Residual Herbicides in Weed Management for Glyphosate-Resistant Soybean in Brazil[1]

Herbicidas Residuais em Manejo de Plantas Daninhas na Soja Resistente ao Glyphosate no Brasil

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ABSTRACT - In agricultural production systems where the glyphosate-resistant soybean crop (*Glycine max*) is grown and the practice of crop rotation with alternative herbicides is not adopted, the exclusive and continuous use of glyphosate has led to the occurrence of resistant weed populations that may limit or compromise the benefits of this technology. Thus, the efficacy of weed management programs, including the use of residual herbicides (sulfentrazone, flumioxazin, imazethapyr, diclosulan, chlorimuron and s-metolachlor) applied in preemergence and followed by in-crop postemergence applications of glyphosate (PRE-POST) were compared to glyphosate postemergence only programs – POST. The study was conducted across nine locations during the 2009/2010 and 2010/2011 growing seasons. PRE-POST programs were efficient in the control of *Amaranthus viridis*, *Brachiaria plantaginea*, *Bidens pilosa*, *Commelina benghalensis*, *Eleusine indica*, *Euphorbia heterophylla* and *Raphanus raphanistrum*, with the level of control being similar when comparing the program with two applications of glyphosate POST. Some PRE-POST programs were not efficient in controlling *Cenchrus echinatus*, *Ipomoea hederifolia* and *Ipomoea triloba*. Sulfentrazone and diclosulam PRE-POST programs improved the control of *Ipomoea triloba* compared to sequential applications of glyphosate alone. No significant differences in soybean yield were observed between any of the herbicide treatments or study locations. The use of residual herbicides in preemergence followed by glyphosate in-crop postemergence provides consistent weed control and reducing early season weed competition. Furthermore, these programs utilize at least two herbicide modes of action for herbicide use diversity, which will be needed to stay ahead of resistance build-up, regardless of when weeds may appear.

Keywords: Herbicide resistance management, mode of action, residual herbicides, weed management programs, preemergence, postemergence.

*RESUMO - Em sistemas de produção agrícola onde a cultura da soja tolerante ao glyphosate (**Glycine max**) está inserida e onde não há a prática de rotação de culturas com herbicidas alternativos, o uso exclusivo e contínuo do glyphosate tem levado ao surgimento de populações de plantas daninhas resistentes, que podem limitar ou comprometer os benefícios dessa tecnologia. Nesse sentido, a eficiência de programas de manejo que envolvem herbicidas residuais (sulfentrazone, flumioxazin, imazethapyr, diclosulam, chlorimuron e s-metolachlor) aplicados na pré-emergência seguidos de glyphosate na pós-emergência da cultura (PRE-POST) foi comparada à de programas com apenas glyphosate na pós-emergência – POST. O estudo constituiu-se de nove experimentos realizados durante as safras agrícolas 2009/2010 e 2010/2011. Os programas PRE-POST foram eficientes no controle de **Amaranthus viridis**, **Brachiaria plantaginea**, **Bidens pilosa**, **Commelina benghalensis**, **Eleusine indica**, **Euphorbia heterophylla** e **Raphanus raphanistrum**, sendo semelhantes aos níveis de controle do programa com duas aplicações de glyphosate POST. Alguns programas PRE-POST não foram eficientes para **Cenchrus echinatus**, **Ipomoea hederifolia** e **Ipomoea triloba**. Sulfentrazone e diclosulam PRE-POST melhoraram o controle de **Ipomoea triloba** em relação às aplicações sequenciais de glyphosate. Quanto à*

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produtividade, não foram observadas diferenças significativas entre os tratamentos herbicidas. As aplicações de herbicidas residuais em pré-emergência seguidos da aplicação de glyphosate em pós-emergência resultam em controles consistentes de plantas daninhas e evitam a competição inicial. Além disso, estes programas utilizam pelo menos dois modos de ação que contribuem para a diversidade do uso de herbicidas que será necessária para ficar à frente de novos casos de resistência, independentemente de quando as plantas daninhas possam aparecer.

Palavras-chave: manejo de resistência a herbicida, modo de ação, herbicidas residuais, programas de manejo de plantas daninhas, pré-emergência, pós-emergência.

INTRODUCTION

The adoption of glyphosate-resistant (GR) soybean (*Glycine max*) increased annually after its commercial release in 2005 in Brazil. In 2011, growers cultivated this technology on 20.6 million hectares in 2011 (James, 2011). The popularity of the technology is primarily due to the simplicity and flexibility of the weed control programs that rely on herbicides with efficacy against a broad spectrum of weeds, without crop injury or crop rotation restrictions (Carpenter & Gianessi, 1999). The extensive adoption of the GR technology increased the use of glyphosate herbicide leading to a reduction of the diversity of herbicides for weed management in GR crops (Young, 2006). Some studies stated that the most important factor leading to the evolution of herbicide resistance is overreliance on a single herbicide from the same mode of action (MOA) without using other weed management options (Norsworthy et al., 2012). In Brazil, widespread resistance to glyphosate has been confirmed for five weed species: *Lolium multiflorum*, *Conyza bonariensis*, *Conyza canadensis*, *Conyza sumatrensis,* and *Digitaria insularis* (Heap, 2013).

The widespread adoption of GR crops, and subsequent glyphosate use on a significant portion of the available agronomic cropland, provided a strong selection pressure for weeds that are not controlled by glyphosate, thereby contributing to changes in the weed community (Webster & Sosnoskie, 2010). Weed shift is a change in the relative frequency of weeds in a population in response to a management practice, for example *Ipomoea* and *Commelina* species are becoming more troublesome in GR soybean fields (Culpepper, 2006). The selection of glyphosate resistance for some weed species means that the stewardship of glyphosate use is important to reduce the reliance on this herbicide mode of action for weed control (Nurse et al., 2007). Glyphosate is a broad-spectrum herbicide, but it has different effectiveness on different weed species. *Commelina benghalensis*, *Ipomoea hederifolia,* and *Richardia brasiliensis* are more tolerant to glyphosate than the other species (Monquero et al., 2005). *Ipomoea* spp. and *Commelina* spp. are common weed species in the soybean growing regions of Brazil. One of the Integrated Weed Management concepts is the recommendation of the use of multiple and effective modes of action against the most troublesome weeds and those prone to herbicide resistance. Furthermore, this practice will prevent weed seeds production leading to a reduction of the number of weed seeds in the soil seedbank (Norsworthy et al., 2012). Then, it is a challenge in South America to design herbicide and non-herbicide-based strategies that effectively delay and/or manage the evolution of herbicide-resistant weeds and weed shifting to glyphosate tolerant weeds in cropping systems based on recurrent glyphosate application, such as those used with GR soybeans (Christofoletti et al., 2008).

Depending on the grower's management preference and weed spectrum, there are several viable options to diversify the weed management programs in GR soybean. Weed management programs, consisting of planting preemergence (PRE) applications of residual preemergence herbicides followed by glyphosate POST, provided greater weed control than a single POST application of glyphosate in GR crops (Dirks et al., 2000). The PRE application of residual herbicides, such as sulfentrazone, may delay the establishment of GR weed biotypes (Krauz & Young, 2003). The addition of the PRE residual herbicide in the program can provide more consistent control of hard-to-control weeds, delay the post planting application timing for glyphosate, and reduce selection pressure for resistant biotypes (Walsh & Powles, 2007). However, studies conducted by Nurse et al. (2007) showed no advantage from the use of flufenacet plus metribuzin followed by glyphosate in comparison to a single application of glyphosate on *Echinochloa crus-galli*, *Setaria viridis*, *Chenopodium album*, *Ambrosia artemisiifolia,* and *Abutilon theophrasti*.

Certain PRE residual herbicides could be associated with in-crop POST applications of glyphosate to improve weed control and increase herbicide diversity in GR weed management programs. Tank mixtures of glyphosate plus S-metolachlor in GR cotton increased control of broadleaf signalgrass (*Urochloa platyphylla*), goosegrass (*Eleusine indica*), large crabgrass (*Digitaria sanguinalis*), and yellow foxtail (*Setaria pumila*) by 14% to 43% compared to glyphosate alone (Clewis et al., 2006). In addition, Vanlieshout & Loux (2000) studied the interactions of glyphosate with residual herbicides in no-till soybean production and observed that the foliar activity of residual herbicides can improve the control of emerged weeds when associated with glyphosate. In Brazil, Procopio et al. (2007) observed that the addition of imazethapyr and chlorimuron-ethyl to POST applications of glyphosate in GR soybean improved the control of *Euphorbia heterophylla*, *Commelina benghalensis, Chamaesyce hirta, Leucas martinicensis* and *Ipomoea grandifolia* compared to a single POST application of glyphosate alone. However, glyphosate associated with chlorimuron-ethyl, flumioxazin, imazethapyr, and fomesafen have caused soybean injury and, in some cases, an adversely affected soybean yield (Correia et al., 2008; Albrecht et al., 2012).

In Brazil, more research is needed to determine the benefits and added value of utilizing herbicides with alternative mechanisms of action for weed management in GR soybean. The objective of this multi-location study was to evaluate the weed control and yield benefits of several weed management programs consisting of PRE residual herbicides followed by POST glyphosate (PRE-POST) compared to a glyphosate only program (POST) in GR soybean.

MATERIAL AND METHODS

Five studies were conducted in Brazil at Santa Cruz das Palmeiras, SP (SCP), Não-Me-Toque, RS (NMT), Rolândia, PR (ROL), Cachoeira Dourada, MG (CAD) and Sorriso, MT (SOR), respectively, from December 2009 to April 2010 and four studies were conducted at Santa Cruz das Palmeiras, SP (SCP), Não-Me-Toque, RS (NMT), Rolândia, PR (ROL) and Sorriso, MT (SOR), respectively, from November 2010 to March 2011. The study locations were selected to provide natural infestations of common and troublesome weed species, including glyphosate hard-to-control weed species namely *Ipomoea* spp. and *Commelina benghalensis*, in the major soybean growing regions. The soil characteristics, seeding dates, rainfall, cultivars, application timings, and major weed species for each location are described in Table 1 (Season 2009/2010) and Table 2 (Season 2010/2011). Glyphosate at 1,440 g a.e. ha^{-1} of was applied 14 days before seeding (DBS) followed by the sequential application of glyphosate at 720 g a.e. ha^{-1} of 1 DBS at each location to control all the emerged weeds prior to seeding GR soybean in a no-till system. Both pre-plant glyphosate applications were applied with a tractor sprayer at a 200 L ha^{-1} spray volume.

Phosphorus and potassium fertilizer was applied at a planting time according to the soil sample analysis of each site. Soybean seeds were inoculated with rhizobium for N fixations according to the label recommendation. The plot size was 3 m width by 5 m long, allowing six 50-cm soybean rows. Treatments were: 1- no PRE or POST herbicide application; 2- glyphosate, single application at 960 g a.e. ha^{-1} at 28 days after soybean emergence (DAE); 3- glyphosate 720 g ha^{-1} at 14 (DAE) followed by glyphosate at 480 g ha^{-1} at 28 DAE; 4- sulfentrazone PRE at 400 g a.i. ha^{-1}; 5- flumioxazin PRE at 60 g a.i. ha^{-1}; 6- imazethapyr PRE at 90 g a.i. ha^{-1}; 7- diclosulan PRE at 25 g a.i. ha^{-1}; 8- chlorimuron 20 g a.i. ha^{-1}; and 9- S-metolachlor 1.920 g a.i. ha^{-1}. PRE treatments 4 through 9 were followed by glyphosate at 720 g ha^{-1} at 28 DAE. All PRE and POST herbicide treatments were sprayed with a CO_2-backpack sprayer with TT110015 nozzle tips, at 225 kPa and a delivery rate of 120 L ha^{-1}.

Table 1 - Location, soil characteristics, seeding date, cultivars, application timing, and major weeds in 2009/2010

Parameter - Season 2009/2010	Study Location[1/]				
	SCP	NMT	ROL	SOR	CAD
Location (geographic coordinates)	S 21º48'58" W 47º16'17"	S 8º24'36.3" W52º48'19.4"	S 23º16'10" W 51º28'52"	S 12º25'20.9" W 55º38'11.5"	S 18º36'54" W49º26'14"
Soil Texture	Clay	Clay	Clay	Clay	Clay
Soil Organic matter	3.1%	2.6%	3.1%	4.7%	2.2%
Soil pH	4.8	5.4	6.02	5.0	4.7
Rainfall (mm) Nov. 2009 to April 2010	1125.2	722.3	1394.0	1832.0	1378.5
Seeding Date	11-Dec-09	16-Dec-09	18-Dec-09	24-Nov-09	18-Dec-09
Cultivars	BMX Titan RR	NA 4990RG	Vmax RR	M8849RR	M8199RR
Application – PRE (preemergence)	11-Dec-09	16-Dec-09	18-Dec-09	24-Nov-09	18-Dec-09
Application – EPOST (early postemergence)	30-Dec-09	4-Jan-10	7-Jan-10	8-Dec-09	7-Jan-10
Application - POST (postemergence)	12-Jan-10	18-Jan-10	21-Jan-10	21-Dec-09	21-Jan-10
Major weed in untreated plots[2/] (plant m^{-2}) and stage (leaves) – 28 DAE)	AMAVI (34; 8), IPOHE (12; 5); BIDPI (7; 8)	IPOTR (103; 6)	BIDPI (62; 3)	EPHHL (100; 5)	COMBE (14; 4); ELEIN (8; 3)

[1/] Study Location: SCP = Santa Cruz das Palmeiras, SP, NMT = Não-Me-Toque, RS, ROL = Rolândia, PR, CAD = Cachoeira Dourada, MG and SOR = Sorriso, MT. [2/] Major weed: AMAVI = *Amaranthus viridis*; IPOHF = *Ipomoea hederifolia*; IPOTR = *Ipomoea triloba*; BIDPI = *Bidens pilosa*; EPHHL = *Euphorbia heterophylla*; COMBE = *Commelina benghalensis*; ELEIN = *Eleusine indica*.

Table 2 - Location, soil characteristics, seeding date, cultivars, application timing, and major weeds in 2010/2011

Parameter - Season 2010/2011	Study Location[1/]			
	SCP	NMT	ROL	SOR
Location (geographic coordinates)	S 21º48'55" W 47º16'14"	S 28º24'31" W 52º48'34"	S 23º16'01" W 51º29'02"	S 12º25'06.4" W 55º38'24.8"
Soil Texture	Clay	Clay	Clay	Clay
Soil Organic matter	2.80%	3.10%	3.11%	3.7%
Soil pH	4.9	5.6	5.6	6.2
Rainfall (mm) Nov. 2010 to May 2011	1370.3	1336.6	1185.0	1714.5
Seeding Date	25-Nov-10	10-Dec-10	30-Dec-10	19-Nov-10
Cultivar	BMX Titan RR	NA4990RG	M6707 RR	M8360RR
Application – PRE (preemergence)	25-Nov-10	10-Dec-10	30-Dec-10	19-Nov-10
Application – EPOST (early postemergence)	10-Dec-10	30-Dec-10	18-Jan-11	8-Dec-10
Application - POST (postemergence)	29-Dec-10	14-Jan-11	1-Feb-11	22-Dec-10
Major weed in untreated plots[2/] (plant m^{-2}) and stage (leaves) – 28 DAE)	AMAVI (63; pre-flowering), CCHEC (52; 7), IPOTR (31;12) BIDPI (30; 10)	BRAPL(172; 4) RAPRA (28; flowering)	COMBE (18;2)	ELEIN (13; 3)

[1/] Study Location: SCP = Santa Cruz das Palmeiras, SP, NMT = Não-Me-Toque, RS, ROL = Rolândia, PR, CAD = Cachoeira Dourada, MG and SOR = Sorriso, MT. [2/] Major weeds: AMAVI = *Amaranthus viridis*; IPOTR = *Ipomoea triloba*; BIDPI = *Bidens pilosa*; COMBE = *Commelina benghalensis*; ELEIN = *Eleusine indica; CCHEC = Cenchrus echinatus; BRAPL = Brachiaria plantaginea; RAPRA = Raphanus raphanistrum*.

The experimental design for all the study locations was a randomized complete block with four replications. Treatments with PRE residual herbicides were rated for weed control at 14 and 28 days after application (DAPRE), just prior to POST glyphosate application. Only the 28 DAPRE ratings are reported for PRE treatments. Treatment 3 (two sequential applications of glyphosate) was rated at 7 and 14 days after the second application (DAPOST). All treatments were rated for weed control at 7 and 14 days after POST glyphosate application (DAPOST) at 28 DAE. Only the 14 DAPOST ratings are reported for all treatments. Visual weed control ratings were made on a 0 to 100% scale, where 0% equals no weed control and 100% equals complete weed control. Weed density counting was made at 28 DAPRE to help in weed control evaluation. Soybean injury was evaluated visually on a 1 to 9 EWRC scale (1 indicating no injury and 9 indicating soybean death) at 14 DAPRE for residual herbicide treatments and 14 DAPOST for all treatments. Grain yield of soybean was based on harvesting the three middle rows of the experimental unit and determined at 13% moisture content. The data were subjected to ANOVA and treatment means for weed control, weed density, soybean injury, and grain yield and were separated using Fisher's Protected LSD test at a 5% probability level. Because of different weed species, each trial was analyzed separately. Since the soybean was not harvested at the CAD location in the 2009/2010 season, no yield data are reported for this study location.

RESULTS AND DISCUSSION

Weed Control

Weed control ratings of preemergence residual herbicides at 28 DAPRE before the POST glyphosate application at 28 DAE, for all treatments in 2009/2010 and 2010/2011 are shown in Table 3. The response of weed species to the PRE residual herbicides varied, with S-metolachlor providing the greatest range of response across weed species, from 5% to 100%.

The proper selection of residual herbicide to include in the GR weed management program is dependent on the weed species present and determines the level of early season weed control (Norsworthy et al., 2012). All tested PRE herbicide treatments provided excellent control (96+%) of *Amaranthus viridis* at 28 DAPRE.

Sulfentrazone at 400 g ha^{-1} provided excellent control of *Cenchrus echinatus* (93%), *Commelina benghalensis* (89-95%), *Euphorbia heterophylla* (90%), and *Ipomoea* spp. (91-97%) at 28 DAPRE. Sulfentrazone provided intermediate to very good control of *Bidens pilosa* and *Eleusine indica* ranging from 76 to 96% and 76 to 94%, respectively, and poor control of *Raphanus raphanistrum* (8%) and *Brachiaria plantaginea* (13%). Sulfentrazone has already been reported as an efficient tool in GR soybean crop (Krauz & Young, 2003).

Flumioxazin at 60 g ha^{-1} provided effective control of *Euphorbia heterophylla* (91%), intermediate control *Cenchrus echinatus* (68%) and was variable on *Bidens pilosa* (50-94%), *Ipomoea* spp. (8-84%), *Commelina benghalensis* (64-91%) and *Eleusine indica* (61-90%) at 28 DAPRE. Also for this treatment, poor control was observed on *Raphanus raphanistrum* (10%) and *Brachiaria plantaginea* (10%). Flumioxazin at 25 and 40 g ha^{-1} showed a significant residual effect over *Euphorbia heterophylla* in sandy and clay soils (Jaremtchuk et al., 2009).

Imazethapyr at 90 g ha^{-1} was effective in controlling *Raphanus raphanistrum* (96%), *Ipomoea* spp. (87-98%), *Cenchrus echinatus* (88%), *Commelina benghalensis* (84-92%), and *Brachiaria plantaginea* (83%). Imazethapyr provided inconsistent control of *Bidens pilosa* (63-95%) and *Eleusine indica* (76-90%) and the unsatisfactory control of *Euphorbia heterophylla* (48%). Generally, imazethapyr is highly effective on *Euphorbia heterophylla* susceptible populations (Gelmini et al., 2005). The weed control performance and previous herbicide history at the SOR location suggests that this population of *Euphorbia heterophylla* may be ALS-resistant.

Diclosulan at 25 g ha^{-1} was effective in controlling *Commelina benghalensis* (87-89%), *Raphanus raphanistrum* (90%) and *Ipomoea* spp. (83-98%), intermediate control to *Euphorbia heterophylla* (74%), *Cenchrus echinatus* (79%) and *Eleusine indica* (67-74%). This herbicide

Table 3 - Effect of preemergence residual herbicides on weed management at 28 days after preemergence application (DAPRE) in glyphosate-resistant soybean at study locations

Treatment	Timing[1/]	Rate	Weed Control (%) by Species at Study Locations							
			AMAVI[3/]	AMAVI	IPOHF	IPOTR	IPOTR	BIDPI	BIDPI	BIDPI
		(g ha^{-1})[2/]	09/10 - SCP[4/]	10/11 - SCP	09/10 - SCP	09/10 - NMT	10/11 - SCP	09/10 - SCP	09/10 - ROL	10/11 - SCP
Nontreated	-	-	0	0	0	0	0	0	0	0
Sulfentrazone	PRE	400	100	99	91	91	97	94	76	96
Flumioxazin	PRE	60	96	97	50	8	84	50	78	94
Imazethapyr	PRE	90	100	100	95	87	98	90	63	95
Diclosulan	PRE	25	100	99	93	83	98	99	69	99
Chlorimuron	PRE	20	100	100	91	60	91	96	-	98
S-metolachlor	PRE	1920	100	96	74	5	81	74	43	81
LSD			3.49	2.49	8.17	9.22	12.86	11.7	7.22	12.38
VC (%)			1.88	1.35	5.18	8.04	7.47	7.27	5.79	7.03
Treatment	Timing	Rate	EPHHL	COMBE	COMBE	RAPRA	CCHEC	BRAPL	ELEIN	ELEIN
		(g ha$^{-2)}$	09/10 - SOR	09/10 - CAD	10/11 - ROL	10/11 - NMT	10/11 - SCP	10/11 - NMT	09/10 - CAD	10/11 - SOR
Nontreated	-	-	0	0	0	0	0	0	0	0
Sulfentrazone	PRE	400	90	95	89	8	93	13	94	76
Flumioxazin	PRE	60	91	64	91	10	68	10	6	90
Imazethapyr	PRE	90	48	92	84	96	88	83	76	90
Diclosulan	PRE	25	74	87	89	90	79	40	67	74
Chlorimuron	PRE	20	79	70	91	70	79	40	45	83
S-metolachlor	PRE	1920	5	94	89	9	80	9	94	85
LSD			13.39	25.92	7.65	17.38	18.76	20.14	20.4	19.83
VC (%)			10.48	16.4	4.71	17.97	12.1	27.53	14.42	12.8

[1/] PRE = preemergence. [2/] Herbicide treatments are expressed as g a.i. ha^{-1} or g a.e. ha^{-1}. [3/] Weeds = AMAVI = *Amaranthus viridis*; IPOHF = *Ipomoea hederifolia*; IPOTR = *Ipomoea triloba*; BIDPI = *Bidens pilosa*;. EPHHL = *Euphorbia heterophylla*; COMBE = *Commelina benghalensis*; RAPRA = *Raphanus raphanistrum*; CCHEC = *Cenchrus echinatus*; BRAPL = *Brachiaria plantaginea*; ELEIN = *Eleusine indica*. [4/] Study locations: SCP = Santa Cruz das Palmeiras, SP, NMT = Não-Me-Toque, RS, ROL = Rolândia, PR, CAD = Cachoeira Dourada, MG and SOR = Sorriso, MT.

was efficient on *Bidens pilosa* (99%) at the SCP site and showed poor control over *Brachiaria plantaginea*.

Chlorimuron at 20 g ha^{-1} was effective on *Bidens pilosa* (96-98%) and provided intermediate control of *Commelina benghalensis* (70-91%), *Ipomoea* spp. (60-91%) and *Eleusine indica* (45-83%). This treatment achieves intermediate control over *Euphorbia heterophylla* (79%) and *Cenchrus echinatus* (79%) and poor control over *Brachiaria plantaginea* (40%).

S-metolachlor at 1,920 g ha^{-1} provided the effective control of *Commelina benghalensis* (89-94%) and *Eleusine indica* (85-94%) and poor control on *Euphorbia heterophylla* (5%), *Raphanus raphanistrum* (9%), and *Brachiaria plantaginea* (9%). In addition, intermediate control was observed on *Cenchrus echinatus* (80%) and inconsistent control over *Ipomoea* spp. (5-81%) and *Bidens pilosa* (43-81%).

The PRE residual herbicides that provided intermediate to effective control also reduced the weed density and growth stage of the weed species present on the plots (data not shown). Smaller plants at the time of the follow-up application of glyphosate will result in the improved performance of glyphosate, especially on the hard-to-control species. Thus, depending on the weed species, the PRE residual herbicides in this study could be effective, viable options for early season weed control and could also provide an additional mode of action in a GR soybean weed management system.

The single in-crop POST application of glyphosate at 960 g ha^{-1} provided 88 to 100% control of *Amaranthus viridis, Bidens pilosa, Bracharia plantaginea, Cenchrus echinatus, Eleusine indica, Euphorbia heterophylla*, and *Raphanus raphanistrum* at 14 DAPOST in studies conducted during the 2009/2010 and 2010/2011 growing seasons (Tables 4 and 5). Considerably less control or inconsistent post emergence control was provided by the single application of glyphosate on *Ipomoea hederifolia* (73%), *Ipomoea triloba* (58-73%), and *Commelina benghalensis* (79-89%). The *Ipomoea* spp. was at the 6 to 12-leaf stage upon application, which is larger than recommended for effective control. Control of *Commelina* spp. was greater at the location where the plants were at the 2-leaf stage compared to the location where the plants were at the 5-leaf stage at application. However, glyphosate alone also provided poor control of *Ipomoea* spp. and *Commelina benghalensis* in other studies (Procopio et al., 2007).

Sequential applications of glyphosate at 720 and 480 g ha^{-1} provided 92 to 100% control of all the weed species at 14 DAPOST except *Ipomoea triloba*. Control of *Ipomoea triloba* was 97% and 80% in 2009/2010 and 2010/2011, respectively (Table 4). All the PRE-POST weed management programs provided excellent control of *Amaranthus viridis, Bidens pilosa, Eleusine indica*, and *Euphorbia heterophylla* at 14 DAPOST and the weed control was comparable to two sequential in-crop POST applications of glyphosate. Chlorimuron PRE followed by glyphosate POST was the only program treatment that was not effective on *Cenchrus echinatus*.

All PRE-POST programs were effective on *Raphanus raphanistrum* and provided equal control to sequential POST applications of glyphosate except flumioxazin PRE followed by glyphosate POST and chlorimuron PRE followed by glyphosate POST. For the control of *Bracharia plantaginea*, the only program treatment that was not comparable to sequential POST applications of glyphosate was flumioxazin PRE followed by glyphosate POST. Flumioxazin PRE followed by glyphosate POST and S-metolachlor PRE followed by glyphosate POST were the only treatments that did not provide comparable control of *Ipomoea hederifolia* to sequential POST applications of glyphosate. As indicated previously, *Ipomoea triloba* was the only weed species in these studies that, in 2010/2011, was not controlled effectively with sequential POST applications of glyphosate. Sulfentrazone or diclosulan PRE followed by glyphosate POST were the only PRE-POST treatments that improved the control of *Ipomoea triloba* over sequential POST applications of glyphosate with the sulfentrazone treatment with more consistent results.

Crop injury and grain yield

Crop safety is another important component when use selecting PRE residual

Table 4 - Effect of preemergence residual herbicides followed by glyphosate on control of *Amaranthus viridis* (AMAVI), *Ipomoea hederifolia* (IPOHF), *Ipomoea triloba* (IPOTR) and *Bidens pilosa* (BIDPI) at 14 days after postemergence application (DAPOST) in glyphosate-resistant soybean at study locations

Treatment[1/]	Timing[2/]	Rate	Weed Control (%) by Species at Study Locations						
			AMAVI[4/]	AMAVI	IPOHF	IPOTR	IPOTR	BIDPI	BIDPI
		$(g\ ha^{-1})$[3/]	09/10 - SCP[5/]	10/11 - SCP	09/10 - SCP	09/10 - NMT	10/11 - SCP	09/10 - ROL	10/11 - SCP
Nontreated	-	-	0	0	0	0	0	0	0
Glyphosate	POST	960	100	97	73	58	73	100	97
Glyphosate fb	EPOST	720	100	100	96	97	80	100	100
Glyphosate	POST	480							
Sulfentrazone fb	PRE	400	100	100	93	95	91	100	100
Glyphosate	POST	720							
Flumioxazin fb	PRE	60	100	100	81	59	74	100	100
Glyphosate	POST	720							
Imazethapyr fb	PRE	90	100	100	93	94	79	100	100
Glyphosate	POST	720							
Diclosulan fb	PRE	25	100	100	93	94	86	100	100
Glyphosate	POST	720							
Chlorimuron fb	PRE	20	100	99	95	74	79	-	100
Glyphosate	POST	720							
S-metolachlor fb	PRE	1920	100	96	76	58	80	99	95
Glyphosate	POST	720							
LSD			0.00	7.14	14.11	9.09	16.61	2.00	8.96
CV (%)			0.00	3.37	7.56	5.42	9.69	0.94	4.24

[1/] fb = followed by. [2/] POST = postemergence; EPOST = early postemergence; PRE = preemergence. [3/] Herbicide treatments are expressed as g ai/ha or g a.e. ha. [4/] Weeds = AMAVI = *Amaranthus viridis*; IPOHF = *Ipomoea hederifolia*; IPOTR = *Ipomoea triloba*; BIDPI = *Bidens pilosa*. [5/] Study locations: SCP = Santa Cruz das Palmeiras, SP, NMT = Não-Me-Toque, RS, ROL = Rolândia, PR.

Table 5 - Influence of preemergence residual herbicides followed by glyphosate on control of *Euphorbia heterophylla* (EPHHL), *Comelina benghalensis* (COMBE), *Raphanus raphanistrum* (RAPRA), *Cenchrus echinatus* (CCHEC), *Brachiaria plantaginea* (BRAPL) and *Eleusine indica* (ELEIN) at 14 days after postemergence application (DAPOST) in glyphosate-resistant soybean at study locations

Treatment[1/]	Appl.	Rate	EPHHL[4/]	COMBE	COMBE	RAPRA	CCHEC	BRAPL	ELEIN
	Timing[2/]	(g ha^{-1})[3/]	09/10 - SOR[5/]	09/10 - CAD	10/11 - ROL	10/11 - NMT	10/11 - SCP	10/11 - NMT	10/11 - SOR
Nontreated	-	-	0	0	0	0	0	0	0
Glyphosate	POST	960	91	79	89	94	100	91	88
Glyphosate fb	EPOST	720	99	92	94	98	100	98	95
Glyphosate	POST	480							
Sulfentrazone fb	PRE	400	91	98	98	94	100	93	85
Glyphosate	POST	720							
Flumioxazin fb	PRE	60	94	91	99	83	100	83	93
Glyphosate	POST	720							
Imazethapyr fb	PRE	90	95	95	98	90	100	98	100
Glyphosate	POST	720							
Diclosulan fb	PRE	25	93	88	99	95	100	99	88
Glyphosate	POST	720							
Chlorimuron fb	PRE	20	95	86	94	85	75	96	90
Glyphosate	POST	720							
S-metolachlor fb	PRE	1920	95	98	99	93	100	88	100
Glyphosate	POST	720							
LSD			7.27	12.86	6.31	11.17	39.95	7.03	19.05
VC (%)			3.62	6.64	3.08	5.72	19.34	3.53	9.67

[1/] fb = followed by. [2/] POST = postemergence; EPOST = early postemergence; PRE = preemergence. [3/] Herbicide treatments are expressed as g a.i. ha or g a.e. ha. [4/] Weeds = EPHHL = *Euphorbia heterophylla*; COMBE = *Commelina benghalensis*; RAPRA = *Raphanus raphanistrum*; CCHEC = *Cenchrus echinatus*; BRAPL = *Brachiaria plantaginea*; ELEIN = *Eleusine indica*. [5/] Study locations: SCP = Santa Cruz das Palmeiras, SP, NMT = Não-Me-Toque, RS, ROL = Rolândia, PR, CAD = Cachoeira Dourada, MG and SOR = Sorriso, MT.

Table 6 - Influence of weed management programs on soybean injury rating at 14 days after preemergence application (DAPRE) and 14 days after postemergence application (DAPOST) and grain yield in 2009/2010 and 2010/2011 growing season at study locations

Treatment[1/]	Rate	SCP[4/] - 09/10			SCP – 10/11			NMT – 09/10			NMT – 10/11			CAD – 09/10	
		Soybean Injury[3/]		Yield[5/]	Soybean Injury		Yield	Soybean Injury		Yield	Soybean Injury		Yield	Soybean Injury	
	($g\ ha^{-1}$)[2/]	14 DAPRE	14 DAPOST	($kg\ ha^{-1}$)	14 DAPRE	14 DAPOST	($kg\ ha^{-1}$)	14 DAPRE	14 DAPOST	($kg\ ha^{-1}$)	14 DAPRE	14 DAPOST	($kg\ ha^{-1}$)	14 DAPRE	14 DAPOST
Nontreated	-	-	1	2704	-	1	674	-	1	0	-	1	1829	-	1
Glyphosate	960	-	1	4291	-	1	3695	-	1	4910	-	1	3832	-	1
Glyphosate fb	720	1	1	4060	1	1	4201	1	1	5216	1	1	4050	1	1
Glyphosate	480														
Sulfentrazone fb	400	4	1	4667	1	1	4265	5	1	5107	1	1	3910	6	1
Glyphosate	720														
Flumioxazin fb	60	2	1	4270	1	1	4165	3	1	4902	1	1	4421	1	1
Glyphosate	720														
Imazethapyr fb	90	2	1	4155	2	1	3850	4	1	5265	2	1	4215	1	1
Glyphosate	720														
Diclosulan fb	25	4	1	4376	1	1	3810	5	1	5011	1	1	4426	2	1
Glyphosate	720														
Chlorimuron fb	20	4	1	4414	1	1	3799	4	1	5140	2	1	4419	1	1
Glyphosate	720														
S-metolachlor fb	1920	5	1	4038	1	1	3926	4	1	4877	1	1	4206	4	1
Glyphosate	720														
LSD		1.36	0.0	679	0.98	0.0	1013	1.58	0.0	589	0.75	0.0	869	1.13	0.0
VC (%)		21.9	0.0	6.88	36.09	0.0	11.71	21.79	0.0	5.45	27.04	0.0	9.22	25.33	0.0

[1/] Fb = followed by; [2/] Herbicide treatments are expressed as g a.i. ha or g a.e. ha. [3/] Soybean injury rating measured on a 1-9 EWRC scale, 1 indication of no injury and 9 indication of soybean death. [4/] Study locations: SCP = Santa Cruz das Palmeiras, SP, NMT = Não-Me-Toque, RS and CAD = Cachoeira Dourada, MG. [5/] Soybean grain yield in $kg\ ha^{-1}$ (13%).

Table 7 - Influence of weed management programs on soybean injury rating at 14 days after preemergence application (DAPRE) and 14 days after postemergence application (DAPOST) and grain yield in 2009/2010 and 2010/2011 growing season at study locations

Treatment[1/]	Rate	ROL[4/] - 09/10			ROL – 10/11			SOR – 09/10			SOR – 10/11		
		Soybean Injury[3/]		Yield[5/]	Soybean Injury		Yield	Soybean Injury		Yield	Soybean Injury		Yield
	(g ha-1)[2/]	14 DAPRE	14 DAPOST	(kg ha^{-1})	14 DAPRE	14 DAPOST	(kg ha^{-1})	14 DAPRE	14 DAPOST	(kg ha^{-1})	14 DAPRE	14 DAPOST	(kg ha^{-1})
Nontreated	-	-	1	1328	-	1	2265	-	1	3253	-	1	2293
glyphosate	960	-	1	2853	-	1	2928	-	1	4145	-	1	3572
Glyphosate fb	720	1	1	2912	1	1	2990	1	1	3864	1	1	4111
Glyphosate	480												
Sulfentrazone fb	400	3	1	2923	1	1	3161	1	1	4135	1	1	3886
glyphosate	720												
Flumioxazin fb	60	2	1	2852	1	1	3052	1	1	4091	1	1	3669
Glyphosate	720												
Imazethapyr fb	90	3	1	2876	1	1	2987	1	1	4318	1	1	3641
Glyphosate	720												
Diclosulan fb	25	4	1	3013	1	1	3139	1	1	3973	1	1	3789
Glyphosate	720												
Chlorimuron fb	20	4	1	--	1	1	2969	1	1	4140	1	1	3767
Glyphosate	720												
S-metolachlor fb	1920	4	1	2953	1	1	3106	1	1	4590	1	1	3795
Glyphosate	720												
LSD		0.76	0.0	473	0.0	0.0	599	0.0	0.0	907	0.80	0.0	1373
VC (%)		12.22	0.0	7.36	0.0	0.0	8.43	0.00	0.00	9.3	31.58	0.00	15.8

[1/] Fb = followed by; [2/] Herbicide treatments are expressed as g a.i. ha or g a.e. ha. [3/] Soybean injury rating measured on a 1-9 EWRC scale, 1 indication of no injury and 9 indication of soybean death. [4/] Study locations: ROL = Rolândia, PR and SOR = Sorriso, MT. [5/] Soybean grain yield in kg ha^{-1} (13%).

herbicides in the GR soybean weed management system. In 2009/2010, all PRE residual herbicides in this study caused early soybean injury, mainly sulfentrazone. Dirks et al. (2000) reported that sulfentrazone has caused significant levels of soybean injury under certain environmental conditions at soybean emergence and with certain soybean varieties. Probably, in all locations due to the heavy rain that occurred during this season, the PRE application timing led to an increased availability of this herbicide, increasing the injury measured. However, no injury was observed at 14 days following the POST application. In 2010/2011, no significant soybean injury was observed with any PRE residual herbicide (Tables 6 and 7). Also, no significant difference in soybean yield was observed between any of the herbicide treatments at any of the study locations (Tables 6 and 7). Glyphosate alone or in combination with residual herbicides was also safe on GR soybean in field trials carried out by Vangessel et al. (2001).

The PRE-POST weed management programs evaluated in this study offer viable options to the POST glyphosate only programs in GR soybean. Depending on the PRE residual herbicide and the weed species present, control was equal or superior to two sequential POST applications of glyphosate. The PRE residual herbicide followed by POST glyphosate weed management programs can avoid the need for an early in-crop POST glyphosate application. The residual herbicide can reduce early season weed competition and weed size, which can provide greater flexibility for POST glyphosate application timing, especially in situations with high weed infestation levels. Furthermore, these programs utilize at least two herbicide modes of action for herbicide, reducing resistance selection pressure and improving herbicide use diversity, which will be needed to stay ahead of resistance build-up, regardless of when weeds may appear.

LITERATURE CITED

ALBRECHT, L. P. et al. Effect of glyphosate and associations in post-emergence on the agronomic performance and quality of RR® soybean seeds. **Planta Daninha**, v. 30, n. 1, p. 139-146, 2012.

CARPENTER, J.E.; GIANESSI, L. P. Herbicide tolerant soybeans: why growers are adopting Roundup Ready varieties. **AgBioForum**, v. 2, n. 1, p. 65-72, 1999.

CHRISTOFOLETI, P.J. et al. Glyphosate sustainability in South American cropping systems. **Pest Manag. Sci.**, v. 64, n. 4, p. 422-427, 2008.

CLEWIS, S. B.; WILCUT, J. W.; PORTERFIELD, D. Weed management with S-metolachlor and glyphosate mixtures in glyphosate resistant strip and conventional tillage cotton. **Weed Technol.**, v. 20, n. 1, p. 232-241, 2006.

CORREIA, N. M.; DURIGAN, J. C.; LEITE, G. J. Selectivity of glyphosate-tolerant soybean and effciency of *Commelina benghalensis* control using isolated and mixed herbicides. **Bragantia**, v. 67, n. 3, p. 663-671, 2008.

CULPEPPER, A. S. Glyphosate-induced weed shifts. **Weed Technol.**, v. 20, n. 2, p. 277-281, 2006.

DIRKS, J. T. et al. Use of preplant sulfentrazone in no-till, narrow-row, glyphosate resistant *Glycine max*. **Weed Sci.**, v. 48, n. 5, p. 628-639, 2000.

GELMINI, A. G. et al. Resistance of *Euphorbia heterophylla* L. to ALS-Inhibiting herbicides in soybean. **Sci. Agric.**, v. 62, n. 5, p. 452-457, 2005.

HEAP, I. The international survey of herbicide resistant weeds. Online. Internet. Thursday, June 13, 2013. Available: <www.weedscience.org>.

JAMES, C. **Global status of commercialized biotech/GM crops: 2011**. New York: ISAAA, 2011. (ISAAA Brief, 43)

JAREMTCHUK, C. C. et al. Residual effect of flumioxazin on weed emergence in soils of distinct textures. **Planta Daninha**, v. 27, n. 1, p. 191-196, 2009.

KRAUSZ, R. F.; YOUNG, B. G. Sulfentrazone enhances weed control of glyphosate in glyphosate-resistant soybean (*Glycine max*). **Weed Technol.**, v. 17, n. 2, p. 249-255, 2003.

MONQUERO, P. A.; CURY, J. C.; CHRISTOFFOLETI, P. J. Control with glyphosate and general leaf surface characterization of *Commelina benghalensis*, *Ipomoea hederifolia*, *Richardia brasiliensis* and *Galinsoga parviflora*. **Planta Daninha**, v. 23, n. 1, p. 123-132. 2005.

NORSWORTHY, J. K. et al. Reducing the risks of herbicide resistance: best management practices and recommendations. **Weed Sci.**, v. 60, (sp 1), p. 31-62, 2012.

NURSE, R. E. et al. Is the application of a residual herbicide required prior to glyphosate application in no-till glyphosate-tolerant soybean (*Glycine max*)? **Crop Protec.**, v. 26, n. 4, p. 484-489, 2007.

PROCOPIO, S. O. et al. Chlorimuron-ethyl and imazethapyr applied on Roundup Ready soybean crop. **Planta Daninha**, v. 25, n. 2, p. 365-373, 2007.

VANGESSEL, M. J.; AYENI, A. O.; MAJEK, B. A. Glyphosate in full-season no-till glyphosate-resistant soybean: role of preplant applications and residual herbicides. **Weed Technol.**, v. 15, n. 4, p. 714-724, 2001.

VANLIESHOUT, L.; LOUX, M. Interactions of glyphosate with residual herbicides in no-till soybean (*Glycine max*) production. **Weed Technol.**, v. 14, n. 2, p. 480-487, 2000.

WALSH, M. J.; POWLES, S. B. Management strategies for herbicide-resistant weed population in Australian dryland crop production system. **Weed Technol.**, v. 21, n. 2, p. 332-338, 2007.

WEBSTER, T. M.; SOSNOSKIE, L. M. Loss of glyphosate efficacy: a changing weed spectrum in Georgia cotton. **Weed Sci.**, v. 58, n. 1, p. 73-79, 2010.

YOUNG, B. G. Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. **Weed Technol.**, v. 20, n. 2, p. 301-307, 2006.