Advances in Crop Science and Technology

Martin et al., Adv Crop Sci Tech 2018, 6:2
DOI: 10.4172/2329-8863.1000351

Research Article | Open Access

Effect of Thiamethoxam on Injurious Herbicides in Rice

Martin SM[1*], Norsworthy JK[1], Scott RC[2], Hardke J[3], Lorenz GM[4] and Gbur E[5]

[1]*Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR 72704, USA*

[2]*Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Lonoke, AR 72086, USA*

[3]*Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Stuttgart, AR 72160, USA*

[4]*Department of Entomology, University of Arkansas, Lonoke, AR 72086, USA*

[5]*Agricultural Statistics Laboratory, University of Arkansas, Fayetteville, AR 72703, USA*

[*]**Corresponding author:** Martin SM, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR 72704, USA, Tel: 8708537696; E-mail: steven_martin2010@yahoo.com

Received date: March 01, 2018; **Accepted date:** April 02, 2018; **Published date:** April 09, 2018

Abstract

Increases in the number of herbicide-resistant weeds in rice has led to the need for new herbicides and modes of action to control these troublesome weeds. Previous research has indicated that insecticide seed treatments can safen rice from herbicide drift. In 2014 and 2015, two field experiments were conducted at the Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and at the University of Arkansas Pine Bluff (UAPB) farm near Lonoke, Arkansas, to determine if insecticide seed treatments could prevent unacceptable levels of herbicide injury from preemergence (PRE)- and postemergence (POST)-applied herbicides that are typically injurious to rice. Both studies were planted with the imidazolinone-resistant, inbred variety CL151. 'Treated' plots contained the insecticide seed treatment thiamethoxam while 'nontreated' plots contained no insecticide seed treatment. Seven herbicides were evaluated in the PRE experiment: clomazone, pethoxamid, fluridone, S-metolachlor, thiobencarb, clethodim, and quizalofop to determine crop injury, stand counts, groundcover, and rough rice yield with and without an insecticide seed treatment compared to plots with no herbicide treatments. Overall, an insecticide seed treatment provided increased rice stands and less herbicide injury than the 'nontreated' seed while increasing yield by 500 kg ha^{-1}. Of the herbicides tested, clomazone-, thiobencarb-, clethodim-, and quizalofop-treated plots had equivalent yields to the no-herbicide plots. The POST experiment evaluated propanil, saflufenacil, carfentrazone, and acifluorfen in various tank-mixtures and application timings. Similar to the PRE experiment, plants from treated seed had less herbicide injury 1 and 5 weeks after treatment (WAT) along with an increased canopy height and groundcover percentage. Plants having treated seed also had increased yields when used with some herbicide programs. Overall, the use of an insecticide seed treatment can give the added benefit of less injury from injurious herbicides as well as increased groundcover.

Keywords: Herbicide tolerance; Insecticide seed treatment; Safener

Introduction

Effectively controlling weeds is an important factor in growing a successful rice crop. Some of the most troublesome weeds in rice include barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), red rice (*Oryza sativa* L.), broadleaf signalgrass (*Urochloa platyphylla* (Nash)), Palmer amaranth (*Amaranthus palmeri* (S.) Wats.), and jointvetch (*Aeschynomene* spp.) [1]. If left uncontrolled, these weeds can cause significant yield loss in rice crops. Red rice left uncontrolled can cause up to 82% yield loss while other grasses such as barnyardgrass and broadleaf signalgrass can reduce yields up to 70 and 32%, respectively [2]. Control of barnyardgrass has been achieved through the use of propanil and imazethapyr among other herbicides [3-6]. Since the introduction of propanil and imazethapyr, resistant biotypes of barnyardgrass have evolved to both herbicides [7]. In addition, resistance to clomazone, cyhalofop, quinclorac, and fenoxaprop has been documented in rice-producing regions of the US [7]. With barnyardgrass evolving resistance to multiple modes of action, new herbicides and programs are needed.

Herbicide mixtures and programs that utilize multiple modes of action are recommended for control of troublesome weeds of rice [8]. Research has shown increases in weed control when herbicide programs or tank mixtures with multiple modes of action are used. When propanil was added to a herbicide program of two applications of imazethapyr alone, an increase of up to 31 percentage points was observed in red rice control and up to 36 percentage points in barnyardgrass control [9]. Increased barnyardgrass and broadleaf signalgrass control was also observed when quinclorac was added to an imazethapyr-alone herbicide program [10]. The addition of saflufenacil, carfentrazone, bentazon, and acifluorfen to imazethapyr can also aid in broadleaf weed control [11,12].

Additional herbicide modes of action are needed in rice, especially with the multiple resistance that is increasingly common throughout the midsouthern USA [13]. Currently, there are no WSSA group 15 herbicides labeled for use in rice. Bararpour et al. [14,15] recently screened three group 15 herbicides (acetochlor, pyroxasulfone, and S-metolachlor) for rice tolerance to POST applications. Acetochlor applied at the two- or four-leaf growth stage caused a maximum of 18% injury and did not cause any yield loss. S-metolachlor applied at the same time caused up to 35% injury and yields were inconsistent among rates and application timing [14]. Pyroxasulfone caused up to 60% injury and reduced yields. Injury also was more profound when applied to spiking rice, which led to greater yield reductions at this timing. Injury to rice from these herbicides was generally greater on a silt loam than on a clay soil [15]. Pethoxamid, another group 15 herbicide, is currently being evaluated for use in midsouthern USA rice production systems. Pethoxamid may offer another option for rice growers, with little injury depending on timing of application [16].

With the evaluation of some new herbicides for use in rice and some already registered rice herbicides causing crop injury, interactions with other pesticides need to be evaluated. Increased rice injury from propanil occurs when carbamate or organophosphate insecticides, known inhibitors of aryl acylamidase–the enzyme response for metabolizing propanil are used in mixes with propanil [17]. Other herbicides such as saflufenacil can cause injury to rice; however, there have been no reports of interactions with insecticides [18]. Also, clomazone, a common PRE herbicide used in rice, can cause injury to seedling rice plants. For example, clomazone at 340 g ai ha^{-1} can cause up to 27% injury to rice [19,20]. Like saflufenacil, little research has been conducted to determine if an insecticide seed treatment could be used to safen rice against possible injury from herbicides currently registered in-crop use or those for which tolerance is currently being evaluated. It is known that insecticide seed treatments help to lessen the injury to rice caused by drift rates of imazethapyr and glyphosate [21]. Therefore, the objective of this research was to assess whether an insecticide seed treatment would reduce crop injury caused by a 1X rate of currently registered and non-registered herbicides.

Materials and Methods

Two field experiments were conducted in 2014 and 2015, with the first experiment using herbicides applied PRE (hereafter referred to as the PRE experiment). The second experiment consisted of herbicides that were applied after rice emergence (hereafter referred to as the POST experiment).

The PRE experiment was conducted at the Rice Research and Extension Center (RREC) located near Stuttgart, AR, and the University of Arkansas Pine Bluff (UAPB) farm located near Lonoke, AR. Studies at the RREC were conducted on a Dewitt silt loam soil (Fine, smectitic, thermic Typic Albaqualfs), while the studies at UAPB were conducted on a Calhoun silt loam soil (Fine-silty, mixed, active, thermic Typic Glossaqualfs). Plot sizes at the RREC and UAPB were 1.9 by 5.2 m and 1.9 by 7.6 m, respectively. Each plot contained 10 drill rows spaced 19 cm apart and was planted with the imidazolinone-resistant, inbred variety CL 152 at 83 kg ha^{-1}. Planting and herbicide application dates are shown in Table 1. Plots were fertilized according to the University of Arkansas recommendations for both locations [22]. Plots were kept weed free throughout the growing season using the conventional POST herbicides shown in Table 2.

Location	Year	Planting date	Application date
Stuttgart, AR	2014	April 23	April 25
	2015	May 6	May 8
Lonoke, AR	2014	May 20	May 20
	2015	June 8	June 8

Table 1: Planting dates and application dates for PRE experiment.

Herbicide trade name	Herbicide common name	Rate g ha^{-1}	Manufacturer
Newpath	Imazethapyr	105 ai	BASF Corporation, Research Triangle Park, NC
Command 3 ME[a]	Clomazone	340 ai	FMC Corporation, Philadelphia, PA
Facet[a]	Quinclorac	280 ai	BASF Corporation, Research Triangle Park, NC
Ricestar HT	Fenoxaprop	123 ai	Bayer CropScience, Research Triangle Park, NC
Ultra Blazer[b]	Aciflurofen	140 ai	United Phosphorus, Inc., King of Prussia, PA
Clincher	Cyhalofop	314 ai	Dow AgroSciences LLC, Indianapolis, IN
Permit[c]	Halosulfuron	40 ai	Gowan Company, Yuma, AZ
Weedar 64	2,4-D	560 ae	Nufarm Inc., Alsip, IL

Table 2: Herbicides used to maintain weed-free plots. [a]Herbicide used only in the postemergence (POST) experiment; [b]Herbicide used only at Lonoke location; [c]Herbicide used only at Stuttgart location.

In each year at each location, the experimental design was a randomized complete block with a two-factor factorial treatment arrangement with four replications. The two factors were herbicides and seed treatments. All herbicides and rates evaluated are listed in Table 3. All insecticide-treated seed contained thiamethoxam at 1.405 mg g^{-1} of seed (referred to as "treated seed"). All seed, including the insecticide-treated seed, were treated with the fungicides azoxystrobin at 0.071 mg g^{-1} of seed, mefenoxam at 0.088 mg g^{-1} of seed, and fludioxonil at 0.015 mg g^{-1} of seed. The seed receiving only the fungicide seed treatments will be referred to as "non-treated seed." All herbicide programs for the PRE experiment were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 143 L ha^{-1} using a six-nozzle, 2.5-m spray boom, with AIXR 110015 nozzles immediately after planting.

Injury was evaluated 2, 4, and 7 weeks after emergence (WAE) on a scale of 0 to 100% compared to the non-treated check with the same seed treatment, with 0% being no injury and 100% being plant death. Rice density per meter of row was counted for each plot 2 WAE and compared to the herbicide non-treated. Rice groundcover was estimated using Sigma Scan Pro® (Systat Software, Inc., 501 Canal Blvd. Suite E, Point Richmond, CA 94804) to determine the percentage of green pixels in photographs of each plot. Photographs of each plot were taken 2, 4, and 7 WAE using a 1.8-m monopod [23]. Canopy height was also determined 6 WAE for each treatment and converted to a relative height based on the herbicide non-treated check. The center five drill rows of each plot were harvested at crop maturity using a small-plot combine, and rough rice yields were recorded. Yields were adjusted to a standard of 12% moisture.

Herbicide trade name	Herbicide common name	Rate	Manufacturer
		g ae or ai ha^{-1}	
Command	Clomazone	673	FMC Corporation, Philadelphia, PA
Pethoxamid	Pethoxamid	560	FMC Corporation, Philadelphia, PA
Brake	Fluridone	224	SePro, Carmel, IN
Zidua	Pyroxasulfone	120	BASF Corporation, Research Triangle Park, NC
Dual II Magnum	S-metolachlor	1071	Syngenta Crop Protection, Greensboro, NC
Bolero	Thiobencarb	6720	Valent U.S.A. Corporation, Walnut Creek, CA
SelectMax	Clethodim	135	Valent U.S.A. Corporation, Walnut Creek, CA
Targa	Quizalofop	120	Gowan Company, Yuma, AZ

Table 3: Herbicides and rates evaluated for the preemergence (PRE) experiment.

The POST experiment was conducted in similar fashion to the PRE experiment. The POST experiment was conducted only at the RREC near Stuttgart with soil texture, planting dates, plot size, and application equipment and setup similar to the PRE experiment. Planting and herbicide application dates are shown in Table 4. Herbicide applications were made at the 2-lf, 4-lf, and 6-lf (V2, Early tillering, and Mid-tillering, respectively) growth stages [24]. The POST experiment was also kept weed free throughout the growing season using conventional rice herbicides as shown in Table 2.

			Application date		
Location	Year	Planting date	Two-leaf rice	Four-leaf rice	Six-leaf rice
Stuttgart	2014	April 23	May 16	May 20	June 3
	2015	May 6	May 27	June 2	June 11

Table 4: Planting date and application dates for postemergence (POST) experiment based on rice growth stage.

The experimental design was a randomized complete block with a two-factor factorial treatment arrangement with four replications. The two factors for the POST experiment were also herbicides and seed treatment. Seed treatments remained the same as the PRE experiment with "treated seed" and "non-treated seed."

Visual injury was evaluated 1, 5, and 11 weeks after herbicide treatment (WAT). Photos of all plots were taken at 8 WAT, and groundcover was determined using Sigma Scan Pro. Three canopy height measurements were taken per plot 11 WAT. The five centre rows of each plot was harvested at crop maturity using a small-plot combine, and rough rice yields were recorded and adjusted to 12% moisture.

All data were analyzed in JMP Pro 11(SAS Institute Inc., Cary, NC). Site years and replications nested within site years were included in the model as random effects for the PRE experiment because activation of herbicides generally varies with rainfall. Site years for the POST experiment were analyzed separately. Means were separated using Fisher's protected LSD test at α=0.05. P-values for all evaluations in the PRE and POST experiments are listed in Tables 5 and 6, respectively.

Factor	Injury 2 WAT[a]	Injury 4 WAT	Injury 7 WAT	Groundcover 7 WAT	Stand counts	Yield
Seed treatment	0.0083	0.0024	0.0012	0.0187	0.0408	0.048
Herbicide	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Seed treatment × Herbicide	0.8740	0.6889	0.6446	0.5642	0.7045	0.926

Table 5: P-values from ANOVA for all evaluations in the preemergence (PRE) experiment. [a]WAT, weeks after treatment.

	2014						2015					
Factor	Injury 1 WAT[a]	Injury 5 WAT	Injury 11 WAT	Groundcover 54 DAP	Canopy height 79 DAP	Yield	Injury 1 WAT	Injury 5 WAT	Injury 11 WAT	Groundcover 58 DAP[b]	Canopy Height 80 DAP	Yield
Seed treatment	0.0024	0.0127	0.0061	0.0283	0.0408	0.0479	0.1158	0.1514	0.1678	0.2176	0.0804	0.0398

Herbicide	0.0001	0.0001	0.0001	0.0009	0.0001	0.0016	0.0001	0.0001	0.0007	0.0943	0.2764	0.0001
Seed treatment × Herbicide	0.9274	0.7105	0.6562	0.4813	0.8510	0.0433	0.4812	0.3313	0.7049	0.8149	0.9995	0.0414

Table 6: P-values from ANOVA for all evaluations in postemergence (POST) experiment. [a]WAT, weeks after treatment; [b]DAP, days after planting.

Results and Discussion

PRE experiment

For all evaluations in the PRE experiment, the interaction of herbicide and insecticide seed treatment was not significant ($p>0.05$). However, the main effects of herbicide and insecticide seed treatment were significant for all evaluations (Table 5).

Herbicide effect

About a week after planting, rice plants began to emerge and injury symptoms began to occur by 2 WAT (Table 7). All of the group 15 herbicides, pyroxasulfone, S-metolachlor, and pethoxamid, caused at least 65% injury at 2 WAT. The group 1 ACCase-inhibiting herbicides, clethodim and quizalofop, injured rice 48 and 43%, respectively, even though these herbicides are typically applied POST in other crops. Fluridone and thiobencarb caused 32 and 30% injury, respectively, whereas clomazone, a standard for comparison, injured rice 19% at 2 WAT.

	Injury			Stand counts	Groundcover	
Herbicide	2 WAT[a]	4 WAT	7 WAT	2 WAT	7 WAT	Yield
	%	%	%	Plants 3 m^{-1} of row	%	kg ha^{-1}
Clomazone	19	12	8	112	83	9,000
Pethoxamid	65	61	42	65	55	7,200
Fluridone	32	18	25	98	73	7,200
Pyroxasulfone	78	95	90	68	3	2,150
S-metolachlor	78	98	93	44	5	2,150
Thiobencarb	30	19	17	95	68	8,200
Clethodim	48	36	29	75	60	8,200
Quizalofop	43	40	33	72	63	7,300
Check	-[b]	-	-	111	75	8,200
LSD(0.05)[c]	10	10	11	20	9	950

Table 7: Main effect of herbicide on visible injury, stand counts, groundcover, and rough rice yield for the preemergence (PRE) experiment averaged over site years and seed treatments. [a]Abbreviation: WAT, weeks after treatment; [b]Data for the 'Check' was not included in the injury analysis; [c]Fisher's protected LSD is for comparing means within a column.

By 4 WAT, rice treated with some herbicides began to recover while other plots continued to worsen (Table 7). Thiobencarb, which is currently labeled for use as a delayed PRE herbicide in rice, was the only treatment that did not differ from clomazone for visible injury to rice at both 4 and 7 WAT. Although injury from fluridone at 4 WAT was comparable to clomazone, flooding the field at 5 to 6 WAT caused crop damage from fluridone to increase, likely because of greater availability of the herbicide.

Stand counts were also evaluated 2 WAT to determine if rice densities in each herbicide-treated plot were comparable to the non-treated check. Clomazone, thiobencarb, and fluridone had rice densities comparable to the non-treated check, which had 111 plants per 3 m of row (Table 7). S-metolachlor had the least number of plants emerge.

In conjunction with the last injury rating, groundcover photos were taken at 7 WAT. At 7 WAT, rice groundcover percentage varied greatly among treatments and followed the same trend as injury 7 WAT. Stand reductions and increased injury led to the pyroxasulfone- and S-metolachlor-treated plots having only 3 and 5% groundcover, respectively, 7 WAT (Table 7). Clomazone remained the best herbicide option, having 83% groundcover, with thiobencarb and fluridone remaining similar to the non-treated check. Overall, the percent of groundcover in each plot depended upon the amount of injury and number of plants per plot.

Rice yields following the PRE herbicides ranged from 9,000 kg ha^{-1} for the clomazone treatment to 2150 kg ha^{-1} for pyroxasulfone and S-metolachlor (Table 7). Only rice treated with clomazone, thiobencarb, clethodim, or quizalofop had yield comparable to the non-treated check (8,200 kg ha^{-1}).

Insecticide seed treatment effect

Averaged over herbicides and site-years, the insecticide seed treatment lessened injury compared to its absence at 2, 4, and 7 WAT (Table 8). The use of an insecticide seed treatment also increased the number of emerged plants 2 WAT and improved rice groundcover at 7 WAT. It is unknown whether this improvement in crop growth caused by the insecticide seed treatment is partially a function of insecticide efficacy on rice water weevil (*Lissorhoptrus oryzophilus* Kuschel). Rice water weevil pressure was not determined in this research and, depending on the population, could have an effect on the parameters evaluated. It is obvious that insecticide-treated plots showed less injury and more plants, which eventually led to increased yield. The insecticide-treated plots yielded 500 kg ha^{-1} better than the non-treated plots, which is similar to that seen in other research when an elevated population of insects were present in the field [25].

	Injury			Stand counts	Groundcover	
Insecticide seed treatment	2 WAT[a]	4 WAT	7 WAT	2 WAT	7 WAT	Yield
	%	%	%	Plants 3 m^{-1} of row	%	kg ha^{-1}
Treatedb	45	43	37	85	54	6,900
Nontreated	53	51	47	72	48	6,400
LSD(0.05)[c]	5	5	6	10	4	450

Table 8: Main effect of insecticide seed treatment on visible injury, stand counts, groundcover and rough rice yield for the preemergence (PRE) experiment. [a] Abbreviation: WAT, weeks after treatment; [b]'Treated seed' received thiomethoxam; [c]Fisher's protected LSD is for comparing means within a column.

POST experiment

For the POST experiment, there was a significant interaction between years; therefore, data were analyzed separately for 2014 and 2015. The interaction of herbicide program and insecticide seed treatment was significant only for rough rice yield both years; however, the main effects of herbicide program and insecticide seed treatment were significant for all other assessments such as visible injury, canopy height, and groundcover (Table 6).

Herbicide effect

Herbicides were applied according to Table 4, while injury ratings were recorded 1, 5, and 11 weeks after the final herbicide treatment (WAT). At 1 WAT, injury ranged from 12% to 87% in 2014 (Table 9). Both programs containing carfentrazone had at least 65% injury while all other programs had 25% injury or less. At both 5 and 7 WAT only the carfentrazone alone program had significantly more injury than all other treatments (Table 9). Injury trends for the 2015 growing season were similar to the results from the 2014 growing season, although overall levels of injury were greater in 2015. Once again, 1 WAT both carfentrazone-containing programs had increased injury over all other treatments. However, rice plants in both treatments never recovered through 11 weeks of evaluation. At the 11-week evaluation, only the single application of propanil along with the propanil+saflufenacil treatments had less than 15% injury (Table 9).

			Injury						Canopy height	Ground cover
			2014			2015			2014	
Herbicide	Rate	Timing	1 WAT[a]	5 WAT	11 WAT	1 WAT	5 WAT	11 WAT	79 DAP[a]	54 DAP
	g ai ha^{-1}		---------------------------------------%---------------------------------------						cm	%
Propanil	6,720	2-lf[a]	25	16	7	11	9	6	61	54
Propanil fb[a] Propanil	4,480 4,480	2-lf 4-lf	24	25	13	21	31	28	56	34
Propanil fb Propanil	4,480 4,480	2-lf 6-lf	21	22	7	14	24	36	59	45
Propanil fb propanil+acifluorfen	4,480 4,480 224	2-lf 6-lf 6-lf	12	4	3	21	19	23	64	66
Saflufenacil fb Saflufenacil	25 25	2-lf 6-lf	12	19	9	19	34	36	63	57
Propanil+Saflufenacil	4,480 25	2-lf 2-lf	21	11	7	25	19	11	63	59
Carfentrazone	560	2-lf	87	59	42	65	58	50	52	9
Propanil+Carfentrazone	4,480 560	2-lf 2-lf	65	27	15	74	68	69	60	45

Citation: Martin SM, Norsworthy JK, Scott RC, Hardke J, Lorenz GM, et al. (2018) Effect of Thiamethoxam on Injurious Herbicides in Rice. Adv Crop Sci Tech 6: 351. doi:10.4172/2329-8863.1000351

LSD(0.05)[b]			6	10	9	15	20	27	6	10

Table 9: Main effect of herbicide program on visible injury, canopy height, and groundcover for 2014 and 2015 for the postemergence (POST) experiment. [a]Abbreviations: WAT, weeks after treatment; DAP, days after planting; fb, followed by; lf, leaf; [b]Fisher's protected LSD is for comparing means within a column.

In addition to injury ratings, groundcover percentages were taken for both years, but groundcover was significant only in 2014. Groundcover percentages ranged from 9% to 66% for the herbicide programs (Table 9). The percent groundcover generally followed the trend of visual injury. Plots with the least amount of injury generally had the highest amount of groundcover.

As with groundcover percentages, only data from 2014 were statistically different for canopy heights. Only two herbicide programs showed significant stunting when compared to the numerically tallest program (saflufenacil, 64 cm). Rice treated with propanil followed by (fb) propanil and carfentrazone alone was shorter than the 64 cm of the tallest program (Table 9). The carfentrazone alone program also had the most visual injury 11 WAT; however, the two applications of propanil had injury levels similar to most other programs.

Insecticide seed treatment effect

Averaged over herbicide programs, an insecticide seed treatment had a significant effect on injury, canopy height, and groundcover in 2014. The use of an insecticide seed treatment helped reduce herbicide injury at all ratings. Overall, there was 5 to 6% less injury when the rice seed was treated with an insecticide (Table 10), similar to that observed in other research [21]. The insecticide-treated seed also produced plants 3 cm taller than untreated along with an additional 7 percentage points of groundcover (Table 10). In 2014, the insecticide-treated seed produced an overall healthier rice plant than in 2015.

Yield

There was a significant interaction between herbicide program and seed treatment for both the 2014 and 2015 growing season. Among herbicide programs in 2014, rough rice yields were increased in herbicide programs containing propanil, with the exception of the propanil plus saflufenacil program, with the use of an insecticide seed treatment. Among treated seed, only the carfentrazone alone program had reduced yields when compared to the check. However, among non-treated seed, all herbicide programs without saflufenacil had reduced yields compared to the check without an insecticide seed treatment (Table 11). There was also no statistical difference between the non-treated checks with or without the insecticide seed treatment in 2014 or 2015. Among herbicide programs, yields were increased in the propanil fb propanil plus acifluorfen program along with both programs containing only saflufenacil with an insecticide seed treatment in 2015. In comparison to the non-treated check, all herbicide programs, both treated and non-treated seed, had reduced yields, with the exception of the non-treated seed in the propanil plus saflufenacil program.

	Injury			**Canopy height**	**Groundcover**
Insecticide seed treatment	1 WAT[a]	5 WAT	11 WAT	79 DAP[a]	54 DAP
	-------------------- % --------------------			cm	%
Treated	31	20	16	61	50
Nontreated	36	26	10	58	43
LSD(0.05)[b]	3	5	5	2	5

Table 10: Main effect of insecticide seed treatment on injury, canopy height, and groundcover for the postemergence (POST) experiment in 2014. [a] Abbreviations: WAT, weeks after treatment; DAP, days after planting; [b]Fisher's protected LSD is for comparing means within a column.

			Yield			
			2014		**2015**	
Herbicide	**Rate**	**Timing**	**Treated[a]**	**Nontreated**	**Treated[a]**	**Nontreated**
	g ai ha^{-1}		---------------------------kg ha^{-1}----------------------			
Propanil	6,720	2-lf[b]	7,050	6,450	7,950	8,100
Propanil fb[b] Propanil	4,480 4,480	2-lf 4-lf	6,750	6,300	8,500	8,250
Propanil fb	4,480	2-lf	6,700	6,050	8,050	7,450

Propanil	4,480	6-lf				
Propanil fb propanil+acifluorfen	4,480 4,480 224	2-lf 6-lf 6-lf	7,250	6,950	8,500	7,900
Saflufenacil fb saflufenacil	25 25	2-lf 6-lf	6,950	7,350	8,500	7,850
Propanil+saflufenacil	4,480 25	2-lf 2-lf	7,050	6,750	8,350	8,450
Carfentrazone	560	2-lf	6,150	6,350	7,400	7,050
Propanil+carfentrazone	4,480 560	2-lf 2-lf	6,550	6,100	6,950	7,350
Nontreated			6,900	7,000	9,100	8,900
LSD(0.05)[c]			-----450-----		-----550-----	

Table 11: Interaction of herbicide program and insecticide seed treatment on rough rice yield for 2014 and 2015. [a]Treated seed received thiamethoxam; [b]Abbreviations: fb, followed by; lf, leaf; [c]Fisher's protected LSD is for comparing all means within a year.

In both years, increased yields were observed when acifluorfen was combined with propanil and was used with an insecticide seed treatment. Depending on year, other herbicide programs that included propanil and saflufenacil had some yield benefit from the insecticide seed treatment. In all herbicide programs, there was never a yield loss from using the insecticide seed treatment.

Practical implications

A healthy rice crop is often necessary to optimize yield. With increased weed resistance, more herbicides and multiple modes of actions are required to keep a clean field. Some herbicides, although labeled for use in rice, can injure the crop [18]. Increased injury can also lead to increased chance for potential yield loss. However, with the use of insecticide seed treatments some injury can be alleviated, while protecting the potential rice yield when used in conjunction with some herbicides. It is speculated that a possible upregulation of stress genes caused by the neonicotinoid seed treatment could reduce herbicide injury in rice [26]. Consequently, if left unattended, weed pressure can cause a significant yield loss as well [2].

Acknowledgement

Funding for this research was provided by the Arkansas Rice Research and Promotion Board.

References

1. Webster TM (2012) Weed survey-grass crops subsection. Proc South Weed Sci Soc 65: 267-288.
2. Smith RJJr (1988) Weed thresholds in southern U.S. rice, Oryza sativa. Weed Technol 2: 232-241.
3. Smith RJJr (1961) 3,4-Dichloropropionanilide for control of barnyardgrass in rice. Weeds 9: 318-322.
4. Klingaman TE, King CA, Oliver LR (1992) Effect of application rate, weed species and weed stage of growth on imazethapyr activity. Weed Sci 40: 227-232.
5. Masson JA, Webster EP, Williams BJ (2001) Flood depth, application timing and imazethapyr activity in imidazolinone-tolerant rice (Oryza sativa). Weed Technol 15: 315-319.
6. Webster EP, Masson JA (2001) Acetolactate synthase-inhibiting herbicides on imidazolinone-tolerant rice. Weed Sci 49: 652-657.
7. Heap I (2016) The international survey of herbicide resistant weeds.
8. Riar DS, Norsworthy JK, Steckel LE, Stephenson IVDO, Eubank TW, et al. (2013) Adoption of best management practices for herbicide-resistant weeds in midsouthern United States cotton, rice, and soybean. Weed Technol 27: 788-797.
9. Carlson TP, Webster EP, Salassi ME, Hensley JB, Blouin DC (2011) Imazethapyr plus propanil programs in imidazolinone-resistant rice. Weed Technol 25: 204-211.
10. Norsworthy JK, Scott RC, Bangarwa SK, Griffith GM, Wilson MJ, et al. (2011) Weed management in a furrow-irrigated imidazolinone-resistant hybrid rice production system. Weed Technol 25: 25-29.
11. Pellerin KJ, Webster EP, Zhang W, Blouin DC (2003) Herbicide mixtures in water-seeded imidazolinone-resistant rice (Oryza sativa). Weed Technol 17: 836-841.
12. Montgomery GB, Bond JA, Golden BR, Gore J, Edwards HM, et al. (2015) Utilization of saflufenacil in a Clearfield rice (Oryza sativa) system. Weed Technol 29: 255-262.
13. Norsworthy JK, Scott RC, Johnson DB (2013) A six-year summary of the herbicide-resistance weed screening program in rice at the University of Arkansas: 2006-2012. BR Wells Rice Research Studies, Arkansas Agricultural Experiment Station Research Series 609: 153-158.
14. Bararpour MT, Norsworthy JK, Johnson DB, Scott RC (2013) Influence of rate and application timing on rice tolerance to acetochlor and S-metolachlor. BR Wells Rice Research Studies, Arkansas Agricultural Experiment Station Research Series 609: 133-137.
15. Bararpour MT, Norsworthy JK, Johnson DB, Scott RC, Barber LT (2014) Influence of rate and application timing on rice tolerance to pyroxasulfone. BR Wells Rice Research Studies, Arkansas Agricultural Experiment Station Research Series 617: 188-193.
16. Godwin J (2017) Evaluation of very-long chain fatty acid-inhibitors in Arkansas Rice Production. MS Thesis. Fayetteville, AR: University of Arkansas.
17. Frear DS, Still GG (1968) The metabolism of 3,4-dichloropropionanilide in plants. Partial purification and properties of an aryl acylamidase from rice. Phytochemistry 7: 913-920.

18. Montgomery GB, Bond JA, Golden BR, Gore J, Edwards HM, et al. (2014) Evaluation of saflufenacil in drill-seeded rice (Oryza sativa). Weed Technol 28: 660-670.

19. Scherder EF, Talbert RE, Clark SD (2004) Rice (Oryza sativa) cultivar tolerance to clomazone. Weed Technol 18: 140-144.

20. O'Barr JH, McCauley GN, Bovey RW, Senseman SA, Chandler JM (2007) Rice response to clomazone as influenced by application rate, soil type, and planting date. Weed Technol 21: 199-205.

21. Miller MR, Scott RC, Lorenz G, Hardke J, Norsworthy JK (2016) Effect of insecticide seed treatment on safening rice form reduced rates of glyphosate and imazethapyr. Int J Agron 2016: 7623743.

22. Hardke JT (2012) Arkansas Rice Production Handbook. Arkansas Cooperative Extension Service Miscellaneous Publications 192. Little Rock, AR: University of Arkansas.

23. Purcell LC (2000) Soybean canopy coverage and light interception measurements using digital imagery. Crop Sci 40: 834-837.

24. Counce PA, Keisling TC, Mitchell AJ (2000) A uniform, objective, and adaptive system for expressing rice development. Crop Sci 40: 436-443.

25. Plummer WA, Lorenz GM, Taillon NM, Thrash BC, Fortner JW, et al. (2012) Impact of insecticide seed treatments in large block field trials in Arkansas, 2009 to 2011. BR Wells Rice Research Studies, Arkansas Agricultural Experiment Station Research Series 600: 128-131.

26. Ming Z, Zhang W, Feng L, Xiaobo C, Li H, et al. (2016) Characterization of an Apis cerana cerana P450 gene (AccCYP336A1) and its role in oxidative stresses responses. Gene 584: 120-128.