Effects of Low Rates of Glyphosate and Glufosinate on Rice

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ABSTRACT

Off-target movement of herbicides have been detrimental to crop yields. When new technology is released, it is necessary to understand the potential impact it may have on off-target crops. Field studies were conducted in 2007 and 2008 to evaluate and compare the effects of low rates of glufosinate and glyphosate on rice. Glyphosate (1× rate = 0.77 lb/acre) and glufosinate (1× rate = 0.55 lb/acre) were applied to rice at 0.5×, 0.25×, and 0.125× of the recommended usage rate at the 3- to 4-leaf, panicle initiation (PI), and boot growth stages. At comparable rates, glufosinate caused substantially greater visual injury than glyphosate to rice. Rice grain yield was reduced up to 80% with either herbicide. Because glyphosate is more readily translocated, overall sensitivity of off-target crops may be higher to lower rates or "drift rates" of glyphosate than glufosinate. However, because of a perception that glufosinate damage is "cosmetic" and will not harm off-target crops as much as glyphosate, educational efforts are needed to demonstrate potential negative impacts of glufosinate to off-target crops.

INTRODUCTION

Glyphosate is the most popular non-selective herbicide on the market. With the wide adoption of glyphosate-tolerant soybean technology throughout the state, there is inevitably an increased risk of off-target movement of glyphosate onto rice. However with this heavy reliance on glyphosate, resistant weeds have evolved. With this increase in glyphosate-resistant weeds, a new technology is needed. The 2009 growing season marked the release of glufosinate-tolerant soybean, which allows the use of glufosinate in over-the-top applications throughout the soybean growing season. The potential for off-target movement from soybean to rice is possibly due to the production practices in Arkansas of growing both crops in close proximity to each other.

MATERIALS AND METHODS

Field experiments were conducted at the University of Arkansas at Pine Bluff research farm near Lonoke, Ark., in 2007 and 2008 to evaluate the effects of low rates of glyphosate and glufosinate on rice and to evaluate potential yield loss. Rice was planted on 15 May 2007, and 21 May 2008, at a seeding rate of 18.5 lb/acre for 'Wells' and 6 lb/acre for 'XP723'. The experimental area was field cultivated twice prior to planting. The soil type was a Calhoun silt loam with a pH of 4.8. Plots were maintained weed free with a preemergence application of clomazone at 0.06 lb/acre plus quinclorac at 0.05 lb/acre and a postemergence application of halosulfuron at 0.01 lb/acre plus quinclorac at 0.04 lb/acre.

Plot size was 5 ft wide and 20 ft long with 5 ft alleys between replications. The experimental design was a randomized complete block with a three-factor factorial treatment arrangement with four replications. Treatment factors were rice cultivar, herbicide, and application timing. The first factor was cultivar where Wells and XP723 were seeded. The second factor was herbicide. Herbicides were glufosinate applied at 0.071, 0.13, and 0.27 lb/acre and glyphosate applied at 0.10 , 0.19, and 0.39 lb/acre. In earlier research, significant injury to rice occurred at these glyphosate rates (Meier et al., 2006). The rates for each herbicide represent 0.5×, 0.25×, and 0.125× the usage rate. The third factor was application timing. An early postemergence treatment was applied to 3- to 4-leaf rice on 6 June 2007 and 18 June 2008; a mid-postemergence application at 0.25-in. internode (PI) on 3 July 2007 and 25 July 2008; and a late postemergence application at boot stage on 31 July 2007 and 23 August 2008. Treatments were applied with a CO_2-backpack sprayer calibrated to deliver 10 gal/acre using a four-nozzle, 5-ft spray boom, with DG110015 tips. An untreated check was included for each cultivar for comparison.

Injury was visually rated on a scale of 0% to 100% compared to the untreated check, with 0% being no injury and 100% being plant death. Injury was rated for chlorosis and stunting. Ratings were taken at 1 and 3 weeks after treatment (WAT). Heading dates were recorded when 50% of the rice heads had emerged. Flag leaf length was measured at 100% emergence of the flag leaf in the nontreated plots. Canopy height was determined at heading (50%) and at harvest. Plots were harvested for yield and test weight on 20 September 2007 and 27 October 2008, with a small-plot combine. Percentage germination was determined post harvest using steps similar to those previously described (Lovelace, 2000; Stoller and Wax, 1974; Taylorson, 1970). Grain weight per 100 seed per plot treatment was recorded post harvest. Data were subjected to analysis of variance using PROC GLM in SAS. Means were separated by Fisher's Least Significance Difference test at P = 0.05.

RESULTS AND DISCUSSION

Visual Injury

Injury mainly consisted of necrosis of leaf tissue from glufosinate and chlorosis of leaf tissue to no symptoms for glyphosate, depending on application timing. Similar symptoms have been reported for wheat (Deeds et al., 2006). Injury 1 WAT was minimal for glyphosate and peaked at only 14% (Table 1). Later application of glyphosate during the reproductive stages resulted in no visual injury. Injury at the later timings manifested in other parameters. Injury from glufosinate was significantly higher and peaked at 60% at the boot stages. Glufosinate visual injury was much more apparent than that of glyphosate consisting of necrotic leaves. Similar trends were observed in other research in rice with later timings of glyphosate having minimal injury compared to earlier (Ellis et al., 2003). Visual injury from glyphosate at the later application timings was not apparent until the rice began to head. Applications at the PI stage injured the young seed head which, when emerged, was malformed with smaller heads and curled seeds. Glufosinate symptoms were apparent and consisted of necrosis of the tissue that had come into contact with the herbicide. Applications at the boot stage did not malform seed heads as with glyphosate at the PI stage, but both herbicides ceased rice growth and did not allow the seed head to fully emerge from the sheath. This in turn caused many panicles to “rot” in the leaf sheath.

This data suggest that rice is more susceptible to visual injury from glufosinate than glyphosate. This could be due to the nature of the two herbicides behaviors in the plant. Glyphosate is readily translocated within the plant compared to glufosinate and what little symptoms show up are on newly emerging vegetation. In contrast, glufosinate is not as readily translocated within the plant and generally causes foliar burn as documented. This data also suggests that rice may show a slightly higher sensitivity to an early application with glyphosate and later application from glufosinate. Ellis and others also documented the greatest injury occurring from 0.05 lb/acre of glufosinate when applied to 2- to 3-leaf rice (Ellis et al., 2003). In general, glyphosate injury was minimal compared to glufosinate at this time.

Canopy Height

The only treatments that reduced canopy height at heading applied at the 3- to 4-leaf stage were glyphosate at the 0.25× and 0.5× rates where canopy height was reduced by 10% to 15% and glufosinate applied at the 0.5× rate by 10% (Table 2). All other 3- to 4-leaf applications did not reduce canopy height. Ellis et al. (2003) documented 50% and 5% height reductions from glyphosate and glufosinate applied at 2- to 3-leaf stage on rice. Both herbicides applied at the 0.5× rate at the PI stage reduced canopy height; however, glyphosate reduced canopy height 5% less than glufosinate, which reduced canopy height 23% at the 0.5× rate applied at the boot stage. Reduction in height from glufosinate at the boot stage was 23% and glyphosate was 18%. At panicle differentiation, Ellis et al. (2003) documented similar reduction in canopy height from glufosinate and glyphosate at higher rates with reduction ranging from 10% to 25%. Glyphosate reduced canopy height by ceasing growth and stunting plants, in contrast glufosinate reduced canopy height by complete desiccation of the upper portion of the canopy.

Glyphosate and glufosinate applied at the 3- to 4-leaf stage at the 0.125× and 0.25× rate did not reduce canopy height at harvest (Table 3). However, all other treatments significantly reduced canopy height at harvest. The greatest reduction from glufosinate (25%) occurred when applied at the 0.5× rate at the boot stage. Glyphosate reduced canopy height the greatest (29%) when applied at PI. There is a slight trend of greater canopy height reduction from both herbicides at later application timings at all rates. Rice at the PI application timing appeared to be slightly more sensitive to glyphosate than glufosinate. This could be partly explained by the fact that glyphosate is readily translocated and ceased growth and stunts plants at this application timing. In contrast, glufosinate desiccates crop canopy to reduce height, however, does not cease rice growth. At the boot application stage, the rice plant is close to ceasing growth and focusing all resources on seed fill, in turn little canopy height reduction is noted. Both herbicides responded similarly at the boot stage. Similarly Meier et al. (2006) noted similar rice canopy reductions from glyphosate applied at 0.08 lb/acre at the boot application stage. Conversely, Ellis documented 50% canopy height reduction when glyphosate was applied at the 2- to- 3 leaf stage, with only 5% reduction from glufosinate. He also noted canopy height reduction from 10% to 25% from glyphosate and glufosinate, respectively, applied at panicle initiation (Ellis et al., 2003). These contradictory results are indicative of the random nature of low rates of herbicides and may be explained by differences in environmental conditions or specific application timings.

Flag Leaf Length

Even though both herbicides reduced flag leaf length, the forms of reduction were much different (Table 4). Glyphosate is translocated readily within the plant and at the PI stage is translocated to the actively developing flag leaf (Vencill, 2002). In turn, the flag leaf slows growth and is stunted, emerging as a shortened leaf. Glufosinate, however, is not as readily translocated and is fairly immobile (Vencill, 2002). Therefore at PI, glufosinate does not affect the formation of the flag leaf as great as glyphosate. Glufosinate does cause necrosis of the flag leaf once emerged resulting in a reduction in photosynthetically active leaf area.

Days to Heading

Glufosinate delayed heading the greatest when applied at the boot stage (25 to 47 days) (Table 5). The greatest delay in heading occurred when glufosinate was applied at the 0.5× rate at the boot stage (47 days). The early (PI) and later (boot) reproductive stage applications appear to be more detrimental to delaying maturity than application at the vegetative stage with either herbicide. Meier et al. (2006) reported similar results with glyphosate applied at the boot stage, with heading delayed for 'Bengal' rice from 21 to 42 days depending on rate. This delay may be caused by the interruption of the growth of the young seed head. Glyphosate applied at the boot stage and PI stage at the 0.25× and 0.5× rates prevented the panicle from emerging from the sheath, in turn causing the seed head to rot before harvest. Glufosinate affected the seed head by completely desiccating the upper portion of the plant and not allowing the seed head to fully emerge. When glufosinate was applied at the 0.25× and 0.5× rates at the boot stage, seed heads never emerged and rotted within the leaf sheath. In contrast, others have observed a greater reduction in yields at the earlier rather than at the later reproductive timings, with yield losses as great as 95% from applications at jointing or PI (Deeds et al., 2006).

Seed Weight

The greatest reduction in seed weight on Wells occurred from the 0.25× rate applied at the PI and boot stages and the 0.5× rate applied at the boot stage with reductions ranging from 7% to 11% (Table 6). Seed weight reduction ranged from 12% to 14% with XP723 when either herbicide was applied at the 0.25× or 0.5× rate. These trends are similar to flag leaf length reductions and reduced seed weights observed from either herbicide applied at the higher rates and applied at the reproductive stages. Similar results have been documented with leaf removal significantly reducing rice yield (Counce et al., 1994). This is a possible explanation for the reduced seed weight observed and corresponding injury from application made during reproductive development.

Germination of Harvested Grain

There were no significant interactions among cultivar, rate, herbicide, or application timing for rice germination. Regardless of treatment, rice germination ranged from 97% to 99% (data not shown). Germination could possibly be lower if all seed were tested. Plots were harvested with a commercial combine, which provides a very clean, trash-free sample as small malformed seeds are discharged from the rear of the combine. Deeds et al. (2006) also documented no significant difference in germination of wheat when glyphosate was applied. Similarly, Ellis et al. (2003) documented no reduction in rice germination following sublethal glyphosate rates.

Yield

All treatments regardless of cultivar, herbicide, or application timing reduced rice yield when averaged across rate. Glufosinate had the greatest reduction in yield for both cultivars when applied at the boot stage (81%) (Table 7). Glufosinate applied at PI reduced yield of Wells and XP723 by 30%. Glyphosate reduced yields for both cultivars when applied at the boot stage by 80%. Similarly, others have noted rice yield reductions from glyphosate applied at boot, ranging from 87% to 97% (Kurtz and Street, 2003). When glyphosate was applied at PI, yield reductions ranged from

31% on Wells to 51% on XP723 (Table 7). Kurtz and Street (2003) documented similar results with rice response to glyphosate applied at PI resulting in yield reductions of 66%. The response was similar for glufosinate applied at PI and boot stages on both cultivars. Both cultivars also responded similarly to glyphosate applied at the boot stage; however, glyphosate applied at PI appeared to have a greater affect on XP723 than on Wells. Yield was reduced 20% more on XP723 than Wells. Based on the data, a varietal response to glyphosate may exist when applied at both the 3- to- 4 leaf and PI growth stages for XP723. Results also suggest that rice is more sensitive to later applications of either herbicide. Ellis et al. (2003) concluded that rice and corn were able to recover from glufosinate injury; however, they were unable to recover from glyphosate, suggesting a higher sensitivity to glyphosate. Koger et al. (2005) reported a possible varietal difference in rice yield between ‘Priscilla’ and ‘Cocodrie’ rice cultivars. Though very minimal injury was noted for glyphosate, yield reductions were similar to those from glufosinate.

Rice yield losses reflect similar trends seen in several other parameters documented, such as flag leaf length, days to maturity, and seed weight. Later applications, after the vegetative stages, with higher rates are very detrimental to rice yields, regardless of herbicide.

SIGNIFICANCE OF FINDINGS

Glufosinate injured rice rapidly and to a greater degree than did glyphosate. Glyphosate caused very minimal injury, however yield reduction caused by the two herbicides was comparable. Flag leaf length was reduced by both herbicides. However, where glufosinate caused rapid necrosis of the flag leaf and upper portion of the plant when applied at the boot stage, glyphosate (which is more readily translocated to points of active cell division) caused flag leaf reductions when applied at PI, before the flag leaf had emerged.

In general, visual glyphosate injury was minimal when compared to glufosinate. However, yield reductions from both herbicides were comparable at the rates evaluated. Glufosinate drift to rice does have the potential to be detrimental to yield.

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Table 1. Interaction of herbicide and application timing on rice injury one week after treatment, averaged across rates and cultivars.

	Percent visual injury	
Application timing	Glufosinate	Glyphosate
3- to 4-leaf	53	14
Panicle initiation	53	3
Boot	60	1
LSD (0.05)	---------------------------3--------------------------	

Table 2. Interaction of herbicide (glufosinate and glyphosate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing on rice canopy height at heading as a percent of nontreated check, averaged across cultivars.[z]

	Canopy height at heading					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	98	97	90	96	90	85
Panicle initiation	92	81	76	90	75	60
Boot	89	83	77	86	82	82
LSD (0.05)	5					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 3. Interaction of herbicide (glufosinate and glyphosate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing interaction on rice canopy height at harvest averaged across cultivars.[z]

	Canopy height at harvest					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	99	97	93	98	95	89
Panicle initiation	93	88	85	94	80	71
Boot	93	83	75	87	81	78
LSD (0.05)	3					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 4. Interaction of herbicide (glufosinate and glyphosate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing on rice flag leaf length as percent of nontreated check, averaged across cultivars.[z]

	Rice flag leaf length					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	98	87	89	92	87	93
Panicle initiation	97	90	91	88	52	48
Boot	68	46	46	90	91	88
LSD (0.05)	7					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 5. Interaction of herbicide (glyphosate and glufosinate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing in delaying heading compared to 89 days for the nontreated check, averaged across cultivars.[z]

	Delay in heading					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
3- to 4-leaf	0	2	8	2	5	17
Panicle initiation	2	9	17	3	10	17
Boot	25	48	48	39	48	48
LSD (0.05)	----------4----------					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 6. Interaction of cultivar/hybrid, rate (0.125×, 0.25×, and 0.5× labeled rate) and application timing on rice seed weight as percent of nontreated check, averaged across herbicides.[z]

	Rice seed weight					
	Wells			XP723		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	---------- (% of check) ----------					
3- to 4-leaf	98	98	97	99	98	95
Panicle initiation	97	93	89	99	94	95
Boot	94	89	95	95	88	86
LSD (0.05)	----------4----------					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 7. Interaction of cultivar/hybrid, herbicide (glufosinate and glyphosate), and application timing on rice yield as percent of the nontreated check, averaged across rates.

	Rice yield			
	Wells		XP723	
Application timing	Glufosinate	Glyphosate	Glufosinate	Glyphosate
3- to 4-leaf	86	79	85	68
Panicle initiation	71	69	70	49
Boot	19	17	19	20
LSD (0.05)	----------8----------			