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Impact of Off-Site Deposition of Glufosinate to Non-Clearfield Rice

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Field studies were conducted near Crowley, LA to evaluate the effects of simulated herbicide drift on 'Cocodrie' rice. Each treatment was made with the spray volume varying proportionally to herbicide dosage based on a spray volume of 234 L ha^{-1} and a glufosinate rate of 493 g ai ha^{-1}. The 6.3%, 31 g ha^{-1}, herbicide rate was applied at a spray volume of 15 L ha^{-1} and the 12.5%, 62 g ha^{-1}, herbicide rate was applied at a spray volume of 29 L ha^{-1}. Glufosinate applied at one-tiller, panicle differentiation (PD) growth stage, and boot resulted in crop injury at 7 and 14 d after treatment. At 21 and 28 d after treatment, crop injury was still evident but was less than 10%. Glufosinate applied at one-tiller resulted in plant height reductions of 4 to 6%; however, at harvest, height reductions were 1% or less. Glufosinate applied to rice in the boot stage had lower rice yield in the primary crop, but no difference was observed in the ratoon crop. Harvested seed from the primary crop germinated 7 to 11% less than the nontreated when rice was treated with 31 and 62 g ha^{-1} of glufosinate. Seedling vigor was reduced when treated with 31 and 62 g ha^{-1} of glufosinate.
Nomenclature: Glufosinate; rice, *Oryza sativa* L. 'Cocodrie'.
Key words: Simulated herbicide drift, sublethal herbicide rates.

Se realizaron estudios de campo cerca de Crowley, Louisiana, para evaluar los efectos de la deriva simulada de herbicida sobre el arroz 'Cocodrie'. Cada tratamiento fue realizado con un volumen de aspersión que varió en forma proporcional a la dosis del herbicida, basándose en un volumen de aplicación de 234 L ha^{-1} y una dosis de glufosinate de 493 g ai ha^{-1}. La dosis de herbicida de 6.3%, 31 g ha^{-1}, fue realizada a con un volumen de 15 L ha^{-1} y la de 12.5%, 62 g ha^{-1}, se hizo con un volumen de aspersión de 29 L ha^{-1}. Cuando se aplicó glufosinate en el estadio de desarrollo de un hijuelo, diferenciación de panícula (PD), o en el de engrosamiento del tallo floral, el cultivo sufrió daño, 7 y 14 d después del tratamiento. A 21 y 28 d después del tratamiento, el daño del cultivo era todavía evidente, pero era menor a 10%. Glufosinate aplicado en el estadio de un hijuelo resultó en reducciones en altura de planta de 4 a 6%. Sin embargo, en la cosecha, las reducciones en altura fueron de 1% o menores. El glufosinate aplicado a arroz en el estadio de engrosamiento del tallo floral tuvo un menor rendimiento en el cultivo primario, pero no se observaron diferencias en el cultivo de la soca. La semilla cosechada del cultivo primario germinó 7 a 11% menos que el testigo sin tratamiento cuando el arroz fue tratado con 31 y 62 g ha^{-1} de glufosinate. El vigor de la plántula se redujo con los tratamientos de 31 y 62 g ha^{-1} de glufosinate.

Glufosinate is a nonselective, POST herbicide used to control annual and perennial weeds in noncrop areas and for weed control in glufosinate-resistant crops (Senseman 2007). The mechanism of action of glufosinate is the inhibition of the enzyme glutamine synthetase (EC 6.3.1.2) that converts glutamate and ammonia to glutamine (Lea et al. 1984; Senseman 2007). This inhibition of glutamine synthetase results in a toxic accumulation of ammonia in treated plants and inhibition of photosynthesis (Hess 2000; Sauer et al. 1987; Senseman 2007; Tachibana et al. 1986; Wild et al. 1987).

The symptoms expressed in plants from the inhibition of glutamine synthase are that chlorosis and wilting usually occur within 3 to 5 d followed by necrosis in 7 to 14 d after application to susceptible species (Senseman 2007). The rate of symptom development is increased in bright sunlight, high humidity, and moist soil (Hess 2000).

Rice is a major crop produced in the five-state region of Arkansas, Louisiana, Mississippi, Missouri, and Texas, with these states accounting for 79%

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of the 963,000 total hectares of rice planted in the United States and 79% of the $3 billion of total value of rice produced in the United States in 2013 (U.S. Department of Agriculture Economic Research Service [DAERS] 2014). Glufosinate-resistant corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] cultivars became available for commercial soybean producers in Louisiana in 2009 (Ronald J. Levy, Jr., personal communication, Louisiana State University Agricultural Center Soybean, Corn, and Grain Sorghum specialist). Because many of the rice-producing parishes in Louisiana also produce soybean and corn (National Agricultural Statistics Service [NASS] 2014), the potential exists for off-target herbicide drift from one of these crops to rice. In 2014, approximately 3% of the 640,000 ha of soybean and approximately 3% of the 320,000 ha corn planted in Louisiana was glufosinate-resistant cultivars (Ronald J. Levy, Jr., personal communication, Louisiana State University Agricultural Center Soybean, Corn, and Grain Sorghum Specialist).

It has been reported that fine spray droplets less than 150 μm in size have a greater potential to drift off-target (Hanks 1995; Spray Drift Task Force [SDTF] 1997). The use of adjuvants and selection of proper spray nozzle type, size, and application pressure can be beneficial in reducing the amount of fine spray droplets in the spray cloud (Hanks 1995; Jones et al. 2007; Nuyttens et al. 2007; VanGessel and Johnson 2005). This increase in droplet size can reduce the potential for off-target drift from droplets larger than 150 μm; however, environmental conditions at the time of herbicide application can also impact the off-target drift of spray solutions (Bouse et al. 1976; Crabbe et al. 1994; Thistle 2004).

Through the use of simulated herbicide drift studies, the potential effects of glufosinate drift to rice can be evaluated. In previous research, simulated drift studies varying the spray volume proportionally with reduced herbicide rates to simulate herbicide drift has resulted in increased crop injury compared with the same lower herbicide rates at a constant high spray volume (Banks and Schroeder 2002; Ellis et al. 2002; Ramsdale et al. 2003; Roider et al. 2008). The no-effect glyphosate rate for sweet corn was four times lower when using a spray volume proportional to the reduced glyphosate rate compared with reduced glyphosate rates applied in a constant spray volume (Banks and Schroeder 2002).

However, Ellis et al. (2002) reported constant versus variable spray volume differed for glufosinate and glyphosate on corn; however, data were averaged over active ingredient. Glufosinate and glyphosate applied in a constant versus a variable carrier volume on soybean did not differ. Other researchers suggest the reduced carrier volume may be unrealistic in drift research and/or may confound results (Everitt and Keeling 2009; Marple et al. 2008). Sawchuck et al. (2006) suggested it is difficult to extrapolate or generalize results for one specific herbicide–plant interaction to another herbicide–plant interaction, and these comparisons should not be applicable to all situations.

Glufosinate applied to rice at a simulated drift rate of 53 g ha^{-1} in a constant spray volume reduced rice yield 30% (Ellis et al. 2003). When glufosinate was applied to grain sorghum (*Sorghum bicolor* L.) at 1, 3, 10, and 33% of its labeled use rate only the 10 and 33% rates resulted in reduced grain sorghum yield (Al-Khatib et al. 2003).

Rapid rice seed germination and seedling growth can enhance plant stand establishment in commercial fields (Krishnasamy and Seshu 1989; Pollock and Roos 1972; Wright 1980). Rice seed germination was reduced by simulated glufosinate drift when evaluated at 16 C (Ellis et al. 2003). Bennett and Shaw (2000) found that applications of glufosinate applied preharvest in soybean reduced seed germination of sicklepod [*Senna obtusifolia* (L.) Irwin and Barnaby] and pitted morningglory (*Ipomoea lacunosa* L.). Glufosinate applied for preharvest desiccation of grain sorghum [*Sorghum bicolor* (L.) Moench] did not affect grain sorghum seed germination (Bovey et al. 1999). Glyphosate applied to wheat at first node, boot, and early flowering growth stages resulted in 16 to 36% reductions in seed weight (Roider et al. 2007). A negative correlation between 100-count seed weight and rice seed germination has been observed (Krishnasamy and Seshu 1989). A need exists to evaluate the possible effects of a glufosinate drift event on rice seed germination and seedling vigor. This is particularly important if the impacted rice is designated as a seed rice field.

Even though a published study evaluating the effects of simulated glufosinate drift on rice exists (Ellis et al. 2003), this study was not conducted with spray volumes proportional with reduced herbicide dosage, and rough rice yield was not evaluated in the ratoon crop. The objectives of this research were to evaluate the effects of simulated glufosinate drift applied to rice during the primary rice crop on the crop response and impact on the seed produced on treated rice in the primary and ratoon rice crops.

Materials and Methods

Simulated Glufosinate Drift Field Study. A field study was conducted on rice grown in 2005 through 2007 at the Louisiana State University (LSU) Agricultural Center Rice Research Station near Crowley, LA on a Crowley silt loam with pH 5.5 and 1.2% organic matter. Field preparation consisted of a fall and spring disking and two passes in opposite directions with a two-way bed conditioner equipped with S-tine harrows 15 cm deep and rolling baskets. The long-grain rice cultivar 'Cocodrie' was drill-seeded between March 28 and April 17 in 2005 through 2007. Cocodrie is a commonly grown long-grain rice in the midsouth, and growth characteristics are similar to other long grains released from the LSU Agricultural Center rice breeding program (Steven D. Linscombe, personal communication, LSU Agricultural Center Rice Breeder).

The experimental design was an augmented two-factor factorial arrangement of treatments in a randomized complete block with four replications. Factor A consisted of glufosinate applied at simulated drift rates of 6.3 and 12.5% of the labeled usage rate of 493 g ai ha^{-1}, or 31 and 62 g ha^{-1}, respectively. Factor B consisted of application timings at different growth stages: one-tiller, panicle differentiation (PD), boot, and physiological maturity. A nontreated group was added for comparison. Each herbicide treatment was made with the spray volume varying proportionally to herbicide dosage based on a constant spray volume of 234 L ha^{-1}. The 12.5% herbicide rate was applied at a spray volume of 29 L ha^{-1} and the 6.3% herbicide rate was applied at a spray volume of 15 L ha^{-1}. Each treatment was made with a tractor-mounted CO_2-pressurized sprayer calibrated to deliver a constant carrier volume with speed adjusted to vary application rate and equipped with Teejet® TX-2 Conejet® 800033 nozzles (Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60187). A ratoon rice crop was not produced in 2006 because of unfavorable weather following primary crop harvest. Plots consisted of twelve 18-cm spaced rows 6 m long.

The study area was maintained weed-free with the use of clomazone at 420 g ai ha^{-1} applied preemergence followed by propanil at 4,480 g ai ha^{-1} plus halosulfuron at 53 g ai ha^{-1} applied postemergence. For the primary rice crop, a preplant application of 280 kg ha^{-1} of 8–24–24 (N–P_2O_5–K_2O) fertilizer and a preflood application of 365 kg ha^{-1} 46–0–0 urea fertilizer were applied to the study area and for the ratoon rice crop a preflood application of 100 kg ha^{-1} 46–0–0 urea fertilizer was applied to the study area to maintain proper fertility and to maximize yields in the primary and ratoon crops. Standard agronomic and pest management practices were implemented throughout the growing season to maximize yield.

Rice plant height and rice injury in the primary rice crop were recorded 7 d after herbicide treatment (DAT) and continued weekly for 28 DAT. Plant height was obtained by measuring four plants per plot from the soil surface to the tip of the extended uppermost emerged leaf for the one-tiller, PD, and boot timing measurements or from the soil surface to the tip of the extended rice panicle for the maturity timing. Injury was evaluated based on chlorosis and necrosis of foliage and reduced plant height on a scale of 0 to 100%, where 0 = no injury and 100 = plant death. Rice plant height at primary crop harvest and rough rice yield, 100-count seed weight, and stem and panicle counts for the primary and ratoon crop were also recorded. Whole plots were mechanically harvested and rough rice yield was adjusted to 12% moisture. Total stem and panicle counts were calculated by hand harvesting a 0.46-m section of row and determining the number of stems present at the midheight, approximately 40 cm, of the plants and the number of panicles with bases emerged beyond the sheath of the flag leaf, or the last leaf to emerge prior to the panicle.

All data were subjected to the Mixed Procedure of SAS (SAS 2003). Year, replications (nested within year), and all interactions containing either of these effects were considered random effects. Application timing and rate were considered fixed effects. Considering year or combination of year as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989; Leon et

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al. 2008). Type III statistics were used to test all possible effects of fixed factors (application timing and rate) and least-square means employing PDIFF were used for mean separation at the 5% probability level ($P \leq 0.05$).

Seed Germination Study. Germination studies were conducted to determine the impact of glufosinate drift on a commercial seed field. Germination potential of seed collected from grain harvested in the simulated glufosinate drift field study at primary crop harvest, 2005 through 2007, and at ratoon crop harvest, 2005 and 2007, was evaluated at multiple temperatures. Seed collected from each plot was air-dried and stored at 8 C. Germination temperatures evaluated were 13, 16, 19, 22, and 25 C. Temperature selection and germination testing procedure for this study were based on procedures previously described by Webster et al. (2003) and follow standard germination procedures recommended by the Association of Official Seed Analysts (AOSA 2006). Temperature selection was based on 19 C being the historical mean 10-cm soil temperature in Crowley on April, 1, which corresponds to 50% of the rice being planted across the state (Webster et al. 2003).

One hundred seeds from each field plot were prepared by soaking for 30 min in a 50 : 50 ($v\ v^{-1}$) solution of chlorine bleach and distilled water to decrease seedling diseases. After soaking, seeds were triple rinsed with distilled water. After seed preparation, seeds were placed in a 10-cm plastic petri dish between two 9-cm germination blotters (Anchor Steel Blue Seed Germination Blotter®, SDB 3.5, Anchor Paper Company, 480 Broadway, St. Paul, MN 55101). Next, 10 ml of a carboxin (5,6-dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carboxamide) plus thiram (tetramethylthiuram disulfide) plus distilled water solution, 52 ml of a 10% carboxin and 10% thiram premix liquid fungicide combined with 948 ml distilled water, was applied in each petri dish to reduce seedling diseases. Petri dishes were sealed with Parafilm M® (Pechiney Plastic Packaging, Menash, WI 54952) to prevent moisture loss and placed in a constant-temperature growth chamber in total darkness. Germination counts were taken 5, 9, and 14 d after initiation (DAI) of the study. A seed was considered germinated if the radicle end had reached a length of 1 mm.

Seed germination data were subjected to the Mixed Procedure of SAS (SAS 2003). Year, replications (nested within year), DAI (nested within replications), and all interactions containing either of these effects were considered random effects. Application timing and rate and germination temperature were considered fixed effects. Mean separation was the same as previously described.

Seedling Vigor Study. Vigor of seedlings from grain collected at primary crop harvest in the simulated glufosinate drift field study in 2006 and 2007 was examined. Approximately 100 seeds from each field plot were prepared by soaking for 30 min in a 50 : 50 (v/v) solution of chlorine bleach and distilled water to decrease seedling diseases (Webster et al. 2003). After soaking, seeds were triple rinsed with distilled water. Following seed preparation, seeds were pregerminated by soaking in distilled water for 24 h. Ten pregerminated seeds from each field plot were placed on a single sheet of nontreated germination paper cut to fit a 12 by 23 by 0.3–cm acrylic sheet. Germination paper was moistened by submerging it in distilled water for 5 s to facilitate adherence to the acrylic sheet and provide residual moisture to rice seeds. Seeds were placed along the center of germination paper oriented with the radical end of the seed toward the lower half of the sheet. A one-ply paper-towel strip was placed over the seed, and 5 ml of a mancozeb [ethylene (bis)-dithiocarbamate] plus distilled water solution, dry formulation of mancozeb at 1,640 mg ai L^{-1} distilled water, was applied on top of the strip to reduce seedling diseases. The plated seeds were then placed vertically in a rack and then placed in a 30 by 51 by 5–cm dish with 1,420 ml of distilled water to allow for evaporation. The dish and racks of plates were wrapped in plastic wrap to prevent desiccation. The glass dish was placed in a constant-temperature growth chamber at 21 C for 12 d in total darkness. At the end of 12 d, shoot lengths were measured and an average of the 10 shoot lengths was obtained for data analysis.

Seed-vigor data were subjected to the Mixed Procedure of SAS (SAS 2003). Year, replications (nested within year), and all interactions containing either of these effects were considered random effects. Application timing and rate were considered fixed effects. Mean separation was the same as previously described.

Results and Discussion

Simulated Glufosinate-Drift Field Study. An application timing by rating date interaction occurred for injury in the primary crop; therefore, data were averaged over application rate. At 7 and 14 DAT, averaged across application rates, the greatest crop injury was 24 and 14% on rice treated at the boot timing, respectively (Table 1). Crop injury at 21 DAT was 6% with glufosinate applied at PD and boot, and at 28 DAT crop injury was less than 5% on rice treated with all timings evaluated. These data indicate a trend of increased crop injury when glufosinate is applied at later growth stages. At the boot stage vegetative growth has slowed and recovery from injury is slower compared with rice in the one-tiller and PD stages. Ellis et al. (2003) reported similar findings when evaluating glufosinate drift on rice.

Foliar symptoms observed on rice plants treated with glufosinate begin as small reddish-brown lesions within 2 DAT (Figure 1A) becoming irregularly shaped chlorotic lesions within 7 DAT on affected leaves (Figures 1B and 1C). By 14 DAT, new leaf growth had initiated in plants treated at one-tiller and PD with chlorotic lesions increasing in size on the lower leaves, resulting in necrosis of the leaf (Figure 1D). By 28 DAT, visual symptoms were often undetectable.

A glufosinate application timing by rating date interaction occurred for plant height in the primary crop; therefore, data were averaged over application rate. Rice plant height at 7 through 28 DAT was 94 to 96% of the nontreated when glufosinate was applied to rice at one-tiller. Regardless of timing, no rice plant height was less than 98% of the nontreated at harvest (Table 2). This suggests rice has the ability to recover from early injury caused by glufosinate drift with little or no impact on plant height.

An application-timing interaction occurred for crop yield in the primary, ratoon, and total crop yield; therefore, data were averaged over application rate. Primary crop yield was reduced to 90% of the nontreated when simulated glufosinate drift was applied to rice at the boot growth stage (Table 3). A reduction in ratoon crop yield was not observed; however, total crop yield was 93% of the nontreated when glufosinate was applied at the boot stage. These data suggest rice yield is reduced when glufosinate drift occurs at the boot growth stage.

Table 1. Effects of simulated glufosinate drift application timing on primary rice crop injury 7, 14, 21, and 28 d after treatment (DAT), 2005–2007, Crowley, LA.[a]

Glufosinate timing	Injury 7 DAT	14 DAT	21 DAT	28 DAT
	%[b]			
One-tiller	10 c	4 c	1 b	1 b
PD[c]	15 b	9 b	6 a	1 b
Boot	24 a	14 a	6 a	3 a
Maturity	0 d	0 d	0 b	0 b

[a] Means within a column followed by the same letter were not statistically different according to the Fisher's protected LSD *t* test on difference of least-square means at $\alpha = 0.05$.

[b] Data averaged across application rates of 31 and 62 g ai ha^{-1} glufosinate applied at spray volumes of 15 and 29 L ha^{-1}, respectively.

[c] Abbreviation: PD, panicle differentiation growth stage of rice.

This result supports the trend of increased crop injury with a glufosinate drift event at the boot stage (Table 1). The rice plant stem and panicle counts in the primary and ratoon crop were not affected by simulated glufosinate drift (data not shown).

Others have reported yield reductions from rice treated with glufosinate, glyphosate, and imazethapyr. Ellis et al. (2003) reported a late reproductive growth stage application of glufosinate and glyphosate reduced rice yield. Yield reductions observed from simulated glyphosate drift on rice resulted in a more significant decrease in primary crop yield than glufosinate (Ellis et al. 2003; Hensley et al. 2009, 2013). Hensley et al. (2012) reported similar findings with simulated drift of imazethapyr on rice in the boot stage. The carbohydrate source for developing rice grain is from the three or four uppermost leaves of the rice plant (Dunand and Saichuk 2014). Because the crop injury with a simulated glufosinate drift at the boot stage would affect these uppermost leaves, this late-season injury could account for the reduction in primary crop yield.

Seed Germination. Simulated glufosinate drift did not affect primary crop rice seed weight (Table 4) or ratoon crop rice seed weight (data not shown). It is expected that any unfilled or malformed grain on rice panicles on treated plants would be separated and expelled by the mechanical plot harvester. This separation is similar to a commercial harvesting operation, so any effect on seed weight, germina-

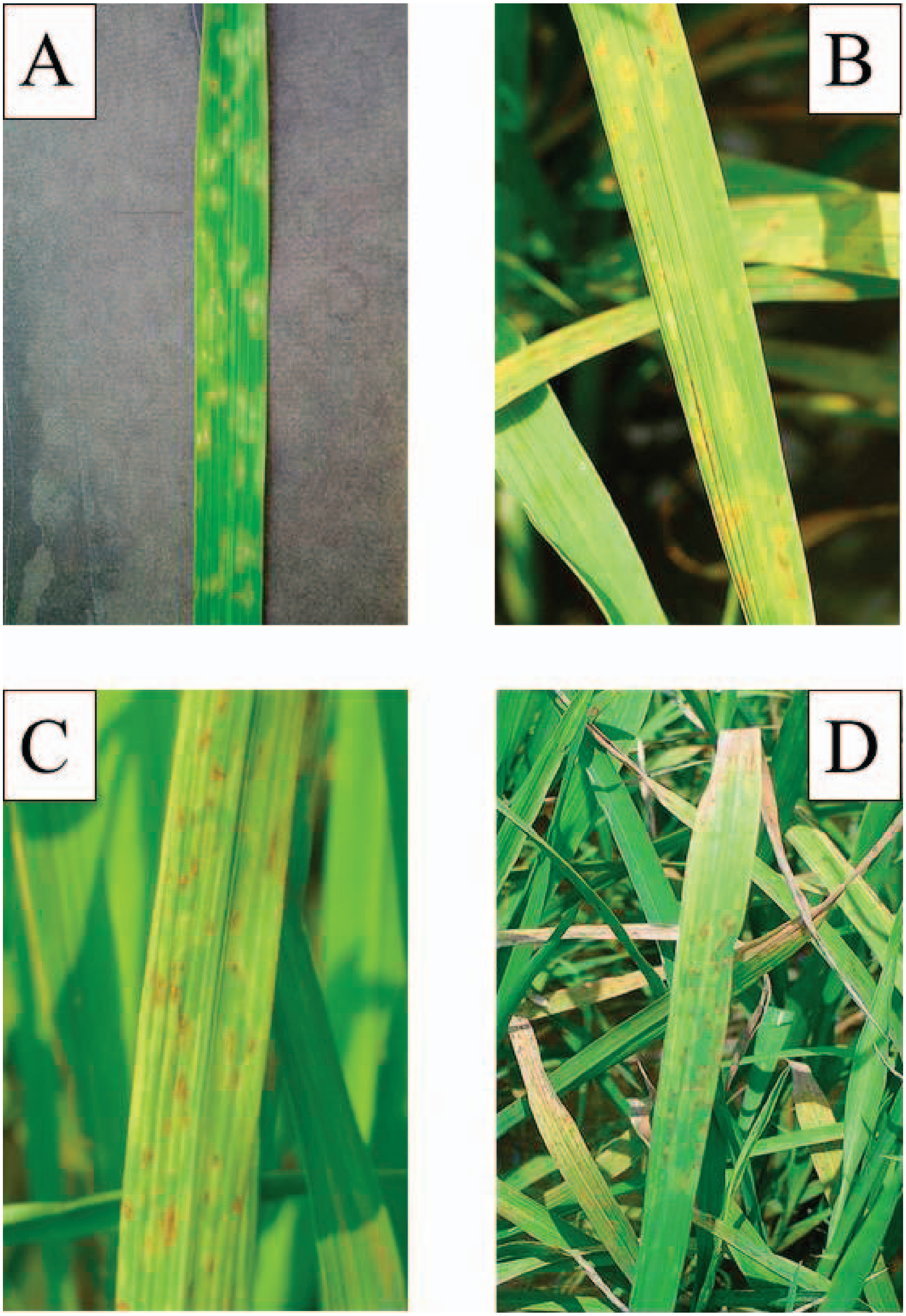

Figure 1. Rice response to simulated drift of glufosinate applied to rice in the boot growth stage: (A) Foliar injury symptoms 2 d after treatment. (B) Irregular shaped chlorotic lesions within 7 d after treatment. (C) Chlorotic and red lesions within 7 d after treatment. (D) Chlorosis and necrosis at 14 d after treatment. (Color for this figure is available in the online version of this paper.)

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Table 2. Effects of simulated glufosinate drift application timing on primary crop rice plant height at 7, 14, 21, and 28 d after treatment (DAT) and at harvest, 2005–2007, as percent of the nontreated, Crowley, LA.[a]

Glufosinate timing	Rice plant height[b]				
	7 DAT	14 DAT	21 DAT	28 DAT	Harvest[c]
	% of nontreated[d]				
One-tiller	94 b (41)	96 b (54)	96 c (65)	96 c (71)	99 ab
PD[e]	98 a (65)	99 a (71)	99 ab (78)	98 b (88)	98 b
Boot	99 a (93)	98 ab (99)	98 b (98)	99 ab (97)	98 b
Maturity	99 a (51)	100 a (56)	100 a (60)	99 ab (64)	100 a

[a] Means within a column followed by the same letter were not statistically different according to the Fisher's protected LSD *t* test on difference of least-square means at $\alpha = 0.05$.

[b] Actual heights of nontreated rice in parentheses for the one-tiller, PD, and boot timings taken from the soil surface to the tip of the extended uppermost emerged leaf, and soil surface to the tip of the extended panicle for the maturity. Overall height higher for extended uppermost leaf than tip of the extended panicle.

[c] Actual height of nontreated rice at primary crop harvest was 96 cm.

[d] Data averaged across application rates of 31 and 62 g ai ha^{-1} glufosinate applied at spray volumes of 15 and 29 L ha^{-1}, respectively.

[e] Abbreviation: PD, panicle differentiation growth stage of rice.

tion, and seedling vigor of harvested grain observed in this study is reflective of the impact expected on commercial seed rice producers. Studies in which seeds are hand-harvested, such as Walker and Oliver (2008), which bypass a separation process, may misrepresent the impact of herbicides on seed in mechanically harvested grain crops.

A glufosinate application rate by temperature interaction occurred for seed germination of primary crop seed; therefore, data were averaged over application timing. Glufosinate applied at 31 and 62 g ha^{-1} resulted in rice seed germination of 92 to 93% of the nontreated when evaluated at 19 C (Table 5). Simulated glufosinate drift applications had no effect on rice seed germination when evaluated at 13, 16, 22, and 25 C. Ellis et al. (2003) reported a simulated glufosinate drift application to rice resulted in a reduction in primary crop seed germination. Reductions in germination of this magnitude can lead to an increase in seed cost to rice producers.

A glufosinate timing by temperature interaction occurred for ratoon rice seed germination; therefore, data were averaged over glufosinate rate. Ratoon crop rice seed germination was not reduced by

Table 3. Effects of simulated glufosinate drift application timing on primary crop rice yield, 2005–2007, and ratoon and total crop rice yield, 2005 and 2007, as percent of the nontreated, Crowley, LA.[a]

Glufosinate timing	Yield		
	Primary crop	Ratoon crop	Total crop
	% of nontreated[b]		
One-tiller	100 a	98 a	98 a
PD[c]	100 a	102 a	99 a
Boot	90 b	106 a	93 b
Maturity	103 a	93 a	99 a
Nontreated[d]	6100	7500	7600

[a] Means within a column followed by the same letter were not statistically different according to the Fisher's protected LSD *t* test on difference of least-square means at $\alpha = 0.05$.

[b] Data averaged across application rates of 31 and 62 g ai ha^{-1} glufosinate applied at spray volumes of 15 and 29 L ha^{-1}, respectively.

[c] Abbreviation: PD, panicle differentiation growth stage of rice.

[d] Actual yield of nontreated rice for the primary, ratoon, and total crops.

Table 4. Effects of simulated glufosinate drift application rate on primary crop rice seed weight, 2005–2007, and seedling vigor, 2006 and 2007, as percent of the nontreated, Crowley, LA.[a]

Glufosinate rate	100-seed weight	Seedling vigor
g ai ha^{-1}	% of nontreated[b]	
31	100 a	88 b
62	100 a	91 b
Nontreated[c]	2,400 mg	43 mm

[a] Means within a column followed by the same letter were not statistically different according to the Fisher's protected LSD *t* test on difference of least-square means at $\alpha = 0.05$.

[b] Data averaged across the one-tiller, PD, boot, and maturity application timings.

[c] Actual nontreated 100-seed weight and seedling vigor shoot length.

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Table 5. Effects of simulated glufosinate drift application rate on primary crop rice seed germination at various temperatures, 2005–2007, as percent of the nontreated, Crowley, LA.[a]

	Temperatures				
Glufosinate rate	13 C	16 C	19 C	22 C	25 C
g ai ha^{-1}	% of nontreated[b]				
31	125 a	93 a	92 b	103 a	102 a
62	113 a	89 a	93 b	100 a	100 a
Nontreated[c]	8	45	59	76	68

[a] Means within a column followed by the same letter were not statistically different according to the Fisher's protected LSD t test on difference of least-square means at $\alpha = 0.05$.

[b] Data averaged across the one-tiller, PD, boot, and maturity application timings.

[c] Actual germination of the nontreated seed at 13, 16, 19, 22, and 25 C.

simulated glufosinate drift applications, compared with the nontreated (Table 6).

Seedling Vigor Studies. A glufosinate application rate interaction occurred for rice seedling vigor; therefore, data were averaged over glufosinate application timing. Glufosinate applied at 31 and 62 g ha^{-1} resulted in primary crop rice seedling vigor 88 to 91% of the nontreated (Table 4). This data indicates that even with no notable reduction in seed weight, rice seed germination and seedling vigor may be affected by glufosinate drift. If seed rice is affected by a glufosinate drift event, extra caution should be taken before that seed is sold to producers.

In conclusion, simulated glufosinate drift to rice at the one-tiller, PD, and boot growth stages resulted in crop injury and reduced rice plant height. Primary and total crop rice yield was reduced by simulated glufosinate drift applied at the boot growth stage. Averaged across application timings, primary crop rice seed germination and rice seedling vigor were reduced by simulated glufosinate drift applications, regardless of rate. Simulated glufosinate drift applications did not affect rice treated at primary crop maturity.

A glufosinate drift event occurring at the boot growth stage of rice can reduce yield. The negative effects of a glufosinate drift event occurring to a seed producer's field to rice in the boot growth stage has the potential to be twofold. Decreased profitability the year of the event can result from reduced yield, and a reduction in seed germination and seedling vigor can lessen profitability in the subsequent year's crop because of an increase in seeding rate to offset the reduced seed germination and seedling vigor.

Table 6. Effects of simulated glufosinate drift application timing on ratoon crop rice seed germination at various temperatures, 2005 and 2007, as percent of the nontreated, Crowley, LA.[a]

	Temperatures				
Glufosinate timing	13 C	16 C	19 C	22 C	25 C
	% of nontreated[b]				
One-tiller	100 a	127 a	113 a	117 a	120 a
PD[c]	67 a	105 b	102 b	98 c	112 b
Boot	67 a	109 ab	107 ab	112 ab	120 a
Maturity	100 a	91 b	98 b	106 b	97 c
Nontreated[d]	3	22	46	52	59

[a] Means within a column followed by the same letter were not statistically different according to the Fisher's protected LSD t test on difference of least-square means at $\alpha = 0.05$.

[b] Data averaged across application rates of 31 and 62 g ai ha^{-1} glufosinate applied at spray volumes of 15 and 29 L ha^{-1}, respectively.

[c] Abbreviation: PD, panicle differentiation growth stage of rice.

[d] Actual germination of the nontreated seed at 13, 16, 19, 22, and 25 C.

Caution should be taken when applying glufosinate near adjacent susceptible rice fields, especially when making applications near rice in the boot growth stage. The potential effect on grain yield and the seed germination and seedling vigor potential of the harvested grain could be highly detrimental to rice producers.

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