Effect of Thiamethoxam on Injurious Herbicides in Rice

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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 reduce injury 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, indra 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 Glossaqualfs), while the studies at UAPB were conducted on a Callihou 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.

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

| 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           |

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 and 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 CO₂ 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 converted into 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.

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

| Herbicide trade name | Herbicide common name | Rate  | Manufacturer                     |
|---------------------|-----------------------|-------|----------------------------------|
| Command             | Clomazone             | 673 g ae or ai ha^{-1} | FMC Corporation, Philadelphia, PA |
| Pethoxamid          | Pethoxamid            | 560 g ae or ai ha^{-1} | FMC Corporation, Philadelphia, PA |
| Brake               | Fluridone             | 224 g ae or ai ha^{-1} | SePro, Carmel, IN                |
| Zidua               | Pyroxasulfone         | 120 g ae or ai ha^{-1} | BASF Corporation, Research Triangle Park, NC |
| Dual II Magnum      | S-metolachlor         | 1071 g ae or ai ha^{-1} | Syngenta Crop Protection, Greensboro, NC |
| Bolero              | Thiobencarb           | 6270 g ae or ai ha^{-1} | Valent U.S.A. Corporation, Walnut Creek, CA |
| SelectMax           | Clethodim             | 135 g ae or ai ha^{-1} | Valent U.S.A. Corporation, Walnut Creek, CA |
| Targa               | Quizalofop            | 120 g ae or ai ha^{-1} | Gowan Company, Yuma, AZ          |

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-leaf, 4-leaf, and 6-leaf (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.

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

| 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      |

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.

### Table 5: P-values from ANOVA for all evaluations in the preemergence (PRE) experiment.

| Factor                  | 2014 | 2015 |
|-------------------------|------|------|
| Seed treatment          | 0.0024 | 0.0027 |
| Injury 1 WAT           | 0.0001 | 0.0001 |
| Injury 5 WAT           | 0.0001 | 0.0001 |
| Injury 11 WAT          | 0.0001 | 0.0001 |
| Groundcover 54 DAP     | 0.0001 | 0.0001 |
| Canopy height 79 DAP   | 0.0001 | 0.0001 |
| Yield                   | 0.0479 | 0.2176 |
| Injury 1 WAT          | 0.0479 | 0.0804 |
| Injury 5 WAT          | 0.0479 | 0.0804 |
| Injury 11 WAT         | 0.0479 | 0.0804 |
| Groundcover 58 DAP     | 0.0479 | 0.0804 |
| Canopy height 80 DAP   | 0.0479 | 0.0804 |

### Table 6: P-values from ANOVA for all evaluations in the postemergence (POST) experiment. 

| Factor                  | 2014 | 2015 |
|-------------------------|------|------|
| Seed treatment          | 0.0024 | 0.0027 |
| Injury 1 WAT           | 0.0001 | 0.0001 |
| Injury 5 WAT           | 0.0001 | 0.0001 |
| Injury 11 WAT          | 0.0001 | 0.0001 |
| Groundcover 54 DAP     | 0.0001 | 0.0001 |
| Canopy height 79 DAP   | 0.0001 | 0.0001 |
| Yield                   | 0.0479 | 0.2176 |
| Injury 1 WAT          | 0.0479 | 0.0804 |
| Injury 5 WAT          | 0.0479 | 0.0804 |
| Injury 11 WAT         | 0.0479 | 0.0804 |
| Groundcover 58 DAP     | 0.0479 | 0.0804 |
| Canopy height 80 DAP   | 0.0479 | 0.0804 |

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Herbicide and insecticide seed treatment was not though these herbicides are typically applied POST in other crops.

Herbicide
were least 65% injury at 2 W AT. 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 W AT (Table 7). All of the group 15 ACCase-inhibiting herbicides, pyroxasulfone, S-metolachlor, and pethoxamid, caused at least 65% injury at 2 W AT. The group 1 ACCase-inhibiting herbicides, clomazone 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 W AT.

By 4 W AT, 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 W AT. Although injury from fluridone at 4 W AT was comparable to clomazone, flooding the field at 5 to 6 W AT caused crop damage from fluridone to increase, likely because of greater availability of the herbicide.

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. Abbreviation: WAT, weeks after treatment; Data for the ‘Check’ was not included in the injury analysis; Fisher’s protected LSD is for comparing means within a column.

Table 6: P-values from ANOVA for all evaluations in postemergence (POST) experiment. WAT, weeks after treatment; 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).

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 2,150 kg ha\(^{-1}\) for pyroxasulfone and S-metolachlor (Table 7). Only rice treated with clomazone, thiobencarb, clodhodim, 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](https://en.wikipedia.org/wiki/Lissorhoptrus_oryzophilus)) and 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

| Insecticide seed treatment | 2 WAT a | 4 WAT | 7 WAT | 2 WAT | 7 WAT | Yield |
|----------------------------|--------|-------|-------|-------|-------|-------|
| Treated b                  | 45     | 43    | 37    | 85    | 54    | 6,900 |
| Non treated                | 53     | 51    | 47    | 72    | 48    | 6,400 |

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).
Table 9: Main effect of herbicide program on visible injury, canopy height, and groundcover for 2014 and 2015 for the postemergence (POST) experiment. AAbbreviations: WAT, weeks after treatment; DAP, days after planting; fb, followed by; lf, leaf; bFisher’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.

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

Table: 2014 2015
Herbicide Rate Timing Treated g ai ha⁻¹ Non-treated g ai ha⁻¹
Propanil 6,720 2-lf 7,050 6,450 7,950 8,100
Propanil fb 4,480 2-lf 6,750 6,300 8,500 8,250
Propanil fb 4,480 2-lf 6,700 6,050 8,050 7,450
Labeled for use in rice, can injure the crop [18]. Increased injury can from using the insecticide seed treatment.

Caused by the neonicotinoid seed treatment could reduce herbicide herbicides. It is speculated that a possible upregulation of stress genes

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 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 not 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].

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

| Herbicide Program | Yield (kg/ha) |
|-------------------|--------------|
| Propanil          | 4,480        |
| Propanil+acifluorfen | 4,480  |
| Saflufenacil+acifluorfen | 224  |
| Propanil+saflufenacil | 25    |
| Carfentrazone     | 560          |
| Propanil+carfentrazone | 4,480  |
| Non-treated       | 6,900        |

LSD(0.05) = 450

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