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Late-Season Grass Weed Management with In-Crop and Post-Harvest Herbicides in Twin-Row Glyphosate-Resistant Soybean

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Abstract

Emergence of grasses late in the season has become a problem in glyphosate-resistant (GR) soybean production in the southern US. A 3-yr field study was conducted from 2011 to 2013 at Stoneville, MS to determine efficacy of post-harvest and pyroxasulfone-based in-crop herbicides on late-season grasses and yield in twin-row glyphosate-resistant soybean. Experiments were conducted in a split-plot arrangement of treatments in a randomized complete block design with fall herbicides (with and without pendimethalin at 1.12 kg ai ha^{-1} and paraquatat 0.84 kg ai ha^{-1}) as main plots and in-crop herbicides as subplots with four replications. The six in-crop herbicide programs were: glyphosate applied early postemergence (EPOST) at 0.84 kg·aeha^{-1} followed by (fb) glyphosate late postemergence (LPOST) at 0.84 kg·ha^{-1} with and without pyroxasulfone preemergence (PRE) applied at 0.18 kg ai ha^{-1}, pyroxasulfone PRE fb glyphosate at 0.84 kg·ha^{-1} LPOST or glyphosate at 0.84 kg·ha^{-1} + *S*-metolachlor at 1.68 kg ai ha^{-1} EPOST, pyroxasulfone PRE fb *S*-metolachlor at 1.12 kg·ha^{-1} + fomesafen at 0.27 kg ai ha^{-1} EPOST fb clethodim at 0.14 kg ai ha^{-1}, and a no-herbicide control. Browntop millet, *Digitaria* spp., and junglerice densities at 2 weeks after LPOST, grass weed dry biomass at harvest, and soybean yield were similar regardless of post-harvest herbicides in all three years. At 2 weeks after LPOST, browntop millet, *Digitaria* spp. and junglerice densities were greatly reduced in all five in-crop herbicide treatments compared with no herbicide plot in all three years. Grass weed dry biomass in no-herbicide plots was 3346, 6136, and 6916 kg·ha^{-1} in 2011, 2012, and 2013, respectively and the five herbicide treatments reduced grass weed dry biomass by at least 87%, 84%, and 99% in 2011, 2012, and 2013, respectively. Soybean yield was higher with all five in-crop herbicide treatments compared to no herbicide control in all three years. These results indicate that browntop millet, *Digitaria* spp., and junglerice infestations can be reduced with pyroxasulfone-based in-crop herbicide programs in twin-row GR soybean.

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Keywords

Browntop Millet, *Digitaria* spp., Junglerice, *S*-Metolachlor, Pyroxasulfone, Soybean, Twin-Row

1. Introduction

The wide-spread adoption of glyphosate resistant crops (GRCs) coupled with over-reliance on glyphosate and inadequate diversity in weed management tactics in GRCs have resulted in weed species shifts [1]-[3]. Weed species shifts refers to a relative change in weed population (abundance) or species (diversity) along with late-season weed emergence in an agricultural system in response to weed management tactics [2]. Weed species shifts in GRCs are a result of weeds that have escaped control because of a natural high level of tolerance to glyphosate or glyphosate avoidance from late-emerging cohorts. Glyphosate avoidance (non-exposure) through late-season emergence is a mechanism by which some species are increasing in prominence. Emergence of weeds late in the cropping season has become a problem in GRCs [2]. This is due to elimination of competition from early-season weeds controlled by glyphosate, the absence of residual control with glyphosate alone, and the decision by producers not to use a residual herbicide that will extend weed control later into the cropping season. In the southern US, soybean [*Glycine max* (L.) Merr] is usually harvested during August. The long time period between harvest and killing frost (October-November) provides a favorable environment for certain weeds to emerge and complete a life cycle [4].

Emergence of grasses such as browntop millet [*Urochloa ramosa* (L.) Nguyen], *Digitaria* spp. [*D. sanguinalis* (L.) Scop. And *D. ciliaris* (Retz.) Koel.], and junglerice [*Echinochloa colona* (L.) Link] late in the season has become a problem in glyphosate-resistant (GR) soybean production in the southern US, where soybean is harvested beginning in August. The time between harvest in August and frost (October-November) provides a favorable environment for these grasses to emerge, establish, and replenish the soil seedbank. To reduce the risk of late-season weeds and to sustain crop yields, it is imperative to develop and improve strategies to manage these weed shifts using preemergence (PRE), postemergence (POST), and post-harvest applications of herbicides.

Pyroxasulfone is relatively a new herbicide used for control of many grass and some broadleaf weeds in corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and soybean [5]. It can be applied from fall through early preplant, PRE to early POST. Pyroxasulfone has been investigated for broad-spectrum weed control in several agronomic crops [6]-[9]. It is comparable to other common PRE residual herbicides such as acetochlor, dimethenamid, and *S*-metolachlor in controlling broadleaf signalgrass [*Urochloa platyphylla* (Nash) R.D. Webster] [10]. However, its efficacy on late-seasongrass weed control in twin-row glyphosate-resistant soybean is lacking. Therefore, the objectives of this study were: 1) to determine the efficacy of pyroxasulfone as preemergence herbicide for control of late-season grass (browntop millet, *Digitaria* spp., and junglerice) weeds and 2) to determine the efficacy of pyroxasulfone-based in-crop and post-harvest herbicides on late-season grass weeds and yield in twin-row glyphosate-resistant soybean.

2. Materials and Methods

Field studies were conducted from 2011 through 2013 at the USDA-ARS Crop Production Systems Research Unit farm, Stoneville, MS. The soil was a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualf) with pH 6.4, 1.1% organic matter, a CEC of 15 cmol·kg^{-1}, and soil textural fractions of 26% sand, 55% silt, and 19% clay. The experimental area was predominantly and uniformly infested with browntop millet, *Digitaria* spp., and junglerice. Field preparation consisted of disking and bedding in the fall of the previous year. The beds were spaced 102-cm apart. In the spring, the beds were re-hipped and the raised beds were conditioned by flattening the top and firming up with bed conditioner. The conditioned seedbeds had slightly raised flat tops of about 50-cm wide with small furrows which enable soybean planting in 25-cm twin rows and furrow irrigation during the growing season.

The experimental area was treated with paraquat at 0.84 kg ai ha^{-1} one week prior to soybean planting to desiccate the existing vegetation. Glyphosate-resistant soybean cultivars and planting dates were AG 4605RR on April 18, 2011; and ARMOR DK 4744 RR2/STS on April 23, 2012 and April 29, 2013. Cultivars were selected based on regional use patterns of producers and seed availability. Soybean was planted in twin-rows 25-cm apart on flattened beds spaced on 102-cm centers using a Monosem NG-3 (Monosem Inc., Edwardsville, KS) twin-row planter at 268,000 seeds ha^{-1}.

The experiment was conducted in a split-plot arrangement of treatments in a randomized complete block design with post-harvest herbicides as main plots and in-crop herbicides as subplots with four replications. Each subplot consisted of eight twin-rows of 25-cm on a 102-cm center and 15.2 m long. Main plot treatments were with and without pendimethalin at 1.12 kg ai ha^{-1} plus paraquat at 0.84 kg ai ha^{-1}. The six subplot subplot treatments were: glyphosate applied early POST (EPOST) at 0.84 kg ae ha^{-1} followed by (fb) glyphosate late POST (LPOST) at 0.84 kg·ha^{-1} with and without pyroxasulfone PRE applied at 0.18 kg ai ha^{-1}, pyroxasulfone PRE fb glyphosate at 0.84 kg·ha^{-1} LPOST or glyphosate at 0.84 kg·ha^{-1} + *S*-metolachlor at 1.68 kg ai ha^{-1} EPOST, pyroxasulfone PRE fb *S*-metolachlor at 1.12 kg·ha^{-1} + fomesafen at 0.27 kg ai ha^{-1} EPOST fb clethodim at 0.14 kg ai ha^{-1}, and a no-herbicide control (**Table 1**). Because the focus of this research was to assess efficacy of pyroxasulfone as a residual herbicide, the in-crop herbicide programs were designed to compare with commonly used glyphosate and other nonglyphosate POST treatments. Herbicides were applied with a tractor-mounted sprayer equipped with TeeJet 8004 standard flat spray nozzles, delivering 187 L·ha^{-1} water at 179 kPa. The PRE herbicide treatments were applied immediately after planting. The EPOST and LPOST treatments were applied 3 to 4 and 6 to 7 weeks after planting (WAP), respectively. Soybean was furrow irrigated on an as-needed basis each year.

Browntop millet, *Digitaria* spp. and junglerice plant counts were recorded at random from one 1-m^2 area between the second and third twin-rows at 1 to 5 days before EPOST application and at 2 weeks after LPOST application from each plot. At harvest, the weeds were harvested at random from one 1-m^2 area between the second and third twin-rows from each plot and the total dry weight of browntop millet, *Digitaria* spp. and junglerice were recorded. Soybean from all eight twin-rows was harvested on October 3, 2011, September 14, 2012, and September 20, 2013 using a combine, and grain yield was adjusted to 13% moisture. After harvest, pendi-

Table 1. *Digitaria* spp., junglerice, and browntop millet densities as affected by in-crop and post-harvest herbicides at 2 weeks after LPOST in glyphosate-resistant soybean at Stoneville, MS, from 2011 to 2013.[a,b]

Main effect	Herbicide		*Digitaria* spp.			Junglerice			Browntop millet		
	Rate[c]	Timing	2011	2012	2013	2011	2012	2013	2011	2012	2013
	kg·ha^{-1}		------------------				number·m^{-2}				------------------
Post-harvest herbicides											
No herbicide			7.6 a	163.0 a	32.8 a	5.9 a	0.8 a	3.1 a	7.3 a	4.9 a	0.4 a
Pendimethalin + Paraquat	1.12 0.84	Post-harvest[d]	6.6 a	106.0 a	26.5 a	6.0 a	5.0 a	4.9 a	4.5 a	2.1 a	0.4 a
In-crop herbicides											
No herbicide			41.1 a	413.4 a	178.0 a	34.5 a	17.0 a	24. 1 a	34.0 a	11.9 a	2.6 a
Glyphosate fb Glyphosate	0.84 0.84	EPOST LPOST	0 b	318.5 ab	0 b	0.3 b	0 b	0 b	0.1 b	0 b	0 b
Pyroxasulfone fb Glyphosate fb Glyphosate	0.18 0.84 0.84	PRE EPOST LPOST	0 b	28.6 b	0 b	0 b	0 b	0 b	0 b	0 b	0 b
Pyroxasulfone fb Glyphosate	0.18 0.84	PRE LPOST	0.1 b	35.0 b	0 b	0.1 b	0 b	0 b	0.1 b	0 b	0 b
Pyroxasulfone fb Glyphosate + *S*-metolachlor	0.18 0.84 1.68	PRE EPOST EPOST	0.3 b	4.8 b	0 b	0.6 b	0 b	0 b	0.4 b	0.3 b	0 b
Pyroxasulfone fb *S*-metolachlor + Fomesafen fb Clethodim	0.18 1.12 0.27 0.14	PRE EPOST EPOST LPOST	1.0 b	6.9 b	0 b	0.4 b	0.5 b	0 b	0.9 b	9.1 b	0 b

[a]Abbreviations: EPOST, early postemergence; LPOST, late postemergence; PRE, preemergence; [b]Means within a column for each main effect followed by same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test; [c]Glyphosate is expressed as acid equivalent (ae) and all other herbicides as active ingredient (ai); [d]Pendimethalin at 1.12 kg ai ha^{-1} and plus paraquat 0.84 kg ai ha^{-1} were applied aroundmid-October in 2011 and 2012.

methalin and paraquat were applied around mid-October in 2011 and 2012. Paraquat was applied to kill existing weeds and pendimethalin was used to provide residual weed control. The purpose was to prevent post-harvest weeds establishment and seed set.

Data were subjected to analysis of variance with mean squares partitioned appropriately for split-plot treatment arrangement using PROC MIXED (SAS software, release 8.2, Windows version 5.1.2600, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC). The treatment means were separated at the 5% level of significance using Fisher's protected LSD test.

3. Results and Discussion

There were no differences in browntop millet, *Digitaria* spp. and junglerice density between post-harvest herbicides and no post-harvest herbicide in May 2011, at 1 - 5 days before EPOST application of in-crop herbicides (data not shown).Overall, pyroxasulfone applied preemergence gave adequate control of these grass weeds compared to no herbicide in all 3 years (data not shown). Similarly, other researchers have shown that pyroxasulfone applied preemergence effectively controlled (>90%) rigid ryegrass (*Lolium rigidum* Gaudin) and broadleaf signalgrass [6] [8]. Pendimethalin and paraquat applied post-harvest in 2011 and 2012 did not reduce density of these weeds compared to that with no herbicide 2 weeks after LPOST (**Table 1**). At 2 weeks after LPOST, browntop millet, *Digitaria* spp. and junglerice densities were greatly reduced in all five in-crop herbicide treatments compared with no herbicide plot in all three years (**Table 1**). There were no differences in interactions between post-harvest and in-crop herbicide treatments in all three years.

Pendimethalin and paraquat applied post-harvest did not decrease total weed dry biomass (browntop millet, *Digitaria* spp. and junglerice) at harvest in all three years (**Table 2**). However, all in-crop herbicide treatments markedly reduced weed dry biomass of these weeds compared to no herbicide (**Table 2**). Grass weed dry biomass in no-herbicide plots was 3346, 6136 and 6916 kg·ha^{-1} in 2011, 2012, and 2013, respectively, and the five

Table 2. Total grass weed dry biomass (*Digitaria* spp., junglerice, and browntop millet)at harvest as affected by in-crop and post-harvest herbicides in glyphosate-resistant soybean at Stoneville, MS, from2011 to 2013.[a,b]

Main effect	Herbicide application		Grass weed dry biomass		
	Rate[c]	Timing	2011	2012	2013
	kg·ha^{-1}		---------------------------- kg·ha^{-1}----------------------------		
Post-harvest herbicides					
No herbicide			768 a	1353 a	1298 a
Pendimethalin + Paraquat	1.12 0.84	Post-harvest[d]	613 a	1481 a	1037 a
In-crop herbicides					
No herbicide			3346 a	6136 a	6916 a
Glyphosate fb Glyphosate	0.84 0.84	EPOST LPOST	87 b	970 b	30 b
Pyroxasulfone fb Glyphosate fb Glyphosate	0.18 0.84 0.84	PRE EPOST LPOST	11 b	268 b	18 b
Pyroxasulfone fb Glyphosate	0.18 0.84	PRE LPOST	53 b	701 b	13 b
Pyroxasulfone fb Glyphosate + *S*-metolachlor	0.18 0.84 1.68	PRE EPOST EPOST	165 b	155 b	21 b
Pyroxasulfone fb *S*-metolachlor + Fomesafen fb Clethodim	0.18 1.12 0.27 0.14	PRE EPOST EPOST LPOST	480 b	272 b	9 b

[a]Abbreviations: EPOST, early postemergence; LPOST, late postemergence; PRE, preemergence; [b]Means within a column for each main effect followed by same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test; [c]Glyphosate is expressed as acid equivalent (ae) and all other herbicides as active ingredient (ai); [d]Pendimethalin at 1.12 kg ai ha^{-1} and plus paraquat 0.84 kg ai ha^{-1} were applied aroundmid-October in 2011 and 2012.

herbicide treatments reduced grass weed dry biomass by at least 87%, 84%, and 99% in 2011, 2012, and 2013, respectively.

There were no differences in soybean yields between pendimethalin plus paraquat post-harvest and no herbicide treatment or among five in-crop herbicide treatments in all 3 years (**Table 3**). Soybean yield was higher with all five in-crop herbicide treatments compared with no herbicide control in all three years. Soybean yield ranged from 5218 to 5456 kg·ha^{-1} in 2011; 3778 to 4341 kg·ha^{-1} in 2012; and 4614 to 4878 kg·ha^{-1} in 2013 among five in-crop herbicide treatments.

After soybean harvest, many annual grass weeds emerge, establish, and replenish soil seed bank. These post-harvest weeds are becoming major weed problems in the lower Mississippi River valley alluvial flood plain. Most growers perform various tillage operations to prepare the seedbed following soybean harvest. Yet, tillage alone cannot completely prevent the grass weeds reestablishment. Even after seedbed preparation and if conditions are favorable, weeds can reestablish and replenish seed bank. Absence of differences in weed density, weed dry biomass, and soybean yield among the five in-crop herbicide programs suggest that these herbicide programs provided effective control weeds. Furthermore, early canopy closure in soybean grown in twin-rows may have suppressed germination and establishment of late-season weeds. Previous studies have shown that cotton grown in twin-rows (spaced 38-cm apart on 102-cm beds) closed canopy 2 weeks earlier and reduced weed dry biomass compared to 102-cm single rows [11].

4. Conclusion

Browntop millet, *Digitaria* spp., and junglerice densities at 2 weeks after LPOST, grass weed dry biomass at harvest, and soybean yield were similar in all five in-crop herbicide programs regardless of post-harvest herbicides in all three years. These results indicate that browntop millet, *Digitaria* spp. and junglerice infestations could be reduced with pyroxasulfone-based in-crop herbicide programs in twin-row glyphosate-resistant soybean.

Table 3. Effect of in-crop and post-harvest herbicides on soybean yield at Stoneville, MS, from2011 to 2013.[a,b]

	Herbicide application		Soybean yield		
Main effect	Rate[c]	Timing	2011	2012	2013
	kg·ha^{-1}		----------kg·ha^{-1}----------		
Post-harvest herbicides					
No herbicide			4955 a	3640 a	4504 a
Pendimethalin + Paraquat	1.12 0.84	Post-harvest[d]	4979 a	3678 a	4532 a
In-crop herbicides					
No herbicide			2976 b	1836 b	3239 b
Glyphosate fb Glyphosate	0.84 0.84	EPOST LPOST	5456 a	3778 a	4614 a
Pyroxasulfone fb Glyphosate fb Glyphosate	0.18 0.84 0.84	PRE EPOST LPOST	5218 a	4000 a	4756 a
Pyroxasulfone fb Glyphosate	0.18 0.84	PRE LPOST	5441 a	4341 a	4876 a
Pyroxasulfone fb Glyphosate + *S*-metolachlor	0.18 0.84 1.68	PRE EPOST EPOST	5426 a	4192 a	4878 a
Pyroxasulfone fb *S*-metolachlor + Fomesafen fb Clethodim	0.18 1.12 0.27 0.14	PRE EPOST EPOST LPOST	5285 a	3805 a	4744 a

[a]Abbreviations: EPOST, early postemergence; LPOST, late postemergence; PRE, preemergence; [b]Means within a column for each main effect followed by same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test; [c]Glyphosate is expressed as acid equivalent (ae) and all other herbicides as active ingredient (ai); [d]Pendimethalin at 1.12 kg ai ha^{-1} and plus paraquat 0.84 kg ai ha^{-1} were applied aroundmid-October in 2011 and 2012.

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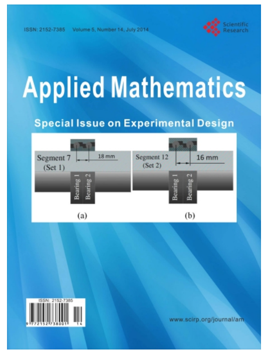
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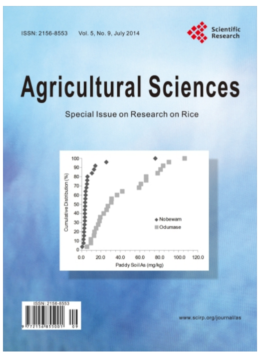
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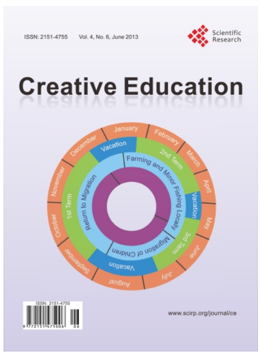
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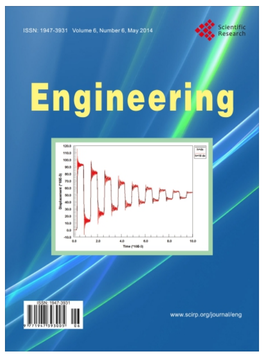
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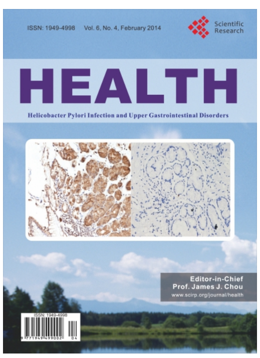
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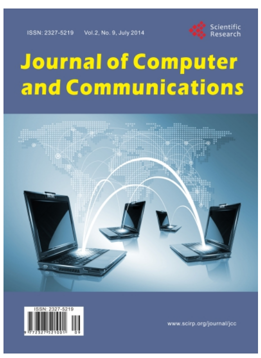
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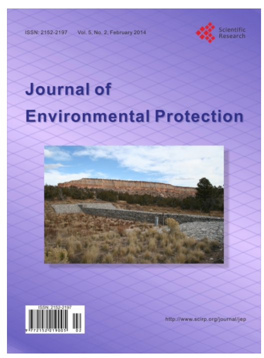
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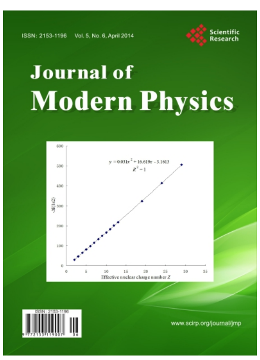
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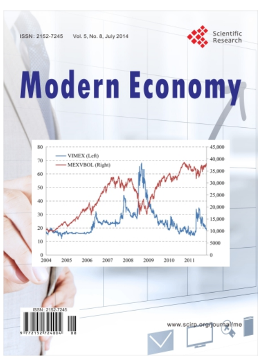
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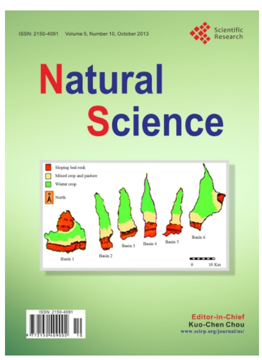
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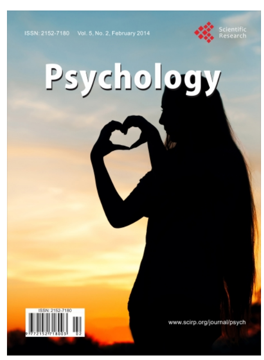
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