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Article

A Multy-Year Study Reveals the Importance of Residual Herbicides on Weed Control in Glyphosate-Resistant Soybean

Estudo Multianos Revela a Importância dos Herbicidas Residuais no Controle de Plantas Daninhas em Soja RR

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ABSTRACT - A 3-year field study was conducted to assess the potential for using pre-emergent (PRE) herbicides tank mixed with glyphosate as a means of controlling weed species in soybean. In 2011/12, 2012/13 and 2013/14 growing sessions soybean cultivar Brasmax Apollo RR was planted under residues of rye. The herbicide treatments glyphosate (gly) (1,296 g a.i. ha^{-1}), gly + S-metolachlor (1,296 + 1,920), gly + imazaquin (1,296 +161), gly + pendimethalin (1,296 + 1,000), gly + metribuzin (1,296 + 480), gly + 2.4-D amine (1,296 + 1,209) was applied in pre-emergence (PRE) over rye crop residues two days before soybean sowing. In addition, full season weed-free and weedy control plots were included. Gly + S-metolachlor and gly + pendimethalin reduced the horseweed density from 48 to 3 and 6 plants m^{-2}, respectively. The mix containing gly + metribuzin and gly + 2.4-D amine and gly applied alone had no effect in the horseweed control. The mix containing gly + metribuzin, gly + 2.4-D amine, gly + imazaquin and gly applied alone had no effect in the crabgrass control. In contrast gly + S-metolachlor and gly + pendimethalin reduced the crabgrass density from 70 to 0 and 1 plant m^{-2}, respectively. The soybean yield was higher with weed-free, S-metolachlor and metribuzin treatments. The use of an herbicide with residual effect had impact on weed management and soybean yield. In conclusion, a greater control of horseweed and crabgrass occurred when S-metolachlor or pendimethalin was applied PRE.

Keywords: *Glycine max*; 2.4-D; metribuzin; S-metolachlor; *Conyza* spp.

RESUMO - Um estudo de campo de três safras foi conduzido para avaliar o potencial de uso de herbicidas pré-emergentes misturados com glyphosate como meio de controlar as espécies de plantas daninhas na cultura da soja. Nas safras 2011/12, 2012/13 e 2013/14, o cultivar Brasmax Apollo RR foi semeado sob resíduos de colheita de centeio. Os tratamentos herbicidas foram o glyphosate (gly) (1.296 g i.a. ha^{-1}), gly + S-metolachlor (1.296 + 1.920), gly + imazaquin (1.296 + 161), gly + pendimethalin (1.296 + 1.000), gly + metribuzin (1.296 + 480) e gly + 2,4-D (1.296 + 1.209) aspergidos em pré-emergência (PRE) dois dias antes da semeadura da soja. Além disso, foram incluídas as testemunhas capinada e sem capina. Gly + S-metolachlor e gly + pendimethalin reduziram a densidade de buva de 48 para 3 e 6 plantas m^{-2}, respectivamente. A mistura contendo gly + metribuzin e gly + 2,4-D amina e o gly aplicado isoladamente não apresentaram controle dessa planta daninha. As misturas contendo gly + metribuzin, gly + 2,4-D amina, gly + imazaquin e gly aplicado isoladamente não mostraram qualquer efeito no controle de milhã. Em contraste, gly + S-metolachlor e gly + pendimethalin reduziram a densidade de milhã de 70 para 0 e 1 planta m^{-2}, respectivamente. O rendimento de soja foi

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maior na testemunha sem capina, gly + S-metolachlor e gly + metribuzin. O uso de herbicida com efeito residual teve impacto no manejo de plantas daninhas e na produtividade da soja. Os maiores níveis de controle de buva e milhã ocorreram com os herbicidas S-metolachlor e metribuzin.

Palavras-chave: *Glycine max*, 2,4-D, metribuzin, S-metolachlor, *Conyza* spp.

INTRODUCTION

The release of the Roundup Ready® (RR) soybeans cultivation in Brazil from 2005 allowed that the farmers replaced the herbicides used in agriculture by only one, glyphosate. The exclusive use of this herbicide occurred due to the fact that glyphosate is a broad-spectrum systemic herbicide and has an effective control about Liliopsidas and Magnoliopsidas weed species (Senseman, 2007). However, we observed over the years the proliferation of tolerant species and the selection of biotypes resistant to this herbicide. Under these circumstances is necessary to diversify the management programs for weed control. Examples are the use of herbicide tank mixture with glyphosate, pre-emergent herbicides and crop rotation that allow the use of alternative mechanisms of action to glyphosate. Thus, allowing the management of resistant plants and reducing the selection pressure of glyphosate on weed plants.

Although glyphosate is considered as a non-selective broad-spectrum herbicide, its residual effect is non-existent. This is due to the strong adsorption of glyphosate molecules on soil particles and their degradation by microorganisms (Sidoli et al., 2016). Thus, it is necessary in up to three post-emergence applications in soybean crop (Vargas et al., 2007). The search for pre-emergent herbicides that can be used in tank mixture with glyphosate may reduce the constant need of post-emergence applications. The mixtures with glyphosate provide a residual effect that will prevent or delay the first emergency flow, keeping the weeds in a favorable stage to do a post-emergence control (Kalsing and Vidal, 2013; Oliveira Neto et al., 2013). In addition to delaying the period before the interference (PBI), a period in which the weed-crop competition is not initialized. These benefits can lead to delaying or reduction in the number of post-emergence applications. Therefore, in addition to residual benefits, the use of pre-emergence herbicides helps in the rotation of mechanisms of action, delaying the selection of new glyphosate-resistant biotypes and contributing to the suppression of tolerant and herbicide-resistant populations (Norsworthy et al., 2012).

With the introduction of no-tillage system in the 1980s, weed species like *Conyza bonariensis* came to be seen more frequently, as they found ideal conditions of development in the system. Plant characteristics such as self-pollination, seed production of approximately 200,000 and dispersion at distances greater than 500 m (Dauer et al., 2007), contribute to their good adaptation, survival and high rate of infestation in the agricultural system. Glyphosate-resistant *Conyza bonariensis* biotypes were selected due to the intense use of this herbicide (Vargas et al., 2007). Later, in 2006, was found glyphosate-resistant *Conyza canadensis* (Lamego et al., 2013). Subsequently in 2010, in the Paraná state, biotype of *Conyza sumatrensis* resistant to chlorimuron-ethyl and glyphosate were found (Santos et al., 2014). It is becoming increasingly important to make decisions that will reduce the selection pressure of glyphosate.

Brazil show great diversity of genus Digitaria with 26 native and 12 exotic species (Do Canto-Dorow and Longhi-Wagner, 2001). The predominant species in the Rio Grande do Sul state are *Digitaria ciliaris* and *D. sanguinalis* where they can be found as weeds in rice and soybean crops (Agostinetto et al., 2016). The crabgrass (*Digitaria ciliaris*) is an annual narrow-leaf plant with decumbent development that reproduces by seeds, being very competitive with the agricultural crops (Kissmann and Groth, 1997). Crops such as flooded rice and soybeans showed a decrease in yield in weed-crop competition needing to remain free of this weed between 23 and 50 days after emergence (Agostinetto et al., 2014). Normally, there is success in controlling crabgrass with glyphosate application. However, despite herbicide efficiency, seedlings may be left in the crop due to their emergence after post-emergence glyphosate application (Scursoni and Satorre, 2010).

In the crop field the weed community is composed from a broad species from Magnoliopsides (eudicot) and Liliopsides (monocotyledons) classes, mainly plants from the Asteracea and Poaceae families (Santos et al., 2015). Through knowledge of the weed community it is possible to make the best decisions regarding the active ingredient, mechanisms of action and control methods to be used. Thus, this study aimed to verify the efficiency of pre-emergent herbicide + glyphosate on weed control, as well as selectivity to soybean.

MATERIALS AND METHODS

Field studies were established at the Federal Institute of Education, Science and Technology of Rio Grande do Sul - *Campus* Sertão, Brazil (28º02'46" S, 52º16'00" W) in 2011/12, 2012/13 and 2013/14 growing seasons on Typic Paleudalf soil with pH 5.9 and 2.4% organic matter. Soybean cultivar Brasmax Apollo RR was planted under crop residues of rye cultivar BR 01 on December 17th, 2011, December 18th, 2012 and November 27th, 2013 at a seeding rate of 330,000 seeds ha^{-1} in 45 cm rows. Plots were 3.15 m wide (seven rows) by 6 m long. The experimental design was a randomized complete block with four replications in three growing seasons.

The herbicide treatments (Table 1) was applied PRE in the rye crop residues two days before soybean planting. In addition, full season weed-free and weedy control plots were included. The herbicides doses were chosen according to the label and soil type. The rye crop residues biomass was 5,400 kg ha^{-1} in 2011/12 and 5,800 kg ha^{-1} in 2012/13 and 2013/14 growing seasons. Herbicide treatments were applied with a CO_2 pressurized sprayer at 200 kPa delivering 200 L ha^{-1} using Teejet XR110.01 nozzle types (Spraying Systems Co., Wheaton, IL 60187).

Table 1 - Herbicide common names, trade names, rates, concentration, formulation and manufacturer names used in PRE application

Common name	Trade name	Rate (g a.i. ha^{-1})	Concentration / formulation	Manufacter
Glyphosate (Gly)	Roundup Ready	1296	648 S	Monsanto
Gly + S-metolachlor	Dual-gold	1,296 + 1,920	960 EC	Syngenta
Gly + Imazaquin	Imazaquin Ultra	1,296 + 161	161 S	Nortox SA
Gly + Pendimethalin	Herbadox	1,296 + 1,000	500 EC	BASF
Gly + Metribuzin	Sencor 480	1,296 + 480	480 SC	Bayer CropScience
Gly + 2.4-D amine	Aminol 806	1,296 + 1209	806 S	ADAMA

Abbreviations: EC, emulsifiable concentrate; S, solution; SC, suspension concentrate.

The injury of herbicides on soybean was evaluated by seedling emergence 14 days after soybean emergence (DAE). Weed species were counted in a randomly selected area (1.0 m^2) within and between the middle two rows of each plot, 10 and 30 DAE to determine the level of weed control. Soybean emergence started 7 days after seeding in all growing seasons. Horseweed (*Conyza* spp.) and crabgrass (*Digitaria ciliaris*) were the predominant weed species in the three growing seasons. Soybean yield was determined by hand-harvesting the middle three rows in each plot at soybean maturity on April 20, 2012; April 20, 2013 and April 15, 2014 to determine yield in the three growing seasons. Weather data during the growing seasons were obtained from Brazilian Agricultural Research Corporation (EMBRAPA).

Variables were subjected to ANOVA using the ASSISTAT Software (Silva and Azevedo, 2002). Data were transformed to square root plus one to stabilize variances for analysis. Year was considered a random variable, and the herbicide treatment main effects were tested for error associated with the appropriate year by treatment interaction. Data were pooled across years when no significant year-by-treatment interaction occurred. Treatment means were separated using Tukey at $p \leq 0.05$.

RESULTS AND DISCUSSION

Growing conditions differed between the three crop seasons (Figure 1). The growing season 2011/12 was dry, having less rainfall amount compared to the growing seasons 2012/13 and 2013/14. In the growing season 2011/12 the rainfall amount was 444 mm and in the growing seasons 2012/13 and 2013/14 were 729 and 810 mm, respectively. The climatological normal data indicate that the average rainfall amount for the period is 734 mm. In addition, the rainfalls in the 2013/14 season were better distributed during the crop cycle. The average temperature varied between the three crop seasons with values of 21.7, 20.6 and 21.8 °C, respectively. Herbicides, year and interaction of herbicides and years had effect in the weed control and soybean yield (Table 2).

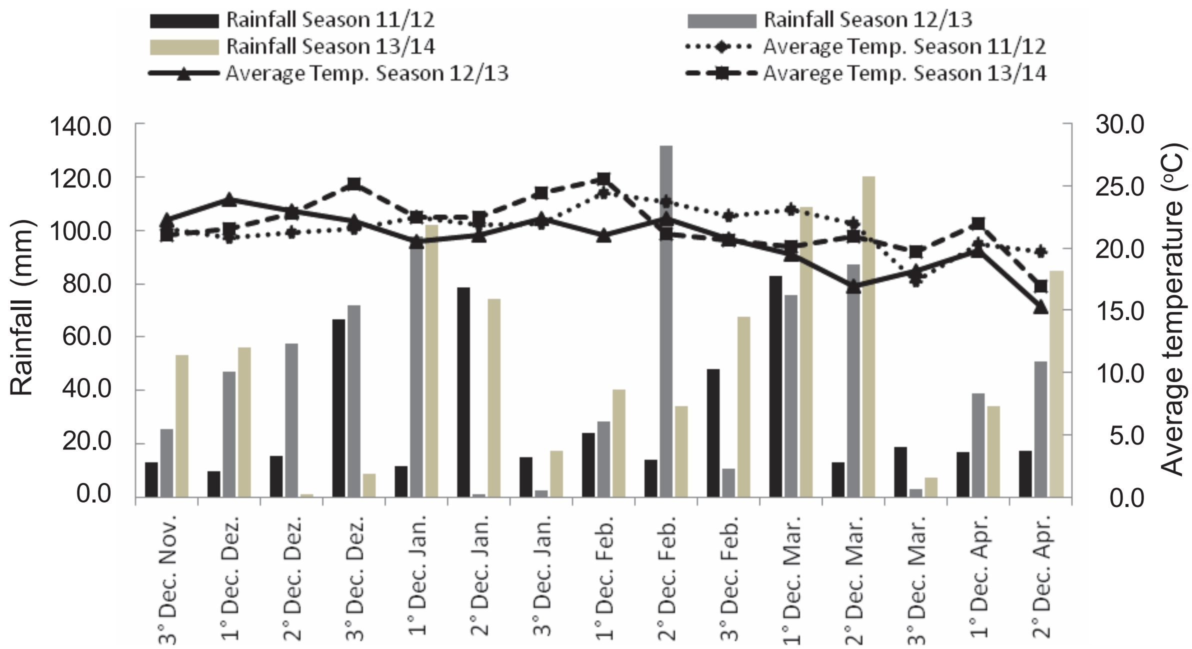


Figure 1 - Rainfall amount and air temperature, average by each ten days period (decennial) in 2011/12, 2012/13 and 2013/14 soybean crop season. Sertão-RS.

Table 2 - ANOVA for herbicides, years and your interaction for horseweed, crabgrass and total weed density at 10 days after emergence (DAE), total weed density at 30 DAE and soybean yield

Effect	Horseweed 10 DAE	Crabgrass 10 DAE	Total weed 10 DAE	Total weed 30 DAE	Yield
Herbicides	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Years	<0.0001	<0.0001	<0.0001	<0.0001	0.0004
Herb. x years	<0.0001	<0.0001	<0.0001	0.0014	0.0381
VC (%)	36.5	52.5	30.2	34.2	11.9

Horseweed Control

In 2011/12 and 2012/13 crop seasons the horseweed emergence at 10 DAE showed low levels (Table 3). In 2011/12 only in gly + imazaquin treatment showed 1.5 plants m^{-2} and in 2012/13 the numbers of horseweed ranged between 0 and 5.7 plants m^{-2}. Dry climate can be responsible for the low presence of this weed in 2011/12 and 2012/13 crop seasons. In Rio Grande do Sul state the main horseweed emergency flow occurs in fall and winter (Vargas et al., 2007) which showed low rainfall levels (data not show). The water availability has been more important than the presence of ground cover in emergency flows of horseweed (Soares, 2014). Germination and its speed of horseweed seeds are reduced by decreased water availability (Constantin et al., 2013).

In 2013/14 crop season the incidence of horseweed at 10 DAE showed high density levels. The mix containing gly + metribuzin and gly + 2.4-D amine and gly applied alone had no effect in the horseweed pre-emergence control. In contrast gly + S metolachlor and gly + pendimethalin

Table 3 - Horseweed density (plants m^{-2}) at 10 after soybean emergence (DAE) in 2011/12, 2012/13 and 2013/14 soybean crop season. Sertão - RS

Treatment/crop season	2011/12	2012/13	2013/14
Glyphosate	0.0 bA	2.5 bA	62.0 aA
Glyphosate + S-metolachlor	0.0 aA	4.2 aA	3.0 aC
Glyphosate + Imazaquin	1.5 bA	3.0 bA	27.0 aB
Glyphosate + Pendimethalin	0.0 aA	2.2 aA	6.0 aC
Glyphosate + Metribuzin	0.0 bA	2.2 bA	60.0 aA
Glyphosate + 2.4-D amine	0.0 bA	0.0 bA	52.0 aAB
Nontreated control	0.0 bA	5.7 bA	48.0 aAB
Weed-free control	0.0 aA	0.0 aA	0.0 aC

Uppercase letters are used to compare herbicide treatments within a same soybean crop season (column) and lowercase letters are used to compare herbicide treatment within different soybean crop season (line). Means followed by the same letter, either lowercase or uppercase, are not different according to Tukey test at 0.05.

reduced the horseweed density to 3 and 6 plants m^{-2}, respectively. Gly + imazaquin reduced horseweed density at 10 DAE, but was less effective than the treatments with S-metolachlor and pendimethalin. Glyphosate resistance has been documented on this horseweed population (Lamego et al., 2013). In Brazil, horseweed has been confirmed with resistance to chlorimuron, an acetolactate synthase (ALS)-inhibiting herbicide, and glyphosate (Heap, 2017). To date, glyphosate-resistant horseweed has been confirmed in many Brazilian states, and in some cases, these biotypes are also resistant to ALS-inhibiting herbicides (Santos et al., 2014).

Metribuzin at 480 g ha^{-1} tank mixed with gly did not control of horseweed at 10 DAE. Metribuzin was applied at low rate and this may be a reason for lowest control observed in this study. Metribuzin applied alone at 420 g a.i. ha^{-1} provided 41% control of Canada fleabane (Moseley and Hagood, 1990). At a higher dose, metribuzin (860 g ha^{-1}) tank mixed with glyphosate provided 53 to 63% control (Eubank et al., 2008). Levels of 97% of control were achieved when used metribuzin at 1,120 g ha^{-1} (Byker et al., 2013). The high control of Canada fleabane in this last study may be due to use of the highest label rate. The dose of 1,120 g ha^{-1} is 2.3 times higher than the recommended dose for the soybean crop in clay soil in Brazil. The use of metribuzin in high dose may cause severe damage mainly on newly released soybean varieties.

The use of 2.4-D + gly has been reported as effective in the post-emergence control of glyphosate-resistant Conyza (Byker et al., 2013). However, the pre-emergence control showed no effect in this study. We evaluated the pre-emergent effect of this treatment because many farmers have used 2.4-D amine before the soybean crop establishment to control glyphosate-resistant horseweed in post-emergence. The 2.4-D soil-residual activity are typically less than 10 days (Shymko et al., 2011). A studied in 114 agricultural soils found that 2.4-D degradation was strongly correlated with the amount of soil organic carbon present (Gaultier and Farenhorst, 2007). Soils with less than 1% of organic carbon generally showed greater 2.4-D degradation rates. The soil organic carbon levels in the experimental area where the field experiments were evaluated were approximately 1.1% organic carbon. Once the horseweed can germinate throughout the crop season and 2.4-D amine provides limited residual weed control, other herbicides with prolonged residual action should be used to provide full-season residual control.

S-metolachlor at 1,920 g ha^{-1} tank mixed with gly reduced in 94% the horseweed density at 10 DAE in the 2013/14 crop season. In pre-emergence, S-metolachlor controls a broad spectrum of grass weeds and small-seeded broadleaves (Senseman, 2007). Five field studies evaluated the gly + S-metolachlor performance in glyphosate-resistant cotton. The conclusion is that S-metolachlor residual activity allowed for an extended period for more effective POST control to smaller weed seedlings instead of weeds that were possibly larger and harder to control (Clewis et al., 2006). However, the presence of gly reduces the persistence of residual herbicide S-metolachlor in one week when compared with the presence of paraquat (Nunes and Vidal, 2008). In Brazil this herbicide is not present in the recommendations to control horseweed. But it could be an interesting strategy to glyphosate-resistant horseweed control mainly in areas where grass plants occur simultaneously. In USA the formulated mixture of gly + S-metolachlor is possible for the glyphosate-resistant Conyza pre-emergence control at 895 g of S-metolachlor ha^{-1} (Syngenta, 2017).

The herbicide pendimethalin at 1,000 g ha^{-1} tank mixed with gly reduced in 87% the horseweed density at 10 DAE in 2013/14 crop season. This herbicide has the same spectrum of S-metolachlor. Pendimethalin inhibits cell division and cell elongation and protects crops like wheat, corn, soybeans, potatoes, cabbage, carrots and others (Oliveira Junior et al., 2011). Two field experiments evaluated the pendimethalin performance in glyphosate-resistant horseweed prior to planting no-till cotton. Pendimethalin at 920 g a.i. ha^{-1} provide residual control at 56 days after application (Steckel et al., 2006). In a sandy loam soil the persistence of this herbicide is up to 90 days (Chopra et al., 2015) and black soil the herbicide persisted up to 60 days (Saha et al., 2015). Like S-metolachlor, pendimethalin could be an interesting pre-emergence strategy to glyphosate-resistant horseweed control due to efficiency and residual effect.

Horseweed has become the most problematic weed in soybean crop in Brazil (Lamego et al., 2013) as a consequence of the resistance to the glyphosate (Heap, 2017). Glyphosate is widely sprayed due to use of genetically modified soybean. In the same crop season the herbicide could be applied two or three times. Once in burndown application and one or two times in POST in transgenic RR Soybean. As cultural control measures farmers have used with success winter cover crops to reduce the amount and size of horseweed plants in burndown (Lamego et al., 2013). The herbicides used before soybean sowing are normally POST and do not offer a horseweed residual control. We believe that the use of PRE herbicides, like S-metolachlor and pendimethalin, tank mixed with POST herbicides in burndown could be an interesting tool to introduce different mechanisms of action in the weed control.

Crabgrass control

The incidence of crabgrass at 10 DAE was lower in 2011/12 and 2012/13 than in 2013/14 season (Table 4). The quantity of crabgrass, in the herbicides treatments, ranged between 0-6,2 and 0-4,2 in 2011/12 and 2012/13 crop seasons, respectively. In 2013/14 the incidence of crabgrass at 10 DAE showed high density levels. The tank-mix containing gly + metribuzin, gly + 2.4-D amine, gly + imazaquin and gly applied alone had no effect in the crabgrass control. The recommended rate of metribuzin in soybean (480 g a.i. ha^{-1}) may be a reason for lower control observed in this study. Metribuzin control Poaceae species when used up to 1,440 g a.i. ha^{-1} in sugar cane (Bayer, 2017). The herbicide 2.4-D amine and imazaquin do not have effect in Poaceae species. In contrast gly + S-metolachlor and gly + pendimethalin reduced the crabgrass density to 0 and 1,0 plant m^{-2}, respectively (Table 4).

S-metolachlor at 1,920 g a.i. ha^{-1} tank mixed with gly reduced in 100% the crabgrass density at 10 DAE in 2013/14 crop season. This herbicide is very effective against Poaceae weeds in PRE application (Senseman, 2007). S-metolachlor at 450 g a.i. ha^{-1} provided best performance in

Table 4 - Crabgrass density (plants m^{-2}) at 10 after soybean emergence (DAE) in 2011/12, 2012/13 and 2013/14 soybean crop season. Sertão - RS

Treatment/crop season	2011/12	2012/13	2013/14
Glyphosate	0.0 bA	1.0 bA	100.0 aA
Glyphosate + S-metolachlor	0.0 aA	1.5 aA	0.0 aC
Glyphosate + Imazaquin	6.2 aA	1.5 aA	19.0 aBC
Glyphosate + Pendimethalin	5.0 aA	2.0 aA	1.0 aC
Glyphosate + Metribuzin	3.7 bA	3.2 bA	57.0 aAB
Glyphosate + 2.4-D amine	5.0 bA	2.7 bA	66.0 aAB
Nontreated control	18.2 bA	13.7 bA	70.0 aA
Weed-free control	0.0 aA	0.0 aA	0.0 aC

Uppercase letters are used to compare herbicide treatments within a same soybean crop season (column) and lowercase letters are used to compare herbicide treatment within different soybean crop season (line). Means followed by the same letter, either lowercase or uppercase, are not different according to Tukey test at 0.05.

control the most common Poaceae weeds in USA (Norsworthy and Smith, 2005). Higher doses ranged between 1,200 and 2,700 g a.i. ha^{-1} provide effective control of *Panicum dichotomiforum* and *Amaranthus spinosus* on organic soil (Odero et al., 2016). However, the residual crabgrass control throughout the growing season could be shortly. We observed at 30 DAE that the residual effect in the 2013/14 crop season was less than 30 days. Similar results was found in no-tillage system where this herbicide at 2.800 g a.i. ha^{-1} tank mixed with gly showed 28 days of residual control under typical Dystrophic Red Argisol composed by 28% clay (Nunes and Vidal, 2008). The rainfall regime was related on S-metolachlor residual. The dissipation was faster under light but frequent rain, due to more humid surface conditions. Leaching of S-metolachlor to deeper soil layers was greater under the less frequent but more intense rain (Aslam et al., 2015).

The herbicide pendimethalin at 1,000 g ha^{-1} tank mixed with gly reduced in 99% the crabgrass density at 10 DAE in 2013/14 crop season (Table 4). The PRE application of pendimethalin is a beneficial weed management practices to increase the soybean yield (Monsefi et al., 2016). This herbicide at 750 g ha^{-1} as PRE followed by propaquizafop as POST was effective in reducing weed growth with viability net monetary return (Sharma and Renjith, 2016). Pendimethalin at 1,006 g ha^{-1} in a Denhawken sandy loam with less than 1.0% organic matter showed effective control of *Urochloa texana* (Grichar et al., 2012). Like S-metolachlor, the pendimethalin residual effect in the 2013/14 crop season was less than 30 days. The residual effect could be greater if this herbicide transpose the straw in no-tillage system (Araldi et al., 2015). In our studies, the herbicides were applied above 5.8 ton ha^{-1} of rye crop residues. The high Kow value makes that small amounts of pendimethalin reaches the soil solution due to strong herbicide-straw interaction. If the pendimethalin reach the ground, its residual effect is high because in the soil the dissipation and mobility is very slow (Senseman, 2007). In golf courses more than 30% of applied pendimethalin was present after 310 days of soil treatment (Belden et al., 2003).

Usually crabgrass has no problems in soybeans. The use of POST herbicides like ACCase inhibitors shows higher levels of control. Nevertheless, the use of PRE herbicides to manage Poaceae weeds in soybeans could be an applicable strategy to avoid the initial interference due to high emergencies flow and delays the first POST application. The use of soil-residual herbicides not only increase the number of MOAs used in a management program, but can also extended weed control compared to POST herbicides

Total weed control

Sometimes we have a dominant weed in an agricultural area, but in most cases, we have a community of weeds interfering the crop. Thus, the ideal residual herbicide should control grasses and broadleaf weeds. In this way, when we analyze the total weed density at 10 DAE we found that S-metolachlor and pendimethalin herbicides showed better weed control (Table 5). This is due to two dominant species in the field that were the horseweed and the crabgrass. Both herbicides control a broad spectrum of grass weeds and small-seeded broadleaf weeds (Senseman, 2007). The weed density increased significantly at 30 DAE (Table 5), especially in treatments that showed residual effect at 10 DAE. The increasing in the weed community was 954% and 575% in the treatments with S-metolachlor and pendimethalin, respectively. Nevertheless, residual weed control throughout the growing season was improved significantly with the addition of S-metolachlor or pendimethalin.

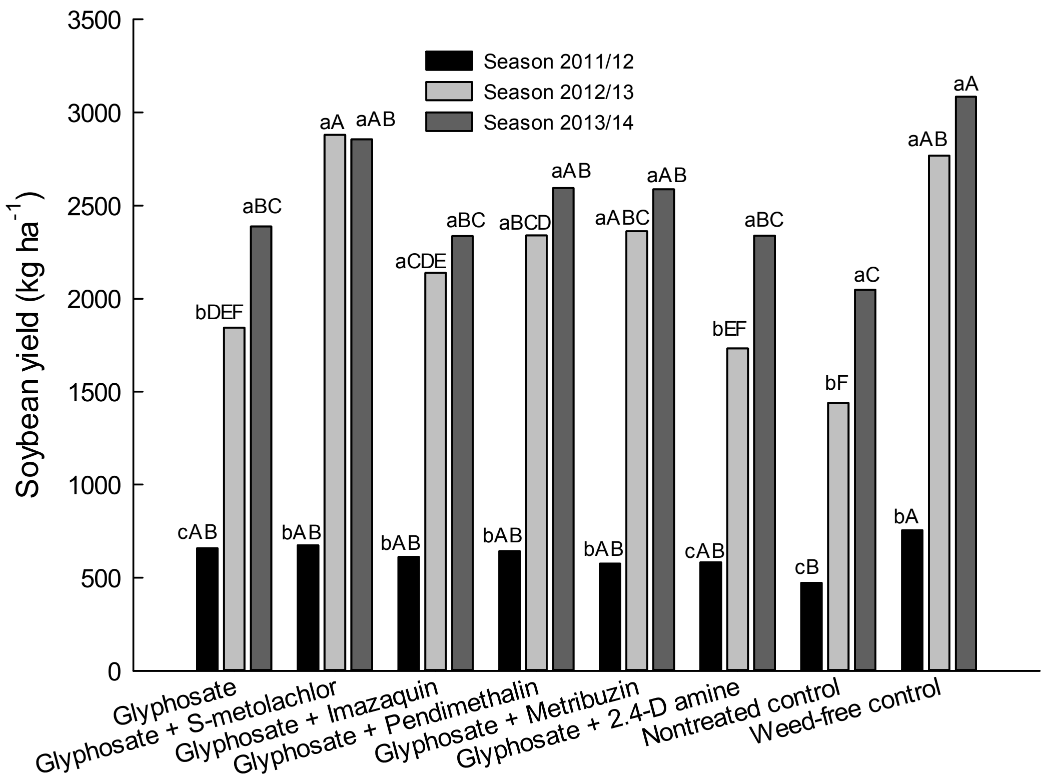
Soybean grain yield

The crop season and herbicide treatments influenced soybean grain yield (Figure 2). In 2011/12, 2012/13 and 2013/14 seasons the average yield was 622, 2,188 and 2,529 kg ha^{-1}, respectively (Figure 1). The crop season 2011/12 was dry, having less rainfall compared to 2012/13 and 2013/14 seasons (Figure 1). In crop season 2011/12 the herbicides treatments do not showed difference, probably due to the residual herbicides have little activity due to low soil moisture. In the next season, treatment with S-metolachlor showed the highest yield as well as with metribuzin and the weed-free control treatment. In 2013/14 season the soybean yield was higher in weed-free, S-metolachlor, pendimethalin and metribuzin treatments. This is due to the residual activity of this herbicide in the first 30 days of the soybean crop establishment. It is important to point

Table 5 - Total weed density (plants m^{-2}) at 10 and 30 days after soybean emergence (DAE) in 2011/12, 2012/13 and 2013/14 soybean crop season. Sertão - RS

Treatment/crop season	10 DAE			30 DAE		
	2011/12	2012/13	2013/14	2011/12	2012/13	2013/14
Glyphosate	6 cBC	15 bB	185 aA	22 bAB	21 bAB	184 aA
Glyphosate + S-metolachlor	4 cBC	23 aAB	13 bD	24 bAB	26 bAB	124 aA
Glyphosate + Imazaquin	14 bAB	18 bB	37 aC	27 bAB	21 bAB	155 aA
Glyphosate + Pendimethalin	6 bBC	20 aB	16 aD	26 bAB	24 bAB	92 aA
Glyphosate + Metribuzin	6 cBC	16 bB	145 aB	19 bAB	20 bAB	172 aA
Glyphosate + 2.4-D amine	13 bBC	10 bBC	131 aB	20 bAB	13 bAB	148 aA
Nontreated control	26 cA	51 bA	178 abA	59 bA	60 bA	191 aA
Weed-free control	0 aC	0 aC	0 cD	0 aB	0 aB	0 aB

Uppercase letters are used to compare herbicide treatments within a same soybean crop season (column) and lowercase letters are used to compare herbicide treatment within different soybean crop season (line). Means followed by the same letter, either lowercase or uppercase, are not different according to Tukey test at 0.05.



Uppercase letters are used to compare herbicide treatments within a same soybean crop season and lowercase letters are used to compare herbicide treatment within different soybean crop season. Means followed by the same letter, either lowercase or uppercase, are not different according to Tukey test at 0.05.

Figure 2 - Soybean yield (kg ha^{-1}) in 2011/12, 2012/13 and 2013/14 soybean crop season at Sertão-RS.

out that no POST herbicide was applied over the crop to highlight the residual effect on soybean grain yield.

Practical implications

The use of an herbicide with residual effect had impact on weed management. This kind of herbicide can aid in suppressing early-season weeds emergence and limit the initial interference of weeds growing in conjunction with the crop. In conclusion, a greater control of horseweed and crabgrass occurred when S-metolachlor or pendimethalin was applied PRE. No POST herbicide was applied over the crop to highlight the residual effect. However, we believe that a greater control of weeds occurred when PRE herbicides followed by POST herbicides compared to a POST-only management program. Thus, leading to less selection pressure on POST herbicides. In the case of PRE, these studies showed that to control the weed community the best situation is apply two PRE herbicides, one that control grasses and another the control mainly broadleaf weeds. The next step is finding a broadleaf PRE to increase the spectrum together with S-metolachlor or pendimethalin and the weed control costs. This situation, the use of POST herbicides and integrated weed management strategies can mitigate the interference, mainly of glyphosate-resistance weeds.

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