Weed Technology

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Research Article

Cite this article: Avent TH, Norsworthy JK, Butts TR, Roberts TL, Bateman NR (2022) Evaluation of rice tolerance and weed control with acetochlor and fenclorim. Weed Technol. **36**: 844–850. doi: 10.1017/wet.2022.93

Received: 12 August 2022
Revised: 28 November 2022
Accepted: 1 December 2022
First published online: 3 January 2023

Associate Editor:
Eric Webster, Louisiana State University AgCenter

Nomenclature:
Acetochlor; fenclorim; barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv; weedy rice, *Oryza sativa* L.; rice, *Oryza sativa* L.

Keywords:
Herbicide-tolerance; chloroacetamide; safener; weed control; application timing; microencapsulation

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Evaluation of rice tolerance and weed control with acetochlor and fenclorim

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Abstract

Many problematic weeds have evolved resistance to herbicides in mid-southern U.S. rice fields. With the lack of new effective herbicides, rice producers seek alternatives that are currently not labeled for rice production. Inhibitors of very-long chain fatty acid elongase (VLCFA) are currently not labeled for use with U.S. rice crops but are labeled for use in other U.S. row cropping systems and rice production in Asia. Previous research has demonstrated the utility of VLCFA inhibitors for weed control in rice; however, these herbicides induce variable amounts of injury to the crop when applied early in the growing season. Experiments were initiated in 2020 and 2021 at the Rice Research and Extension Center near Stuttgart, AR, to evaluate rice tolerance and weed control with acetochlor and seed treatment with a herbicide safener, fenclorim. Three rates of a microencapsulated formulation of acetochlor (630, 1,260, and 1,890 g ai ha^{-1}), four application timings (preemergence, PRE; delayed-preemergence, DPRE; spiking; and 1-leaf), and without or with the fenclorim seed treatment (2.5 g kg^{-1} of seed) were used to evaluate rice tolerance, weedy rice control, and barnyardgrass control. Acetochlor applied DPRE at 1,260 g ai ha^{-1} provided better weedy rice and barnyardgrass control than applications at the 1-leaf stage at the same rate. Acetochlor rates of 1,260 and 1,890 g ai ha^{-1} reduced barnyardgrass and weedy rice densities by more greater than the 630 g ai ha^{-1} rate. The fenclorim seed treatment did not influence weedy rice or barnyardgrass control but did reduce injury for DPRE acetochlor applications. Based on these results, acetochlor can be safely applied to rice DPRE (≤19% injury) at 1,260 g ai ha^{-1} when the seed is treated with fenclorim, leading to ≥88% barnyardgrass and ≥45% weedy rice control 28 d after treatment.

Introduction

Rice is one of the most consumed grains globally, and within the United States, Arkansas is the leading rice producer (USDA-FAS 2021). Arguably one of the most limiting factors for rice production in Arkansas is weed control. The availability of only a few sites of action (SOAs) that herbicides can affect in rice plants limits producers and has led to some problematic weeds developing herbicide resistance to many of the commonly used modes of action (Barber et al. 2020; Heap 2022).

Two of the most problematic weeds for rice producers to control are barnyardgrass and weedy rice (Butts et al. 2022). Barnyardgrass has developed resistance to five different SOAs across the mid-southern United States. In Arkansas, barnyardgrass has developed resistance to propanil (a photosystem II inhibitor); quinclorac (a synthetic auxin); clomazone (an inhibitor of 1-deoxy-D-xylulose-5-phosphate synthase); imazethapyr, penoxsulam, and bispyribac-sodium (inhibitors of acetolactate synthase; ALS); and fenoxaprop-ethyl, cyhalofop-butyl, and quizalofop-P (inhibitors of acetyl CoA carboxylase; Barber et al 2020; Heap 2022; Hwang et al. 2022; Lovelace et al. 2007; Talbert and Burgos 2007). Without the previously mentioned herbicides, rice producers have only a select few options for controlling barnyardgrass, indicating the need for an alternative SOA (Barber et al. 2020).

The third-most problematic weed of rice, weedy rice, is resistant to only one known SOA (Heap 2022). Furthermore, because weedy rice and cultivated rice are the same species, weedy rice is tolerant to the same herbicides as cultivated rice (Barber et al. 2020). Therefore, to control resistant populations of weedy rice, growers must use either water-seeded practices with thiobencarb (Group 8 lipid synthesis inhibitors as categorized by the Weed Science Society of America) or quizalofop-P-resistant (Provisia; BASF, Research Triangle Park, NC or Max-

Ace; RiceTec, Inc, Alvin, TX) rice, which uses the active ingredient quizalofop-P (Barber et al. 2020; Lancaster 2017). Most Arkansas rice producers plant drill-seeded rice, and cannot use thiobencarb to control weedy rice (Hardke 2021). Additionally, with quizalofop-P-resistant rice, the potential for outcrossing to weedy rice has already been demonstrated with imidazolinone-resistant rice technology (Burgos et al. 2008; Gealy et al. 2015; Shivrain et al. 2007). Thus, mid-southern U.S. rice producers need an alternative method for controlling weedy rice within a nontransgenic, drill-seeded production system.

Currently, herbicides that inhibit very long-chained fatty acid elongase (VLCFA) are not labeled for U.S. rice production, but rice production systems in Asia use pretilachlor, a VLCFA not labeled for use in the United States (Chen et al. 2013; Quadranti and Ebner 1983). Herbicides that inhibit VLCFA disrupt the biosynthesis of saturated and unsaturated fatty acids longer than 18 carbons in length (Babczinski et al. 2012). These fatty acids are important for various lipids, particularly the lipids that facilitate cell division, which are needed in root and shoot growth of emerging seedlings. Additionally, VLCFA-inhibiting herbicides provide residual control of grasses and small-seeded broadleaf weeds but offer little to no control of emerged weeds (Anonymous 2018; Barber et al. 2020).

The use of acetochlor, another chloroacetamide herbicide more efficacious than pretilachlor, can provide weed control in rice production systems (Fogleman 2018; Godwin 2017; Norsworthy et al. 2019). Godwin (2017) demonstrated that acetochlor applied at delayed-preemergence (DPRE) provided significantly better weed control than later applications. However, VLCFA inhibitors such as acetochlor are water-activated residual herbicides, and earlier applications also posed an increased risk to injure rice (Babczinski et al. 2012; Fogleman et al. 2019).

Fogleman et al. (2019) concluded that an emulsifiable concentrate (EC) formulation versus a microencapsulated (ME) formulation elicited significantly greater rice phytotoxicity than the ME formulation. The decrease in rice injury with the ME formulation was due to the controlled release of the active ingredient, which distributes the soil concentration of the herbicide over time rather than being immediately available for uptake (Bernards et al. 2006; Dowler et al. 1999). However, high variability in rice tolerance with ME acetochlor has also resulted in unacceptable crop injury (Fogleman et al. 2019; Godwin et al. 2018). The need for a secondary enhancement for rice tolerance to chloroacetamides drove the consideration of including a herbicide safener as a seed treatment.

Fenclorim, the seed safener, works in several ways to reduce the phytotoxicity of chloroacetamides in rice. Fenclorim reduces total uptake and persistence of pretilachlor and increases glutathione-*S*-transferase (GST) enzyme activity, the primary pathway by which rice metabolizes pretilachlor (Chen et al. 2013; Scarponi et al. 2003, 2005; Usui et al. 2001). While the aforementioned studies have demonstrated the effects of foliar or seeds soaked in fenclorim, previous research has demonstrated the ability of a fenclorim seed treatment to reduce acetochlor injury in rice (Avent et al. 2020). Although the fenclorim seed treatment did not provide adequate crop tolerance to EC acetochlor, fenclorim at 2.5 g kg^{-1} of seed provided acceptable crop tolerance to the ME acetochlor formulation at 1,260 g ai ha^{-1}.

Because current research has not demonstrated rice tolerance and weed control with acetochlor and a commercial fenclorim seed treatment, experiments were conducted to determine the influence of a fenclorim seed treatment with various application timings and acetochlor rates. The objectives of this study were to evaluate barnyardgrass and weedy rice control as well as rice tolerance. In consideration of previous research, the hypotheses for this experiment were that earlier application timings and increasing rates of acetochlor would increase weed control, and the fenclorim seed treatment would not influence weed control but would reduce rice injury from acetochlor.

Materials and Methods

Experimental Design

The experiment was designed as a randomized complete block with a three-factor factorial treatment structure with four replications. The three factors were fenclorim seed treatments of 0 and 2.5 g kg^{-1} of seed; ME acetochlor applications at preemergence (PRE), DPRE, spiking and 1-leaf; at PRE, delayed-PRE (DPRE), spiking, and 1-leaf rice; and three rates of acetochlor at 630, 1,260, and 1,890 g ai ha^{-1}. Rice with both fenclorim rates were planted with no herbicides applied to allow for comparisons for a total of 26 treatments. The experiment was initiated in spring 2020 and 2021 at the Rice Research and Extension Center (RREC) near Stuttgart, AR, on a Dewitt silt loam composed of 27.1% sand, 54.4% silt, and 18.5% clay; pH 5.6; and 1.8% organic matter. Each study was managed based on University of Arkansas Cooperative Extension Services recommendations for direct-seeded, delayed-flooded rice production. Soil fertility was amended preplant and based on University of Arkansas System Division of Agriculture Marianna Soil Test and Research Laboratory recommendations with no preplant nitrogen. The research area was cultivated before trial initiation to remove any emerged weeds and produce a fine seedbed. Urea (46-0-0) was applied at 316 kg ha^{-1} before flooding the entire field.

The rice cultivar 'Diamond' was planted at 72 seeds m^{-1} row on May 11, 2020, and April 28, 2021, with a base seed treatment of clothianidin, carboxin, thiram, metalaxyl, fludioxonil, and gibberillins at 0.75, 0.38, 0.33, 0.16, 0.03, and 0.04 g ai kg^{-1} of seed, respectively. Plots were 1.5 m wide and 5.2 m long, with 1.5 m between plots in each block and 0.9 m between each block. Nine rows of rice were planted on 19-cm row spacings to a 1.5-cm depth. PRE herbicides were applied the day of planting, and DPRE applications of acetochlor were made after the rice seed had germinated but before emergence (4 and 7 dafter planting for 2020 and 2021, respectively). Herbicides were also applied at the spiking and 1-leaf rice stages (Table 1). All herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPA and 4.8 kph with four AIXR 110015 nozzles (TeeJet, Glendale Heights, IL) spaced 51 cm apart.

Data Collection and Analysis

Rainfall data were collected from the RREC weather station (TE525 rain gauge; Texas Electronics, Inc, Dallas, TX). Rice phytotoxicity was visually evaluated relative to the nontreated control 14, 21, and 28 d after treatment (DAT) ±3 d on a 0% to 100% scale, with 0% representing no injury and 100% being plant death (Frans and Talbert 1977). Additionally, barnyardgrass and weedy rice control were visually evaluated relative to the nontreated control 14, 21, and 28 DAT from 0% to 100%, with 0% representing no control and 100% representing no weeds present (Frans and Talbert 1977). Quantitative assessments included densities of weedy rice and barnyardgrass from two randomly established 0.25-m^2 quadrats per plot, counted 28 d after rice emergence. Yield data were not

https://doi.org/10.1017/wet.2022.93 Published online by Cambridge University Press

Table 1. Dates for cultural management practices, herbicide applications, and total rainfall from planting until flooding.[a,b]

Year	Planting/PRE	DPRE	Spiking	1-Leaf	Flooding	Harvest	Rainfall
2020	May 11	May 14	May 21	May 25	June 11	September 29	24.3
2021	Apr. 28	May 6	May 12	May 15	June 12	November 2	38.0

[a]Abbreviations: DPRE, delayed-preemergence; PRE, preemergence.
[b]Rainfall data were measured in centimeters and collected from a weather station located at the Rice Research and Extension Center.

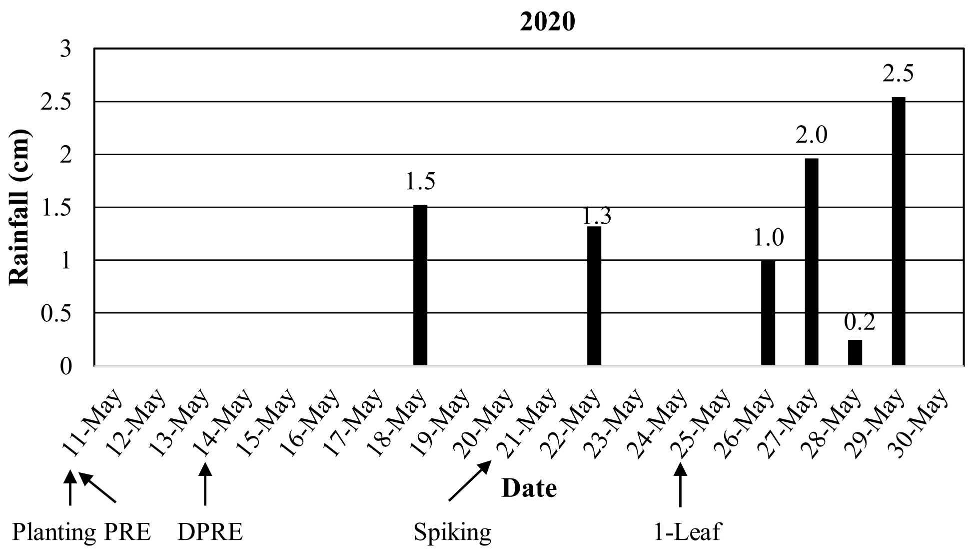

Figure 1. Rainfall amount each day associated with planting and herbicide applications at the Rice Research and Extension Center near Stuttgart, AR, in 2020 totaling 8.5 cm of rain. Rainfall data were collected from a weather station located at the Rice Research and Extension Center. Abbreviations: DPRE, delayed-preemergence; PRE, preemergence.

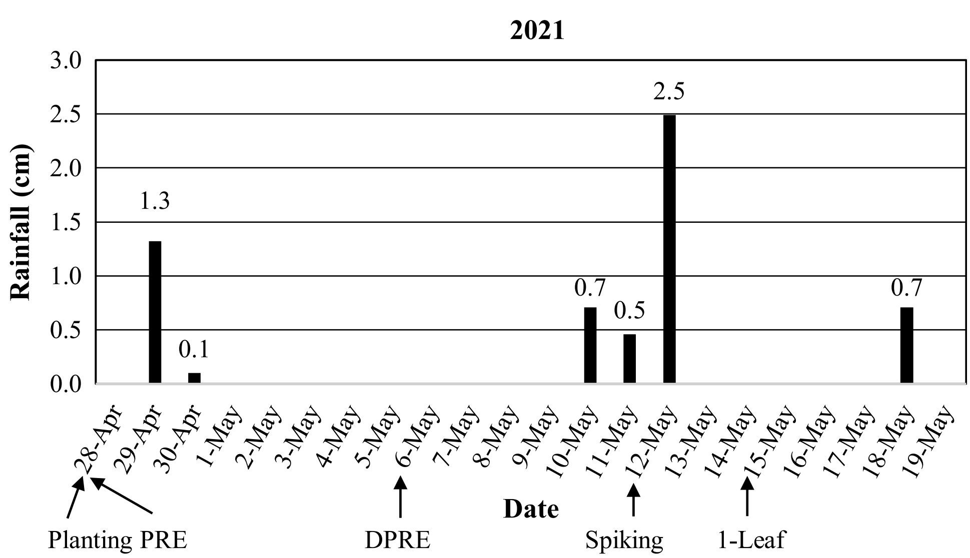

Figure 2. Rainfall amounts each day in associated with planting and herbicide applications at the Rice Research and Extension Center near Stuttgart, AR, in 2021 totaling 5.8 cm of rain. Rainfall data were collected from a weather station located at the Rice Research and Extension Center. Abbreviations: DPRE, delayed-preemergence; PRE, preemergence.

included due to the lack of postemergence weedy rice and barnyardgrass control. At crop maturity, the majority of plots had lodged.

All data distributions were checked using JMP pro software version 16.1 (SAS Institute Inc, Cary, NC) and found to be gamma-distributed. Data distribution selections were based on best fit using least log-likelihood and Akaike information criterion. Data were analyzed by year due to herbicide activation from rainfall (Figures 1 and 2). Because evaluations of injury and weed control occurred 7 d apart for 3 wk and evaluations showed increases or decreases, an ANOVA with repeated measures was used to determine the differences between treatments and evaluation timings. An unstructured covariance structure was selected for repeated measures analysis based on the model of best fit. All other

Table 2. Influence of application timing, evaluation timing, and fenclorim seed treatment on rice injury.[a–d]

		Injury					
		2020			2021		
Timing	Fenclorim	14 DAT	21 DAT	28 DAT	14 DAT	21 DAT	28 DAT
		%					
PRE	Without	40 A	42 A	47 A	85 A	72 A	91 A
	With	17 BC	17 B	16 CD	62 B	64 AB	85 A
DPRE	Without	33 A	39 A	39 A	45 C	59 B	65 B
	With	13 CD	15 B	15 D	16 D	22 C	22 E
Spiking	Without	17 BC	15 B	27 B	3 E	20 CD	49 C
	With	5 D	5 C	15 D	2 E	18 CD	23 E
1-Leaf	Without	22 B	20 B	25 BC	4 E	14 CD	35 D
	With	16 BC	13 BC	13 D	2 E	8 D	25 DE
P-value		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
RM P-value			0.6025			0.0892	

[a]Abbreviations: DAT, days after treatment; DPRE, delayed-preemergence; PRE, preemergence; RM, repeated measures.
[b]Means within a column for the fenclorim by timing interaction not containing the same letter are different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using the GLIMMIX procedure without repeated measures using SAS software version 9.4 with a gamma distribution.
[d]RM P-values were generated using the GLIMMIX procedure with repeated measures using SAS software version 9.4 with a gamma distribution.

data were subjected to ANOVA. All data were analyzed using SAS software version 9.4 with the GLIMMIX procedure with a gamma distribution (Gbur et al. 2012). Means were separated using Tukey's honestly significant difference test with α = 0.05.

Results and Discussion

Rice Injury

In the absence of fenclorim averaged over acetochlor rates, rice tolerance to the herbicide generally increased in 2020 and 2021 as application timing was delayed (Table 2). The increased tolerance with delayed acetochlor application timing was highly evident in 2021 when 85% injury was observed at 14 DAT following a PRE application of acetochlor in the absence of fenclorim and only 3% to 4% injury occurred following applications at the spiking and 1-leaf stages, respectively. At 14 DAT, averaged over acetochlor rate, and without fenclorim, rice injury in 2020 and 2021 decreased from 33% and 45% (DPRE) to 17% and 3% (spiking), and from 22% and 4% (1-leaf), respectively (Table 2). In similar studies with acetochlor applied at 1,050 g ai ha^{-1}, injury decreased as application timing was delayed (Godwin et al. 2018). In addition, Godwin et al. (2018) reported that in 2016 at 14 DAT, injury was 89% following DPRE, 43% following spiking, and 10% following an application of acetochlor at the 1- to 2-leaf stage. The excessive injury following the DPRE-applied acetochlor was attributed to a rainfall of 10 cm that occurred 4 DAT (Godwin et al. 2018), emphasizing the variability of acetochlor activity based on activation timing (Babczinski et al. 2012). In other research with quizalofop-P-resistant rice, injury at 14 d following a DPRE application of ME acetochlor increased from 51% at a rate of 1,050 g ai ha^{-1} to 73% following 1,470 g ai ha^{-1}, respectively (Norsworthy et al. 2019). Similarly, in 2020 and 2021 at 28 DAT, averaged over herbicide application timing, and without fenclorim, injury 28 DAT increased from 33% to 53% and from 66% to 79% following acetochlor applied at 1,260 and 1,890 g ai ha^{-1} in 2020 and 2021, respectively (Table 3).

Emerging crops and weeds uptake acetochlor through roots and shoots shortly after germination. Activation and incorporation of acetochlor typically requires at least 1.3 cm of rainfall or irrigation (Anonymous 2018; Babczinski et al. 2012). In 2020, rice was planted into adequate moisture to allow for germination, but an activating rainfall did not occur until 7 d after the PRE application (Figure 1). In 2021, the PRE application was activated by rainfall the next day (Figure 2), resulting in increased rice injury and weed control. Additionally, the fenclorim seed treatment did not statistically improve tolerance at 21 and 28 DAT for PRE applications of acetochlor in 2021 (Table 2). The lack of substantial safening is likely a function of the activation timing of the herbicide. Conversely, fenclorim reduced injury for DPRE applications of acetochlor averaged over herbicide rate by 29 to 43 percentage points in 2021.

When evaluating the uptake and conjugation of fenclorim and pretilachlor in rice shoots, previous research has reported that fenclorim uptake did not occur until 48 h after treatment, and pretilachlor uptake occurred 24 h after treatment (Scarponi et al. 2003). Additionally, GST activity for fenclorim-treated rice did not statistically separate from the nontreated control until 48 h after treatment, and a reduction in pretilachlor persistence from fenclorim-treated shoots was not observed until 72 h after treatment. Therefore, applications of acetochlor should be delayed until rice seeds have sprouted, and PRE applications of acetochlor should be avoided to allow the seed treatment to provide a safening effect.

A reduction in rice injury was observed at all evaluation timings with the addition of fenclorim for PRE applications in 2020 averaged over herbicide rate (Table 2). Rice was planted into moist soil and germinated prior to the first activating rainfall event, which likely contributed to the enhanced tolerance in 2020 versus the greater injury observed in 2021 following the PRE-applied acetochlor. In general, the fenclorim seed treatment reduced injury for all applications of acetochlor occurring earlier than the 1-leaf stage. The lack of a safening response for the 1-leaf applications of acetochlor is likely due to fenclorim no longer improving conjugation of a chloroacetamide herbicide by 5 DAT (Scarponi et al. 2003). However, Scarponi and others evaluated foliar-applied fenclorim. The persistence and uptake of fenclorim as a seed treatment has not been studied and GST activity could be prolonged, which may explain why safening can still be observed for acetochlor applied at spiking.

It is important to note that in 2020, <20% rice injury was observed with the fenclorim seed treatment when acetochlor was applied at 630 and 1,260 g ai ha^{-1} at all application timings and evaluations (Table 3). However, in 2021, rice injury caused by PRE-applied acetochlor ranged from 37% to 91% with the fenclorim seed treatment (data not presented). Additionally, in 2021, <20% rice injury was observed with the fenclorim seed treatment and 630 and 1,260 g ai ha^{-1} acetochlor applied at DPRE or later

Table 3. Influence of acetochlor rate, evaluation timing, and fenclorim seed treatment on rice injury.[a–c]

		Injury					
		2020			2021		
Rate	Fenclorim	14 DAT	21 DAT	28 DAT	14 DAT	21 DAT	28 DAT
g ai ha^{-1}		%					
630	Without	17 FGH	17 FGH	18 FG	25 GHIJ	31 E-H	35 EFG
	With	6 I	8 I	9 HI	16 J	20 IJ	24 G-J
1,260	Without	29 CDE	30 CD	33 BC	37 EF	42 DE	66 B
	With	12 GHI	12 GHI	13 GHI	22 HIJ	27 F-I	38 E
1,890	Without	39 B	40 B	53 A	40 E	51 CD	79 A
	With	20 EFG	19 FG	23 DEF	24 HIJ	37 EF	54 C
RM P-value		0.0159			<0.0001		

[a]Abbreviations: DAT, days after treatment; DPRE, delayed-preemergence; PRE, preemergence; RM, repeated measures.
[b]Means within a year for the fenclorim by herbicide timing interaction not containing the same letter are different according to Tukey's honestly significant difference test (α = 0.05).
[c]RM P-values were generated using the GLIMMIX procedure with repeated measures using SAS software version 9.4 with a gamma distribution.

Table 4. Influence of application timing, acetochlor rate, and evaluation timing on barnyardgrass control in rice.[a–c]

		Barnyardgrass control					
		2020			2021		
Timing	Rate	14 DAT	21 DAT	28 DAT	14 DAT	21 DAT	28 DAT
	g ai ha^{-1}	%					
PRE	630	87 AB	82 ABC	73 A-F	75 A-D	83 ABC	91 AB
	1,260	91 A	83 ABC	84 ABC	86 ABC	92 AB	95 A
	1,890	94 A	86 AB	88 AB	95 AB	95 AB	98 A
DPRE	630	77 A-D	72 A-F	75 A-F	33 EFG	80 ABC	69 BCD
	1,260	93 A	88 AB	89 AB	47 C-F	96 A	88 AB
	1,890	92 A	90 A	87 AB	69 A-D	98 A	95 A
Spiking	630	51 FG	50 GF	52 D-G	15 HI	14 I	38 EF
	1,260	69 A-F	69 A-F	59 B-F	53 B-C	74 A-D	74 A-D
	1,890	80 ABC	80 ABC	83 ABC	52 B-C	70 A-D	89 AB
1-Leaf	630	19 I	26 HI	36 GH	19 HIJ	24 GH	35 EF
	1,260	56 C-F	59 B-F	51 EFG	24 FGH	22 GH	66 BCD
	1,890	77 A-D	77 A-D	63 A-F	44 DEF	44 DEF	73 A-D
	RM P-value	0.0042			< 0.0001		

[a]Abbreviations: DAT, days after treatment; DPRE, delayed-preemergence; PRE, preemergence; RM, repeated measures.
[b]Means within a year not containing the same letter are different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using the GLIMMIX procedure with repeated measures using SAS software version 9.4 with a gamma distribution.

(data not presented). Therefore, PRE-applied acetochlor and rates greater than 1,260 g ai ha^{-1} should be discouraged if the use of fenclorim and acetochlor becomes registered in U.S. rice production systems.

In general, rice injury from acetochlor at 630 g ai ha^{-1} averaged over application timing and the fenclorim seed treatment did not increase as evaluation timings progressed from 14 to 28 DAT; however, applications of 1,260 g ai ha^{-1} in 2021 and 1,890 g ai ha^{-1} for both years showed an increase in injury from 14 to 28 DAT (Table 3). Because injury did not decrease as evaluation timings progressed, the evaluations may not have continued long enough to capture the recovery of rice from acetochlor injury. Future studies should consider continuing evaluations further into the growing season.

Weed Control

Acetochlor applied DPRE at 1,260 g ai ha^{-1} controlled barnyardgrass by 88% to 96% 21 and 28 DAT, respectively, in both years (Table 4). Similarly, control was 62% to 88% and 63% to 90% with acetochlor applied at 1,050 and 1,470 g ai ha^{-1}, respectively (Norsworthy et al. 2019). Fogleman (2018) reported barnyardgrass control of 77% and 94% averaged over DPRE applications of acetochlor at 1,050 and 1,470 g ai ha^{-1} 14 and 28 DAT, respectively. In 2020 and 2021, application of acetochlor at 630 g ai ha^{-1} at the 1-leaf stage did not achieve comparable barnyardgrass control as those of PRE and DPRE acetochlor applications at the same rate 21 and 28 DAT, indicating that as application timing delayed, barnyardgrass control decreased. Furthermore, no rate of acetochlor applied at the 1-leaf timing controlled barnyardgrass by 80%, whereas DPRE applications of acetochlor at 1,260 g ai ha^{-1} achieved ≥88% barnyardgrass control 21 and 28 DAT. The reduction in control with delayed application timings is attributed to the emergence of barnyardgrass prior to the acetochlor treatment. Acetochlor providing primarily residual weed control is well documented (Babczinski et al. 2012).

In 2020 and 2021, weedy rice control trended similarly to that of barnyardgrass control (Table 5). As application timing was delayed and as rates decreased, weedy rice control generally decreased. PRE and DPRE applications of acetochlor at 1,260 g ai ha^{-1}, averaged over presence and absence of fenclorim, provided better weedy rice control than acetochlor applied at spiking and 1-leaf stages at the same rate 28 DAT. Additionally, the lowest rate of acetochlor did

Table 5. Influence of application timing, acetochlor rate, and evaluation timing on weedy rice control in rice.[a–d]

		Weedy rice control					
		2020			2021		
Timing	Rate	14 DAT	21 DAT	28 DAT	14 DAT	21 DAT	28 DAT
	g ai ha^{-1}	%					
PRE	630	22	22	18 D	49	50	50 EF
	1,260	39	41	48 B	66	70	65 C
	1,890	52	56	73 A	81	75	79 AB
DPRE	630	22	23	24 CD	21	38	49 EF
	1,260	38	46	45 B	29	62	69 BC
	1,890	37	58	76 A	49	76	83 A
Spiking	630	21	15	11 D	4	10	23 G
	1,260	39	26	20 CD	26	32	55 DE
	1,890	42	43	49 B	23	31	69 BC
1-Leaf	630	22	22	23 CD	0	11	22 G
	1,260	26	28	24 CD	12	14	37 F
	1,890	41	40	38 BC	23	24	44 EF
	P-value	0.2069	0.1479	< 0.0001	0.1412	0.0512	0.0025
	RM P-value	0.4974			0.1781		

[a]Abbreviations: DAT, days after treatment; DPRE, delayed-preemergence; PRE, preemergence; RM, repeated measures.
[b]Means within an evaluation timing not containing the same letter are different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using the GLIMMIX procedure with repeated measures using SAS software version 9.4 with a gamma distribution.[d]RM P-values were generated using the GLIMMIX procedure with repeated measures using SAS software version 9.4 with a gamma distribution.

Table 6. Influence of herbicide application timing and acetochlor rate on barnyardgrass and weedy rice densities evaluated 28 d after emergence.[a–e]

Weed densities				
	2020		2021	
Factor	Barnyardgrass	Weedy rice	Barnyardgrass	Weedy rice
Herbicide timing	% of nontreated			
PRE	13 B	43 C	4 D	55 B
DPRE	16 B	34 D	17 C	30 C
Spiking	17 B	63 B	25 B	72 A
1-Leaf	29 A	113 A	28 A	58 B
P-value	0.0002	< 0.0001	< 0.0001	< 0.0001
Herbicide rate g ai ha^{-1}				
630	32 A	73 A	27 A	64 A
1,260	15 B	56 B	13 B	47 B
1,890	12 B	45 B	12 B	44 B
P-value	< 0.0001	< 0.0001	< 0.0001	0.0003

[a]Abbreviations: DPRE, delayed-preemergence; PRE, preemergence.
[b]Average barnyardgrass densities in the nontreated were 19 and 26 m^{-2} for 2020 and 2021, respectively.
[c]Average weedy rice densities in the nontreated were 19 and 21 m^{-2} for 2020 and 2021, respectively.
[d]Means within a column for each factor level not containing the same letter are different according to Tukey's honestly significant difference test (α = 0.05).
[e]P-values were generated using the GLIMMIX procedure using SAS software version 9.4 with a gamma distribution.

not achieve comparable weedy rice control as the highest rate of acetochlor 28 DAT for each application timing in both years. In previous research, weedy rice control was better with DPRE-applied acetochlor, averaged over acetochlor rates, than control with applications at the 1- to 2-leaf stages (Fogleman 2018).

Relative barnyardgrass and weedy rice densities trended similarly to visually estimated control. For both years, acetochlor at 1,260 and 1,890 g ai ha^{-1} provided a greater reduction in barnyardgrass and weedy rice densities 28 d after emergence averaged over application timing and fenclorim (Table 6). Applications of acetochlor at the DPRE timing reduced weedy rice and barnyardgrass densities greater than 1-leaf applications averaged over acetochlor rate and fenclorim. The optimum timing of acetochlor applications for improved weedy rice and barnyardgrass control with reduced injury appears to be at the DPRE timing, which coincides with reports by Fogleman (2018) and Norsworthy et al. (2019).

For all barnyardgrass and weedy rice evaluations, there was never a significant main effect of fenclorim or interaction with the other factors ($P > 0.05$). These results would indicate that fenclorim aids rice protection and does not negatively affect the level of weed control provided by acetochlor. Originally, fenclorim was used with pretilachlor in spray solution (Quadranti and Ebner 1983). Broadcast applications of fenclorim could potentially reduce weed control by providing enhanced metabolism of chloroacetamides. Field studies conducted in 2021 demonstrated a 10% to 20% reduction in broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster] control when fenclorim was added to spray solution with acetochlor at 1,260 g ai ha^{-1} (J.K. Norsworthy et al., unpublished data). However, with the application of fenclorim as a seed treatment, the herbicide safener is directly placed in-furrow, where only cultivated rice receives enhanced tolerance to acetochlor.

Practical Implications

Based on previous and current research, applications of acetochlor at 1,050 to 1,260 g ai ha^{-1} can provide adequate control of barnyardgrass and suppression of weedy rice (Fogleman 2018; Norsworthy et al. 2019). If labeled, the addition of acetochlor to current rice herbicide programs would provide residual barnyardgrass control, including control of populations known to be resistant to the PRE-applied herbicides clomazone and quinclorac. Furthermore, acetochlor would also provide some weedy rice suppression to aid postemergence applications in imidazolinone-resistant or quizalofop-P-resistant rice. Reducing the number and size of weeds present at the time of postemergence applications would reduce selection pressure and prolong the efficacy of the current herbicide options available to rice producers.

In general, greater levels of rice injury and weed control were observed for PRE and DPRE acetochlor applications in 2021 compared with 2020 due to the adverse growing conditions with greater total rainfall and earlier activation of the PRE applications (Table 1). However, rice injury was <20% for DPRE applications of acetochlor at 1,260 g ai ha^{-1} or less with the fenclorim seed treatment (data not presented). Other PRE herbicides such as clomazone can bleach rice by up to 35% without causing any yield loss (Zhang et al. 2005). Based on visual estimates of weed control, weed densities, and visual estimates of crop injury, the optimal application timing and rate for acetochlor in these trials was 1,260 g ai ha^{-1} applied DPRE with fenclorim-treated rice seed at 2.5 g kg-seed^{-1}. For this treatment at 28 DAT, acetochlor controlled weedy rice by 45% to 69% and barnyardgrass by 88% to 89% (Tables 4 and 5). Acetochlor at the same rate and timing caused as much as 74% injury in the absence of the fenclorim seed treatment. In comparison, adding the fenclorim seed treatment reduced rice injury to no more than 19%. Current research with acetochlor and fenclorim has been conducted predominately on silt loam soils, which encompass only 50% of Arkansas rice hectares (Hardke 2021). Future studies should consider a rate response of acetochlor on different textured soils since acetochlor activity is negatively correlated with clay content (Reinhardt and Nel 1990).

Acknowledgments. Funding for this research was provided by UPL Ltd. And the Arkansas Rice Research and Promotion Board. Additionally, we are grateful to UPL Ltd. for providing the fenclorim seed treatment and the University of Arkansas System Division of Agriculture, the Pine Tree Research Station personnel, and the Rice Research and Extension Center personnel for their facilitation of this research. No conflicts of interest have been declared.

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