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# Impact of environmental and agronomic conditions on rice injury caused by florpyrauxifen-benzyl

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**Research Article**

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## Abstract

Environmental conditions surrounding herbicide applications are known to affect weed control and crop response. Variable levels of rice injury caused by florpyrauxifen-benzyl have been observed across cropping systems and environmental conditions, warranting research in which single environmental and management strategies are isolated to understand the effect of each factor on rice injury and subsequent reductions in rice growth. A field study was conducted to determine the effects of planting date, rice cultivar, and florpyrauxifen-benzyl rate on rice injury, maturity, and yield. Two greenhouse studies were conducted to determine the effect of soil moisture and time of flooding after florpyrauxifen-benzyl application on rice injury caused by the herbicide. Growth chamber experiments were conducted to isolate the effects of temperature and light intensity on rice injury caused by florpyrauxifen-benzyl. In the field study, levels of injury varied across planting dates in both years, indicating the influence of environment on the crop response to florpyrauxifen-benzyl applications. Under dry (40% soil moisture) and saturated (100%) soil conditions, rice injury increased to 36% and 35%, respectively, compared with 27% and 25% injury at 60% and 80% soil moisture, respectively. Flooding rice 0 to 6 d after florpyrauxifen-benzyl application reduced visible injury; however, a reduction in rice tiller production occurred when the rice was flooded the same day as application. Visible rice injury increased when florpyrauxifen-benzyl was applied under low light intensity (700 μmol $m^{-2}$ $s^{-1}$) and high temperatures (35/24 C day/night). Based on these findings, applications of florpyrauxifen-benzyl are least likely to cause unacceptable rice injury when applied to soils having 60% and 80% saturation in high light, low temperature environments, and the crop is flooded 3 to 6 d following application.

## Introduction

Florpyrauxifen-benzyl, labeled under the trade name Loyant (Corteva Agriscience, Wilmington, DE), is a synthetic auxin herbicide (Weed Science Society of America Group 4) formulated for weed control in rice (Anonymous 2018). Rather than targeting the transport inhibitor response 1 auxin F-box protein, like other auxin herbicides, florpyrauxifen-benzyl favors *Arabidopsis* auxin receptor F-Box protein 5 indole-3-acetic acid co-receptor, allowing use of the herbicide to control resistant weed species such as quinclorac-resistant barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], although florpyrauxifen-benzyl-resistant barnyardgrass has since been discovered (Bell et al. 2015; Heap 2021; Miller et al. 2018). Following the commercial release of florpyrauxifen-benzyl in 2018, varying levels of rice sensitivity to the herbicide was noted (JKN, personal communication). Research has since determined rice sensitivity to the herbicide to vary considerably among cultivars. Hybrid-long grain rice cultivars are more susceptible to florpyrauxifen-benzyl than most pureline-long grain cultivars, leading to a varietal sensitivity warning being placed on the label (Anonymous 2018; Wright et al. 2020).

Crop response to herbicides can also vary with environmental conditions. Air temperature affects crop sensitivity to multiple herbicides, with more injury observed during high temperatures in many cases (Burt and Akinsoritan 1976; Ferreira et al. 1990). Light intensity surrounding application influences crop injury as well, as light intensity is known to affect the rate of photosynthesis and other metabolic processes occurring in plants, and the ability of the plant to metabolize herbicides (Bazzaz and Carlson 1982). Translocation and metabolism of quinclorac, another synthetic auxin herbicide used in rice production, is believed to be affected by light intensity because rice grown in low light conditions exhibits greater symptomology than that grown in high light (Bond and Walker 2012). Wright et al. (2020) attributed the varying differences in rice injury caused by florpyrauxifen-benzyl in field experiments compared to those conducted in greenhouses and growth chambers to the amount of light present.

Soil moisture status near herbicide application has been known to affect herbicide efficacy. Applications of clethodim and glyphosate on monocot species were influenced by the soil moisture at the time of application (Boydston 1990; Tanpipat et al. 1997; Waldecker and Wyse 1985). Soil moisture influenced the efficacy of florpyrauxifen-benzyl through increased uptake, translocation, and metabolism of the herbicide in barnyardgrass, hemp sesbania [*Sesbania herbacea* (Mill) McVaugh], and yellow nutsedge (*Cyperus esculentus* L.; Miller and Norsworthy 2018), leading to recommendations for producers to make applications when soils are saturated and to flood rice paddies immediately after application for maximum herbicide efficacy. However, if translocation, uptake, and metabolism of florpyrauxifen-benzyl into the active florpyrauxifen-acid increases in weed species as soil moisture increases, so should potential for rice injury.

Although rice is well known to be a flood-tolerant crop, there are plant stresses associated with flooding the crop (Yamauchi et al. 1994). Flood timing of rice can be used as a preventive strategy against many common pests in rice production, and is used as a tool to aid in weed, insect, and disease control (Rice et al. 1999; TeBeest et al. 2012). Due the proven effect of soil moisture on florpyrauxifen-benzyl, it is possible that flood timing could be used to mitigate any potential rice injury caused by the herbicide.

The objective of this research was to determine the effect of environmental conditions surrounding application of florpyrauxifen-benzyl on rice injury. Ambient temperature, light intensity, soil moisture, and flooding have been proven to affect either herbicide efficacy or crop injury caused by herbicides and were specifically examined in this research.

## Materials and Methods

### *Environmental Conditions for Field Study*

A field study was conducted in 2019 and 2020 at the Rice Research and Extension Center near Stuttgart, AA, to determine the effect of environmental conditions on rice injury caused by application of florpyrauxifen-benzyl. The soil at the test site was a DeWitt silt loam (fine, smectic, thermic typic Albaqualf) consisting of 19% clay, 27% sand, and 54% silt, 5.6 pH, and 2% organic matter. Prior to planting the study in both years, the seed bed was prepared using shallow tillage and a burndown application of glyphosate (Roundup PowerMax II, Bayer CropScience, Creve Coeur, MO). Rice was planted in 4.7-m-long plots with 17-cm row spacing, 9 rows wide with a 1-m alley between plots. Pureline rice cultivars were planted at 72 seeds per meter row and hybrid cultivars were planted at 36 seeds per meter row. The trials were maintained weed-free using a preemergence application of clomazone at 560 g ai ha$^{-1}$ (Command 3ME; FMC, Philadelphia, PA) and postemergence applications propanil at 4,480 g ha$^{-1}$ (Riceshot; UPL, King of Prussia, PA) at 1-leaf rice, and an application of fenoxaprop at 124 g ai ha$^{-1}$ (Ricestar HT; Gowan Co., Yuma, AZ) with or without a separate application of halosulfuron-methyl (Permit 75WG; Gowan Co.) post-flood if needed. Uniform injury caused by clomazone was observed (<20%) following preemergence application but was not present near florpyrauxifen-benzyl application timings. Potassium and phosphorus were applied pre-plant based on soil test values. Nitrogen at 135 kg N ha$^{-1}$ in the form of urea (460 g N kg$^{-1}$) was applied to the test site when rice reached the 5-leaf stage.

The study was designed as a randomized complete block with a split-plot arrangement with two subplot factors. The whole-plot factor was planting date, which consisted of mid-April, early May, and late May. Actual planting of rice occurred on April 2, May 1, and May 31 in 2019; and April 11, May 2, and June 1 in 2020. The use of staggered planting dates was to ensure that applications of florpyrauxifen-benzyl were made during varying atmospheric temperatures, levels of soil moisture, and other weather conditions. The first subplot factor was rice cultivar. Two cultivars of rice, 'Diamond' (Rice Research and Extension Center, Stuttgart, AR) and 'XP753' (RiceTec Inc., Alvin, TX) were randomized within each planting date. The second subplot factor was florpyrauxifen-benzyl rate at 0, 15, 30, and 60 g ae ha$^{-1}$. All applications of florpyrauxifen-benzyl included methylated seed oil at 0.58 L ha$^{-1}$. The applications of florpyrauxifen-benzyl were made to 4- to 5-leaf rice. All applications were made using a $CO_2$-pressurized backpack sprayer equipped with 110015 AIXR nozzles (TeeJet Technologies, Springfield, IL) delivering 140 L ha$^{-1}$ at 276 kPa. Applications in 2019 occurred on May 7, June 6, and June 24. Applications in 2020 occurred on May 21, May 28, and June 24. A levee was constructed between each planting date so that each bay could be fertilized and flooded 5 d after herbicide application.

### *Impact of Soil Moisture on Rice Injury Caused by Florpyrauxifen-benzyl*

A greenhouse experiment was conducted using a complete randomized design at the Altheimer Laboratory in Fayetteville, AR, to determine the impact of soil moisture on rice injury caused by florpyrauxifen-benzyl. The treatment structure single factor experiment consisting of four moisture levels (40%, 60%, 80%, and 100% of pore space filled by water). A silt-loam soil, collected from Fayetteville, AR was analyzed using Soil Plant Air Water (SPAW) software. The SPAW software used the percent clay, sand, and organic matter from a soil test conducted at the University of Arkansas Agricultural Diagnostic Lab (Fayetteville, AR) to determine the bulk density and pore space of the sample. The soil was then air-dried in the greenhouse until it neared 0% soil moisture. Air-dried soil weighing 8,000 g was added to 7.6-L buckets, and water was added to each bucket based on the weight of the bucket and the determined soil bulk density to achieve the desired soil water content for each treatment. The amount of water to add to each bucket was calculated using the equation:

$$W_w = (F * [V/M]) * W_s \quad 1$$

where $W_w$ is the amount of the water (g or mL) added to each bucket to reach the desired level of soil moisture (F), V stands for volumetric water content, M represents the matric bulk density of the soil sample (1.44 g cm$^{-3}$), and $W_s$ is weight of the dried soil placed in each bucket (8,000 g). Rice hybrid XP753 was planted in each bucket. Hybrid XP753 was chosen based on results from the field experiment exhibiting the hybrid's sensitivity to florpyrauxifen-benzyl and the popularity of the hybrid among growers After emergence, rice plants in each bucket were thinned to ensure that there were only six plants per bucket. The buckets were watered to the desired field capacity every 3 d (six buckets per treatment) using the total weight of the bucket. Florpyrauxifen-benzyl at 30 g ae ha$^{-1}$ plus methylated seed oil at 0.58 L ha$^{-1}$ were applied to three "treated" buckets when rice reached the 4- to 5-leaf stage using TeeJet 1100067 nozzles (TeeJet Technologies) and using water as a carrier at 187 L $ha^{-1}$ at 276 kPa. Three buckets per treatment remained without herbicide application to serve as a nontreated control. As a result, this study had three spatial replicates and two temporal replicates. Moisture levels were maintained until all buckets were flooded to a 5-cm depth 5 d after application. At the time of flooding, nitrogen was applied at 135 kg N $ha^{-1}$ in the form of urea fertilizer (460 g N $kg^{-1}$; 46-0-00). The rice remained flooded until termination of the trial. The environmental conditions in the greenhouse were a high daytime temperature of 31 C and a low night temperature of 24 C with humidity at 41%, maintained by the heating and cooling system inside of the greenhouse. Lights were provided at an average of 800 μmol $m^{-2}$ $s^{-1}$ to maintain a 14-h photoperiod daily.

### Impact of Flooding Date on Rice Injury Caused by Florpyrauxifen-benzyl

A second experiment was conducted in the same greenhouse in Fayetteville, AR, under the same growing conditions. The experiment aimed to determine the impact of flood timing following application of florpyrauxifen-benzyl on rice injury. Rice hybrid XP753 was planted in buckets filled with 8,000 g of soil that were maintained similarly to those used in the previous experiment. However, in these experiments, all buckets were maintained at 100% soil moisture after emergence until flooding. The experiments were conducted as a complete randomized design with treatment structures allowing for analysis as a two-factor factorial. The first factor was florpyrauxifen-benzyl application. Three buckets per treatment received an application of florpyrauxifen-benzyl at 30 g ae $ha^{-1}$ plus methylated seed oil at 0.58 L $ha^{-1}$, and another three buckets remained nontreated to serve as a control. The second factor was application of a 5-cm depth flood established 0, 3, 6, 9, and 12 d following florpyrauxifen-benzyl application (i.e., days after treatment; DAT). The experiment had three replications spatially and two replications temporally. Nitrogen fertilizer was applied prior to flooding at the same rate as used before. Buckets remained flooded until termination of the experiment.

### Impact of Light Intensity and Air Temperature on Rice Injury Caused by Florpyrauxifen-benzyl

A third experiment was conducted in a Conviron Growth Chamber (Controlled Environments Ltd., Winnipeg, MB, Canada) at the Altheimer Laboratory to determine the effect of light intensity and temperature on rice injury caused by florpyrauxifen-benzyl. Buckets of soil were filled with 8,000 g of the silt-loam soil, planted to XP753, and maintained at 100% soil moisture using identical methods as those described for the previous experiments. However, buckets used in this experiment were transferred to a growth chamber to create the environment necessary to satisfy the treatments of this experiment. The study was designed as randomized complete block with a split-plot setup with two subplot factors. The whole-plot factor was ambient temperature. The growth chamber was programmed to maintain low/high temperatures of 24/35 C (high temperature treatment) and 13/24 C (low temperature treatment) with a 12-h photoperiod daily. Temperatures used in this experiment were determined by using the average high and low temperature in April, May, and June in Stuttgart, AR, with a higher than average treatment and a lower than average treatment determined using data collected from the weather station used in Experiment 1. The first subplot factor was light intensity with treatments of high light intensity (1,100 μmol $m^{-2}$ $s^{-1}$) and low light intensity (700 μmol $m^{-2}$ $s^{-1}$), achieved by dividing the growth chamber in half using a curtain and modifying the amount of light output through the removal of bulbs. Light intensity thresholds were limited by the light production of the growth chamber, with the high light treatment representing approximately 50% of the maximum light observed on a sunny day. The second subplot factor was with or without an application of florpyrauxifen-benzyl at 30 g ae $ha^{-1}$ plus 0.58 L $ha^{-1}$ methylated seed oil to rice at the 5-leaf stage. All buckets were fertilized using the same rate of nitrogen as in the greenhouse experiments and flooded 5 d after treatment to 5-cm depth. The soil in the buckets remained flooded until the experiment was terminated. The experiment had three replications spatially and two replications temporally.

## Data Collection

### Environmental Conditions for Field Study

Visual estimations of crop injury (injury ratings) were recorded 21 and 28 DAT. Injury ratings were taken on a 0% to 100% scale where 0 indicates no herbicide injury and 100 represents crop death. Rice injury ratings were based on visual estimations of leaf malformation, stunting, loss of groundcover, decreased biomass, and chlorosis. The date at which 50% of the rice in each plot reached heading was recorded and reported relative to the nontreated control for each cultivar in every block for all three planting dates. Rough rice grain yield was collected using an Almaco plot combine (Almaco, Nevada, IA) and was adjusted to 12% moisture. Temperature, rainfall, and solar radiation were monitored for 7 d prior to the application until 7 d after application using a weather station (Davis Instrument Corporation, Hayward, CA) positioned approximately 25 m from the study in both years. Temperature was reported as an average of daily temperature and average daytime high temperature for the 7-d period spanning either side of the application day, including the day of application. Similarly, solar radiation across this period was reported as a total and average radiation per day. Rainfall was measured from 7 d before the application until the flood was established 5 d after application and reported as total rainfall over the 12-d period as well as average rainfall per day. Soil moisture was not directly monitored.

### Greenhouse and Growth Chamber Experiments

Data collection for the greenhouse and growth chamber experiments occurred 14 and 28 DAT. Data collected from each experiment consisted of visual estimations of rice injury, rice tiller counts, rice height, groundcover analysis, and aboveground rice biomass. Estimations of visible injury were recorded on a similar scale in the early study. The number of rice tillers produced per bucket were counted at each data collection time point. Heights of all rice plants present were recorded. Images were taken above each bucket at a height of 90 cm using a high definition 1080p camera. Rice groundcover was quantified using Canopeo (Oklahoma State University, Stillwater, OK). At 28 d after application, aboveground rice biomass was collected, dried for 3 d to constant mass, and weighed. Both groundcover and biomass were made relative to the respective nontreated control.

## Statistical Analysis

Data were analyzed using R Statistical Software v 4.0.3 (R Core Team 2021). Data that were not deemed normal or heterogeneous through use of a Shapiro-Wilkes and Levene's test were subject to a nonparametric analysis (Kniss and Streibig 2018). All estimations of visible injury from the field study, and all data collected from the

**Table 1.** P-values derived from analysis of the effect of planting date, rice cultivar, and florpyrauxifen-benzyl rate on rice injury in the field study.[a,b]

| Factor | Rice injury | | | |
|---|---|---|---|---|
| | 21 DAT | 28 DAT | Heading | Yield |
| Planting date | <0.0001* | <0.0001* | 0.4649 | 0.0970 |
| Rate | <0.0001* | <0.0001* | 0.1990 | 0.1480 |
| Cultivar | 0.1517 | 0.1033 | 0.0675 | 0.2245 |
| Planting date × rate | 0.2316 | 0.0844 | 0.9899 | 0.3597 |
| Cultivar × rate | 0.3834 | 0.4436 | 0.0209* | 0.3283 |
| Planting date × cultivar | 0.0011* | 0.0601 | 0.5229 | 0.8362 |
| Planting date × rate × cultivar | 0.6784 | 0.9899 | 0.8295 | 0.0760 |

[a]Abbreviation: DAT, days after treatment.
[b]P-values followed by * are significant (α = 0.05).

growth chamber study were deemed nonparametric and subject to analysis using the Kruskal-Wallis test (Kruskal and Wallis 1952; Shah and Madden 2004). Heading dates and rough rice grain yield were deemed parametric and analyzed using the (*nlme*) function.

Data from the soil moisture and flood timing greenhouse experiments were analyzed as a two-factor factorial using the *RankFD* function for nonparametric data (estimations of visible injury) and the (*lme*) function for parametric variables (height, tiller counts, biomass, and groundcover; Brunner et al. 1997, 2019). Parametric variables were also assessed using Dunnett's procedure to determine differences from the nontreated control. All means were subject to Tukey's honestly significant difference test to determine differences between treatments at α = 0.05.

## Results and Discussion

### *Environmental Conditions for Field Study*

The injury caused to rice by florpyrauxifen-benzyl was characterized by an erect posture of all leaves on the plant and visual appearance of biomass and groundcover loss as well as leaf malformation in the form of leaves cupping around the mid-rib and in severe cases, the leaf tip would remain trapped inside of the leaf sheath. The P-values derived from estimations of visible injury occurring 21 and 28 DAT indicate a strong impact of environmental conditions (planting date) on injury caused by florpyrauxifen-benzyl (Table 1). The strong effect of environment on damage to rice is further supported by estimations of visible injury occurring 28 DAT where planting date was significant (Table 2). The variable levels of injury observed at 28 DAT among planting dates could possibly be attributed to the weather conditions surrounding times of application. The highest levels of rice injury caused by florpyrauxifen-benzyl occurred when the crop was planted in late May in 2019 and early May in 2020 with 17% and 16% injury, respectively (Table 2). The florpyrauxifen-benzyl application to rice planted in late May 2019 was made during a warm period, with an average high temperature of 27 C. The rice planted in early May of 2020 received the greatest amount of rainfall during the period observed, which likely resulted in a high soil moisture content at or near application. Conversely, the lowest injury levels were observed for mid-April planted rice in 2019 (2%) and late May in 2020 (<1%). Average temperature surrounding the application to mid-April planted rice in 2019 was the coolest of the time periods sampled, with an average high temperature of 20 C (Table 3).

Based on findings from this study, there is a possible effect of temperature and moisture on the levels of rice injury following a florpyrauxifen-benzyl application. However, there are other factors that can contribute to the levels of injury observed and identification and isolation of these factors could lead to better recommendations on how to minimize rice injury caused by florpyrauxifen-benzyl or injury expectations under certain conditions. Variation of environmental conditions may also be the cause of differences in rice response to florpyrauxifen-benzyl in previously published research. For instance, in one study, hybrid CL XL745 was injured no more than 10% following florpyrauxifen-benzyl at 58 g ae ha$^{-1}$, whereas in another study as much as 20% injury resulted from the herbicide at the same rate on this hybrid (Sanders et al 2021; Wright et al. 2020).

The rate of florpyrauxifen-benzyl affected the amount of injury observed 21 and 28 DAT (Table 1), but to a lesser extent than the environmental conditions surrounding the application. Less injury occurred when florpyrauxifen-benzyl was applied at 15 g ae ha$^{-1}$ compared with applications at 60 g ae ha$^{-1}$. Although Hybrid XP753 also exhibited a general delay in heading (<1 d) following an application of florpyrauxifen-benzyl at 15 and 60 g ae ha$^{-1}$. Although it is significant, the delay in maturity is minimal and should not affect production operations. The discovery that florpyrauxifen-benzyl can be applied at 15 g ae ha$^{-1}$ under varying environmental conditions without causing long-term rice injury is significant for producers attempting to use less-than-labeled rates of the herbicide for broadleaf and sedge weed control, which is currently the most widely used rate of this herbicide in Arkansas based on conversations with growers (JKN, personal communication). Considering the use of lower-than-labeled rates could lead to development of resistance and reductions in target weed control, producers should incorporate the use of florpyrauxifen-benzyl in a herbicide program to ensure elimination of target species. No relative rice yield reductions were observed following applications of florpyrauxifen-benzyl at any rate under any of the environmental conditions observed.

### *Impact of Soil Moisture on Rice Injury Caused by Florpyrauxifen-benzyl*

Visible injury was affected by soil moisture levels following application of florpyrauxifen-benzyl (Table 4). At 14 DAT, florpyrauxifen-benzyl caused the least amount of injury (21%) when soil was maintained at 80% moisture until flooding. At 28 DAT, injury (25% to 27%) was similar when soil moisture was 60% and 80% until flooding. The highest amount of injury (35% to 36%) occurred under 40% and 100% soil moisture, indicating that both stress from drought and extremely wet, saturated soils can solicit more symptomology on rice following an application of florpyrauxifen-benzyl (Table 5).

Weed species are known to uptake, translocate, and metabolize the herbicide at higher rates under saturated soil conditions, explaining the interaction of soil moisture with rice injury caused by florpyrauxifen-benzyl (Miller and Norsworthy 2018). However, the excessive visible injury caused under extremely dry conditions could be due to the compounding of drought stress with florpyrauxifen-benzyl further hindering the ability of the rice to grow properly. In order to minimize visible injury caused by florpyrauxifen-benzyl, applications should occur between 60% and 80% field capacity when possible, although applications at all levels of soil moisture elicited injury.

Although injury was observed in the form of leaf malformation, differences were not observed in height, tiller production, groundcover, or biomass production as a result of soil moisture treatment (Table 6). *T*-tests revealed that florpyrauxifen-benzyl alone did cause reductions in rice tiller production and biomass. Rice tiller

**Table 2.** Estimations of visible rice injury and date to 50% heading as relates to injury caused by florpyrauxifen-benzyl by planting date, cultivar, and application rate in the field study.[a–d]

| Factor | | | Cultivar | Rate | Injury 21 DAT | Injury 28 DAT | Heading |
|---|---|---|---|---|---|---|---|
| | | | | g ae ha$^{-1}$ | % | % | days |
| Planting date × cultivar | 2019 | Mid-April | Diamond | | 5 de | 2 | −1 |
| | | | XP753 | | 5 de | 2 | 0 |
| | | Early May | Diamond | | 4 e | 7 | 0 |
| | | | XP753 | | 5 de | 4 | 3 |
| | | Late May | Diamond | | 14 bc | 16 | 1 |
| | | | XP753 | | 22 a | 18 | 1 |
| | 2020 | Mid-April | Diamond | | 13 bc | 9 | 0 |
| | | | XP753 | | 8 c-e | 4 | 0 |
| | | Early May | Diamond | | 17 ab | 15 | 0 |
| | | | XP753 | | 12 b-d | 17 | −1 |
| | | Late May | Diamond | | 0 e | 1 | 0 |
| | | | XP753 | | 0 e | 0 | 0 |
| Cultivar × rate | | | Diamond | 15 | 5 | 5 | 0 a |
| | | | | 30 | 8 | 8 | 0 a |
| | | | | 60 | 13 | 12 | 0 a |
| | | | XP 753 | 15 | 5 | 5 | <1 ab |
| | | | | 30 | 7 | 7 | 0 a |
| | | | | 60 | 14 | 11 | 1 b |
| Planting date | 2019 | Mid-April | | 5 | 2 | b 0 | |
| | | Early May | | | 4 | 6 ab | 1 |
| | | Late May | | | 17 | 17 a | 1 |
| | 2020 | Mid-April | | | 10 | 7 ab | 0 |
| | | Early May | | | 15 | 16 a | 0 |
| | | Late May | | | 0 | <1 b | 1 |
| Rate | | | | 15 | 5 b | 6 b | 0 |
| | | | | 30 | 8 b | 8 ab | 0 |
| | | | | 60 | 13 a | 11 a | 1 |

[a]Abbreviation: DAT, days after treatment.
[b]Means within the same column and grouping followed by the same letter are not significantly different according to Tukey's adjusted honestly significant difference test (α = 0.05).
[c]Heading is days before or after the nontreated check reached 50% heading. Average days from emergence to heading for 'Diamond' were 80 in both 2019 and 2020 and 83 and 85 for 'XP753' in 2019 and 2020, respectively.
[d]Application rates of florpyrauxifen-benzyl applied to 4- to 5-leaf rice.

**Table 3.** Weather data collected near the experiment site.[a,b,c]

| Planting date | | Injury 28 DAT | Temperature Average | Temperature Average high | Rainfall Average day$^{-1}$ | Rainfall Total | Solar radiation Average day$^{-1}$ | Solar radiation Total |
|---|---|---|---|---|---|---|---|---|
| | | % | C | C | cm | cm | W m$^{-2}$ | W m$^{-2}$ |
| 2019 | Mid-April | 2 b | 20 | 20 | 0.48 | 5.8 | 168 | 2,520 |
| | Early May | 6 ab | 25 | 26 | 0.49 | 5.9 | 238 | 3,570 |
| | Late May | 17 a | 26 | 27 | 0.36 | 4.3 | 246 | 3,690 |
| 2020 | Mid -April | 7 ab | 23 | 24 | 0.31 | 3.7 | 238 | 3,570 |
| | Early May | 16 a | 24 | 25 | 0.45 | 5.4 | 272 | 4,080 |
| | Late May | <1 b | 23 | 23 | 0.48 | 5.8 | 223 | 3,345 |

[a]Data recorded from 7 d prior to application to 7 d past application.
[b]Total rainfall was recorded from 7 d prior to application until flooding 5 d after application.
[c]Abbreviation: DAT, days after treatment.

**Table 4.** P-values determined using ANOVA from the greenhouse experiment to determine the effect of soil moisture on rice injury.[a,b]

| Assessment date | Assessment | P-value |
|---|---|---|
| 14 DAT | Rice injury | 0.0424* |
| | Tiller count | 0.8951 |
| | Rice height | 0.8951 |
| 28 DAT | Rice injury | 0.0389* |
| | Tiller count | 0.1332 |
| | Rice height | 0.7907 |
| | Groundcover | 0.9356 |
| | Biomass | 0.8083 |

[a]Abbreviation: DAT, days after treatment.
[b]P-values followed by * are significant (α = 0.05).

**Table 5.** Estimations of visible rice injury caused by applications of florpyrauxifen-benzyl at differing soil moistures from the greenhouse study.[a,b,c]

| Factor | | Rice injury 14 DAT | Rice injury 28 DAT |
|---|---|---|---|
| | | (%) | (%) |
| Soil Moisture | 40 | 32a | 36a |
| | 60 | 22b | 27bc |
| | 80 | 21b | 25c |
| | 100 | 26ab | 35ab |

[a]Abbreviation: DAT, days after treatment.
[b]Means within the same column followed by the same letter are not significantly different according to Tukey's adjusted honestly significant difference test (α = 0.05).
[c]Applications rates of florpyrauxifen-benzyl applied to 4- to 5-leaf rice.

**Table 6.** Impact of florpyrauxifen-benzyl at 30 g ae ha$^{-1}$ on rice height and tiller production at 14 and 28 DAT and rice groundcover and biomass at 28 DAT averaged over soil moisture regimes in the greenhouse experiment.[a,b,c]

| | | Rice height | | Tiller production | | Groundcover | Biomass |
|---|---|---|---|---|---|---|---|
| Factor | Rate | 14 DAT | 28 DAT | 14 DAT | 28 DAT | 28 DAT | 28 DAT |
| | g ae ha$^{-1}$ | Prob. > *F* | | | | | |
| Florpyrauxifen-benzyl application | 0 vs. 30 | 0.1864 | 0.2319 | 0.0249 | 0.0041 | 0.0453 | 0.0011 |
| | | % of nontreated | | | | | |
| | 30 | 95 | 102 | 83* | 85* | 70* | 67* |

[a]Abbreviation: DAT, days after treatment.
[b]Applications rates of florpyrauxifen-benzyl applied to 4- to 5-leaf rice.
[c]Means displayed as percent of nontreated check are compared to the nontreated with significant differences indicated using an asterisk.

production was reduced 17% by florpyrauxifen benzyl 14 DAT and the crop did not recover by 28 DAT, with a reduction of 15% averaged across soil moisture treatments at the later assessment. Biomass and groundcover data collected 28 d following florpyrauxifen-benzyl application revealed reductions of 33% and 31%, respectively, across soil moisture treatments (Table 6). These findings coincide with previous work that found height, biomass, and groundcover reduction following florpyrauxifen-benzyl applications (Wright et al. 2020). Reduction in groundcover correlates with loss of yield as well as inability of the crop to negatively affect weed emergence and growth (Donald 1998; Norsworthy 2004). The loss of groundcover caused by florpyrauxifen-benzyl, especially in a nonflooded production system such as furrow-irrigated rice, could lead to greater weed emergence and the need for a subsequent herbicide application as a result of crop injury and reduced canopy formation. However, considering applications were made to 5-leaf rice, normal practice in a flooded system dictates that flood establishment occurs soon after application, mitigating the need for a residual herbicide, as most terrestrial weed species do not germinate beyond the permanent flood (Henry et al. 2018).

### Impact of Flooding Date on Rice Injury Caused by Florpyrauxifen-benzyl

Examination of rice injury caused by florpyrauxifen-benzyl application followed by multiple flood timings revealed that more visible injury occurred when the flood was established 9 or 12 DAT (34% and 28%, respectively; Tables 7 and 8). The least amount of visible injury to rice occurred when the flood was established 0 or 3 d after application. The florpyrauxifen-benzyl label for rice recommends that a flood be established within 5 d following application to prevent further emergence of weed species (Anonymous 2020). Therefore, under similar conditions to those maintained in the greenhouse, using current recommendations along with these data, a producer could expect to see 8% to 15% injury 28 d following application of florpyrauxifen-benzyl if flooded within 5 d under the conditions of this study (Table 8). However, as previously noted, many factors can affect contribute the level of injury observed. Findings from this experiment indicate that even though there is a lack of visible injury on rice when the flood is established 0 d after treatment with florpyrauxifen-benzyl, there is a reduction in tiller number, indicating that flood establishment should be withheld until 3 to 6 d following application of the herbicide.

As noted in the previous greenhouse experiment, a single florpyrauxifen-benzyl application reduced rice tiller production (17% 14 DAT, 15% 28 DAT), groundcover (30%), and rice biomass (33%), regardless of flooding date (Table 9). However, previous research indicates that rice will recover from injury caused by a single application of florpyrauxifen-benzyl at 30 g ae ha$^{-1}$ with no

**Table 7.** P-values determined using ANOVA on data from experiment determining the impact of flood timing on florpyrauxifen-benzyl injury observed.

| Assessment date[a] | Assessment | P-value[b] |
|---|---|---|
| 14 DAT | Rice injury | <0.0001* |
| | Tiller count | 0.3308 |
| | Rice height | 0.5167 |
| 28 DAT | Rice injury | <0.0001* |
| | Tiller count | 0.0463* |
| | Rice height | 0.5262 |
| | Groundcover | 0.3951 |
| | Biomass | 0.7154 |

[a]Abbreviation: DAT, days after treatment.
[b]P-values followed by * are significant (α = 0.05).

**Table 8.** Impact of flood establishment timing following florpyrauxifen-benzyl application at 30 g ae ha$^{-1}$ in the greenhouse on visible estimates of rice injury and rice tiller counts.[a,b,c]

| | | Rice injury | | Tiller count |
|---|---|---|---|---|
| Factors | | 14 DAT | 28 DAT | 28 DAT |
| Flood Timing | 0 | 4c | 8b | 79b |
| | 3 | 5c | 8b | 93a |
| | 6 | 15b | 15b | 94a |
| | 9 | 28a | 27a | 97a |
| | 12 | 34a | 31a | 104a |

[a]Abbreviation: DAT, days after treatment.
[b]Means within the same column followed by the same letter are not different according to Tukey's adjusted honestly significant difference test (α = 0.05).
[c]Applications rates of florpyrauxifen-benzyl applied to 4- to 5-leaf rice.

reduction in yield or delay in maturity (Wright et al. 2020). Rice treated with florpyrauxifen-benzyl has been able to compensate for the reductions in tiller production, height, groundcover, and biomass prior to maturity (Wright et al. 2020). However, in order to minimize overall injury, visible or physiological, applications should be made 3 to 6 d prior to flooding.

### Impact of Temperature and Light Intensity on Rice Injury Caused by Florpyrauxifen-benzyl

Analysis of the data evaluating the effects of temperature and light intensity on injury caused by florpyrauxifen-benzyl revealed that both factors contribute to the extent of crop damage based on visible rice injury, groundcover, and biomass assessments (Table 10). The combination of high temperature and low light caused the greatest injury to rice at 14 and 28 DAT, with 20% and 27% observed, respectively (Table 11). Furthermore, no injury was observed at either evaluation for the combination of low temperature and high light. Similarly, for the groundcover and biomass

**Table 9.** Impact of florpyrauxifen-benzyl at 30 g ae ha$^{-1}$ on rice height and tiller production at 14 and 28 DAT and rice groundcover and biomass at 28 DAT averaged over flooding timings in the greenhouse experiment.[a,b,c]

| | | Rice height | | Tiller production | | Groundcover | Biomass |
|---|---|---|---|---|---|---|---|
| Factor | Rate | 14 DAT | 28 DAT | 14 DAT | 28 DAT | 28 DAT | 28 DAT |
| | g ae ha$^{-1}$ | Prob. > *F* | | | | | |
| Florpyrauxifen-benzyl application | 0 vs. 30 | 0.1971 | 0.0907 | 0.0393 | 0.1529 | 0.0497 | 0.0029 |
| | | % of nontreated | | | | | |
| | 30 | 97 | 96 | 86* | 93 | 81* | 81* |

[a]Abbreviation: DAT, days after treatment.
[b]Application rate of florpyrauxifen-benzyl applied to 4- to 5-leaf rice.
[c]Means displayed as percent of nontreated check are compared to the nontreated with significant differences indicated using an asterisk.

**Table 10.** P-values derived from ANOVA in a growth chamber experiment investigating the effect of light and temperature on rice injury caused by florpyrauxifen-benzyl conducted in the laboratory.[a,b]

| | 14 DAT | | | 28 DAT | | | | |
|---|---|---|---|---|---|---|---|---|
| Factor | Injury | Height | Tillers | Injury | Height | Tillers | GC[c] | Biomass |
| Temperature | <0.0001* | 0.1674 | 0.7656 | <0.0001* | <0.0001 | 0.0464 | <0.0001 | 0.5870 |
| Light | <0.0001* | 0.5875 | 0.9075 | <0.0001* | 0.8777 | 0.8808 | <0.0001 | 0.0114 |
| Temp × Light | <0.0001* | 0.7566 | 0.0812 | <0.0001* | 0.7583 | 0.3684 | <0.0001 | 0.1400 |
| Temp × Loyant | <0.0001* | 0.1674 | 0.7656 | <0.0001* | <0.0001 | 0.0464 | <0.0001 | 0.5870 |
| Light × Loyant | <0.0001* | 0.5875 | 0.9075 | <0.0001* | 0.8777 | 0.8808 | <0.0001 | 0.0114 |
| Temp × light × Loyant | <0.0001* | 0.7566 | 0.0812 | <0.0001* | 0.7583 | 0.3684 | <0.0001 | 0.1400 |

[a]Abbreviations: DAT, days after treatment; GC, groundcover.
[b]P-values followed by * are significant (α = 0.05).

**Table 11.** Rice injury, tiller production, height, groundcover, and biomass following florpyrauxifen-benzyl at 30 g ae ha$^{-1}$ in high or low temperature and light regimes in the laboratory experiment.[a–f]

| | | 14 DAT | | 28 DAT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Factor | Temperature | Light | Application | Injury | Tillers | Injury | Tillers | Height | Groundcover | Biomass |
| | g ae ha$^{-1}$ | | | % | | | | | | |
| Temperature * light * application | Low | Low | 0 | 0b | 100 | 0c | 100 | 100 | 100a | 100a |
| | | | 30 | 6bc | 106 | 3c | 105 | 104 | 81bc | 71b |
| | High | | 0 | 0c | 100 | 0c | 100 | 100 | 100a | 100a |
| | | | 30 | 1c | 86 | 0c | 99 | 106 | 111a | 96a |
| | High | Low | 0 | 0c | 100 | 0c | 100 | 100 | 100ab | 100a |
| | | | 30 | 20a | 84 | 27a | 87 | 91 | 56c | 81b |
| | High | | 0 | 0c | 100 | 0c | 100 | 100 | 100ab | 100a |
| | | | 30 | 10b | 97 | 14b | 94 | 98 | 84ab | 90ab |
| Temperature * application | Low | | 0 | 0 | 100 | 0 | 100a | 100ab | 100 | 100 |
| | | | 30 | 3 | 96 | 2 | 101a | 105a | 96 | 86 |
| | High | | 0 | 0 | 100 | 0 | 100a | 100ab | 100 | 100 |
| | | | 30 | 15 | 95 | 20 | 91b | 95b | 70 | 83 |
| Application | | | 0 | 0 | 100a | 0 | 100 | 100 | 100 | 100 |
| | | | 30 | 9 | 93b | 11 | 96 | 100 | 83 | 85 |

[a]Abbreviation: DAT, days after treatment.
[b]Means within the same column followed by the same letter are not different according to Tukey's adjusted honestly significant difference test (α = 0.05).
[c]Data reported relative to nontreated check.
[d]Applications rates of florpyrauxifen-benzyl applied to 4- to 5-leaf rice.
[e]Low and high light regimes were 700 µmol m$^{-2}$ s$^{-1}$ and 1,100 µmol m$^{-2}$ s$^{-1}$, respectively.
[f]Low and high temperature regimes were 13/24 C and 24/35 C (night/day), respectively.

assessments, there was reduction of 44% in groundcover and 19% in biomass caused by florpyrauxifen-benzyl under the high temperature and low light regime (Table 11).

Rice tiller production and height 28 DAT was affected by the interaction of temperature and application of florpyrauxifen-benzyl (Table 10). Florpyrauxifen-benzyl caused a 9% reduction in rice tiller production and a 5% reduction in rice height under the high temperature regime, averaged over light intensities 28 DAT. Florpyrauxifen-benzyl also induced a 7% reduction in rice tillers, averaged across all temperature and light treatments 14 DAT, like observations from previous experiments (Table 11). Findings from this experiment lead to the conclusion that there is increased risk for damage to rice from florpyrauxifen-benzyl in the form of visible injury, stunting, less biomass, and reduced groundcover under prolonged cloudy (low light) periods that are accompanied by warm conditions. While cloudy conditions would be expected to lower air temperature, it is still possible to have air temperatures comparable to those evaluated in this study during summer months when florpyrauxifen-benzyl is being applied in the rice production regions of Arkansas.

### *Practical Implications*

Factors contributing to the amount of injury caused by florpyrauxifen-benzyl have been identified as rate of application, number of applications, rice cultivar receiving the application, preexposure to other herbicides such as quinclorac, as well as environmental conditions and agronomic factors surrounding the application event (JKN personal communication; Wright et al 2020). Understanding the effect of these environmental conditions on the amount of rice injury caused by florpyrauxifen-benzyl observed can allow producers, consultants, and scientists alike to attribute the varying degrees of injury to conditions surrounding the time of application and have a better understanding as to why certain areas appear more susceptible to the herbicide than others, Applicators can also use the findings from these experiments to mitigate visible rice injury caused by florpyrauxifen-benzyl to the best of their ability. Applications should not be made in extremely dry or saturated conditions. Producers should be mindful that applications shortly followed by saturated conditions because of rainfall or flood establishment will impact the extent of injury to rice. Crop injury can be further exacerbated during periods of above average temperatures, especially if cloudy conditions are present. If florpyrauxifen-benzyl is applied to late-planted rice there will be greater risk for warm conditions surrounding application thus injury to the crop. When deciding to apply florpyrauxifen-benzyl, the weed control benefits should be weighed against the risk for injury, knowing that there are few postemergence options for controlling barnyardgrass and Palmer amaranth, two of the most troublesome weeds of rice in the mid-south United States.

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