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Short title: Fluridone evaluation in rice

Rice tolerance to fluridone at different application timings and in mixtures with commonly used herbicides

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Abstract

Introducing new herbicides requires a comprehensive understanding of how crops respond to various herbicide-related factors. Fluridone was registered for rice production in 2023, but research on rice tolerance to this herbicide is lacking. Hence, field research aimed to 1) evaluate the effect of fluridone application timing on rice tolerance and 2) assess rice response to fluridone in a mixture with standard rice herbicides applied to three-leaf rice. Both experiments were conducted in a delay-flooded dry-seeded system using a randomized complete block design, with four replications. Treatments in the first experiment included a nontreated control and ten application timings, ranging from 20 days preplant to postflood. The second experiment had a two-factor factorial structure, with factor A being the presence/absence of fluridone, and factor B being herbicide partners, including bispyribac-sodium, fenoxaprop, penoxsulam, propanil, quinclorac, quizalofop, and saflufenacil. In the first experiment, the maximum injury in 2022 was 28%, caused by the preemergence (PRE) treatment. In 2023, fluridone applied preemergence caused the greatest injury (42%) two weeks after flood establishment, declining to 37% late-season (thirteen days before rice reached 50% heading). Yield reductions of 21% occurred with the delayed-preemergence (DPRE) treatment in 2022 and 42% with the PRE treatment in 2023. Mixing fluridone with standard herbicides increased rice injury by no more than eight percentage points compared to the herbicides alone. Additionally, no adverse effects on rice groundcover or grain yield resulted from fluridone in the mixture. These results indicate a need to avoid fluridone applications near planting because of negative impacts on rice. Furthermore, fluridone can be mixed with commonly used rice herbicides, offering minimal risk to rice.

Nomenclature: bispyribac-sodium; fenoxaprop; fluridone; penoxsulam; propanil; quinclorac; quizalofop; saflufenacil; rice, *Oryza sativa* L.

Keywords: crop response to herbicides; rice injury; herbicide partners

Introduction

Fluridone is classified as a group 12 herbicide by the Herbicide Resistance Action Committee and Weed Science Society of America and was launched for rice use in 2023 by SePRO Corporation (Anonymous 2023). Fluridone is the first herbicide belonging to group 12 to be registered for rice, offering a promising option to complement rice weed control programs. Fluridone controls a broad spectrum of weeds by inhibiting the phytoene desaturase enzyme, which prevents the formation of carotenoids, ultimately resulting in plant bleaching and death (Bartels and Watson 1978; Chamovitz et al. 1991; Sandmann et al. 1991). Fluridone is a residual herbicide in cotton (*Gossypium hirsutum* L.) production in the United States and several studies highlight its effectiveness and safety on the crop (Banks and Merkle 1979; Grichar et al. 2020; Hill et al. 2016; Waldrep and Taylor 1976). However, due to its recent release, limited research has explored its safety on rice.

Research has demonstrated that fluridone should be applied with postemergence herbicides, as fluridone will not control weeds that have emerged before treatment (Anonymous et al. 2023; Hill et al. 2016; King et al. 2024; Waldrep and Taylor 1976). Herbicide mixtures broaden the spectrum of control and/or enhance the management of resistant biotypes by incorporating distinct sites of action that effectively control the target weed species (Dhanda et al. 2023; Hydrick and Shaw 1994; Miller and Norsworthy 2018; Zhang et al. 1995). While herbicide mixtures may not eliminate the need for multiple applications, they decrease the frequency of such applications by providing improved control and reducing total costs. Furthermore, using multiple sites of action in a spray mixture helps prevent the evolution of target-site resistance to herbicides (Diggle et al. 2023; Norsworthy et al. 2012).

The success of herbicide mixtures partly depends on the interaction between products. When two or more herbicides are combined, the interaction can be additive, synergistic, or antagonistic, significantly influencing weed control efficacy and crop response (Colby 1967; Zhang et al. 1995). For instance, a mixture of quizalofop with propanil, imazethapyr, bispyribac-sodium, or penoxsulam resulted in an antagonistic effect on a barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] biotype resistant to propanil and quinclorac (Lancaster et al. 2019). Additionally, mixtures of imazethapyr with varying rates of propanil resulted in antagonistic interactions for barnyardgrass and hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] control,

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but synergistic effects for red rice (*Oryza sativa* L.) (Webster et al. 2018). In addition to weed control effects, herbicide mixtures can increase crop phytotoxicity (Barbieri et al. 2022). Thus, prior knowledge of potential interactions and effects on target weed species and crop tolerance is foundational when applying herbicide mixtures.

The growth stage at the time of application is another critical factor influencing crop tolerance to herbicides. Bond and Walker (2011) observed delayed rice maturity and reduced grain yield when imazamox was applied 14 days after panicle initiation or at the boot stage compared to applications at panicle initiation. Zhang et al. (2005) reported that microencapsulated clomazone caused more bleaching in rice when applied preplant incorporated or as a delayed-preemergence treatment than when applied preemergence.

The current fluridone label prohibits applications before the three-leaf stage in rice (Anonymous 2023). Although fluridone was recently labeled for use in rice, little to no literature addresses the optimal application timing of this herbicide in the crop. Additionally, no research has explored fluridone mixtures with standard rice herbicides. Therefore, this study aimed to evaluate rice tolerance to fluridone at various application timings and in combination with commonly used rice herbicides.

Materials and Methods

Application Timing Experiment

A field experiment was conducted in the 2022 and 2023 growing seasons at the Rice Research and Extension Center near Stuttgart, AR (34.465556° N, 91.400833° W). The soil was a Dewitt silt loam (19% sand, 64% silt, and 17% clay) with a pH of 5.7 and 1.2% organic matter. The cultivar PVL02 was planted at 72 seeds m^{-1} of row and a 1.3 cm depth using a small-plot drill with rows spaced 19 cm on May 20, 2022, and May 2, 2023. Before the experimental setup, conventional tillage was used for seedbed preparation in both years. Plots were 1.8 m by 5.2 m. The experiment was a randomized complete block design with four replications, with treatments consisting of fluridone at 168 g ai ha^{-1} (label rate) applied at ten application timings. The application timings were 20 and 10 days (± 2) preplant, preemergence (PRE) on the day of planting, delayed-preemergence (DPRE) within six days after planting, one-leaf, two-leaf, three-leaf, four-leaf, tillering, and postflood (one to two days after flood establishment). The plots

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treated postflood were in individual bays to avoid herbicide dispersion across plots. A treatment without fluridone (nontreated control) was included for comparison.

The fields were maintained free of weeds using quinclorac (Facet®L, BASF, Research Triangle Park, NC) on the planting date in both years and hand-weeded when needed to prevent being impacted by factors other than the treatments. Quizalofop (Provisia®, BASF, Research Triangle Park, NC) and bentazon (Basagran®, UPL Limited, King of Prussia, PA) with 1% (v/v) crop oil concentrate (Crop Oil Concentrate, Helena Chemical Company, Collierville, TN) were applied when the rice reached the two-leaf growth stage in 2023. All herbicides were applied using a CO_2-pressurized backpack sprayer equipped with four AIXR 110015 nozzles (TeeJet Technologies, Spraying Systems Co., Glendale Heights, IL), calibrated to deliver 140 L ha^{-1} at a speed of 4.8 kph. Agronomic practices and fertility followed the University of Arkansas System Division of Agriculture guidelines for direct-seeded, delayed-flood rice production (Henry et al. 2021; Roberts et al. 2016). Rice emergence and flood establishment occurred on May 26 and June 22, respectively, in 2022 and on May 11 and May 31, respectively, in 2023. A nearby weather station monitored rainfall events and air temperature in both years (Figure 1).

Tank-Mixture Experiment

A field experiment was initiated in 2022 and repeated in the 2023 and 2024 growing seasons at the Pine Tree Research Station (PTRS) near Colt, AR (35.120833° N, 90.957222° W) on a Calhoun silt loam soil with 1.4% organic matter and pH of 8, 8.1, and 7.7, respectively. In 2024, an additional location was established at the University of Arkansas Pine Bluff (UAPB) Small Farm Outreach Center near Lonoke, AR (34.783333° N, 91.881944° W) on an Immanuel silt loam (14% sand, 72% silt, 14% clay), with 1.3% organic matter and a pH of 5.4. The experiment was designed to assess rice tolerance to fluridone alone or in a mixture with commonly used rice herbicides applied at the three-leaf growth stage over a range of environments. Rice was seeded at a 1.3-cm depth with a spacing of 19 cm between each row, following conventional tillage in all sites. Plots were 1.8 and 1.5 m wide by 5.2 and 7.6 m long at PTRS and UAPB, respectively. The cultivar RTv7231 MA was planted in all locations at 52 seeds m^{-1} of row on May 12, 2022, April 11, 2023, and April 18, 2024, at PTRS and on May 16, 2024, at UAPB.

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The experiment was a randomized complete block design with a two-factor factorial treatment structure and four replications. Factor A was the presence or absence of fluridone. Factor B consisted of herbicide partners mixed with or without fluridone, including fenoxaprop, quizalofop, propanil, saflufenacil, penoxsulam, bispyribac-sodium, and quinclorac (Table 1). Rice received the treatments at the three-leaf growth stage. Experimental fields were over-sprayed with a preemergence application of clomazone (Command® 3ME, FMC Corporation, Philadelphia, PA) at 336 g ai ha^{-1} and a preflood application of quizalofop (Highcard®, ADAMA, Raleigh, NC) at 120 g ai ha^{-1} to keep the fields free of weeds. Halosulfuron + prosulfuron (Gambit®, Gowan Company, Yuma, AZ), halosulfuron (Permit®, Gowan Company, Yuma, AZ), or florpyrauxifen-benzyl (Loyant®, Corteva Agriscience, Indianapolis, IN) were used if needed for broadleaf and sedge spp. control. All herbicide applications were made with a CO_2-pressurized backpack sprayer equipped with four AIXR 110015 nozzles (TeeJet Technologies, Spraying Systems Co., Glendale Heights, IL) calibrated to deliver 140 L ha^{-1} at a speed of 4.8 kph at PTRS and with a multiboom, tractor-mounted sprayer equipped with AIXR 110015 nozzles delivering 94 L ha^{-1} at 6.4 kph at UAPB. Agronomic practices and fertility followed the University of Arkansas System Division of Agriculture guidelines for direct-seeded, delayed-flood rice production (Henry et al. 2021; Roberts et al. 2016). A nearby weather station monitored air temperature and daily rainfall (Figure 2).

Data Collection

Visible crop injury was evaluated on a scale of 0 to 100, with 0 being no injury and 100 representing crop death (Frans et al. 1986) at preflood, 2 weeks after flooding (WAF), and late-season (5 and 13 thirteen days before rice reaching 50% heading across treatments in 2022 and 2023, respectively) in the application timing experiment and at 2 and 4 weeks after treatment (WAT) in the herbicide mixture experiment. Aerial images were taken at 6 WAF at RREC and 4 WAT at PTRS using a small unmanned aerial system [DJI Mavic Air 2S (DJI Technology Co., LTD., Nanshan, Shenzhen, China)] from a height of approximately 60 m in 2022, with an image covering twelve plots in width and four plots in length. In 2023, images were captured from a height of 30 m, covering nine plots in width and four plots in length. In 2024, stitched images were collected from a height of approximately 40 m. The groundcover percentage for each plot was quantified by green pixel counts from overhead images using Field Analyzer (Green

Research Services, LLC., Fayetteville, AR). Groundcover data were not collected at UAPB. Shoot density and days to 50% heading were assessed only in the application timing experiment. Shoot density was collected in two 1-m sections of row per plot at 3 and 2 weeks after rice emergence in 2022 and 2023, respectively, on all soil-applied treatments (20 and 10 days preplant, PRE, and DPRE) and the nontreated control. Days for rice to reach 50% heading were recorded for each plot and reported relative to the nontreated control. Rough rice grain yield was harvested from the center four rows of all plots using a small-plot combine and adjusted to 12% moisture.

Data Analysis

Data were analyzed using R statistical software (v. 4.3.3; R Core Team 2023). A generalized linear mixed model was fit to all data using the *glmmTMB* function (GLMMTMB package; Brooks et al. 2017). Assumptions of normality were assessed using the Shapiro-Wilk and Levene's tests. Beta (injury and groundcover) and negative binomial (rough rice yield) distributions were used if the data did not meet the assumptions of normality (Gbur et al. 2012; Stroup 2015).

In the application timing experiment, application timing and year were considered fixed effects and block a random effect. The mixture experiment aimed to evaluate rice tolerance to commonly used herbicides alone or in combination with fluridone across various environments. Therefore, site-year and block nested within site-year were considered random effects. Fluridone presence/absence and herbicide partners were treated as fixed effects.

All data were subjected to a Type III Wald chi-squares analysis of variance using the CAR package (Fox and Weisberg 2019). Following this analysis, treatment-estimated marginal means were assessed using the EMMEANS package (Lenth 2022; Searle et al. 1980) and adjusted for multiple comparisons using Tukey's honestly significant difference (α =0.05). Differences among treatments were visualized through a compact letter display, created with the *multcomp:cld* function (Hothorn et al. 2008).

Results and Discussion

Application Timing Experiment

The interaction between year and application timing was significant ($P < 0.05$) for all variables evaluated in the application timing experiment. Therefore, all data in this experiment were analyzed by year. Rainfall accumulation at the experimental sites totaled 65 mm and 149 mm from 20 days before the preplant application to planting in 2022 and 2023, respectively (Figure 1). Visible rice injury in 2022 was less than 5% for all treatments before flood establishment and as much as 28% at the final evaluation (Table 2). In 2023, up to 30% injury was observed before flood establishment and up to 42% at 2 WAF. By the final evaluation, no treatment caused more than 14% injury to rice, except for the PRE treatment, which resulted in 37% injury in 2023.

Fluridone has low water solubility, and its adsorption coefficient (K_{oc}) ranges from 350 to 2,460 mL/g, depending on organic matter content, soil texture, and pH (Banks et al. 1979; Malik and Drennan 1990; Schroeder and Banks 1986; Shaner 2014; Shea and Weber 1983; Waldrep and Taylor 1976; Weber et al. 1986). After adhering to soil sediments, fluridone gradually desorbs into the water (Shaner 2014). Previous research indicates that fluridone availability increases following irrigation, resulting in increased rice injury (Butts et al. 2024; Martin et al. 2024). Likewise, the elevated phytotoxicity in the preflood assessment in 2023 compared to 2022 is likely associated with the higher moisture content from rainfall accumulation. Furthermore, Martin et al. (2018) reported that injury to rice from fluridone increases with flood establishment. In the present study, an increase in injury following the establishment of the flood was observed for only a few treatments in both years by 2 WAF, whereas the final evaluation in 2022 showed an increase of up to 27 percentage points compared to the preflood assessment.

A similar trend occurred in both years, with applications near planting generally causing more injury to rice (Table 2). Previous research reported comparable results, where fluridone applied PRE caused more injury to rice than applications at the three-leaf growth stage in an herbicide program containing clomazone and/or florpyrauxifen-benzyl (King et al. 2024). Reduced injury with later fluridone applications is attributed to diminished postemergence activity, resulting in greater rice tolerance (Waldrep and Taylor 1976).

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Shoot density was assessed one week before the preflood evaluation (3 and 2 weeks after emergence in 2022 and 2023, respectively). Although injury levels at this evaluation differed between years, no difference in shoot density was detected among treatments in either year, indicating that fluridone did not cause stand loss early in the season (Table 3). However, fluridone applied PRE, DPRE, and at the 1-leaf stage in 2022 and PRE and DPRE in 2023 reduced rice groundcover by 6 WAF. Rice groundcover is a predictor of grain yield (Wan et al. 2019). Therefore, a reduction in groundcover is likely to result in a yield penalty. Other research has shown that rice treated with fluridone at the three-leaf stage in a precision-leveled field had a groundcover reduction at six and eight weeks after treatment, but the crop recovered by ten weeks after application (Butts et al. 2024). However, a previous study indicated that rice cultivars respond differently to fluridone (Souza et al. 2025). In the same study, the cultivar DG263L exhibited reduced chlorophyll content and yield reduction at the labeled rate of 168 g ai ha^{-1} when treated at the three-leaf stage, while most of the other cultivars did not experience reduced yield, emphasizing the importance of selecting tolerant cultivars when using fluridone for weed management in rice.

A delay in rice maturity, as indicated by the 50% heading date, was no more than four days relative to the nontreated control in both years (Table 2). In 2022, rice in the postflood treatment reached 50% heading two days earlier than the nontreated control. The treatments PRE and DPRE caused similar levels of rice injury, groundcover reduction, and maturity delay in 2022. However, only the DPRE application caused a yield penalty, with a 21% reduction compared to the control. Furthermore, no statistical difference was detected among the nontreated, PRE, and one-leaf treatments in 2022; however, the yield difference between DPRE and either PRE or one-leaf was 190 kg ha^{-1} or less. In 2023, the high injury levels associated with decreased rice groundcover and a delay in heading resulted in a 42% yield loss to rice treated at PRE compared to the control. Although the DPRE application caused injury of up to 23% and reduced rice groundcover, no yield loss resulted from this treatment in 2023, and further research is needed to understand rice response when treated with fluridone DPRE. Similarly to the results of this study, a rough rice yield reduction of 20% occurred following PRE fluridone at 224 g ai ha^{-1} on Dewitt and Calhoun silt loam soils (Martin et al. 2018). As seen here, fluridone applied to three-leaf rice at the same rate on a precision-leveled Sharkey-Steele

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clay soil did not cause a yield decrease, even though almost 30% visible injury resulted after herbicide treatment (Butts et al. 2024).

Herbicide Partners Experiment

There was an interaction between fluridone and herbicide partners for visible injury at 2 and 4 WAT (Table 4). Saflufenacil, with and without fluridone, generally caused the most injury (up to 23%) at 2 WAT. By 4 WAT, there was no more than 14% injury, and only rice in the saflufenacil-containing treatments had ≥10% injury. Similarly, saflufenacil plus imazethapyr applied to two- to three-leaf imazethapyr-resistant rice caused 16% to 50% injury 2 WAT (Camargo et al. 2012). When applied alone to four- and six-leaf rice, saflufenacil caused no more than 14% injury by 18 days after treatment (Camargo et al. 2011). In the present study, adding fluridone to the standard rice herbicides seldom caused an increase in rice injury, and even when elevated injury occurred, the increase was no more than eight percentage points.

For groundcover and rough rice yield, only the main effect of herbicide partner was significant (Table 5). Therefore, data were pooled over the main effect of fluridone presence or absence. Rice treated with saflufenacil displayed the greatest groundcover reduction besides bispyribac-sodium at 4 WAT. Saflufenacil was the only treatment that resulted in a yield penalty.

Practical Implications

According to the results of this study, fluridone applications from the three-leaf or later stages of rice are suitable to cause minimal rice injury, as indicated by the label (Anonymous 2023). Although postflood applications are not permitted, fluridone caused no more than 3% visible injury when applied at this time and appears to pose minimal risk for rice. Fluridone applied near planting, especially PRE and DPRE was too injurious to rice, similar to results from previous research (King et al. 2024; Martin et al. 2018). Further research is necessary to evaluate the influence of early-season fluridone applications in a furrow irrigation system on rice response, as rice in this system is grown under non-flooded conditions in most of the field, with a frequent water supply. Furthermore, using fluridone in mixtures with standard rice herbicides poses little to no risk of crop injury, and it does not negatively affect groundcover or grain yield. Hence, fluridone can be safely applied with other postemergence herbicides to enhance weed control in rice.

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Competing Interests

The authors declare none.

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Table 1. Herbicides used in the tank-mixture experiment conducted at the Pine Tree Research Station, near Colt, AR, and at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, AR in 2022, 2023, and 2024.[a,b]

Herbicide	Rate	Trade Name	Manufacturer
	g ai ha^{-1}		
Bispyribac-sodium	32	Regiment	Valent, San Ramon, CA
Fenoxaprop	122	Ricestar®HT	Bayer CropScience, St. Louis, MO
Fluridone	168	Brake®	SePRO Corporation, Carmel, IN
Penoxsulam	40	Grasp® SC	Corteva Agriscience, Indianapolis, IN
Propanil	4,490	Stam® M4	UPL Limited, King of Prussia, PA
Quinclorac	565	Facet® L	BASF Corporation, Research Triangle, NC
Quizalofop	120	Highcard®	ADAMA, Raleigh, NC
Saflufenacil	50	Sharpen®	BASF Corporation, Research Triangle, NC

[a] Crop oil concentrate at 1% (v/v) was added in applications with penoxsulam, quinclorac, quizalofop, and saflufenacil.

[b] Oil-based adjuvant (Dyne-A-Pak; Helena Chemical Co., Collierville, TN) was added at 2.5% (v/v) in applications with bispyribac-sodium.

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Table 2. Visible rice injury following fluridone treatment for the application timing experiment at the Rice Research and Extension Center, near Stuttgart, AR in 2022 and 2023.[a,b,c,d,e,f,g]

	2022						2023					
Application timing	Preflood		2 WAF		Late-season		Preflood		2 WAF		Late-season	
	--%--											
20 days preplant	3	ab	3	cd	11	cd	7	c	6	bc	4	b
10 days preplant	4	a	5	bcd	10	cd	16	b	20	ab	14	ab
PRE	1	abc	16	a	28	a	30	a	42	a	37	a
DPRE	2	abc	12	ab	25	ab	21	ab	23	ab	6	b
One-leaf	2	abc	7	abc	21	abc	14	bc	14	abc	12	ab
Two-leaf	1	abc	5	bcd	13	bcd	15	bc	8	bc	6	b
Three-leaf	0	bc	4	cd	15	abcd	15	bc	7	bc	5	b
Four-leaf	0	bc	4	cd	8	d	11	bc	14	abc	5	b
Tillering	-	-	1	d	7	d	-	-	24	ab	9	ab
Postflood	-	-	3	cd	1	e	-	-	2	c	3	b
P-value	0.0006		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	

[a] Abbreviations: DPRE, delayed-preemergence; PRE, preemergence; WAF, weeks after flooding.

[b] Fluridone was applied at 168 g ai ha^{-1} in all treatments besides the nontreated control.

[c] Postflood treatments were applied one and two days after flood establishment in 2022 and 2023, respectively.

[d] Preflood evaluations were assessed on the day of flood establishment in 2022 and two days after flood establishment in 2023.

[e] Late-season evaluations were assessed 5 and 13 days prior to rice reaching 50% heading across treatments in 2022 and 2023, respectively.

[f] Hyphens (-) indicate the treatments have not been applied at the time of evaluation.

[g] Means within a column followed by the same letter are not different according to Tukey HSD ($\alpha = 0.05$).

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Table 3. Rice shoot density, groundcover, and rough rice yield following fluridone treatment for the application timing experiment at the Rice Research and Extension Center, near Stuttgart, AR in 2022 and 2023.[a,b,c,d,e,f,g]

Application timing	Shoot density		Groundcover				Heading				Rough rice yield			
	2022	2023	2022		2023		2022		2023		2022		2023	
	plants m^{-1}		-----------%-----------				days delayed				-------------kg ha^{-1}-------------			
Nontreated control	38	49	100	a	99	a	*		*		9,720	abc	8,355	a
20 days preplant	36	47	100	a	99	a	1	ab	0	b	9,045	abcd	8,505	a
10 days preplant	32	46	100	a	99	a	0	ab	3	ab	9,300	abcd	9,030	a
PRE	38	42	95	c	83	c	3	a	4	a	7,860	cd	4,860	b
DPRE	35	43	96	c	94	b	2	a	2	ab	7,670	d	8,460	a
One-leaf	-	-	99	b	99	a	1	ab	1	ab	7,830	cd	8,475	a
Two-leaf	-	-	100	a	99	a	1	ab	0	b	8,240	bcd	6,690	ab
Three-leaf	-	-	100	a	99	a	1	ab	0	b	8,270	bcd	8,790	a
Four-leaf	-	-	100	a	99	a	1	ab	2	ab	9,410	abcd	8,325	a
Tillering	-	-	100	a	99	a	1	ab	2	ab	9,950	ab	7,470	a
Postflood	-	-	100	a	100	a	-2	b	0	b	10,910	a	6,960	ab
P-value	0.1499	0.1567	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		0.0012	

[a] Abbreviations: DPRE, delayed-preemergence; PRE, preemergence

[b] Groundcover was assessed six weeks after flood establishment (9 and 20 days before rice reaching 50% heading across treatments in 2022 and 2023, respectively).

[c] Shoot density was assessed 3 and 2 weeks after rice emergence in 2022 and 2023 for the soil-applied treatments and the nontreated control.

[d] Fluridone was applied at 168 g ai ha^{-1} in all treatments besides the nontreated control.

[e] Postflood treatments were applied one and two days after flood establishment in 2022 and 2023, respectively.

[f] Hyphens (-) indicate shoot density was not assessed.

[g] Asterisks (*) represent nontreated control delay in heading as zero.

[h] Means within a column followed by the same letter are not different according to Tukey HSD ($\alpha = 0.05$).

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Table 4. Visible rice injury following herbicide applications alone (-) or with fluridone (+) for the tank-mixture experiment, averaged over four total site-years at the Pine Tree Research Station, near Colt, AR, and at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, AR in 2022, 2023, and 2024.[a,b]

Fluridone	Herbicide partner	2 WAT		4 WAT	
		-----------------	%	------------------	
-	None	2	e	1	g
+	None	7	bcd	6	bcd
-	Bispyribac-sodium	5	bcde	5	bcde
+	Bispyribac-sodium	11	abc	6	bcd
-	Fenoxaprop	5	bcde	3	cdefg
+	Fenoxaprop	9	bcd	6	bcd
-	Penoxsulam	5	bcde	2	fg
+	Penoxsulam	8	bcd	7	bc
-	Propanil	4	de	3	cdefg
+	Propanil	12	ab	6	bcd
-	Quinclorac	5	bcde	3	cdefg
+	Quinclorac	8	bcd	4	cdef
-	Quizalofop	4	de	2	fg
+	Quizalofop	9	bcd	5	bcde
-	Saflufenacil	21	a	10	ab
+	Saflufenacil	23	a	14	a
P-values					
Fluridone		0.0051		0.1338	
Herbicide partner		<0.0001		<0.0001	
Fluridone × Herbicide partner		0.0147		0.0023	

[a] Abbreviations: WAT, weeks after treatment.

[b] Means within a column followed by the same letter are not different according to Tukey HSD (α = 0.05).

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Table 5. Rice groundcover and rough rice yield following herbicide partner treatments for the tank-mixture experiment, averaged over site-years and fluridone tank-mixture inclusion at the Pine Tree Research Station, near Colt, AR, and at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, AR in 2022, 2023, and 2024.[a,b,c]

Herbicide partner	Groundcover		Rough rice yield	
	%		kg ha^{-1}	
None	97	a	11,140	ab
Bispyribac-sodium	96	ab	11,350	ab
Fenoxaprop	98	a	11,420	a
Penoxsulam	97	a	11,350	ab
Propanil	97	a	10,870	ab
Quinclorac	98	a	11,430	a
Quizalofop	97	a	11,010	ab
Saflufenacil	94	b	10,380	b
P-values				
Fluridone	0.3109		0.7036	
Herbicide Partner	0.0028		0.0061	
Fluridone × Herbicide partner	0.6454		0.1273	

[a] Groundcover was assessed four weeks after treatment.

[b] Groundcover was not assessed at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, AR.

[c] Means within a column followed by the same letter are not different according to Tukey HSD (α = 0.05).

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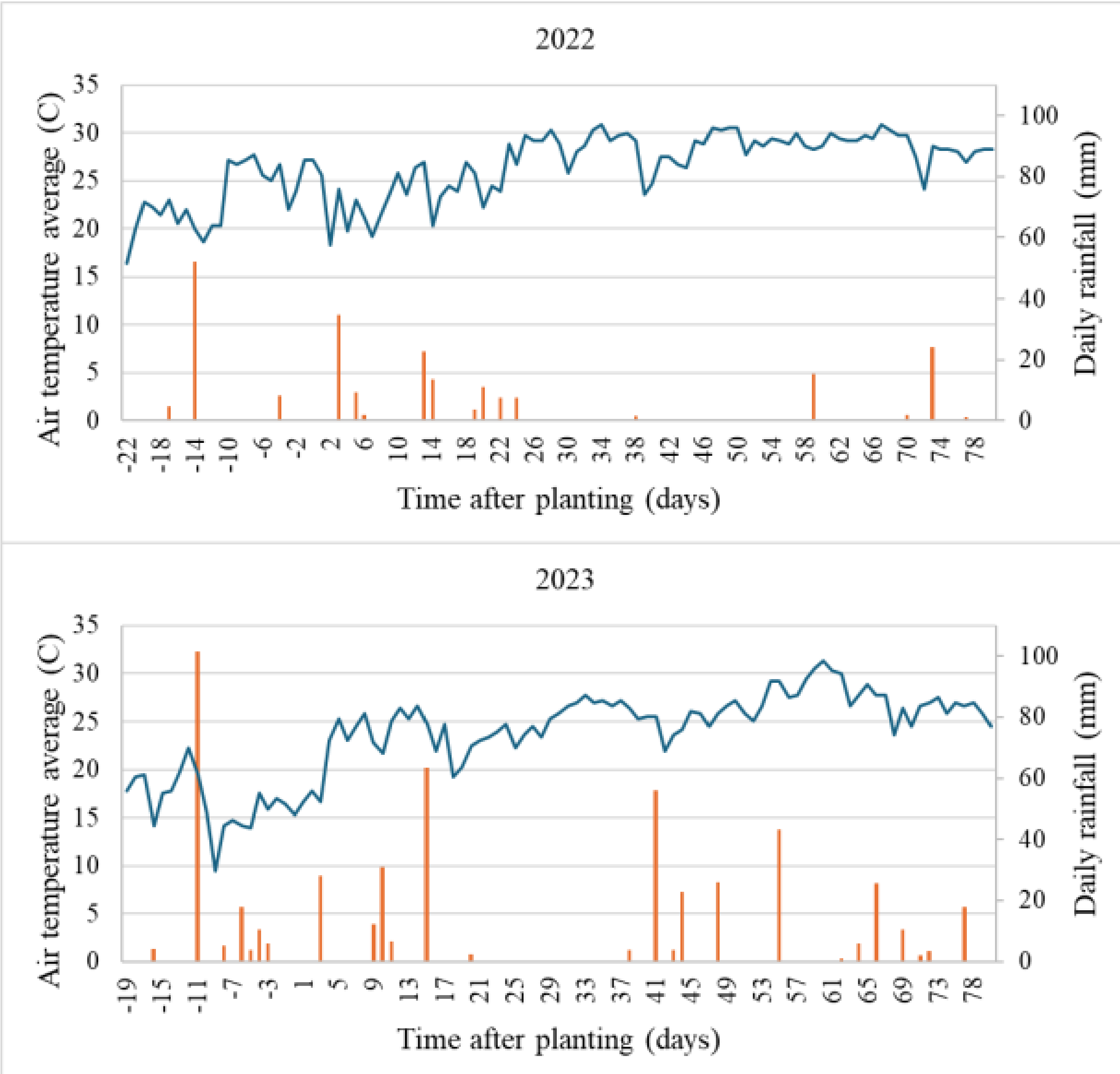

Figure 1. Daily results of observed average air temperature (C) and rainfall events (mm) over 24 hours, from the planting until the last injury assessment at the Rice Research and Extension Center, near Stuttgart, AR, in 2022 and 2023. Planting occurred on day zero. The blue line represents the daily average air temperature, and the orange bars indicate daily rainfall.

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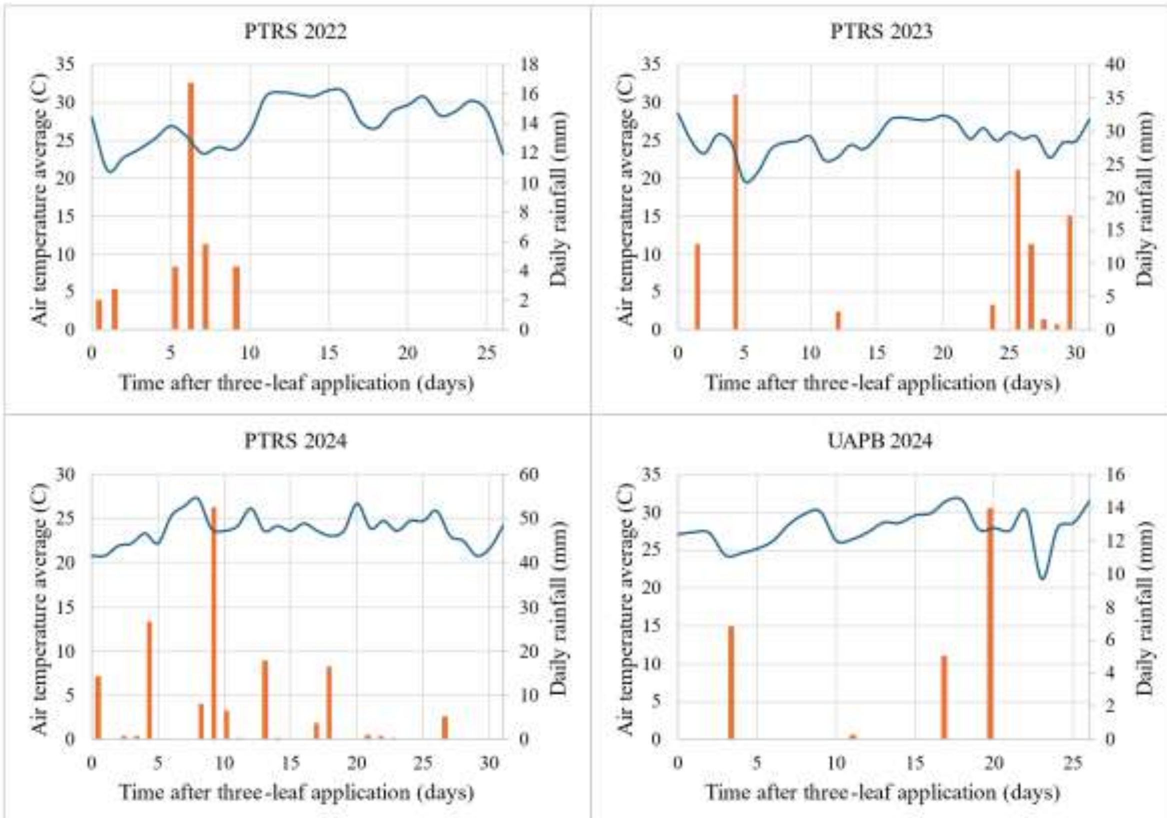

Figure 2. Daily results of observed average air temperature (C) and rainfall events (mm) over 24 hours, from the three-leaf application until the last injury assessment at the Pine Tree Research Station (PTRS), near Colt, AR, in 2022, 2023, and 2024, and at the University of Arkansas Pine Bluff Small Farm Outreach Center (UAPB) near Lonoke, AR in 2024. The blue line represents the daily average air temperature, and the orange bars indicate daily rainfall.

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