX inhibitor, was more

effective when sprayed after crop sowing (plant-then-spray system), whereas S-metolachlor was more effective when sprayed after crop sowing (plant-then-spray). Overall, treatments containing mesotrione, flumioxazina,

flumioxazina + imazethapyr, or pendimethalin herbicides (as well as sS-metolachlor when sprayed prior to seeding) were efficient for white-eye control regardless of application timing, as control percentages did not differ from untreated weed-free checks. Clomazone, on the other hand, allowed for control levels (~60%) slightly below herbicide treatments discussed above. Such results resemble those reported by Costa et al. (2015), at which a s-metolachlor and clomazone mixture allowed for efficient control of *Richardia scabra*, a close relative to white-eye (*R.*

brasiliensis). Flumioxazin spraying was also an effective means for white-eye control according to Vitorino et al. (2012). It is noteworthy the fact that both white-eye and pigweed control levels were, for most herbicides, higher when spraying took place after crop sowing. Such could be attributed to straw movement during seeding and subsequent exposure of crop rows to herbicide molecules, avoiding any sorption to straw. However, such claim remains to be validated.

Table 4. White-eye (*Richardia brasiliensis*) control percentages recorded at 39 days after herbicide spraying.

Treatments	Application timing			
	Plant-then-spray ¹	Spray-then-plant ²		
Untreated control	0.00	^{ns} d	0.00	e
Diclosulam	58.75	^{ns} bc	61.25	cd
Flumioxazin	70.00	^{ns} bc	78.75	abcd
Flumioxazin + imazethapyr	73.25	^{ns} abc	78.75	abcd
Sulfentrazone	75.00	Aabc	61.25	Bcd
Clomazone	61.25	^{ns} bc	63.75	abcd
S-Metolachlor	63.32	Bbc	95.00	Aab
Pendimethalin	75.00	^{ns} abc	88.20	abc
Trifluralin	53.25	^{ns} c	52.50	d
Imazapic + imazethapyr	82.50	^{ns} ab	68.75	bcd
Mesotrione	75.00	^{ns} abc	83.75	abc
Untreated weed-free checks	100.00	^{ns} a	100.00	a
CV (%)	34.01		22.01	

¹Herbicide treatments were sprayed after soybean sowing; ²Herbicide treatments were sprayed before crop sowing; ³Significantly different means according to Tukey's HSD test ($p \leq 0.05$) are indicated by different lowercase letters within a column; ^{ns}no significant difference among means within a row, according to Tukey's HSD test ($p \leq 0.05$); ⁴Significantly different means according to Tukey's HSD test ($p \leq 0.05$) are indicated by different uppercase letters within a row.

The only best options for pre-emergence control of black oats at the present work were treatments containing either flumioxazin, mesotrione, or a flumioxazin + imazapic mixture (Table 5). However, as mentioned previously, mesotrione is not currently registered for use in Brazilian soybean fields. Moreover, its usage led to a 700 kg ha⁻¹ soybean yield loss relative to the highest yielding treatment (S-metolachlor; Table 2). Unlike previous results, there was

no significant interaction between application timing and herbicide treatments regarding black oats control. Control level averages per treatment were lower than those observed for pigweed and white-eye, as only three herbicides were able to achieve satisfactory control levels, i.e. at least 80%, or greater (FRANS, 1972). Thus, these results suggest that black oats are a tougher target for most pre-emergent herbicides available for use in soybean fields.

Table 5. Black oats (*Avena strigosa*) control percentages recorded at 39 days after herbicide spraying.

Treatments	% Control	
Untreated control	0.00	e
Diclosulam	63.75	abcd
Flumioxazin	89.37	ab
Flumioxazin + imazethapyr	83.12	ab
Sulfentrazone	29.37	de
Clomazone	65.62	abcd
S-Metolachlor	43.12	bcde
Pendimethalin	26.25	abcd
Trifluralin	78.75	a
Imazapic + imazethapyr	31.87	cde
Mesotrione	85.62	ab
Untreated weed-free checks	100.00	a
CV (%)	44.56	

¹Significantly different means according to Tukey's HSD test ($p \leq 0.05$) are indicated by different lowercase letters within a column.

4. Conclusions

The actual timing of pre-emergent herbicide spraying relative to soybean sowing significantly changed the weed control efficiency achieved by most herbicide active ingredients tested. Importantly, no change to their selectivity to crop plants was noticed. Therefore, decisions regarding the actual timing of pre-emergent herbicide spraying should be made on a per active ingredient basis, as some molecules were not affected by spraying timing whatsoever. The only herbicide treatments allowing for satisfactory (>70%) control levels of all target weed species (white-eye, pigweed, and black oats) at 39 days after herbicide spraying are flumioxazin, mesotrione, and a flumioxazin + imazethapyr mixture. Since Only® (a mixture of imazapic + imazethapyr) is not currently registered for use in soybeans, its usage rates were increased by 33% relative to rates commonly used in tolerant crops, which might have adversely impacted its selectivity to soybeans. Furthermore, spraying pre-emergent herbicides after crop sowing (plant-then-spray system) allowed for larger soybean yields, which is likely related to better pigweed and white-eye control levels. This constitutes useful information from a weed-management standpoint, especially considering that switching from spraying pre-emergent herbicides prior to sowing to spraying right after this operation is done does not require any additional resources nor investment.

References

- Costa, A. G. F.; Sofiatti, V.; Maciel, C. D.; Lira, A. J.; Cordeiro Jr, A. F, Silva, R. L. Weed management with herbicides applied in pre and postemergence on castor crop. **Planta Daninha**, 33: 551-559, 2015.
- Ferreira, E. B.; Cavalcanti, P. P.; Nogueira, D. A. ExpDes: an R package for ANOVA and experimental designs. **Appl. Math.**, 5: 2952, 2014.
- Frans, R. E. Measuring plant responses. In: Wilkinson RE (Ed.). Research methods in weed science. Southern Weed Science Society, p.28-41. Puerto Rico, 1972.
- Guglielmini, A. C.; Verdú, A. M.; Satorre, E. H. Competitive ability of five common weed species in competition with soybean. **Int J Pest Manage**, 63: 30-36, 2017.
- Heap I. **The International Survey of Herbicide Resistant Weeds**. Online. Internet. Tuesday, April 6. Available in: www.weedscience.org, 2020.
- Legleiter, T. R.; Bradley, K. W.; Massey, R. E. Glyphosate-resistant waterhemp (*Amaranthus rudis*) control and economic returns with herbicide programs in soybean. **Weed Technol.**, 23: 54-61, 2009.

- Lopez-Ovejero, R. F.; Soares, D. J.; Oliveira W. S.; Fonseca, L. B.; Berger, G. U.; Soteris, J. K.; Christofoletti, P. J. Residual herbicides in weed management for glyphosate-resistant soybean in Brazil. **Planta Daninha**, 31: 947-959, 2013.
- Lopez-ovejero, R. F.; Soares, D. J.; Oliveira, N. C.; Kawaguchi, I. T.; Berger, G. U.; Carvalho, S. J.; Christofoletti, P. J. Interferência e controle de milho voluntário tolerante ao glifosato na cultura da soja. **Pesq. agropec. Bras.**, 51: 340-347, 2016.
- Nepomuceno, M.; Alves, P. L. C. A.; Dias, T. C. S.; Pavani, M. C. M. D. Periods of weed interference in soybean under tillage and no-tillage systems. **Planta Daninha**, 25 (1): 43-50, 2007.
- Nunes, A. L.; Lorenset, J. L.; Gubiani, J. E.; Santos, F. M. A Multy-Year Study Reveals the Importance of Residual Herbicides on Weed Control in Glyphosate-Resistant Soybean. **Planta Daninha**, 36: epub, 2018.
- Osipe, J. B.; Oliveira Jr, R. S, Constantin, J.; Takano, H. K.; Biffe, D. F. Spectrum of weed control with 2, 4-D and dicamba herbicides associated to glyphosate or not. **Planta Daninha**, 35: epub, 2017.
- Peterson, M. A.; Collavo, A.; Lopez-Ovejero, R. F.; Shivrain, V.; Walsh, M. J. The challenge of herbicide resistance around the world: a current summary. **Pest Manag. Sci.**, 74: 2246-2259, 2018.
- Pedroso, R. M.; Avila Neto, R. C. Antigo Aliado. **Revista Cultivar Grandes Culturas**, 230: 30-34, 2018.
- RStudio Team (2020). **RStudio: Integrated Development for R**. RStudio, PBC, Boston, MA URL <http://www.rstudio.com/>.
- Santos, W. F.; Procopio, S. O.; Silva, A. G.; Fernandes, M. F.; Barroso, A. A. Weed phytosociological and floristic survey in agricultural areas of southwestern Goiás region. **Planta Daninha**, 34: 65-80, 2016.
- Schaedler, C. E.; Burgos, N. R.; Noldin, J. A.; Alcober, E. A.; Salas, R. A.; Agostinetto, D. Competitive ability of ALS inhibitor herbicide resistant *Fimbristylis miliacea*. **Weed Res.** 55: 82-492, 2015.
- Sistema brasileiro de classificação de solos - Embrapa. Embrapa, Brasília, 2018.
- Sousa, J. B.; Teixeira, M. B.; Jakelaitis, A.; Cunha, F. N.; Silva, N. F. Performance of Crops Grown in Succession to Soybeans Treated with Different Residual Herbicides. **Planta Daninha**. 36: epub, 2018.
- Vitorino, H. S.; Martins, D.; Costa, S. I.; Marques, R. P.; Souza, G. S.; Campos, C. F. Eficiência de herbicidas no controle de plantas daninhas latifoliadas em mamona. **Arq. Inst. Biol.**, 79: 129-133, 2012.
- Walsh, K. D.; Soltani, N.; Hooker, D. C.; Nurse, R. E.; Sikkema, P. H. Biologically effective rate of sulfentrazone applied pre-emergence in soybean. **Can. J. Plant Sci.**, 95: 339-344, 2015.
- Zandona, R. R.; Agostinetto, D.; Silva, B. M.; Ruchel, Q.; Fraga, D. S. Interference Periods in Soybean Crop as Affected by Emergence Times of Weeds. **Planta Daninha**, 36: epub, 2017.

