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Weed Spectrum and Size Influence on Control in Rice Following Florpyrauxifen-Benzyl Spray-Applied and Coated On Urea

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Abstract

Following the commercial launch of florpyrauxifen-benzyl, complaints and concerns surrounding the off-target movement of florpyrauxifen-benzyl to soybean arose. Consequently, research was initiated to evaluate an application method to alleviate damage from off-target movement and retain weed control in rice. Field and self-contained tub experiments were conducted in 2020 and 2021 to determine if coating florpyrauxifen-benzyl or mixtures containing florpyrauxifen-benzyl on urea would provide equivalent levels of weed control as spray applications. In the tub experiment, florpyrauxifen-benzyl sprayed at 30 g ae ha^{-1} and a mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} plus penoxsulam at 41 g ai ha^{-1} coated on urea resulted in 100% visible control, mortality, and no biomass production for yellow nutsedge, barnyardgrass, and hemp sesbania. However, for barnyardgrass, coating florpyrauxifen-benzyl on urea at 30 g ae ha^{-1} provided no greater than 27% visible control, 24% mortality, and 87% relative biomass at 4 and 5 WAT. In two separate rice flatsedge field experiments comparing application methods and herbicide combinations containing florpyrauxifen-benzyl, all treatments containing florpyrauxifen-benzyl provided 90% or greater control of ~10-cm rice flatsedge and 93% or greater control of ~25-cm rice flatsedge across all rating timings. In the ~10-cm rice flatsedge experiment, coating florpyrauxifen-benzyl or the mixture containing penoxsulam on urea resulted in greater visible ducksalad control than spray applications at 5 WAT. However, coated urea applications containing florpyrauxifen-benzyl were less effective than the spray and provided 50% and 76% visible California arrowhead and yellow nutsedge control, respectively. Coating either herbicide on urea resulted in 80% or less yellow nutsedge control compared to 96% or greater control following spray applications when applied to ~25-cm rice flatsedge. Coating florpyrauxifen-benzyl on urea provided comparable hemp sesbania, rice flatsedge, and ducksalad control a spray application. Adding penoxsulam to florpyrauxifen-benzyl improved barnyardgrass and yellow nutsedge control when coated on urea.

Keywords: Application method; Application technology; Off-target movement; Rice; Weed control

Introduction

Rice is a staple food grain globally and one of the most productive crops in the mid-southern United States. Rice is grown in the United States in the Arkansas Grand Prairie, Mississippi Delta, Gulf Coast, and the Sacramento Valley of California (USDA-ERS 2022). As of 2021, rice is second to soybean in Arkansas crop production in planted hectares and overall production value (USDA-NASS 2022). In 2021, Arkansas rice producers harvested approximately 483,000 hectares of rice, valued at over $1 billion (USDA-NASS 2022) [1].

Cultivating rice includes many different irrigation systems: the two most common are flood-irrigated and furrow-irrigated. In 2020, approximately 83% of rice grown in Arkansas was flood-irrigated, with conventional levees constructed to maintain flooding throughout the season, and the remaining rice was furrow-irrigated (Hardke 2021). Environmental and soil conditions created by flooding rice can be conducive to the growth and reproduction of aquatic and semiaquatic weeds (Smith 1988). While flooded conditions create a conducive environment for growing rice, weeds can also flourish under the same conditions. Initial flood establishment occurs at a 5-to 7.5-cm depth when rice begins tillering (four-to five-leaf growth stage) and is maintained until harvest (Henry et al. 2018). Additionally, flood depth can be increased to 10 to 15 cm at midseason to aid disease suppression (Henry et al. 2018). Flooding depth also influences weed seed germination, establishment, survival, and growth [2,3].

According to a survey of Arkansas rice weed issues in 2020, barnyardgrass and Cyperus spp. [rice flatsedge, yellow nutsedge, smallflower umbrella sedge *(Cyperus difformis L)*, and white-margined flatsedge *(Cyperus flavicomus Michx.)* were identified as the most problematic weeds in flooded rice (Butts et al. 2022). Additionally, Butts et al. (2022) associated yield losses of 505 to 959 kg ha^{-1} with interference caused by the influence of barnyardgrass. Although barnyardgrass and rice flatsedge are problematic weeds in flooded rice, targeting a smaller, more favorable weed size could aid over control [4].

Weed size at the time of application can also influence herbicide efficacy. In an experiment conducted by Sellers et al. (2009), herbicide efficacy decreased as dogfennel [*Eupatorium capillifolium* (Lam.) Small ex Porter & Britton] height increased from 36-to 154-cm, regardless of rates and mixtures of triclopyr, fluroxypyr, 2,4-D amine, and dicamba. Similarly, bispyribac-sodium, fenoxaprop-p-ethyl + ethoxysulfuron, and penoxsulam + cyhalofop were less effective at controlling eight-

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leaf barnyardgrass compared to four-leaf barnyardgrass (Chauhan and Abugho 2012). Later herbicide application timings can be less efficacious due to larger weed sizes at the time of application [5]. Regardless of the rate, glyphosate provided less control of hemp sesbania at mid and late postemergence application timings compared to early postemergence (Jordan et al. 1997).

An effective preflood herbicide option is needed with flooded rice environments conducive to growing problematic weeds such as barnyardgrass and *Cyperus* spp. Florpyrauxifen-benzyl (Loyant®, Corteva Agrisciences, Wilmington, DE 19805) was commercially released in 2018 as a broad-spectrum, pre-flood rice herbicide and labeled to be applied at 30 g ae ha^{-1} (Anonymous 2018). Florpyrauxifen-benzyl is a synthetic auxin, Herbicide Resistance Action Committee (HRAC)/Weed Science Society of America (WSSA) Group 4 herbicide that offers greater than 75% control of broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], Amazon sprangletop [*Diplachne panicoides* (J. Presl.) McNeil], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], northern jointvetch [*Aeschynomene verginica* (L.) Britton, Sterns & Poggenb.], hemp sesbania, pitted morningglory (Ipomoea lacunosa L.), Palmer amaranth (*Amaranthus palmeri* S. Watson), yellow nutsedge, rice flatsedge, and smallflower umbrella sedge when sprayed at 30 g ha^{-1} (Miller and Norsworthy 2018) [6]. Florpyrauxifen-benzyl at 30 g ha^{-1} controlled barnyardgrass following spray applications, but some resistant biotypes exist in Arkansas and should be controlled through a program approach with overlapped residuals (Miller and Norsworthy 2018; Barber et al. 2022). However, following the commercial release of florpyrauxifen-benzyl, concerns about the off-target movement of the herbicide to soybean arose. The off-target movement of florpyrauxifen-benzyl was exacerbated when aerially applied compared to ground applications (Butts et al., 2022). Additionally, certain rice cultivars have been identified to be less tolerant to florpyrauxifen-benzyl when sprayed at 30 g ha^{-1}, with environmental factors contributing to the level of tolerance (Beesinger et al. 2022; Wright et al. 2020). An alternative application method was desired to apply florpyrauxifen-benzyl safely [7].

Coating herbicides onto fertilizer has previously been documented as a means of weed control in various crops and, consequently, limits off-target movement. When bensulfuron at 111 g ai ha^{-1} was coated onto fertilizer, ducksalad control ranged from 89 to 96% two weeks after treatment (Braverman 1995). However, at any rate, neither quinclorac nor bensulfuron provided greater than 39% control of junglerice [*Echinochloa colona* (L.) Link.] when incorporated with fertilizer (Braverman 1995).

Limited research has been conducted to evaluate the efficacy of florpyrauxifen-benzyl coated on urea to control problematic weeds in rice, and concerns of off-target movement of florpyrauxifen-benzyl are still prevalent. Hence, experiments were conducted to determine the weed control spectrum at a 5-cm flooding depth and different weed sizes on weed control efficacy following preflood applications of florpyrauxifen-benzyl coated urea.

Materials and Methods

Weed control spectrum of florpyrauxifen-benzyl coated on urea

An experiment was conducted in the greenhouse at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas, during the summer of 2020 and 2021 to evaluate the weed control spectrum following applications of florpyrauxifen-benzyl (Loyant™ Herbicide, Corteva Agrisciences™, 9330 Zionsville Road, Indianapolis, IN 46268) and florpyrauxifen-benzyl plus penoxsulam (Novixid™, 9330 Zionsville Road, Indianapolis, IN 46268) coated on urea compared to when the herbicides were spray-applied. Each plot consisted of a plastic tub with 64-by 42-by 36-cm dimensions. Each tub was filled to a 20-cm depth with a Captina silt loam composed of 22.2% sand, 59% silt, and 18.8% clay with 1.8% organic matter and a pH of 6.4. Control of three weeds common to mid-southern U.S. rice was evaluated: yellow nutsedge, barnyardgrass, and hemp sesbania. Weeds were germinated in the greenhouse and transplanted into tubs at approximately 2.5 cm height [8]. Five yellow nutsedge, ten barnyardgrass, and ten hemp sesbania plants were transplanted into the soil in each tub. Yellow nutsedge, barnyardgrass, and hemp sesbania were selected to evaluate control when the herbicide was coated on urea because previous research identified that florpyrauxifen-benzyl could provide effective control of these three weeds when applied as a spray (Miller and Norsworthy 2018). Herbicide treatments were applied, spray-applied, and coated on urea when weeds had grown to a 10-to 14-cm height. Herbicide treatments included no herbicide, florpyrauxifen-benzyl at 30 g ae ha^{-1}, and a premixture of florpyrauxifen-benzyl plus penoxsulam at 24 and 41 g ae/ai ha^{-1}, respectively, coated onto 317 kg ha^{-1} of urea or applied as a spray. Preflood urea at 317 kg ha^{-1} was also applied to treatments receiving the spray-applied herbicides and nontreated controls. Tubs were flooded to maintain a 5-cm depth initiated 6 hours after herbicide applications [9].

The experiment was designed as a randomized complete block with a two-factor treatment structure and four replications. The two factors included herbicide and application method. Florpyrauxifen-benzyl and florpyrauxifen-benzyl plus penoxsulam were coated on urea by spraying the herbicides plus a blue dye onto the fertilizer while mixing in an electric motor-driven cement mixer for 5 min. Urea fertilizer was coated in batches of 23 kg. The plot area (soil surface area in the tub) was used to determine the amount of non-coated and herbicide-coated urea required for each plot. Preflood herbicide applications and flood establishment occurred on June 29, 2020, and July 17, 2021. Flooding was maintained for four weeks following treatment.

Initial weed densities were taken at the time of application and 28 days after treatment to determine percentage mortality. Additionally, visible estimates of yellow nutsedge, barnyardgrass, and hemp sesbania control were taken 3 and 4 weeks after treatment (WAT) on a 0 to 100 scale, with zero indicating no control and 100 representing weed death (Frans and Talbert 1986). Following ratings at 4 WAT, aboveground biomass was collected by weed species for each plot. Biomass samples were dried for five days at 66 C to constant mass, weighed, and reported relative to the nontreated control. Biomass from treated plots may have exhibited greater growth following herbicide treatment, and relative biomass could be reported as greater than 100% compared to the respective nontreated control [10].

General methodology to control rice flatsedge using florpyrauxifen-benzyl coated on urea

Two separate experiments were conducted at the Arkansas Rice Research and Extension Center near Stuttgart, AR, in 2020 and at the Pine Tree Research Station near Colt, AR, in 2021 to evaluate application method influence on rice flatsedge control following applications of florpyrauxifen-benzyl and florpyrauxifen-benzyl plus penoxsulam. One experiment assessed the control of small (~10 cm) rice flatsedge, and the other evaluated the control of large (~25-cm) rice flatsedge. Plots consisted of field bays measuring 7.6-by 2-m with

3.8-m planted in rice and 3.8-m bare ground [11]. Soil texture, in 2020, was a Dewitt silt loam consisting of 27% sand, 54% silt, and 19% clay with 1.8% organic matter. Soil texture, in 2021, was a Calloway silt loam consisting of 1% sand, 83% silt, and 16% clay with 2.3% organic matter. Quizalofop-resistant rice cultivar 'PVL01' (Provisia® technology, BASF, Florham Park, NJ 07932) was planted in 3 rows at 72 seeds per meter of the row with 76-cm row spacings on April 10, 2020, and May 14, 2021. Rice was planted with 76-cm row spacings to promote additional weed growth between the rice rows. All plots received a preemergence application of clomazone (Command 3ME, FMC, Philadelphia, PA 19104) at 336 g ai ha^{-1} at planting to minimize the emergence of grass weeds. Plots were maintained grass-free using postemergence applications of quizalofop (Provisia®, BASF, Florham Park, NJ 07932) when necessary [12].

Both experiments were conducted as a randomized complete block design with a two-factor factorial treatment structure and three replications, with the two factors being herbicide and application method. The first factor of herbicide included two herbicides: florpyrauxifen-benzyl at 30 g ae ha^{-1} and a mixture of florpyrauxifen-benzyl plus penoxsulam at 24 and 41 g ae/ai ha^{-1}, respectively. The second factor of the application method included herbicides being sprayed-applied and coated on urea. Florpyrauxifen-benzyl and florpyrauxifen-benzyl plus penoxsulam were coated onto 317 kg ha^{-1} urea at the aforementioned rates. The coating process was as described in the previous experiment. Each bay was measured to determine the herbicide-coated fertilizer equating to the aforementioned rates. Additionally, nontreated urea at 317 kg ha^{-1} was applied to nontreated and herbicide-sprayed bays immediately before liquid spray herbicide applications. All spray-applied treatments included 0.58 L ha^{-1} of methylated seed oil and were applied using a CO2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa with a hand-boom containing four AIXR 110015 (TeeJet Technologies, Springfield, IL 62703) nozzles spaced 48-cm apart. Applications in the first experiment occurred at the pre-flood timing on May 21, 2020, and June 4, 2021, when weeds had reached the targeted height of ~10 cm. Applications in the second experiment occurred at the pre-flood timing on May 28, 2020, and June 15, 2021, when weeds had reached the targeted height of ~25 cm (Table 1). Bays were flooded 24 hours after application to a flood depth of 6 cm and remained flooded throughout the study [13].

Visible estimates of rice flatsedge control were taken at 4 and 5 WAT, as well as a late-season control rating of rice flatsedge and California arrowhead that occurred at rice heading and were evaluated on the 0 to 100% scale previously described (Frans and Talbert 1986). Additionally, in 2021, visible yellow nutsedge control estimates were taken at 4 and 5 WAT for both rice flatsedge experiments. Visible ducksalad control estimates were recorded at 5 WAT and rice heading in the small (~10-cm) and large (~25-cm) rice flatsedge experiments, respectively, in 2021 [14].

Table 1: Weed densities, height, and leaf number for small (~10-cm) and large (~25-cm) rice flatsedge experiments at the time of application.[ab]

Experiment	Weed species	Density m^2	Height cm	Leaf number per plant
A	Rice flatsedge	22	8	3
	Yellow nutsedge	24	10	5
B	Rice flatsedge	23	22	8
	Yellow nutsedge	152	24	9

[a]Weed densities, height, and leaf number were averaged over 2020 and 2021

[b]Abbreviations: A, small rice flatsedge experiment; B, large rice flatsedge experiment

Statistical Analyses

Data were analyzed in SAS 9.4 utilizing the PROC GLIMMIX function (SAS Institute Inc., Cary, NC). A two-factor ANOVA was used to assess each experiment's respective factors. Based on AICc and BIC values in the distribution platform of JMP Pro 16 (SAS Institute Inc., Cary, NC), visible estimated weed control and mortality rates from the tub experiment followed a beta distribution while relative biomass followed a gamma distribution. Relative biomass and mortality rates were only recorded for barnyardgrass due to complete control of yellow nutsedge and hemp sesbania. Additionally, visible estimated weed control from both rice flatsedge experiments followed a beta distribution using the same determination as previously stated. Means were separated using Tukey's honestly significant difference (α=0.05). For all experiments, block and year were considered a random effect with block nested within year. By considering block and year random effects, they are assumed to be uncorrelated with the individual main effects [15].

Results and Discussion

Weed control spectrum of florpyrauxifen-benzyl coated on urea

In the controlled tub environment, applications of florpyrauxifen-benzyl at 30 g ae ha-^{1} and a mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1} coated on urea and spray-applied resulted in 100% control of yellow nutsedge and hemp sesbania, regardless of rating date (Table 2). The high level of yellow nutsedge and hemp sesbania control was observed from every factor and interaction of the factors. However, barnyardgrass control elicited a significant interaction between the herbicides and application methods at 3 and 4 WAT. Both herbicide application methods containing the mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1}, as well as florpyrauxifen-benzyl spray-applied at 30 g ae ha^{-1}

Table 2: Effects of herbicide and application method of florpyrauxifen-benzyl on visible estimates of rice weed control.[abcde]

		Control					
		Yellow nutsedge		Barnyardgrass		Hemp sesbania	
Source		3 WAT	4 WAT	3 WAT	4 WAT	3 WAT	4 WAT
Herbicide	FPB	100	100	96	95	100	100
	FPB+P	100	100	100	100	100	100
	P-value	1	1	<0.0001	0.0002	1	1
App method	Coated	100	100	96	95	100	100
	Spray	100	100	100	100	100	100
	P-value	1	1	<0.0001	0.0002	1	1
Herbicide* app method	FPB*coated	100	100	26	27	100	100
	FPB*spray	100	100	100	100	100	100
	FPB+P*coated	100	100	100	100	100	100
	FPB+P*spray	100	100	100	100	100	100
	P-value	1	1	<0.0001*	0.0002*	1	1

[a]Applications of florpyrauxifen-benzyl at 30 g ae ha-1 and a mixture of florpyrauxifen-benzyl at 24 g ae ha-1 and penoxsulam at 41 g ai ha-1 were applied to 2- to 3-leaf weeds

[b]Abbreviations: WAT, weeks after treatment; FPB, florpyrauxifen-benzyl; FPB+P, florpyrauxifen-benzyl + penoxsulam

[c]Means within the same column and source not containing the same letter are different according to Tukey's HSD (α=0.05)

[d]P-values followed by * are significant (P<0.05)

[e]Data included from 2020 and 2021.

resulted in 100% barnyardgrass control. Unlike when florpyrauxifen-benzyl was spray-applied at 30 g ae ha^{-1}, the herbicide was much less effective at controlling barnyardgrass when coated on urea at the same rate. Florpyrauxifen-benzyl at 30 g ae ha^{-1} coated on urea only provided 26% and 27% barnyardgrass control at 3 and 4 WAT, respectively. The lack of barnyardgrass control from florpyrauxifen-benzyl coated on urea points to the importance of foliar herbicide interception for the effectiveness of florpyrauxifen-benzyl on grass control, like Braverman (1995) found when coating quinclorac onto fertilizers [16].

A two-way interaction between application method and herbicide was observed for both barnyardgrass relative biomass and mortality. As previously stated in Table 2, florpyrauxifen-benzyl at 30 g ae ha^{-1} spray-applied and the mixture of florpyrauxifen-benzyl, both spray-applied and coated on urea at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1} all provided 100% barnyardgrass control. Consequently, the previously mentioned treatments resulted with barnyardgrass relative biomass being 0%, and barnyardgrass mortality being 100%. However, failed barnyardgrass control following florpyrauxifen-benzyl at 30 g ae ha^{-1} coated on urea caused differences in relative biomass and mortality between herbicide and application method. Since all combinations of factors provided 100% yellow nutsedge and hemp sesbania control, relative biomass and mortality and excluded from Table 3. Differences in relative biomass and mortality were only observed for barnyardgrass, where florpyrauxifen-benzyl was less effective at controlling the weed species [17].

Overall, relative barnyardgrass biomass following a single spray application of florpyrauxifen-benzyl at 30 g ae ha^{-1} was 87% of the nontreated relative barnyardgrass biomass (Table 3). An inverse response in barnyardgrass mortality was observed compared to the relative biomass. Where there was lower relative barnyardgrass biomass after applying florpyrauxifen-benzyl at 30 g ae ha^{-1} coated on, higher barnyardgrass mortality occurred. A lack of barnyardgrass control resulted in barnyardgrass mortality being 24% when combined between 2020 and 2021. Since florpyrauxifen-benzyl at 30 g ae ha^{-1} coated on urea slightly decreased barnyardgrass relative biomass and mortality, the results indicated that the herbicide coated on urea had some activity on barnyardgrass but was limited. Barnyardgrass is currently not listed as a controlled or suppressed weed for applications of florpyrauxifen-benzyl coated on urea (Anonymous 2021). Hence, florpyrauxifen-benzyl at 30 g ae ha^{-1} alone coated on urea should not be expected to control barnyardgrass effectively. Even though florpyrauxifen-benzyl alone coated on urea failed to provide adequate control of barnyardgrass, florpyrauxifen-benzyl coated on urea at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1} provided promising results to help control the problematic weed while utilizing the new application method.

Coating florpyrauxifen-benzyl on urea to control small (~10-cm) rice flatsedge

While only 3 percentage points separated the amount of rice flatsedge control at 4 and 5 WAT, respectively, a significant interaction between application methods was observed. When sprayed treatment containing florpyrauxifen-benzyl was applied, rice flatsedge was 100% controlled at 4 and 5 WAT. When florpyrauxifen-benzyl was coated on urea and applied, barnyardgrass control was 97% at 4 and 5 WAT. Although statistically different, both application methods offered high levels of rice flatsedge control at 4 and 5 WAT. Rice flatsedge control ratings at rice heading elicited a two-way interaction between herbicide and application method where florpyrauxifen-benzyl coated on urea provided the lowest (90%) ducksalad control compared to when the herbicide was sprayed or mixed with penoxsulam in either application method. Per Miller and Norsworthy (2018), sprayed florpyrauxifen-benzyl at 30 g ae ha^{-1} provided 94% control of rice flatsedge, so both application methods provided comparable results to previous research [18].

Application method was the only factor that elicited differences in California arrowhead control at the rice heading rating timing. Sprayed applications containing florpyrauxifen-benzyl provided 31 percentage points greater control of California arrowhead than when any herbicide treatment was coated on urea. At rice heading, sprayed applications of florpyrauxifen-benzyl provided 81% California arrowhead control, while coating the herbicide on urea only provided 50% control. However, an opposite effect of application method occurred for ducksalad control. When florpyrauxifen-benzyl or a mixture of florpyrauxifen-benzyl and penoxsulam was coated on urea, ducksalad was controlled 19 percentage points greater than sprayed applications at 5 WAT, achieving 94% visible ducksalad control. This level of ducksalad control is comparable to research by Rustom (2020), where ducksalad was controlled 89 to 99% with florpyrauxifen-benzyl at 11 to 29.5 g ae ha^{-1}. The increased visible ducksalad control suggests that decreased foliar interception of florpyrauxifen-benzyl-containing coated on urea treatments allowed greater amounts of herbicide to become suspended in the flood, hindering ducksalad growth at this preflood application which is inverse of what was expected.

However, ducksalad and California arrowhead are aquatic weeds that germinated later than those at the preflood timing. Typically, crop

Table 3: Effects of year, herbicide, and application method of florpyrauxifen-benzyl on barnyardgrass biomass and mortality.[abcdefg]

		Barnyardgrass			
Source		Relative biomass		Mortality	
Herbicide * app method	FPB*coated	87	A	24	B
	FPB*spray	0	B	100	A
	FPB+P*coated	0	B	100	A
	FPB+P*spray	0	B	100	A
	P-value	<0.0001*		<0.0001*	

[a]Applications of florpyrauxifen-benzyl at 30 g ae ha^{-1} and a mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1} were applied to 2- to 3-leaf weeds

[b]Biomass harvested at 4 weeks after treatment

[c]Abbreviations: FPB, florpyrauxifen-benzyl; FPB+P, florpyrauxifen-benzyl + penoxsulam

[d]No biomass or mortality measured for yellow nutsedge and hemp sesbania

[e]Means within the same column and source not containing the same letter are different according to Tukey's HSD (α=0.05)

[f]P-values followed by * are significant (P<0.05)

[g]Data included from 2020 and 2021

residue interception decreases soil activity of preemergence herbicides (Khalil et al. 2018). While florpyrauxifen is expected to have limited soil activity, coating and applying the herbicide on urea allows for more herbicide to meet the soil and, indirectly, flood water. By more herbicide entering flood waters, duck salad control is likely to increase. However, based on the results of this experiment, California arrowhead is not easily controlled by florpyrauxifen-benzyl, and the previous explanation does not apply to California arrowhead control.

Generally, spray applications containing florpyrauxifen-benzyl provided greater yellow nutsedge control at 4 and 5 WAT than coated urea applications containing the herbicide (Table 4). Spray applications averaged across herbicides and provided 98% and 99% yellow nutsedge control at 4 and 5 WAT, respectively. Conversely, coating florpyrauxifen-benzyl and florpyrauxifen-benzyl mixtures on urea never achieved yellow nutsedge control greater than 76% at 4 WAT or 73% at 5 WAT. As previously mentioned, plant interception of a herbicide is often key to controlling more problematic weeds. Yellow nutsedge has been outlined as one of the toughest to control weeds in Arkansas (Butts et al. 2022). When florpyrauxifen-benzyl or mixtures of the herbicide are spray-applied at 30 g ae ha^{-1}, greater than 98% control of yellow nutsedge was achieved, likely due to adequate foliar interception of the herbicide. However, coating florpyrauxifen-benzyl or mixtures of the herbicide on urea never achieved enough plant interception to provide greater than 76% yellow nutsedge control [19].

Coating florpyrauxifen-benzyl on urea to control large (~25-cm) rice flatsedge

An application method difference in rice flatsedge control was observed at the 4 and 5 WAT rating timing. Even though the application methods elicited differences in rice flatsedge control with coating on urea applications providing less control than sprayed applications, coated on urea treatments still provided 95% or greater rice flatsedge control at 4 and 5 WAT. A significant interaction between herbicide and application method in rice flatsedge control was observed at the rice heading. Even though florpyrauxifen-benzyl and the addition of penoxsulam coated on urea provided 98% and 99% rice flatsedge control, respectively, those control levels were statistically lower than the complete control provided from either spray application.

At 4 WAT, a significant interaction for yellow nutsedge control was observed between the herbicide and application method (Table 5). Florpyrauxifen-benzyl and the mixture containing penoxsulam spray-applied both provided 97% yellow nutsedge control. No significant interaction for yellow nutsedge control was observed between herbicide and application method at 5 WAT, but each factor elicited a significant response. Between herbicides, florpyrauxifen-benzyl alone provided only 77% yellow nutsedge control; adding penoxsulam to florpyrauxifen-benzyl increased yellow nutsedge control to 91% at 5 WAT. Similarly, spraying treatments containing florpyrauxifen-benzyl provided 97% yellow nutsedge control, while coated-on urea treatments only provided 53% control. It is well established that when fewer herbicide particles are intercepted by plant foliage, and there are no concentrated droplets, there is a reduction in the efficacy of most postemergence sprays (Norsworthy et al. 1999). With urea prills likely causing less foliar interception by the herbicide, a problematic weed, such as yellow nutsedge, would be harder to control than a spray application. Based on these results, yellow nutsedge was not controlled as effectively with the coated-on urea application compared to the sprayed applications.

No herbicide, application method, or interaction was better than the other at controlling ducksalad and California arrowhead when evaluated at rice heading. Hence, the foliar interception effect explained in the previous experiment following applications of florpyrauxifen-benzyl coated on urea where rice flatsedge control increased compared to sprayed applications was not observed in this experiment. As outlined in Table 1, this experiment had a dense distribution of emerged rice flatsedge and yellow nutsedge. This dense weed population likely affected the initial herbicide-coated prill-to-soil contact [20].

Table 4: Effects of herbicide, application method, and year on visible estimates of weed control in rice following spray-applied and coated on urea herbicide applications.[abcdefg]

		Control												
		Rice flatsedge							Yellow nutsedge				Ducksalad	
Source		4 WAT		5 WAT		Heading	Heading		4 WAT		5 WAT		5 WAT	
		-------------------------%-------------------------												
Herbicide	FPB	99		99		97	65		94		93	B	85	
	FPB+P	100		98		99	69		93		94	A	91	
	P-value	0.5281		0.7418		0	0.6103		0.9965		0.7654		0.3072	
Method	Spray	100	A	99	A	99	81	A	98	A	99	A	75	B
	Coated	97	B	97	B	96	50	B	76	B	73	B	94	A
	P-value	<0.0001*		0.0008*		0	0.0003*		0.0027*		0.0030*		0.0136*	
Herbicide* method	FPB*Spray	100		100		99	82		99		99		74	
	FPB*Coated	96		97		90	44		67		60		92	
	FPB+P*Spray	100		99		99	80		98		98		77	
	FPB+P*Coated	98		98		97	55		83		84		97	
	P-value	0.5145		0.0889		0.0043*	0.4013		0.2048		0.1544		0.4714	

[a]Applications of florpyrauxifen-benzyl at 30 g ae ha^{-1} and a mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1} were targeted ~10-cm tall rice flatsedge

[b]Heading evaluations took at 50% rice heading

[c]Abbreviations: WAT, weeks after treatment; FPB, florpyrauxifen-benzyl; FPB+P, florpyrauxifen-benzyl + penoxsulam

[d]Means within the same column and source not containing the same letter are different according to Tukey's HSD (α=0.05)

[e]P-values followed by * are significant (P<0.05)

[f]Rice flatsedge and California arrowhead control is reported for 2020 and 2021

[g]Yellow nutsedge and ducksalad control is only reported for 2021

Table 5: Effects of herbicide, application method, and year on visible estimates of weed control in rice following spray-applied and coated on urea herbicide applications.[abcdefg]

		Control						
		Rice flatsedge			California arrowhead	Yellow nutsedge		Ducksalad
Source		4 WAT	5 WAT	Heading	Heading	4 WAT	5 WAT	Heading
		---------------------%	----------------------------					
Herbicide	FPB	98	98	99	88	84	77 B	79
	FPB+P	99	99	99	91	92	91 A	68
	P-value	0.5546	0.6567	0.8059	0.4025	0.0183	0.0144*	0.05
Method	Spray	100 A	100 A	100	88	97	97 A	77
	Coated	96 B	95 B	98	91	63	53 B	70
	P-value	0.0002	<0.0001*	<0.0001	0.4863	<0.0001	0.0001*	0.14
Herbicide* method	FPB*Spray	100	100	100 A	86	97 A	96	84
	FPB*Coated	94	93	98 B	90	42 C	33	72
	FPB+P*Spray	100	100	100 A	90	97 A	97	68
	FPB+P*Coated	97	99	99 B	91	80 B	72	69
	P-value	0.5149	0.4002	0.0371*	0.7333	0.0194*	0.1053	0.1

[a]Applications of florpyrauxifen-benzyl at 30 g ae ha^{-1} and a mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} and penoxsulam at 41 g ai ha^{-1} were targeted ~25-cm tall rice flatsedge

[b]Heading evaluations took at 50% rice heading

[c]Abbreviations: WAT, weeks after treatment; FPB, florpyrauxifen-benzyl; FPB+P, florpyrauxifen-benzyl + penoxsulam

[d]Means within the same column and source not containing the same letter are different according to Tukey's HSD (α=0.05)

[e]P-values followed by * are significant (P<0.05)

[f]Rice flatsedge and California arrowhead control is reported for 2020 and 2021

[g]Yellow nutsedge and ducksalad control is only reported for 2021

Conclusions

Findings from these experiments indicate that coating florpyrauxifen-benzyl at 30 g ae ha^{-1} or a mixture of florpyrauxifen-benzyl at 24 g ae ha^{-1} plus penoxsulam at 41 g ai ha^{-1} on urea has value as an alternative application to control rice weeds. Preflood applications of either herbicide treatment coated on urea provided control of rice flatsedge, hemp sesbania, and ducksalad comparable to spray applications like results produced by Miller and Norsworthy (2018). Similarly, adding penoxsulam to florpyrauxifen-benzyl provided an additional herbicide site-of-action to control susceptible barnyardgrass accessions when coated on urea. However, florpyrauxifen-benzyl alone coated on urea did not adequately control barnyardgrass, indicating the need for overlapping early-season residual herbicides with this application option. Consistent, effective yellow nutsedge control should not be expected following the application of florpyrauxifen-benzyl coated on urea, especially as weeds increase in size (~25 cm). It is recommended that florpyrauxifen-benzyl coated on urea be applied postflood (Anonymous 2021). The proposed recommendation should include applications at the pre-flood timing as many aerial N applications occur before flooding, or florpyrauxifen-benzyl should be evaluated on potash. The fertilizer could be more easily applied postflood, but different results may be expected. The results from this research lead to the conclusion that coating florpyrauxifen-benzyl or a mixture of florpyrauxifen-benzyl and penoxsulam onto urea at labeled rates offers potential for control of some weeds evaluated here but unlikely to provide consistent, effective control of barnyardgrass. Weed spectrum and size will largely impact whether applications of florpyrauxifen-benzyl coated on urea are successful. Additional research should be conducted to evaluate the off-target movement potential of this application method.

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Nomenclature

florpyrauxifen-benzyl; penoxsulam; barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv.; California arrowhead, *Sagittaria montevidensis* Cham. & Schltdl; ducksalad, *Heteranthera limosa* (Sw.) Willd.; hemp sesbania, *Sesbania herbacea* (Mill.) McVaughn; rice flatsedge, *Cyperus iria* L.; yellow nutsedge, *Cyperus esculentus* L.; rice, Oryza sativa L.; soybean, *Glycine max* (L.) Merr.

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