This is a “preproof” accepted article for Weed Science. This version may be subject to change in the production process, *and does not include access to supplementary material*.
DOI: 10.1017/wet.2024.27

Running Title: FPB Urea Flood Timing and Loss

Flood Timing and Flood Loss Impact on Effectiveness of Florpyrauxifen-benzyl Coated on Urea in Rice

Bodie L. Cotter[1], Jason K. Norsworthy[2], Thomas R. Butts[3], Trenton L. Roberts[4], Andy Mauromoustakos[5]

[1]Graduate Research Assistant, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR, USA; [2]Professor and Elms Farming Chair of Weed Science, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR, USA; [3]Assistant Professor and Extension Weed Scientist, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Lonoke, AR, USA; [4]Professor of Soil Fertility/Soil Testing, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR, USA and [5]Professor, Department of Agriculture Statistics, University of Arkansas, Fayetteville, AR, USA

Corresponding author: Bodie L. Cotter, University of Arkansas, 1354 W. Altheimer Dr., Fayetteville, AR 72704 (blcotter@uark.edu)

ABSTRACT

Florpyrauxifen-benzyl applications generated complaints and concerns around rice injury and off-target movement to soybean after the commercial launch in 2018. A precise application method for florpyrauxifen-benzyl was imperative for its continued use. Experiments were conducted in 2020 and 2021 to evaluate rice weed control as influenced by preflood application interval and flood loss following florpyrauxifen-benzyl at 30 g ai ha^{-1} applied as a spray or coated on urea. In the preflood application experiment, coating florpyrauxifen-benzyl on urea and applying it the day of flood establishment, 5, and 10 d prior to flooding (DPTF) resulted in lower yellow nutsedge, broadleaf signalgrass, and barnyardgrass control than when the herbicide was spray at 3 and 5 wk after final treatment (WAFT). Coating florpyrauxifen-benzyl on urea only provided 61 to 63% yellow nutsedge control at 3 and 5 WAFT, which was 35 to 37 percentage points lower than when spray applied at 5 or 10 DPTF. Likewise, rice yields following applications of florpyrauxifen-benzyl coated on urea were 1200 kg ha^{-1} less than yields following spray applications. Florpyrauxifen-benzyl coated on urea and clomazone provided lower levels of weed control than spraying the herbicide, suggesting an explanation for the yield losses. The timing of flood loss experiment suggested that when florpyrauxifen-benzyl coated on urea at 30 g ai ha^{-1} was applied preflood and flood was relinquished at 2 hours, 24 hours, and 7 d after flood establishment, hemp sesbania and yellow nutsedge control were not affected. However, loss of floodwater 2 hours after flood establishment resulted in lower barnyardgrass control than when the flood was lost 24 hours and 7 d after flooding. Generally, the period between a herbicide application and flooding completion should be minimized to aid in weed control. These results indicate the importance of maintaining a flood for weed control and nutrient management.

Nomenclature: clomazone; florpyrauxifen-benzyl; barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv.; hemp sesbania, *Sesbania herbacea* (Mill.) McVaughn; yellow nutsedge, *Cyperus esculentus* L.; rice, *Oryza sativa* L.; soybean, *Glycine max* (L.) Merr.

Keywords: application method; application technology; off-target movement

INTRODUCTION

The commercialization of florpyrauxifen-benzyl (Loyant^{TM}, Corteva Agrisciences, Wilmington, DE, 19805) in 2018 in rice was followed by complaints of off-target movement to soybean, varying levels of rice tolerance, and trouble controlling some barnyardgrass biotypes (Wright et al. 2020; Beesinger et al. 2022). Florpyrauxifen-benzyl is a synthetic auxin [Herbicide Resistance Action Committee (HRAC)/Weed Science Society of America (WSSA) Group 4] herbicide labeled at 30 g ai ha^{-1} for use in rice, mostly applied at the preflood or postflood timing for control of an array of weeds, including barnyardgrass, broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], Amazon sprangletop [*Diplachne panicoides* (J. Presl.) McNeil], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], northern jointvetch [*Aeschynomene verginica* (L.) Britton, Sterns & Poggenb.], hemp sesbania, pitted morningglory (*Ipomoea lacunosa* L.), Palmer amaranth (*Amaranthus palmeri* S. Watson), yellow nutsedge, rice flatsedge (*Cyperus iria* L.), and smallflower umbrella sedge (*Cyperus difformis* L.) (Anonymous 2018; Miller and Norsworthy 2018a). Some biotypes of barnyardgrass have been identified as tolerant to florpyrauxifen-benzyl and are better controlled through utilizing multiple residual herbicide applications and multiple herbicide sites of action (Hwang et al. 2022; Barber et al. 2022; Takano et al. 2023).

Generally, most pure-line, long-grain rice cultivars are more tolerant to florpyrauxifen-benzyl than hybrid, long-grain cultivars (Wright et al. 2020). Rice injury from florpyrauxifen-benzyl has been linked to environmental conditions such as soil moisture, air temperature, and light intensity, with certain cultivars being better able to tolerate the herbicide than others (Beesinger et al. 2022; Wright et al. 2020). Butts et al. (2022) also determined that florpyrauxifen-benzyl off-target movement was a concern among growers and consultants. When comparing multiple row crops, soybean was the most sensitive row crop to florpyrauxifen-benzyl, exemplifying the increased likelihood of injury following an off-target movement event where rice and soybean are grown nearby (Miller and Norsworthy 2018b; Butts et al. 2022b). With the off-target movement of florpyrauxifen-benzyl and varying rice tolerance being the main concerns for applying the herbicide, a safer alternative application method was necessary by industry professionals and researchers to support the continued the use of florpyrauxifen-benzyl.

Rice is an economically important crop in Arkansas where it accounts for 480,800 hectares and $1.2 billion annual value (USDA-NASS 2022; USDA-ERS 2022). However, rice requires more intensive management than other Arkansas row crops including additional expenses for herbicide applications and water management expenses. Rice is typically grown in flood-irrigated paddies. However, incorporating an alternative irrigation system utilizing furrows and polyethylene pipes to irrigate rice has become increasingly common in Arkansas (Hardke 2021). However, flood-irrigated rice still accounts for most of the rice grown in the state, with over 80% of rice hectares being flood-irrigated in 2021 (Hardke 2021). Once the rice is established and reaches the 5-leaf growth stage, a 5- to 7.5-cm flood depth produces an environment where rice, along with aquatic and semiaquatic weeds, can flourish, creating additional issues with weed control (Henry et al. 2018; Smith 1988). In this flooded culture, barnyardgrass and *Cyperus* spp. [rice flatsedge, yellow nutsedge, smallflower umbrella sedge, and white-margined flatsedge (*Cyperus flavicomus* Michx.)] were ranked as the most problematic weeds of Arkansas rice (Butts et al. 2022a). A spray application of florpyrauxifen-benzyl effectively controls most of these weeds (Miller and Norsworthy 2018a), albeit a safer application for minimizing off-target movement of the herbicide may be through coating it on urea as urea may have a lower likelihood to move off-target than water droplets. Unfortunately, the effectiveness of florpyrauxifen-benzyl coated on urea relative to a spray application of the herbicide is unknown.

Fertilizers have been evaluated as herbicide carriers for weed control in crops previously. Kells and Meggett (1985) observed more uniform herbicide coverage in conservation tillage systems from coating herbicides onto granular fertilizer, improving crop canopy and plant residue penetration. However, concerns over decreased precision and accuracy in applications that could lead to increased crop injury or decreased weed control come with this application method (Wells and Green 1991). Generally, a potential concern of utilizing fertilizers as a herbicide carrier is reduced coverage compared to liquid sprays. However, coating bensulfuron onto fertilizer proved to be an effective method for controlling ducksalad [*Heteranthera limosa* (Sw.) Willd.] but less effective on difficult-to-control weeds like junglerice [*Echinochloa colona* (L.) Link] (Braverman 1995). Factors surrounding applications, such as application timing and other untimely events, should also be evaluated when analyzing alternative application methods. Likely, this application method will also require timely interaction of the coated urea with floodwater to allow the herbicide to go into solution to be active. Florpyrauxifen-benzyl is not expected to be active in the soil as florpyrauxifen-benzyl is immobile in the soil (APVMA 2018).

Urea (46-0-0) is a nitrogen fertilizer that could be used as a carrier for florpyrauxifen-benzyl in rice because it is applied to most fields before flood establishment. Currently, a single preflood application of urea is one of two options for fertilizing rice where 100% of the season's total nitrogen requirement is applied at the preflood timing and would be an optimal fertilizer application timing to coat florpyrauxifen-benzyl onto urea prills (Hardke and Mazznati 2022). However, urea is prone to ammonia losses via volatilization when not coated with a urease inhibitor or if the field is not flooded promptly based on soil texture and pH (Norman et al. 2009). Flood timing can also influence weed control and crop tolerance to herbicides. For example, a preflood application of penoxsulam in rice was more injurious to the crop when flooded 1 and 7 d after treatment (DAT) than when flooded 14 DAT as flooding sooner after herbicide application increases the herbicide availability (Willingham et al. 2008). Additionally, the flood must be established within 7 DAT following an imazethapyr application to achieve at least 95% red rice (*Oryza sativa* L.) control, because the early flood is vital for enhancing the herbicide activity of imazethapyr (Avila et al. 2005). Hence, finding the right amount of time between herbicide application and flood establishment is important to provide adequate weed control while reducing the risk for crop injury.

One key to rice water management success is to maintain a continuous flood for the entire season (Henry et al. 2018). However, extenuating circumstances like rice injury, nutrient deficiencies, or a levee failure may cause the floodwater to be relinquished. Likewise, the impact flood loss can occur with its impact on preflood applications of florpyrauxifen-benzyl are unknown. Under greenhouse conditions, a flood loss of 2 cm per day after applying ipfencarbazone resulted in a comparable dry shoot weight of *Echinochloa* spp. compared to no flood loss, explaining that a small amount of flood loss equated to little herbicide loss or reduction in efficacy (Kasahara et al. 2018). However, a flood loss in a commercial rice field would likely lead to large amounts of water being lost and potentially losing herbicide depending on the route of water loss. Moreover, the parent compound, florpyrauxifen-benzyl, has a half-life of <3 days under anaerobic conditions, with the main source of degradation being aqueous photolysis in shallow waters such as those in flooded rice and hydrolysis being a second, slower source of degradation (Anonymous 2019). However, the acid metabolite of florpyrauxifen-benzyl degrades much slower than the parent compound with a half-life of 6.3 to 18 d

(Anonymous 2019). With a short half-life, reduced weed control could be expected when flood loss occurs closer to the florpyrauxifen-benzyl application.

Limited research has been conducted in recent years on coating fertilizers with herbicides as an alternative application method, especially florpyrauxifen-benzyl. Additionally, there is a lack of literature describing the impact of time until flood establishment and flood loss effects on florpyrauxifen-benzyl effectiveness. Hence, an experiment was conducted to assess the effectiveness of florpyrauxifen-benzyl as influenced by flood establishment timing after application with the herbicide applied on urea or as a spray. An additional experiment was conducted to examine the influence of flood loss timing after establishment on the effectiveness of florpyrauxifen-benzyl coated on urea.

MATERIALS AND METHODS

Flood Timing Experiment

An experiment on flood establishment timing following spray-applied and fertilizer-applied florpyrauxifen-benzyl was conducted at the Pine Tree Research Station (PTRS) near Colt, Arkansas, in 2020 and 2021. In both years, the soil texture was a Calloway silt loam, consisting of 0.7% sand, 83% silt, and 16.3% clay with 2.3% organic matter and a pH of 7.7. Plot sizes were 1.8- by 5.2-m with a 1-m alley between replications. The previous crop was rice, and the seedbed was prepared using conventional tillage. A quizalofop-resistant rice cultivar 'PVL01' (Provisia® technology, BASF, Florham Park, NJ 07932) was drill-seeded (Hege Company, Waldenburg, Germany, F.R.) in 9 rows with 19-cm row spacings at a 1.3-cm depth on May 5, 2020, and May 14, 2021, at 72 seeds per meter row. A preemergence application of clomazone (Command 3ME, FMC, Philadelphia, PA 19104) at 168 g ae ha^{-1}, one-half of the recommended rate, was applied across the entire experiment immediately after rice planting to provide early season weed control during rice establishment. The lower-than-labeled rate of clomazone was intended to provide some early-season weed suppression yet allow for enough weeds to evaluate the effectiveness of the florpyrauxifen-benzyl treatments.

The experiment was conducted as a randomized complete block design with a factorial arrangement of treatments and four replications. Nontreated plots were included in the study to provide a representation of herbicide-free check but excluded from statistical analysis. The two factors included the number of days until flood establishment (0, 5, and 10 d after herbicide

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

treatment) and florpyrauxifen-benzyl (Loyant™ Herbicide, Corteva Agrisciences™, 9330 Zionsville Road, Indianapolis, IN 46268) application method (spray applied or coated on urea). Florpyrauxifen-benzyl applications were initiated when the weeds at the 10-day preflood timing had reached approximately 8 cm in height. Florpyrauxifen-benzyl at 30 g ai ha^{-1} was applied as a liquid spray that included 0.58 L ha^{-1} of methylated seed oil or coated on urea. Urea was applied at 317 kg ha^{-1}, either coated on urea or without the herbicide at each florpyrauxifen-benzyl timing. Spray applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} with a hand-held boom containing four AIXR 110015 (TeeJet Technologies, Springfield, IL 62703) nozzles spaced 48-cm apart. Urea fertilizer was coated using an electric motor-driven mixer in batches of 23 kg. To match the desired herbicide rate, 2.18 g ai of florpyrauxifen-benzyl was measured and applied as a mist onto the 23 kg of urea via a plastic spray bottle. A blue dye was added to the mixture to provide a visual representation of the evenness of the herbicide coat. The urea, florpyrauxifen, and dye were then mixed continuously for 5 min to ensure even coating and to provide sufficient time for drying of the herbicide. The coated urea was then stored in plastic totes and used within one week of mixing. Preflood applications 10 d before flooding were the first preflood applications and occurred when targeted weeds reached 7.5 to 10 cm tall. Applications at each respective timing were sprayed and spread on the same day. The preflood applications at 0 and 5 d before flood establishment were based on the 10 days before flooding application (Table 1). At each respective preflood application, weed densities (1-m^2) were taken from each plot immediately before application. Levees were constructed to maintain bays with a 5- to 7.5-cm flood depth following preflood applications until crop maturity. Rice was managed using direct-seeded, delayed-flood cultural management practices (Henry et al. 2018).

Visual evaluations of weed control was rated at 3 and 5 wk following the final flooding event on a scale of 0 to 100, where 0 represents no weed control, and 100 represents complete weed control (Frans and Talbert 1986). When present at the test site, visible weed control ratings were taken for hemp sesbania, yellow nutsedge, broadleaf signalgrass, barnyardgrass, and ducksalad. Non-florpyrauxifen-benzyl treated plots treated with clomazone at 168 g ai ha^{-1} at planting were used to compare the efficacy of florpyrauxifen-benzyl and yield impacts. Visual evaluations of weed control ratings were based on aboveground biomass, stunting, leaf malformations, mortality, and overall ground cover. Rough rice grain was harvested from the four rows in the center of each plot using a small-plot combine (Kubota Corporation, Naniwa-ku, Osaka, Japan). Rough rice grain yield was calculated, and moisture was adjusted to 12%.

Data were analyzed in SAS 9.4 utilizing the PROC GLIMMIX function (SAS Institute Inc., Cary, NC). Percent visible weed control 3 and 5 wk after final treatment (WAFT) was determined to follow a beta distribution, and grain yield followed a normal distribution based on AICc and BIC values in the distribution platform of JMP Pro 16 (SAS Institute Inc., Cary, NC). A two-factor ANOVA was used to assess application method and flood timing following application. Block and year were considered a random effect with block nested within year. By considering block and year random effects, they are assumed to be uncorrelated with the individual main effects. Means were separated using Tukey's honestly significant difference (HSD) test (α=0.05). Additionally, the SLICEDIFF function was utilized within PROC GLIMMIX to test pairwise differences between application methods where application timing was a fixed level.

Flood loss experiment

An experiment was conducted at the Pine Tree Research Station (PTRS) near Colt, Arkansas, in 2020 and 2021 to evaluate the influence of flood loss and the varying application of florpyrauxifen-benzyl coated on urea applied on resulting rice weed control. In both years, the soil texture was the same as that described in the previous experiment. Plot size, tillage, cultivar, planting dates, and clomazone overspray were the same as in the described in the previous experiment.

The experiment was conducted as a randomized complete block design with four replications. Four losses of the established flood were evaluated following a preflood application of florpyrauxifen-benzyl coated on urea - no loss of flood, loss occurring at 2 hours, 24 hours, and 7 d after application. Flood loss was complete drainage of the plot. Plots took approximately two hours to flood and approximately 30 min to drain. Plots were flooded from a single inlet. Additionally, a no-florpyrauxifen-benzyl treatment was included. Florpyrauxifen-benzyl was coated on urea using the method described in the previous experiment. Florpyrauxifen-benzyl at 30 g ai ha^{-1} was coated on urea, and the fertilizer was applied at 317 kg ha^{-1}. Florpyrauxifen-benzyl applications were prepared and applied utilizing the same methods explained in the previous experiment. Flood water release timings were initiated following flood completion on

June 1, 2020, and June 15, 2021. Following each flood loss timing, bays were reflooded 24 hours after flood waters were removed and remained flooded until the crop reached maturity.

Visual evaluations of weed control ratings were based on aboveground biomass, stunting, leaf malformations, mortality, and overall ground cover and were made relative to a plot that lacked herbicide treatment. Visual evaluations of barnyardgrass, yellow nutsedge, and hemp sesbania control was rated similarly to the previous trial at 4 and 5 wk following the final flooding loss event (Frans and Talbert 1986). Non-florpyrauxifen-benzyl treated plots treated with clomazone at 168 g ai ha^{-1} at planting were used to compare the efficacy of florpyrauxifen-benzyl and yield impacts. Rice grain was harvested at crop maturity and reported as rough rice yield after adjusting to 12% moisture.

Data were analyzed in SAS 9.4 utilizing the PROC GLIMMIX function. Percent visible weed control 4 and 5 WAT was determined to follow a beta distribution, and grain yield followed a normal distribution based on AICc and BIC values in the distribution platform of JMP Pro 16. A single-factor ANOVA was used to assess flood loss timing effects following application. Block and year were considered random effects with block nested within year. By considering block and year random effects, they are assumed to be uncorrelated with the individual main effects. Means were separated using Tukey's HSD (α=0.05).

RESULTS AND DISCUSSION

Flood Timing Experiment

The main effect of application method was significant yellow nutsedge control at 3 WAFT (Table 2). Additionally, the interaction between timing till flood and application method was significant for barnyardgrass control at 3 WAFT. At 3 WAFT, coated and sprayed applications of florpyrauxifen-benzyl provided at least 98% control of hemp sesbania (data not shown). Additionally, spraying florpyrauxifen-benzyl at 30 g ai ha^{-1} provided 37 percentage points greater control of yellow nutsedge at 3 WAFT than when the herbicide was coated on urea and applied (Table 2). At 5 WAFT, the main effect of application method was significant for yellow nutsedge barnyardgrass (Table 2).

Like results at 3 WAFT, yellow nutsedge experienced an application method difference at 5 WAFT, where florpyrauxifen-benzyl coated on urea provided 63% control, and spraying the herbicide provided 35 percentage points greater control (Table 2). Coating florpyrauxifen-benzyl on urea likely did not provide adequate coverage to control yellow nutsedge at high plant densities (Table 1), and florpyrauxifen-benzyl tends to provide variable control of yellow nutsedge across environments, an indication that the weed is not highly sensitive to the herbicide. Additionally, differences in application methods were compared at each respective flood establishment timing at 3 and 5 WAFT. At both observation times, spraying florpyrauxifen-benzyl provided greater yellow nutsedge control when compared using a pairwise test to coating the herbicide on urea at all application timings (Table 2).

Like the high levels of hemp sesbania control, coating florpyrauxifen-benzyl at 30 g ai ha^{-1} onto urea still provided 98% or greater control of broadleaf signalgrass at 3 WAFT (data not shown). Likewise, the same level of broadleaf signalgrass control was observed at 5 WAFT (data not shown).

Differences at 3 WAFT in barnyardgrass control was best explained by the significant interaction between timing till flood and application method (Table 2). Coating florpyrauxifen-benzyl on urea and applying the day of flooding resulted in the lowest barnyardgrass control (89%) at 3 WAFT where the level of control was lower than control provided by sprayed florpyrauxifen-benzyl at day of flooding and 10 d prior to flooding application timings. However, only the main effect of application method elicited differences in barnyardgrass control (Table 2). Spraying florpyrauxifen-benzyl provided 96% barnyardgrass control while coating the herbicide on urea only provided 80% barnyardgrass control. However, when comparing the pairwise differences in application methods at each respective flood establishment timing at 5 WAFT, spraying florpyrauxifen-benzyl resulted in greater barnyardgrass control when applied at 0 and 10 d prior to flood establishment (Table 2).

Any differences between application methods yellow nutsedge or barnyardgrass control were likely attributed to the weeds not taking up enough florpyrauxifen-benzyl to prove fatal when the herbicide was dispersed in the flood water via coated on urea. Prior to this research, it was unknown if yellow nutsedge and barnyardgrass were sensitive enough to florpyrauxifen-benzyl to be controlled by an application method that has little foliar interception at application. Weeds, such as hemp sesbania and broadleaf signalgrass, that are more sensitive to florpyrauxifen-benzyl are easier to control by coating urea with florpyrauxifen-benzyl at 30 g ai ha^{-1}. Sensitivity to florpyrauxifen-benzyl appeared to be one of the main issues with coating the herbicide on urea. Based on research by Miller and Norsworthy (2018a), barnyardgrass and yellow nutsedge are generally harder to control with florpyrauxifen-benzyl than hemp sesbania. As explained by Table 1, weed density at the time of herbicide application and flooding appeared to play a role in variable weed control of tougher to control weeds. Herbicide dose and weed density have proved to go together when modeling rice-weed competition. Generally, as weed densities increased, more herbicide was needed to eliminate the weed population (Moon et al. 2014). Hence, florpyrauxifen-benzyl coated on urea at 30 g ai ha^{-1} was not enough herbicide to control the populations of yellow nutsedge and barnyardgrass based on the weed densities in Table 1.

Weed control variability, primarily highlighted by barnyardgrass control at 3 and 5 WAFT, provided by florpyrauxifen-benzyl coated on urea helped explain why differences in yield were apparent for the main effect of application method (Table 3). Rice yields harvested from plots that were treated with a sprayed florpyrauxifen-benzyl application were 7700 kg ha^{-1}. However, plots treated with florpyrauxifen-benzyl coated on urea produced a lower rice yield of 6500 kg ha^{-1}. Typically, as rice weed populations increase, lower rice yields are observed (Smith 1968). Plots not containing florpyrauxifen-benzyl were overtaken with weeds and only produced a rice yield of 3300 kg ha^{-1}. Pairwise tests comparing application methods within each application timing provided indications that plots sprayed with florpyrauxifen-benzyl at 0 and 5 d prior to flood produced higher yields than those treated with florpyrauxifen-benzyl (Table 3). Historically, as barnyardgrass control increases, rice yield components increase, explaining the importance of barnyardgrass control in rice (Ottis and Talbert 2007). Likewise, weeds, such as barnyardgrass, are a main source of nutrient removal in flooded rice fields (Saudy et al. 2021). Generally, lower weed control was directly associated with lower rice yields. While an economic yield loss was apparent following applications of florpyrauxifen-benzyl coated on urea, the potential safeness from adjacent soybean injury may outweigh the economic losses in specific scenarios. Additionally, other herbicides paired with florpyrauxifen-benzyl coated on urea may help bridge the gap in weed control and economic losses.

Flood loss experiment

When making evaluations of visual weed control following a loss of flood water event at 4 and 5 WAFT, no differences between flood loss timings were experienced for hemp sesbania, yellow nutsedge control, or rice yield (Table 4). Likewise, no differences in barnyardgrass control between any flood loss timings at 5 WAFT. However, barnyardgrass control at 4 WAFT

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

was the only instance in this experiment that elicited a flood loss difference (Table 4). No flood loss and flood loss 2 hours following flood establishment caused 87 and 88% barnyardgrass control, respectively. However, following a flood loss event at 24 hours and 7 days after flood establishment, florpyrauxifen-benzyl provided 94% barnyardgrass control at 4 WAFT. Florpyrauxifen goes through hydrolysis at a rapid pace and is a primary degradation method of the herbicide molecule, along with photolysis (Anonymous 2019). The rapid hydrolysis of florpyrauxifen-benzyl explains why barnyardgrass control was less following a flood loss 2 hours after flood establishment where the herbicide is at a higher concentration in the flood water compared to later flood loss timings where there is less hydrolyzed herbicide. The overall lack of statistical differences in hemp sesbania and yellow nutsedge was explained by the overall sensitivity of the weed to florpyrauxifen-benzyl. Hemp sesbania is very sensitive to florpyrauxifen-benzyl while yellow nutsedge is not as sensitive as other broadleaf weeds to florpyrauxifen-benzyl (Miller and Norsworthy 2018a). Additionally, yellow nutsedge control with florpyrauxifen-benzyl coated on urea suffered from the stand-alone preflood application, likely because the weed is a perennial with varying densities across the test site along with lower sensitivity to florpyrauxifen-benzyl than other weeds (Miller and Norsworthy 2018a). Coating florpyrauxifen-benzyl on urea provided less yellow nutsedge control than previous research where florpyrauxifen-benzyl was spray-applied at 30 g ai ha^{-1} (Miller and Norsworthy 2018a).

No differences in rice yield were observed in this experiment. Florpyrauxifen-benzyl has a relatively short half-life in water with the acid metabolite having a longer half-life, and its primary decomposition pathways are hydrolysis and photolysis (AVPMA 2018). Hence, longer time intervals between a florpyrauxifen-benzyl application and a flood loss event were expected to lower the effect on weed control. However, this relationship was only highlighted by slight differences in barnyardgrass control. Additionally, the underlying ideas of variable weed sensitivities and densities may have had an impact on the overall efficacy of florpyrauxifen-benzyl coated on urea. Moreover, flooding depth may have an overall impact on the in-water florpyrauxifen-benzyl concentration leading to potential differences in rice weed control.

PRACTICAL IMPLICATIONS

An alternative application method of florpyrauxifen-benzyl was imperative for more safely applying florpyrauxifen-benzyl. For that reason, safely applying florpyrauxifen-benzyl to rice with a reduced risk of off-target movement is critical for the continued use of the herbicide since soybean are highly sensitive to florpyrauxifen-benzyl (Miller and Norsworthy 2018b). However, based on these experiments, the alternative application method of coating florpyrauxifen-benzyl on urea comes with costs. Since this application method relies solely on activation by flood water or large rainfall events, research was conducted to determine the associated effects. The time interval between application and flooding proved less important on difficult-to-control weeds like yellow nutsedge and barnyardgrass. Coating florpyrauxifen-benzyl at 30 g ai ha^{-1} on urea does not appear to effectively control yellow nutsedge and barnyardgrass without using preemergence residual herbicides or alternative postemergence herbicides. However, additional research may be needed to identify the correct herbicide programs that incorporate florpyrauxifen-benzyl coated on urea and effectively control yellow nutsedge and barnyardgrass. Intervals between flooding and florpyrauxifen-benzyl applications should be minimized to prevent extra growth in weed size during that time. Once flood water is established, the best approach to maximizing weed control is to maintain a flood without loss. Aside from herbicide loss with flood loss, N losses through volatilization should be expected following flood losses if applied before flood establishment. Florpyrauxifen-benzyl alone coated on urea struggles to control barnyardgrass effectively and consistently, and PRE residual herbicides should be utilized to provide additional grass control. A program approach should be used with florpyrauxifen-benzyl coated on urea to offer greater control of barnyardgrass, yellow nutsedge, and hemp sesbania. Future research is needed to identify herbicide programs where florpyrauxifen-benzyl can be utilized for preflood or postflood weed control. Additionally, research is needed to observe any potential interactions of urease inhibitors with florpyrauxifen-benzyl when coated on urea.

ACKNOWLEDGMENTS

This research was conducted in cooperation with Corteva Agriscience. Facilities and equipment were provided by the University of Arkansas System Division of Agriculture.

FUNDING

Corteva Agriscience provided partial research funding and florpyrauxifen-benzyl. Additional funding for this research was provided by the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board.

COMPETING INTERESTS

Competing Interests: The author(s) declare none.

REFERENCES

Anonymous (2021) Loyant™ 2(ee) Recommendation. Aerial Applications of Loyant Impregnated on Dry Fertilizer. Corteva Agrisciences, Indianapolis, IN 46268. Accessed: July 30, 2022

Anonymous (2019) Review of Florpyrauxifen-benzyl for Application to Massachusetts Lakes and Ponds. Massachusetts Department of Agriculture Division of Crop and Pest Services. Massachusetts Department of Environmental Protection Office of Research and Standards. 3 p.

Anonymous (2018) Loyant™ Herbicide Product Label. Corteva Agrisciences Publication 010-02342. Indianapolis, IN. Accessed: July 30, 2022

Avila LA, Senseman SA, McCauley GN, Chandler JM, O'Barr JH (2005) Effect of flood timing on red rice (*Oryza* spp.) control with imazethapyr applied at different dry-seeded rice growth stages. Weed Technol 19:476-480

APVMA (2018) Public release summary on evaluating the new active florpyrauxifen-benzyl (Rinskor™) in the product GF-3301 herbicide. Australian Pesticides and Veterinary Medicines Authority, Australian Government

Barber LT, Butts TR, Boyd JW, Cunningham K, Selden G, Norsworthy JK, Burgos N, Bertucci M (2022) MP44: Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture, Cooperative Extension Service. 90 p.

Beesinger JW, Norsworthy JK, Butts TR, Roberts TL (2022) Impact of environmental and agronomic conditions on rice injury caused by florpyrauxifen-benzyl. Weed Technol 36:93-100

Braverman MP (1995) Weed control in rice (*Oryza sativa*) with quinclorac and bensulfuron coating of granular herbicides and fertilizer. Weed Technol 9:494-498

Butts TR, Kouame KB-J, Norsworthy JK, Barber LT (2022a) Arkansas rice: herbicide resistance concerns, production practice, and weed management costs. Front Agron 4:881667

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

Butts TR, Fritz BK, Kouame BJ, Norsworthy JK, Barber LT, Ross WJ, Lorenz GM, Thrash BC, Bateman NR, Adamczyk JJ (2022b) Herbicide spray drift from ground and aerial applications: implications for potential pollinator foraging sources. Scientific Reports 12:18017

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

ERS (Economic Research Service) USDA (United States Department of Agriculture) Rice Sector at a Glance. http://www.ers.usda.gov/topics/crops/rice/rice-sector-at-a-glance/. Accessed July 30, 2022.

Hardke JT, Mazzanti R (2022) 2022 Arkansas Rice Quick Facts. University of Arkansas Division of Agriculture, Cooperative Extension Service

Hardke JT (2021) Trends in Arkansas rice production, 2020. B.R. Wells Arkansas Rice Research Studies 2020:11-18. University of Arkansas Division of Agriculture, Cooperative Extension Service

Henry C, Daniels M, Hamilton M, Hardke JT (2018) Water Management. *In* Rice Production Handbook 10:103-128. Arkansas Cooperative Extension Service

Hwang J, Norsworthy JK, Gonzalez-Torralva F, Piveta LB, Priess GL, Barber LT, Butts TR (2022) Absorption, translocation, and metabolism of florpyrauxifen-benzyl and cyhalofop-butyl in cyhalofop-butyl resistant barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.]. Pesticide Biochemistry and Physiology 180:104999

Kasahara T, Takeuchi T, Koyama K, Kuzuma S (2018) Effects of environmental factors on the herbicidal activity and phytotoxicity of ipfencarbazone. J Pestic Sci 43:255-260

Kells JJ, Meggitt WF (1985) Conservation tillage and weed control. A Systems Approach to Conservation Tillage. 1st ed. Pp 123-129

Miller MR, Norsworthy JK (2018a) Florpyrauxifen-benzyl weed control spectrum and tank-mix compatibility with other commonly applied herbicides in rice. Weed Technol 32:319-325

Miller MR, Norsworthy JK (2018b) Row crop sensitivity to low rates of foliar-applied florpyrauxifen-benzyl. Weed Technol 32:398-403

NASS (National Agricultural Statistics Service) USDA (United States Department of Agriculture) (2022) 2021 State Agricultural Overview. Arkansas. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ARKANSAS. Accessed July 30, 2022

Norman RJ, Wilson CE, Slaton NA, Griggs BR, Bushong JT, Gbur EE (2009) Nitrogen fertilizer sources and timing before flooding dry-seeded, delayed-flood rice. Soil Sci Soc Am J 73:2184-2190

Ottis B, Talbert R (2007) Barnyardgrass (*Echinochloa crus-galli*) control and rice density effects on rice yield components. Weed Technol 21:110-118

Saudy HS, El-Metwally, Shahin MG (2021) Co-application effect of herbicides and micronutrients on weeds and nutrient uptake in flooded irrigated rice: does it have a synergistic or an antagonistic effect? Crop Protect 149:105755.

Smith RJ (1988) Weed thresholds in southern U.S. rice, *Oryza sativa*. Weed Technol 2:232-241

Smith RJ (1968) Weed competition in rice. Weed Technol 16:252-255

Takano H, Greenwalt S, Ouse D, Zielinshi M, Schmitzer P (2023) Metabolic cross-resistance to florpyrauxifen-benzyl in barnyardgrass (*Echinochloa crus-galli*) evolved prior to its commercialization. Weed Sci DOI: https://doi.org/10.1017/wsc.2023.11

Wells KL, Green JD (1991) Using solid, bulk blended mix-grade fertilizers. University of Kentucky Plant and Soil Sciences. Soil Science News and Views 12:1-3

Willingham SD, McCauley GN, Senseman SA, Chandler JM, Richburg JS, Lassiter RB, Mann RK (2008) Influence of flood interval and cultivar on rice tolerance to penoxsulam. Weed Technol 22:114-118

Wright HE, Norsworthy JK, Roberts TL, Scott R, Hardke J, Gbur EE (2020) Characterization of rice cultivar response to florpyrauxifen-benzyl. Weed Technol 35:82-92

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

Table 1. Dates of preflood florpyrauxifen-benzyl applications at respective preflood time intervals and weed densities in 2020 and 2021.[ab]

Time interval	Date	Weed species	Density	Height	Leaf Number
			# m^{-2}	cm	# $plant^{-1}$
0 days	May 28, 2020	Hemp sesbania	22	5	4
		Broadleaf signalgrass	42	5	6
		Barnyardgrass	96	6	6
		Yellow nutsedge	137	6	6
	June 15, 2021	Hemp sesbania	89	8	3
		Broadleaf signalgrass	91	8	6
		Barnyardgrass	248	10	6
		Yellow nutsedge	290	11	7
5 days	May 25, 2020	Hemp sesbania	5	4	3
		Broadleaf signalgrass	20	4	4
		Barnyardgrass	75	4	5
		Yellow nutsedge	115	5	5
	June 9, 2021	Hemp sesbania	14	5	3
		Broadleaf signalgrass	40	4	4
		Barnyardgrass	77	5	4
		Yellow nutsedge	233	5	6
10 days	May 21, 2020	Hemp sesbania	3	3	2
		Broadleaf signalgrass	17	3	3
		Barnyardgrass	52	3	3
		Yellow nutsedge	98	3	4
	June 4, 2021	Hemp sesbania	5	3	2
		Broadleaf signalgrass	36	3	4
		Barnyardgrass	60	3	3
		Yellow nutsedge	153	3	5

[a] Preflood application occurred at ±2 days before the targeted application timing

[b] Flooding of all plots occurred at the “0 days” time interval

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

Table 2. Effects of timing till flood and florpyrauxifen-benzyl application method on visible weed control estimates in rice at 3 and 5 WAFT.[abcdef]

Source		Control at 3 and 5 WAFT							
		Yellow nutsedge				Barnyardgrass			
		3 WAFT		5 WAFT		3 WAFT		5 WAFT	
Timing	DOF	95		95		96		92	
	5 DPTF	84		86		95		88	
	10 DPTF	92		92		98		92	
	P-value	0.2315		0.2936		0.2613		0.6540	
Method	Spray	98	A	98	A	98		96	A
	Coated	61	B	63	B	93		80	B
	P-value	<0.0001*		<0.0001*		0.0012		0.0020*	
Timing* method	DOF*spray	99	(*S*)	99	(*S*)	98	A	97	(*S*)
	DOF*coated	73		74		89	B	81	
	5 DPTF*spray	97	(*S*)	97	(*S*)	95	AB	90	(*NS*)
	5 DPTF*coated	48		52		95	AB	87	
	10 DPTF*spray	98	(*S*)	98	(*S*)	99	A	98	(*S*)
	10 DPTF*coated	61		61		93	AB	71	
	P-value	0.9241		0.9105		0.0311*		0.0755	

[a] Applications of florpyrauxifen-benzyl were initiated when weeds reached approximately 3-leaf growth stage, and subsequent applications were applied based on the single flood timing

[b] All plots were treated with clomazone at 168 g ae ha^{-1} (1/2X rate) at planting

[c] Abbreviations: DOF, day of the flood; DPTF, days before the flood; WAFT, weeks after the final treatment

[d] Data included from 2020 and 2021

[e] Pairwise differences are signified by (*S*) for significant, adjusted p-value less than 0.05, and (*NS*) for non-significant, adjusted p-value greater than 0.05, as compared within each application timing

[f] Means within the same column not containing the same letter are different according to Tukey's HSD (α=0.05)

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

Table 3. Effects of timing till flood and florpyrauxifen-benzyl application method on rough rice grain yield.[abcdefg]

Source		Yield	
		kg ha $^{-1}$	
Timing	DOF	8000	
	5 DPTF	7300	
	10 DPTF	6900	
	P-value	0.6216	
App method	Spray	7700	A
	Coated	6500	B
	P-value	0.0020*	
Timing* method	DOF*spray	7800	(*S*)
	DOF*coated	6400	
	5 DPTF*spray	8000	(*S*)
	5 DPTF*coated	6500	
	10 DPTF*spray	7200	(*NS*)
	10 DPTF*coated	6500	
	P-value	0.5339	

[a] Applications of florpyrauxifen-benzyl were initiated when weeds reached approximately 3-leaf growth stage, and subsequent applications were applied based on the single flood timing

[b] All analyzed plots were treated with clomazone at 168 g ae ha^{-1} (1/2X rate) at planting

[c] Abbreviations: DOF, day of the flood; DPTF, days before the flood; WAFT, weeks after the final treatment

[d] Data included from 2020 and 2021

[e] Nontreated plots resulted in a yield of 3300 kg ha^{-1}, averaged between 2020 and 2021

[f] Pairwise differences are signified by (*S*) for significant, adjusted p-value less than 0.05, and (*NS*) for non-significant, adjusted p-value greater than 0.05, as compared within each application timing

[g] Means within the same column not containing the same letter are different according to Tukey's HSD (α=0.05)

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press

Table 4. Effects flood loss timing on rice weed control 4 and 5 WAFT and rough rice grain yield.[abc]

Source		Control							
		Hemp sesbania		Yellow nutsedge		Barnyardgrass			
		4 WAFT	5 WAFT	4 WAFT	5 WAFT	4 WAFT		5 WAFT	Yield
		---------------------------------------%--							kg ha^{-1}
Flood	None	95	95	61	58	87	B	87	6100
loss	2 hrs	93	92	59	56	88	B	89	6400
	24 hrs	96	95	53	66	94	A	93	6500
	7 days	95	94	43	38	94	A	91	5400
	P-value	0.7557	0.5913	0.5879	0.1957	<0.0001*		0.0665	0.3130

[a] All analyzed plots were treated with florpyrauxifen-benzyl at 30 g ae ha^{-1} coated on urea at 4- to 5-leaf rice growth stage and subsequently flooded 24 hours later, where flood drainage commenced following the completion of the initial flooding

[b] All analyzed plots were treated with clomazone at 168 g ae ha^{-1} (1/2X rate) at planting

[c] Non-florpyrauxifen-benzyl treated plots resulted in yields of 5800 and 3000 kg ha^{-1} in 2020 and 2021, respectively, and were treated with clomazone at 168 g ae ha^{-1}with no flood loss

[d] Abbreviations: WAFT, weeks after the final treatment

[e] Means within the same column not containing the same letter are different according to Tukey's HSD (α=0.05)

https://doi.org/10.1017/wet.2024.27 Published online by Cambridge University Press