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Rice cultivar tolerance to florpyrauxifen-benzyl spray-applied vs. coated on urea

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Abstract

Complaints regarding the sensitivity of rice to florpyrauxifen-benzyl and off-target movement of the herbicide occurred following its commercial launch in 2018 in the midsouthern United States. These two concerns encouraged the exploration of an alternative application method for florpyrauxifen-benzyl in rice. A field study was conducted in 2020 and 2021 to determine if coating florpyrauxifen-benzyl on urea would reduce negative impacts of the herbicide to rice. Five commercial rice lines were evaluated: 'Diamond', 'Titan', 'RT7321 FP', 'RT7521 FP', and 'XP753'. Florpyrauxifen-benzyl coated on urea at a 2× rate (60 g ai ha^{-1}) reduced rice injury in one of five commercial rice lines in 2020 and four of five commercial rice lines in 2021, compared to spray applications at the same rate. In 2020, 'RT7521 FP' exhibited a 17-percentage point injury reduction when coating florpyrauxifen-benzyl on urea at a 2× rate vs. the same rate sprayed. In 2021, rice injury was reduced by 26, 10, and 27 percentage points in the commercial rice lines 'Diamond', 'Titan', and 'XP753', respectively, following coated urea vs. spray applications at 4 wk after treatment (WAT). 'XP753' exhibited reduced injury (15 percentage points) by coating florpyrauxifen-benzyl at a 1× rate (30 g ai ha^{-1}) 4 WAT in 2021, and another, 'Diamond', had comparable groundcover to nontreated plots when florpyrauxifen-benzyl was coated on urea at a 1× rate rather than the reductions observed from the spray application at a 2× rate. Yield differences were a function of urea rate rather than application method, where in six out of ten instances greater rough rice grain yield occurred at the higher rate. Findings from this experiment indicate that coating florpyrauxifen-benzyl on urea can reduce the amount of injury observed, especially in areas of overlap where you would have a 2× rate.

Introduction

Commercially launched in 2018 and labeled by Corteva Agriscience (Wilmington, DE), florpyrauxifen-benzyl (Loyant™) is a synthetic auxin, Herbicide Resistance Action Committee (HRAC)/Weed Science Society of America (WSSA) Group 4 herbicide available for broad-spectrum rice weed control. The commercial release of florpyrauxifen-benzyl was followed by varying rice tolerance to the herbicide being reported in the literature (Beesinger et al. 2022b; Wright et al. 2020). Along with the commercial release of new herbicides, new rice commercial rice lines are bred and commercially released each year to offer producers with additional options. Three hybrid, long-grain commercial rice lines were commercially released in 2020: 'RT7301', 'RT7321 FP', and 'RT7521 FP' (Hardke 2021). However, hybrid, long-grain rice commercial rice line 'RT Gemini 214 CL' comprised the greatest total rice hectares (21%) planted in Arkansas. Long-grain commercial rice lines were planted on more hectares (91.5%) in Arkansas, compared to medium-grain commercial rice lines in 2020. Producers tend to favor hybrid rice commercial rice lines because of their greater yield potential and various stress tolerances that are best suited for their particular growing scenario (Laborte et al. 2015; Yuan 1994).

Previous research has established that most pure-line, long-grain commercial rice lines are more tolerant to florpyrauxifen-benzyl than hybrid, long-grain commercial rice lines, except for the pure-line commercial rice line 'Diamond' (Wright et al. 2020). However, environmental conditions can influence the levels of injury to rice from applications of florpyrauxifen-benzyl (Beesinger et al. 2022a). Miller and Norsworthy (2018) discovered that weeds more readily translocated florpyrauxifen-benzyl above treated leaf surfaces under moist compared to dry conditions. Additionally, the florpyrauxifen-benzyl label recommends that fields be flooded within 5 d of application (Anonymous 2018); hence, with fields being flooded shortly after application, greater translocation of florpyrauxifen-benzyl can be expected followed by varying degrees of translocation based on rice commercial rice line. Additionally, previous research has outlined that different rice commercial rice lines can exhibit various levels of sensitivity to a synthetic auxin herbicide (Pantone and Baker 1992).

Based on the varying rice tolerance to florpyrauxifen-benzyl, ideas surrounding alternative application methods arose, especially considering that the herbicide also caused substantial injury to soybean [*Glycine max* (L.) Merr.] in adjacent fields (AAD 2018). Florpyrauxifen-benzyl is primarily absorbed by foliar parts of the plant with some root uptake (Anonymous 2019). Once florpyrauxifen-benzyl is applied to foliage, minimal herbicide will translocate below the treated area or into the roots of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (Miller and Norsworthy 2018). Hence, the amount of foliar interception of florpyrauxifen-benzyl spray drift by soybean is likely the cause of injury (Butts et al. 2022). Likewise, when ^{14}C-glyphosate was applied to Aspen (*Populus tremuloides* Michx.), increasing the herbicide concentration on the plant led to increased herbicide absorption, following the idea that uptake is a diffusion process based on Fick's Laws of Diffusion and can be affected by leaf cuticle characteristics (Liu et al. 1996). Additionally, soil moisture plays an important role in absorption of florpyrauxifen-benzyl in evaluating rice tolerance and weed control. As soil moisture increased, the amount of herbicide absorbed by foliar means increased in yellow nutsedge (*Cyperus esculentus* L.), hemp sesbania [*Sesbania herbacea* (Mill.) McVaughn], and barnyardgrass and indicated higher levels of control of the respective weeds (Miller and Norsworthy 2018). Consequently, an application method that would reduce physical drift and interception of the herbicide by soybean and rice foliage should reduce injury.

Alternative application methods are commonly used in cropping systems to decrease the amount of herbicide used, allow for use in additional crops, and increase crop safety. Shielded sprayers have been used for banded or directed applications by applying herbicides between crop rows rather than over-the-top of the entire crop area (Davis and Pradolin 2016). Directed spraying allows for herbicides to be applied that would be too injurious to spray over-the-top of a crop canopy but are often limited by crop size restrictions and type of crop (Sumner and Culpepper 2017). Coating herbicides on urea entrapped in starches is an application method that has been used to reduce herbicide volatilization and increase crop safety (Shasha and Trimnell 1989). However, florpyrauxifen-benzyl is a low-volatility compound with a vapor pressure of 4.6×10^{-5} at 25 C and is unlikely to cause injury to soybean via volatilization (APVMA 2018). The use of urea to deliver herbicide may reduce rice injury and off-target movement.

Urea granules could provide a less injurious means of applying florpyrauxifen-benzyl than water-based spray, because granules are greater in diameter and density, and are less likely to be intercepted by plant leaves than a water-based spray. Additionally, urea granules have a greater downward terminal velocity than fine water droplets (Hofstee 1992). Coating herbicides on fertilizers has proven to be an effective application method at creating uniform herbicide coverage on the soil surface that can infiltrate a crop canopy and residue in conservation tillage systems (Kells and Meggit 1985. Based on previous success of alternative application methods and uses of urea fertilizer, the potential for a practical alternative application method for florpyrauxifen-benzyl in rice is worth investigating. Florpyrauxifen-benzyl at a rate of 30 g ai ha^{-1} is recommended to coat a minimum of 112 kg ha^{-1} of fertilizer (Anonymous 2021). Additionally, capitalizing on urea being used as a product for which florpyrauxifen-benzyl can be adhered to has the potential to decrease the effects of off-target movement, as urea granules are expected to drift less than liquid spray droplets combined with herbicide (Hofstee 1992). Moreover, florpyrauxifen-benzyl has a greater likelihood to move off-target when applied aerially compared to a ground applicator (Butts et al. 2022). Hence, research was conducted to determine whether an application of florpyrauxifen-benzyl coated on urea would reduce injury to commercial rice lines compared to a spray application.

Materials and Methods

Experimental Setup

An experiment was conducted at the Pine Tree Research Station near Colt, AR (35.12427° N, 90.92988° W), in 2020 and 2021, to test commercial rice line tolerance to florpyrauxifen-benzyl following 1× and 2× rates of the herbicide applied as a spray and coated on urea. The soil texture both years was a Calhoun silt loam, consisting of 0.4% sand, 78.2% silt, and 21.4% clay with 1.69% organic matter and a pH of 7.8. Plot sizes were 1.8 by 5.2 m with a 1-m alley between plots. The previous crop at the site was rice, and the seedbed was prepared using conventional tillage. Rice was drill-seeded using a cone drill (ALMACO, Nevada, IA 50201) in 10 rows with 18-cm row spacings at a 1.3-cm depth on April 24, 2020, and April 12, 2021. The following commercial rice lines were evaluated and planted at each respective rate: 'XP753' at 35 kg ha^{-1}, 'RT7321 FP' at 36 kg ha^{-1}, 'RT7521 FP' at 37 kg ha^{-1}, 'Diamond' at 91 kg ha^{-1}, and 'Titan' at 104 kg ha^{-1}. All plots were maintained weed-free using preemergence applications of clomazone (Command 3ME; FMC, Philadelphia, PA) and postemergence applications of propanil (Stam M4; RiceCO LLC, Memphis, TN) at two-leaf rice and halosulfuron-methyl (Permit 75WG; Gowan Co., Yuma, AZ) with cyhalofop (Ricestar HT; Bayer Crop Science, St. Louis, MO) prior to flooding both years. In 2021, two applications of benzobicyclon (Rogue; Gowan Co., Yuma, AZ) were required for weedy rice (*Oryza sativa* L.) control along with additional hand removal of weeds. Rice was managed as a direct-seeded, delayed-flood production system. No preplant phosphorus or potassium fertilizer was applied either year, and levees were constructed to maintain a 4- to 6-cm flood depth at the test site.

These experiments were designed as a completely random design with two factors for each commercial rice line and year combination with three replications. The two factors were application method (spray-applied or urea-coated) and florpyrauxifen-benzyl (Loyant™ Herbicide; Corteva Agrisciences™, Indianapolis, IN) rate at 0, 30, and 60 g ai ha^{-1}. Commercial rice lines evaluated included three hybrid, long-grains ('XP753', 'RT7321 FP', and 'RT7521 FP'; RiceTec Inc., Alvin, TX), one pure-line, long-grain ('Diamond'; Rice Research and Extension Center, Stuttgart, AR), and one pure-line, medium-grain ('Titan'; Rice Research and Extension Center, Stuttgart, AR). These commercial rice lines were chosen because 'Diamond' and 'Titan' had previously been found to exhibit a high degree of sensitivity to florpyrauxifen-benzyl, and hybrid commercial rice lines are also known to sometimes respond negatively to the herbicide (Beesinger et al. 2022b; Wright et al. 2020).

Preflood applications included florpyrauxifen-benzyl applied at 30 g ai ha^{-1} as a liquid spray immediately following urea applied at 317 kg ha^{-1}. Additionally, a florpyrauxifen-benzyl spray at a

2× rate (60 g ai ha^{-1}) was applied immediately following a 2× rate of urea (634 kg ha^{-1}). All spray-applied florpyrauxifen-benzyl applications included 0.58 L ha^{-1} of methylated seed oil. Likewise, florpyrauxifen-benzyl was coated on urea and applied at rates that would equate to 30 and 60 g ai ha^{-1} of the herbicide when applying urea at 317 and 634 kg ha^{-1}, respectively. Urea was also applied at 317 and 634 kg ha^{-1} in the absence of florpyrauxifen-benzyl. Spray applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kpa with a hand-boom containing four 110015 AIXR (TeeJet Technologies, Springfield, IL) nozzles spaced 48 cm apart. Urea fertilizer was coated using an electric motor-driven cement mixer in batches of 23 kg. Florpyrauxifen-benzyl and a blue dye were sprayed onto the urea and mixed continuously for 5 min to ensure an even mix and to provide sufficient time for drying of the herbicide. Preflood florpyrauxifen-benzyl applications were made on June 10, 2020, and June 3, 2021, when rice had reached on average the four- to five-leaf stage. All plots were flooded the day after preflood applications, and the flood was maintained until the crop reached maturity.

Data Collection

Visible rice injury was rated on a scale of 0 to 100, where 0 represents no crop injury and 100 represents crop death at 3 and 4 wk after the preflood application (Frans and Talbert 1986). Visible rice injury ratings were based on aboveground biomass, stunting, leaf malformations, and groundcover. Aerial images of all plots were taken on the days that injury was rated using a DJI Phantom Pro 4 in 2020 and a DJI Mavic Pro 2 (Sentera, Minneapolis, MN) in 2021. From these aerial images, rice groundcover was determined for each plot using Field Analyzer (Turf Analyzer, Fayetteville, AR). The date of 50% heading was recorded for each plot. Groundcover and heading dates were made relative to the nontreated plots. Rough rice grain was harvested from the center four rows of each plot using a small-plot combine (Kubota Corp., Naniwa-ku, Osaka, Japan). Rough rice grain yield was calculated, and moisture was adjusted to 12%.

Statistical Analyses

Commercial rice lines were analyzed separately, because each commercial rice line was expected to respond differently to applications of florpyrauxifen-benzyl according to research previously mentioned. Additionally, site-years were analyzed separately due to varying levels of rice response each year. By removing site-year from the statistical model, site-year was not a source of variation, allowing each year to be discussed independently. Percent visible rice injury 3 and 4 WAT was determined to have a beta distribution, grain yield followed a gamma distribution, and relative heading date and groundcover had a normal distribution based on AICc and BIC values in the distribution platform of JMP Pro 16 (SAS Institute Inc., Cary, NC). A two-factor ANOVA was used to assess application method and florpyrauxifen-benzyl rate in SAS 9.4 utilizing the PROC GLIMMIX function (SAS Institute Inc., Cary, NC). Block was considered a random effect. Means were separated using Fisher's protected LSD ($\alpha = 0.05$).

Results and Discussion

Crop Injury

A 1× coated application of florpyrauxifen-benzyl on urea did not decrease visible rice injury at either rating in 2020 for any commercial rice line compared to the same rate foliar applied (Table 1). For 'RT7521 FP' at 3 WAT, spraying the herbicide at a 2× rate resulted in 20% injury compared to only 3% when the herbicide was applied at the same rate coated on urea. For all other commercial rice lines at 3 WAT, coating florpyrauxifen-benzyl on urea affected rice injury similarly to the spray application. By 4 WAT, the levels of injury within a commercial rice line did not differ between coated and sprayed treatments for either herbicide rate evaluated. Overall, the level of injury caused by both rates of florpyrauxifen-benzyl in 2020 to 'Diamond', 'Titan', and 'XP753' rice was comparable to that reported in a previous commercial rice line tolerance study (Beesinger et al. 2022b).

Table 1. Visible rice injury caused by urea-coated and spray-applied florpyrauxifen-benzyl on rice cultivars in 2020 and 2021 taken 3 and 4 wk after treatment (WAT).[a–d]

			Visible rice injury			
			2020		2021	
Cultivar	Method	Rate	3 WAT	4 WAT	3 WAT	4 WAT
			%			
'Diamond'	Coated	1×	15	11	20 B	27 B
		2×	20	18	15 C	7 C
	Spray	1×	12	10	19 BC	25 B
		2×	15	9	26 A	33 A
	P value		0.8364	0.0800	0.0098*	<0.0001*
'Titan'	Coated	1×	8	4	18 AB	19 AB
		2×	7	2	11 C	13 B
	Spray	1×	4	1	12 BC	14 B
		2×	7	2	19 A	23 A
	P value		0.1103	0.1465	0.0126*	0.0058*
'RT7321 FP'	Coated	1×	6	4	5	2
		2×	3	2	5	2
	Spray	1×	6	1	7	9
		2×	3	2	10	25
	P value		0.9999	0.3941	0.6362	0.3662
'RT7521 FP'	Coated	1×	7 B	3	8 AB	1
		2×	3 B	1	3 B	2
	Spray	1×	7 B	2	7 AB	11
		2×	20 A	10	12 A	33
	P value		0.0339*	0.0608	0.0186*	0.5612
'XP753'	Coated	1×	12	6	7	8 B
		2×	12	3	3	0 B
	Spray	1×	8	5	15	23 A
		2×	12	6	21	27 A
	P value		0.0534	0.2152	0.3126	0.0466*

[a]Applications of florpyrauxifen-benzyl applied to four- to five-leaf rice.
[b]1× and 2× represent florpyrauxifen-benzyl at 30 and 60 g ai ha^{-1}, respectively.
[c]Means within the same column and cultivar not containing the same letter are different according to Fisher's protected LSD ($\alpha = 0.05$).
[d]P values followed by * are significant ($P < 0.05$).

In 2021, more differences within commercial rice lines were observed among treatments than in 2020 (Table 1). Even with greater differences in 2021, injury for rice treated with the 1× coated application of florpyrauxifen-benzyl on urea was only decreased for one of the five commercial rice lines evaluated regardless of rating date. For 'XP753' at 4 WAT, coating florpyrauxifen-benzyl on urea resulted in no injury compared to 27% injury when the herbicide was applied as a foliar spray. No other commercial rice line exhibited a reduction in injury following a 1× application of florpyrauxifen-benzyl coated on urea.

When florpyrauxifen-benzyl was applied at a 2× rate, four commercial rice lines exhibited a reduction in injury following a coated urea application compared to spray application of the herbicide. For 'Diamond' rice, injury was 33% at 4 WAT following

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Table 2. Rice relative groundcover and heading date in response to urea-coated and spray-applied florpyrauxifen-benzyl applications in 2020 and 2021.[a–f]

			2020		2021	
Cultivar	Method	Rate	Groundcover	Heading date	Groundcover	Heading date
			% of control	No. of days delayed	% of control	No. of days delayed
'Diamond'	Coated	1×	103	1	120 A	−3
		2×	88	0	133 A	−1
	Spray	1×	105	0	123 A	−5
		2×	99	1	79 B	1
	P value		0.6670	0.3641	0.0459*	0.2213
'Titan'	Coated	1×	120	0	62	3
		2×	108	0	90	0
	Spray	1×	110	0	83	0
		2×	96	0	74	−1
	P value		0.9379	0.3454	0.1973	0.2554
'RT7321 FP'	Coated	1×	110	−1	100	2
		2×	110	1	78	0
	Spray	1×	104	−1	73	1
		2×	105	0	93	−1
	P value		0.9797	0.2598	0.2225	0.2313
'RT7521 FP'	Coated	1×	100	−1	86	2
		2×	109	2	81	3
	Spray	1×	116	0	74	−1
		2×	102	3	79	1
	P value		0.2885	0.7067	0.7950	0.7829
'XP753'	Coated	1×	128	0	86	4
		2×	113	0	99	1
	Foliar	1×	106	1	70	5
		2×	90	0	74	−1
	P value		0.9240	0.5438	0.8572	0.5824

[a]Applications of florpyrauxifen-benzyl applied to four- to five-leaf rice.
[b]1× and 2× represent florpyrauxifen-benzyl at 30 and 60 g ai ha^{-1}, respectively.
[c]Groundcover analyzed 3 wk after application and reported as relative to nontreated control of each cultivar. Nontreated control = 100%.
[d]Heading dates observed when rice reached 50% emerged head and made relative to nontreated control of each cultivar. Nontreated control = 0.
[e]Means within the same column and cultivar not containing the same letter are different according to Fisher's protected LSD (α = 0.05).
[f]P values followed by * are significant ($P < 0.05$).

the spray application of florpyrauxifen-benzyl at a 2× rate, whereas the same rate caused only 7% injury when coated on urea. A similar safening of 'Titan' rice to a 2× rate of florpyrauxifen-benzyl coated on urea vs the spray was observed at 3 and 4 WAT. At 3 WAT, injury to 'RT7521 FP' following the 2× rate of florpyrauxifen-benzyl coated on urea was four times less than when the herbicide was applied as a spray. 'XP753' exhibited a similar reduction in injury following a coated-urea application compared to a spray application at 4 WAT, but the rice injury reduction occurred at both rates.

Based on these findings, coating florpyrauxifen-benzyl on urea reduced rice injury in one of five commercial rice lines in 2020 and four of five commercial rice lines in 2021 at either rating timing. Injury caused by florpyrauxifen-benzyl can vary from year to year based on variation in environmental factors. Temperature, light intensity, and soil moisture content can all influence the extent of injury to rice caused by florpyrauxifen-benzyl (Beesinger et al. 2022a). Likewise, most commercial rice lines exhibited numerically greater injury in 2021 than in 2020. Rice injury caused by florpyrauxifen-benzyl appeared to be highly variable within each commercial rice line. The average temperatures of the week immediately following were 26 and 25 C in 2020 and 2021, respectively (data not shown). However, the other previously mentioned environmental factors, like light intensity and soil moisture, were not studied in this experiment; these might have caused rice to respond to an application of florpyrauxifen-benzyl differently from one year to the next. Although rice injury caused by florpyrauxifen-benzyl coated on urea was highly variable within each respective commercial rice line, coating the herbicide on urea appeared to have more opportunity to reduce rice injury in 2021 due to the higher levels of injury in all commercial rice lines except 'RT7321 FP'. Slightly alkaline soil at the testing site and any slight variations in watering techniques between years may have accounted for the variation in injury levels exhibited from year to year. Varying levels of injury have been noted in previous studies following florpyrauxifen-benzyl spray applications (Sanders et al. 2020; Wright et al. 2020). In two separate studies, hybrid 'CL XL745' experienced differing levels of injury ranging from 6% to 20%, exhibiting the varying nature of injury caused by the herbicide. Additionally, a lack of foliar interception of florpyrauxifen-benzyl when coated on urea can help explain the occasional decrease in rice injury of less tolerant commercial rice lines. This function of foliar interception leading to a decrease in injury is similar to the fact that less foliar interception of herbicide leads to a reduction in the effectiveness of postemergence sprays (Norsworthy et al. 1999). For most commercial rice lines observed, the magnitude of injury was not enough to elicit a significant difference between application methods except when florpyrauxifen-benzyl was applied at a 2× rate. Based on these findings, the alternative application method of coating florpyrauxifen-benzyl on urea may help reduce rice injury; however, florpyrauxifen-benzyl–induced injury remained highly variable regardless of application method. Additionally, there may be more root uptake by rice than previously expected, as a result of the levels of injury reported in this work.

Groundcover, Heading Date, and Yield

Examination of groundcover data following an application of florpyrauxifen-benzyl revealed that no commercial rice line in 2020

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Table 3. Effect of urea rate on rough rice grain yield averaged over urea-coated and spray florpyrauxifen-benzyl application methods in 2020 and 2021.[a–e]

Cultivar	Urea rate	Yield 2020	Yield 2021
		kg ha^{-1}	
'Diamond'	1×	6,820 B	5,000 B
	2×	9,390 A	7,930 A
	P value	0.0051	0.0387
'Titan'	1×	7,520 B	5,700 B
	2×	9,950 A	8,600 A
	P value	0.0404	0.0228
'RT7321 FP'	1×	11,710 B	9,900
	2×	13,730 A	11,410
	P value	0.0079	0.0784
'RT7521 FP'	1×	11,660	9,790
	2×	12,670	10,650
	P value	0.2043	0.1214
'XP753'	1×	11,510 B	8,480
	2×	13,830 A	9,740
	P value	0.0079	0.2563

[a]Applications of florpyrauxifen-benzyl and urea applied to four- to five-leaf rice.
[b]1× and 2× represent urea rates at 317 and 634 kg ha^{-1}, respectively.
[c]Respective urea rates include nontreated and florpyrauxifen-benzyl treatments.
[d]P values followed by * are significant ($P < 0.05$).
[e]Means within the same column and cultivar not containing the same letter are different according to Fisher's protected LSD ($\alpha = 0.05$).

or 2021 differed in groundcover for a 1× rate of florpyrauxifen-benzyl, regardless of application method. Regarding the 2× rate, a difference between application methods was only observed for the commercial rice line 'Diamond', where the coated application resulted in safening relative to the spray application (Table 2). Groundcover assessments are a good predictor for crop yield loss (Donald 1998).

No differences were observed following examination of heading date from either year relative to the nontreated plots (Table 2). Regarding yield, commercial rice lines 'Diamond', 'Titan', 'RT7321 FP', and 'XP753' all exhibited a urea rate response in 2020 (Table 3). Likewise, 'Diamond' and 'Titan' exhibited the same yield response in 2021 (Table 3). Regardless of application method or the presence of florpyrauxifen-benzyl, rice in six out of ten treatments exhibited greater yield following a 2× rate of urea compared to a 1× rate. However, rice in all ten treatments exhibited numerical yield differences under the previous parameters following a 2× rate of urea compared to a 1× rate. These urea rate responses indicate that higher urea fertilizer rates may be needed at this site to maximize grain yield, however, overly high urea rates may not optimize yields and profits. Based on no groundcover reductions, limited reductions in yield were expected. Additionally, previous researchers concluded that rice could overcome and recover from early-season setbacks from florpyrauxifen-benzyl at 30 g ai ha^{-1} and result in no delay in heading or yield reduction (Wright et al. 2020). Although varying levels of rice injury occurred, injury had little impact on the maturity and yield.

Practical Implications

Coating florpyrauxifen-benzyl on urea at a labeled rate (30 g ai ha^{-1}) can reduce levels of injury to sensitive commercial rice lines compared to sprayed applications of the herbicide when treated at the four- to five-leaf growth stage, especially in areas of application overlap where you would experience a 2× rate. Florpyrauxifen-benzyl injury to rice appears to be variable when the herbicide was both spray-applied and coated on urea. Comparable effects in heading date, groundcover, and yield should be expected from an application of florpyrauxifen-benzyl coated on urea at a 1× rate compared to spray-applied at the same rate.

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References

Anonymous (2021) Loyant™ 2(ee) Recommendation. Aerial Applications of Loyant Impregnated on Dry Fertilizer. Corteva Agrisciences, Indianapolis, IN 46268. https://s3-us-west-1.amazonaws.com/agrian-cg-fs1-production/pdfs/Loyant_2EE5.pdf. Accessed: July 27, 2022

Anonymous (2019) Loyant™ Rice Fact Sheet. Corteva Agrisciences, Indianapolis, IN 46268. https://www.corteva.us/content/dam/dpagco/corteva/na/us/en/products/files/Loyant-Fact-Sheet.pdf. Accessed: June 22, 2022

Anonymous (2018) Loyant™ Herbicide Product Label. Corteva Agrisciences Publication 010-02342. Indianapolis, IN. 2 p. https://s3-us-west-1.amazonaws.com/agrian-cg-fs1-production/pdfs/Loyant_Label1t.pdf. Accessed: June 22, 2022

Australian Pesticides and Veterinary Medicines Authority [APVMA] (2018) Public release summary on the evaluation of the new active florpyrauxifen-benzyl (Rinskor™) in the product GF-3301 herbicide. Sydney, Australia: Australian Pesticides and Veterinary Medicines Authority

Arkansas Agriculture Department [AAD] (2018) Public release: growers and applicators advised to use caution with Loyant herbicide. Arkansas Agriculture Department, Arkansas State Plant Board. https://www.agriculture.arkansas.gov/wp-content/uploads/2020/05/Arkansas_Growers_and_Applicators_Advised_to_use_Caution_with_Loyant_Herbicide_May_2018.pdf. Accessed: May 25, 2023

Beesinger JW, Norsworthy JK, Butts TR, Roberts TL (2022a) Impact of environmental and agronomic conditions on rice injury caused by florpyrauxifen-benzyl. Weed Technol 36:93–100

Beesinger JW, Norsworthy JK, Butts TR, Roberts TL (2022b) Rice tolerance to multiple applications of florpyrauxifen-benzyl alone and followed by benzobicyclon. Crop Forage Turfgrass Manag 8:e20162

Butts TR, Fritz BK, Kouame BJ, Norsworthy JK, Barber LT, Ross WJ, Lorenz GM, Thrash BC, Bateman NR, Adamczyk JJ (2022) Herbicide spray drift from ground and aerial applications: implications for potential pollinator foraging sources. Scientific Reports 12:18017

Davis AM, Pradolin J (2016) Precision herbicide application technologies to decrease herbicide losses in furrow irrigation outflows in a northeastern Australian cropping system. J Agric Food Chem 64:4021–4028

Donald WW (1998) Estimated soybean (*Glycine max*) yield loss from herbicide damage using ground cover or rated stunting. Weed Sci 46:454–458

Frans R, Talbert R (1986) Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. 3rd edn. Champaign, IL: Weed Science Society of America. Pp 29–46

Hardke JT (2021) Trends in Arkansas rice production, 2020. B.R. Wells Arkansas Rice Research Studies 2020. University of Arkansas Division of Agriculture, Cooperative Extension Service. Pp 11–18

Hofstee JW (1992) Handling and spreading fertilizers: part 2, physical properties of fertilizers, measuring methods and data. J Agric Engng Res 53:141–162

Kells JJ, Meggit WF (1985) Conservation tillage and weed control. Pages 123–129 *in* A Systems Approach to Conservation Tillage 1st edn. Chelsea, MI: Lewis Publishing

Laborte AG, Paguirigan NC, Moya PF, Nelson A, Sparks AH, Gregorio GB (2015) Farmers' preference for rice traits: insights from farm surveys in

central Luzon, Philippines, 1966–2012. PLOS ONE 10(8): e136562. doi: 10.1371/journal.pone.0136562
Liu SH, Campbell RA, Studens JA, Wagner RG (1996) Absorption and translocation of glyphosate in Aspen (*Populus tremuloides* Michx.) as influenced by droplet size, droplet number, and herbicide concentration. Weed Sci 44:482–488
Miller MR, Norsworthy JK (2018) Influence of soil moisture on absorption, translocation, and metabolism of florpyrauxifen-benzyl. Weed Sci 66:418–423
Norsworthy JK, Oliver LR, Purcell LC (1999) Diurnal leaf movement effects on spray interception and glyphosate efficacy. Weed Technol 13:466–470
Pantone DJ, Baker JB (1992) Varietal tolerance of rice (*Oryza sativa*) to bromoxynil and triclopyr at different growth stages. Weed Technol 6:968–974
Sanders TL, Bond JA, Lawrence BH, Golden BR, Allen TW, Famoso A, Bararpour T (2020) Response of acetyl-CoA carboxylase-resistant rice cultivars and advanced lines to florpyrauxifen-benzyl. Weed Technol 34:814–817
Shasha BS, Trimnell D (1989) Urea pellets coated with starch that contains entrapped herbicides. J Controlled Release 9:255–257
Sumner PE, Culpepper S (2017) How to set up post-emergence directed and shielded herbicide sprayer for cotton. Bulletin 1069. Tifton, Georgia: University of Georgia Extension
Wright HE, Norsworthy JK, Roberts TL, Scott R, Hardke J, Gbur EE (2020) Characterization of rice cultivar response to florpyrauxifen-benzyl. Weed Technol 35:82–92
Yuan LP (1994) Increasing yield potential in rice by exploitation of heterosis. Pages 1–6 *in* Virmani SS, ed, Hybrid Rice Technology: New Developments and Future Prospects. Los Baños, Phillipines: International Rice Research Institute