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L. Connor Webster
LSU Agricultural Center

Samer Y. Rustom
LSU Agricultural Center

Eric P. Webster
University of Wyoming College of Agriculture

Ben Stoker
LSU Agricultural Center

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Early Season Weed Management Options in Water-seeded Rice Production

L. Connor Webster[1], Samer Y. Rustom[2], Eric P. Webster[3] and Ben Stoker[4]

[1]Assistant Professor (ORCID 0000-0001-6662-8739), School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA, USA;
[2]Research Associate (ORCID 0000-0001-9938-2827), School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA, USA ;
[3]Associate Dean (ORCID 0000-0003-4809-6876), University of Wyoming College of Agriculture, Life Sciences, and Natural Resources, Laramie WY, USA;
[4]Research Associate (ORCID 0009-0001-8695-4993), School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA, USA.

Author of correspondence: Connor Webster, Assistant professor, Louisiana State University, School of Plant, Environmental, and Soil Science; 104 Sturgis Hall, Baton Rouge, LA 70808 United States, (lwebster@agcenter.lsu.edu)

Nomenclature: Florpyrauxifen; halosulfuron; prosulfuron; rice, *Oryza sativa* L.

Abstract

Two separate field studies were conducted at two locations at the LSU Agricultural Center H. Rouse Caffey Rice Research Station (RRS) near Crowley, LA to evaluate early season applications of florpyrauxifen and a prepackaged mixture of halosulfuron plus prosulfuron in water-seeded rice production. In each study, florpyrauxifen and halosulfuron plus prosulfuron were applied at two rates and either applied to the soil surface 48 hours before the seeding flooding and seeding (SURFACE), directly onto the pregerminated seed 24 hours following seeding and immediately after removal of the seeding flood (SEED), and at pegging (PEG). Data suggests that both florpyrauxifen and halosulfuron plus prosulfuron have a fit in water-seeded rice production. Crop injury of 19% was observed from applications of florpyrauxifen applied directly to pregerminated SEED. Additionally, 28% crop injury was observed when halosulfuron plus prosulfuron was applied directly to SEED. Due to crop injury observations, both herbicides should be avoided when the pregerminated seed is exposed to the soil surface after removing the seeding flood. These data suggest that florpyrauxifen may be a better POST option, whereas halosulfuron plus prosulfuron may be a better PRE option in water-seeded rice production. Overall, the findings show that both herbicide technologies will provide adequate early-season weed control in water-seeded rice production.

Keywords: rice, crop injury, herbicide, water-seeded, weed control

Introduction

Water-seeding was the predominant rice planting method in Louisiana prior to the release of imidazolinone-resistant (IR) cultivars in 2002 (Linscombe 1999; Masson and Webster 2001). Since the release of IR-rice, growers in Louisiana have shifted to a predominantly drill-seeded production system (Ronnie Levy, LSU AgCenter Rice Specialist, personal communication). Although drill-seeding is the predominant planting method, 17% of rice planted in Louisiana in 2020 was water-seeded (Harrell 2020). Of the 17% of water-seeded rice acres, 63% utilized a pin-point flooding system. Due to the popularity of drill-seeded rice in recent years, research is lacking on the use of new technologies in water-seeded rice production.

Water-seeding begins with submerging rice seed in water for approximately 24 h to allow the seed to imbibe water and after soaking, the seed is allowed to drain for 24 h (Masson and Webster 2001). The pregerminated seed is loaded into a plane and aerial seeded. Approximately 24 h after planting, the seeding flood water is then drained for 4- to 7-d to allow for stand establishment. Allowing the rice seed to imbibe water prior to broadcasting into a standing flood will allow the rice seed to sink to the soil surface. Rice seed that has not imbibed water may float on the soil surface after seeding resulting in an inconsistent stand. Historically, water-seeding rice was done as a cultural control measure for red rice (Baker and Sonnier 1983; Smith 1981). In addition to cultural control of red rice, water-seeding can be utilized when excessive rainfall prevents drill-seeding production practices (McKnight 2017).

Florpyrauxifen-benzyl (florpyrauxifen) (Loyant® herbicide with Rinskor™ active, Corteva Agriscience Indianapolis, IN), a synthetic auxin herbicide, was first commercially available in 2018. Florpyrauxifen belongs to a new structural class of synthetic auxins, the arylpicolinates, with activity on grass, broadleaf, and sedge weeds (Miller and Norsworthy 2018a; Telo et al. 2018). Florpyrauxifen has low water solubility, is tightly bound to soil particles, and has a half-life of 1- to 8-d in the soil (Miller and Norsworthy 2018b). Because of these characteristics it is believed that florpyrauxifen does not have season-long soil activity/residual and should be used as a postemergence (POST) foliar herbicide.

Florpyrauxifen-benzyl is considered a pro-herbicide, meaning it is biologically inactive until the molecule undergoes a chemical transformation to its active acid form (Jeschke 2015a). In this case, florpyrauxifen-benzyl must undergo enzymatic hydrolysis to become florpyrauxifen; therefore, soil moisture plays a key role in the activity of florpyrauxifen-benzyl (Epp et al. 2016;

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Jeschke 2015b; Rustom 2020). Miller and Norsworthy et al. (2018b) reported that at 48 hours after application under 60% soil moisture 97, 90, and 86% of florpyrauxifen-benzyl applied was absorbed into leaf tissue of barnyardgrass, hemp sesbania, and yellow nutsedge, respectively. However, under 7.5% soil moisture, florpyrauxifen-benzyl absorption into barnyardgrass, hemp sesbania, and yellow nutsedge was reduced to 54, 53, and 44%, respectively. It was concluded that soil moisture played a key role in the amount of florpyrauxifen-benzyl absorbed into leaf tissue.

A prepackaged mixture of halosulfuron-methyl (halosulfuron) plus prosulfuron (Gambit®, Gowan Company, Yuma, AZ), two acetolactate synthase (ALS)-inhibiting herbicides belonging to the sulfonylurea family, was released for commercial use in 2018. The prepackaged mixture of halosulfuron plus prosulfuron provides control of many common broadleaf, aquatic, and sedge weeds in rice production (Anonymous 2019). Halosulfuron plus prosulfuron is currently used in Louisiana rice production as a preplant burndown, preemergence (PRE) for residual control, POST, and as a salvage treatment for many common broadleaf and sedge weeds in drill-seeded rice production (Rustom 2020).

The potential for halosulfuron plus prosulfuron to injure rice in water-seeded production systems is a concern. Previous research has concluded that ALS inhibiting herbicides labelled for use in rice can cause foliar injury as well as root mass reductions (Bond et al. 2007; Braverman and Jordan 1996; Dunand and Dilly 1994; Ellis et al. 2005; Zhang and Webster 2002). Bispyribac-sodium (bispyribac), an ALS-inhibiting herbicide belonging to the pyrimidinylthiobenzoic acid family, caused reductions to shoot and root growth of medium grain ‘Bengal’ rice in a greenhouse study (Zhang and Webster 2002). It was concluded that medium-grain Bengal rice was less tolerant to bispyribac than long-grain ‘Cocodrie’ rice and crop injury appeared to be more prevalent with earlier application timings. Zhang et al. (2005) concluded that inhibition of root and shoot growth was more prevalent when bispyribac was applied to one- to two-leaf rice compared with two- to three-leaf rice. Grain size as well as application timing appear to both play a role in the tolerance of rice to bispyribac.

Penoxsulam, an ALS inhibiting herbicide belonging to the triazolopyrimidine family, has been reported to cause injury to rice (Bond et al. 2007; Ellis et al. 2005). Ellis et al. (2005) concluded that root mass reductions were observed from 29 to 65% across four different cultivars treated with penoxsulam at 35 g ai ha^{-1} at the four- to five-leaf rice growth stage.

However, when penoxsulam was applied to rice in the panicle initiation stage, no root mass reductions were observed. Bond et al. (2007) observed no reductions in rice height, days to 50% heading, or yield across ten rice varieties consisting of long-, medium-, and short-grain rice varieties treated with penoxsulam at 70 g ha^{-1}; however, a root mass reduction of up to 76% of the nontreated was observed for long-grain rice. In the same study, bispyribac was also observed to cause root mass reductions of 65% of long-grain rice when applied at 28 g ha^{-1}. The soil pH at the location of this study was 8.2, which may have played a role in the reductions of root mass observed (Bond et al. 2007).

Previous research has shown that ALS-inhibiting herbicides can cause foliar injury to rice; however, rice root inhibition may be the more prevalent form of injury. ALS-inhibiting herbicides can cause a reduction in the number of photosynthates that are transported from foliar tissue to root tissue, resulting in reductions in root growth (Bond et al. 2007; Devine 1989; Devine et al. 1990). Multiple ALS inhibiting herbicides belonging to multiple chemical families have been shown to injure rice, which causes concerns for early season applications of halosulfuron plus prosulfuron in water-seeded rice production.

Since the release of these new technologies in 2018, much of the research has been conducted in drill-seeded rice. Rice seed in water-seeded rice production is exposed on the soil surface after seeding and removal of the seeding flood, often leaving the seed vulnerable to early season herbicide applications. Research is needed to determine the optimal window of early season applications of florpyrauxifen and halosulfuron plus prosulfuron. The objective of this study is to evaluate new technologies for their early season weed control and potential crop injury in water-seeded rice production.

Materials and Methods

Two separate field studies were conducted in 2021 and replicated across two different soil types and planting dates at the LSU Agricultural Center H. Rouse Caffey Rice Research Station (RRS) near Crowley, LA. Field studies were conducted to evaluate the early season use of florpyrauxifen and a premixture of halosulfuron plus prosulfuron in water-seeded rice production. Each product was evaluated in separate trials. The soil type for the first planting date, April 14, 2021, at the RRS was a Crowley silt loam (fine smectic, thermic Typic Albaqualfs) with a pH of 6.5 and 2.3% organic matter. The soil type for the second planting date, June 3,

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2021, at the RRS was a Midland silty clay loam (Fine, smectitic, thermic Chromic Vertic Epiaqualfs) with a pH of 5.7 and 3.3% organic matter.

Field preparation consisted of a fall and spring disking followed by two passes in the opposite direction with a two-way bed conditioner consisting of rolling baskets and s-tine harrows set at a depth of 6 cm. The seedbed was rolled with a cultipacker prior to seeding to create furrows for an even distributing of rice seed. A preplant fertilizer of 8-24-24 ($N-P_2O_5-K_2O$) was applied at 280 kg ha^{-1} followed by an application of 280 kg ha^{-1} of 46-0-0 fertilizer when rice reached the four-leaf to one-tiller stage. A seeding flood of 5-cm was introduced to the field and pregerminated 'RT7321 FP' (Fullpage® RiceTec, Alvin, TX 77512) hybrid rice was hand broadcasted at 67 kg ha^{-1}. The rice seed was pregerminated for 48 h before seeding. After seeding, the flood was removed from the field allowing the rice radicle to anchor in the soil and begin vegetative growth. Soon after vegetative growth began, a pinpoint flood was reintroduced to the field, approximately 7 d after seeding, and the depth of the flood was raised as the rice grew vegetatively until a maximum depth of 10-cm was achieved. The flood was maintained until two weeks prior to harvest.

Plot size was 1.5 by 5.2 m^{-2}. Each study was a randomized complete block with an augmented two-factor factorial arrangement of treatments with three replications. Factor A for both studies consisted of herbicides applied to the soil surface 48 h before the seeding flood and seeding (SURFACE), directly onto the pregerminated seed 24 h following seeding and immediately after removal of the seeding flood (SEED), and 10 days following seeding at pegging (PEG). Factor B for the first study consisted of florpyrauxifen applied at 15 or 29 g ai ha^{-1} (Table 1). Factor B for the second study consisted of a prepackaged mixture of halosulfuron plus prosulfuron at 55 or 83 g ai ha^{-1}. A nontreated was added to each study for comparison.

Florpyrauxifen was applied at a late POST (LPOST), four- to five-leaf rice, timing at 29 g ha^{-1} to both studies to remove any remaining weeds. All SEED, PEG, and LPOST applications were applied with a methylated seed oil (MSO) at 0.5% v v^{-1}. All herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1}. The spray boom consisted of five flat-fan 110015 nozzles (Flat Fan AirMix Venturi Nozzle, Greenleaf Technologies, Covington, LA 70434) with 38-cm spacings.

The research area for the florpyrauxifen study was naturally infested with barnyardgrass, Indian joinvetch, and rice flatsedge. The research area for the halosulfuron plus prosulfuron study was naturally infested with Texasweed, Indian joinvetch, and rice flatsedge. Visual evaluations for crop injury and weed control were recorded at 14, 21, and 28 d after treatment (DAT), where 0 = no control and 100 = plant death. Weed control ratings in the florpyrauxifen study were recorded for barnyardgrass, Indian jointvetch, and rice flatsedge. Weed control ratings in the prepackaged mixture of halosulfuron plus prosulfuron study were recorded for Indian jointvetch, rice flatsedge, and Texasweed. Immediately prior to harvest, rice plant height was recorded measuring from the soil surface to the tip of the panicle. Prior to harvest, the plot lengths were trimmed to an average of 4.6 m. The entire plot area, 6.9 m^{-2}, was harvested with a Wintersteiger small plot combine (Wintersteiger Inc, Salt Lake City, UT 84116) to determine the rough rice yield. Grain yield was adjusted to 12% moisture content.

All data from each study were subject to the mixed procedure in SAS (release 9.4, SAS Institute, Cary, NC). Injury and weed control data from each study were analyzed as repeated measures using the mixed procedure in SAS. For each study Type III main effects for rice injury and weed control consisted of herbicide application timing, herbicide rate, and DAT. Type III fixed effects for plant height and rough rice yield consisted of herbicide application timing and herbicide rate. Mean separations were obtained using the Tukey's test with a probability level of 5%. Location, planting date, and replication were considered random effects. The effect of different environmental conditions on herbicide activity across locations and planting dates represent the random effects of the test (Carmer et al. 1989; Hager et al. 2003). A correlation test was performed for the florpyrauxifen study to determine significant impacts from rice injury and weed control on plant heights and rough rice yield.

Results and Discussion

Florpyrauxifen study. Herbicide application timing, rate, and rating interval main effects were observed for rice injury (Table 2). Rice injury was most severe when florpyrauxifen was applied at the SEED timing. This is most likely since florpyrauxifen was applied directly to the pregerminated rice seed which was exposed on the soil surface. Because the radicle was emerged from the seed, it is likely that florpyrauxifen was absorbed via mass flow of water and other solutes. Florpyrauxifen applied at the SURFACE timing resulted in 10% rice injury. Although florpyrauxifen is thought to have little to no soil persistence there appears to be some soil activity. The herbicide 2, 4-D, with a similar mode of action, was thought to persist in the soil for short periods because its half-life is four days (Altom and Stritzke 1973; Bovey and

Mayeux 1980; Wilson and Worsham 1987). Jordan et al. (1997) observed 8% rice injury from an application of 2,4-D at 7 d before planting in drill-seeded rice. The half-life of florpyrauxifen is 1- to 8-d depending on the soil type (Miller and Norsworthy 2018a), so similar injury to rice can be expected. Rice injury was reduced to 3% when florpyrauxifen was applied at the PEG timing. Allowing the rice to establish a root system as well as above ground foliage played a role in the reduction of injury.

Florpyrauxifen injury to rice was reduced to 8% when the lower rate of 15 g ha^{-1} was applied compared with 13% injury when the higher rate of 29 g ha^{-1} was applied (Table 2). At 14 DAT, rice injury averaged across all application timings and rates was 22%. By 21 DAT, injury was reduced to 8% and by 28 DAT rice injury was 4% averaged across all herbicide treatments and applications. This research closely coincides with Wright et al. (2021) who observed florpyrauxifen injury when applied at 30 g ha^{-1} on two- to three-leaf hybrid rice.

An application timing by herbicide rate interaction occurred for barnyardgrass control; therefore, data were averaged over rating date (Table 3). Barnyardgrass control increased as the application timing was delayed and as the rate of florpyrauxifen increased at each application timing. Florpyrauxifen applied prior to the seeding flood at the SURFACE application timing controlled barnyardgrass 25 and 35%, indicating florpyrauxifen has some residual activity. An increase in barnyardgrass control was observed when florpyrauxifen was applied at the SEED application timing compared with the SURFACE application timing; however, the SEED application timing resulted in increased rice injury (Table 2). The optimal application timing for barnyardgrass control was the PEG timing, which controlled barnyardgrass at 87 and 92%.
The increased barnyardgrass control when florpyrauxifen-benzyl was applied at the SEED and PEG timings compared with the SURFACE timings is most likely due to florpyrauxifen-benzyl having
better activity on emerged barnyardgrass with some residual activity observed for florpyrauxifen-benzyl applied at the SURFACE timing. Miller et al. (2018) concluded that 25.7 g ha^{-1} of florpyrauxifen-benzyl was needed in order to control three- to four-leaf barnyardgrass. These results suggest that small barnyardgrass may be controlled with lower rates of florpyrauxifen-benzyl; however, for optimal control the full labelled rate should be used when targeting barnyardgrass.

An application timing by herbicide rate interaction occurred for Indian jointvetch control with florpyrauxifen-benzyl; therefore, data were averaged over rating date (Table 3). Florpyrauxifen-benzyl applied at the SURFACE timing at 15 and 29 g ha^{-1} controlled Indian jointvetch 63 and 75%, respectively; however, florpyrauxifen-benzyl applied at the same timing controlled barnyardgrass 25 and 35%. These results suggest that florpyrauxifen-benzyl has higher residual activity on broadleaf species than grass species present in these trials. Similar to barnyardgrass control, an increase in Indian jointvetch control was observed when florpyrauxifen-benzyl was applied at the SEED timing compared with a SURFACE application. The highest levels of Indian jointvetch control were observed when florpyrauxifen-benzyl was applied at 29 g ha^{-1} at the SEED timing and either rate applied at the PEG timing; however, rice injury is a concern when florpyrauxifen-benzyl is applied directly on pre-germinated seed. Indian jointvetch control did not differ regardless of the rate of florpyrauxifen-benzyl applied PEG. Similar to barnyardgrass control, an increase in Indian jointvetch control was observed when florpyrauxifen-benzyl was applied at the SEED and PEG timings most likely due to Indian jointvetch emergence prior to treatment.

An application timing by herbicide rate interaction occurred for rice flatsedge control; therefore, data were averaged over application timing (Table 3). Similar control of rice flatsedge occurred from both rates of florpyrauxifen-benzyl applied at the SURFACE timing. Similar to barnyardgrass and Indian jointvetch control, an increase in control was observed when florpyrauxifen-benzyl was applied at the SEED timing. Florpyrauxifen-benzyl controlled rice flatsedge at 96 and 97% when applied at the PEG timing, which was similar to Indian jointvetch control, no difference in control was observed for either rate of florpyrauxifen-benzyl applied PEG. Indian jointvetch and rice flatsedge control levels were similar across application timings; however, the control differs from barnyardgrass control when florpyrauxifen-benzyl is applied at the SURFACE timing. These results suggest that a higher rate of florpyrauxifen-benzyl is needed to maximize control of barnyardgrass, but a reduced rate of 15 g ha^{-1} provides similar control of Indian jointvetch and rice flatsedge.

An application by herbicide rate interaction occurred for plant heights taken prior to rice harvest (Table 4). Florpyrauxifen-benzyl applied at the SURFACE timing resulted in reduced plant heights expressed as a percent of the nontreated. Results from a correlation test (Data not shown) suggest that reductions in plant heights when rice was treated at the SURFACE timing

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compared with the SEED and PEG timings are a result of weed interference (Table 3). Reduced weed control from the SURFACE application timing compared with the SEED and PEG timings allowed for weeds to compete with the rice for necessary components needed for plant growth, resulting in reduced rice plant height. Florpyrauxifen-benzyl applied at the SURFACE timing provided the least amount of control of all weed species evaluated, which in turn caused a reduction in plant heights at maturity due to weed interference.

Similar to plant heights, an application by herbicide rate interaction occurred for rough rice yield (Table 4). Rice treated with florpyrauxifen-benzyl applied at 29 g ha^{-1} at the SEED timing and both rates of florpyrauxifen-benzyl applied at the PEG timing resulted in rough rice yields of 6,790 to 7,100 kg ha^{-1}. Florpyrauxifen-benzyl applied at the SEED timing resulted in the most rice injury observed (Table 2); however, rough rice yield was the same when the high rate of florpyrauxifen-benzyl was applied at the SEED timing compared with rice treated with florpyrauxifen-benzyl at the PEG timing with either rate. A correlation test proved that injury did not significantly correlate to rough rice yield (data not shown). Similar to the reductions in plant heights, rough rice yield reductions appear to be a result of weed interference.

For all weeds evaluated, an increase in weed control was observed at the SEED and PEG timings compared with the SURFACE timing. This is most likely due to florpyrauxifen-benzyl having more POST activity compared with soil activity. However, due to the rice injury observed at the SEED timing this application timing should be avoided. The optimal timing for florpyrauxifen-benzyl is the PEG rice growth stage, due to the reduced rice injury as well as increased weed control. At the time of the PEG application the rice that had established a root system with at least one true leaf appears to be more tolerant to applications of florpyrauxifen-benzyl in water-seeded rice production. The results from florpyrauxifen-benzyl applied at the SURFACE timing do suggest that florpyrauxifen-benzyl has soil residual activity, but this residual activity was dependent on weed species (Table 3). Florpyrauxifen-benzyl appears to have more soil activity for Indian jointvetch and rice flatsedge when compared with barnyardgrass. For optimal broad-spectrum weed control, florpyrauxifen-benzyl should be applied to pegging rice at the full labelled rate. If barnyardgrass is not present, a rate of 15 g ha^{-1} will control the broadleaf and sedge weeds evaluated in this study. Early season weed interference proved to play a key role in rough rice yield more so than injury from florpyrauxifen-benzyl. Wright et al. (2021) did not find any differences in grain yield when long grain 'CL111' rice was treated with sequential applications of florpyrauxifen-benzyl at 30 g ha^{-1} in drill-seed rice.

Halosulfuron plus prosulfuron study. An application timing by herbicide rate interaction occurred for rice injury when treated with halosulfuron plus prosulfuron; therefore, data were averaged over evaluation dates (Table 5). Rice treated with halosulfuron plus prosulfuron applied at 83 g ha^{-1} at the SEED timing resulted in 28% injury. Rice treated with either rate of halosulfuron plus prosulfuron and application timings resulted in 3 to 8% rice injury. Applications of ALS-inhibiting herbicides have been shown to cause injury to young rice plants (Bond et al. 2007; Braverman and Jordan 1996; Dunand and Dilly 1994; Ellis et al. 2005; Zhang and Webster 2002). ALS-inhibiting herbicides have been shown to cause root growth reductions in rice, and it is likely that halosulfuron plus prosulfuron inhibited root growth when applied directly to pregerminated seed at 83 g ha^{-1}. Soil pH plays an important role in the chemical hydrolysis of halosulfuron plus prosulfuron, and an increase in crop injury can be expected when soil pH is 7.8 or greater (Anonymous 2019). The soil pH for the two research locations was 5.7 and 6.5, so it can be expected that rice injury levels will be greater on soils with a higher pH.

An application timing by herbicide rate interactions occurred for Texasweed, Indian jointvetch, and rice flatsedge control; therefore, data were averaged over evaluation dates (Table 5). Although significant interactions occurred, control of Texasweed, Indian jointvetch, and rice flatsedge was 92 to 97%, 85 to 96%, and 93 to 97%, respectively. These results suggest halosulfuron plus prosulfuron provides high levels of residual and POST activity for the weeds evaluated in this study across multiple application timings in water-seeded rice production.

Although 95 to 96% control of all weed species was observed from halosulfuron plus prosulfuron applied at 83 g ha^{-1} at the SEED timing, this application timing and rate should be avoided due to increased rice injury.

An application by herbicide rate interaction occurred for plant heights taken at rice harvest maturity (Table 6). Although a significant interaction occurred for plant heights expressed as percentages of the nontreated, plant heights were 98 to 101%. An application by herbicide rate interaction occurred for rough rice yield. All halosulfuron plus prosulfuron treatments resulted in an increase in rough rice yield compared with the nontreated. The nontreated rice had a yield of 4,990 kg ha^{-1} compared with treated rice, which yielded 6,340 to

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6780 kg ha^{-1}. Rice treated with halosulfuron plus prosulfuron at 83 g ha^{-1} at the PEG timing yielded 6,780 kg ha^{-1}; however, a reduction in rice yield was observed at 6,340 kg ha^{-1} when halosulfuron plus prosulfuron was applied at the same rate at the SEED timing. This reduction in yield was probably due to the high level of injury observed with 83 g ha^{-1} of halosulfuron plus prosulfuron applied at the SEED timing.

These results suggest that the high rate of halosulfuron plus prosulfuron applied directly on pregerminated rice seed should be avoided. Overall, halosulfuron plus prosulfuron controlled the broadleaf and sedge weeds evaluated in this trial 85 to 97%. However, due to the lack of grass control from halosulfuron plus prosulfuron (Anonymous 2019), a herbicide that offers grass activity will need to be include in the herbicide program. Future research should be conducted to determine if halosulfuron plus prosulfuron causes reductions in root growth in water-seeded rice production.

Practical Implications

Results for both florpyrauxifen-benzyl and halosulfuron plus prosulfuron studies suggest that these new herbicide technologies have a fit in water-seeded rice production for early season applications. However, applications immediately following aerial seeding and the removal of the seeding flood should be avoided, especially at higher rates. Rice injury was 19% from florpyrauxifen-benzyl applied directly to pre-geminated seed at the SEED timing averaged across rates of 15 and 29 g ha^{-1} (Table 2). Rice injury from halosulfuron plus prosulfuron at 83 g ha^{-1} was 28% when applied at the SEED timing (Table 5). By applying halosulfuron plus prosulfuron at a lower rate, rice injury can be reduced; however, weed control may be impacted.

Weed control was higher with florpyrauxifen-benzyl applied at the SEED and PEG timings compared with the SURFACE application. These results suggest that florpyrauxifen-benzyl has superior POST activity; however, some residual activity was observed. Because florpyrauxifen-benzyl must undergo hydrolysis to the active acid form of florpyrauxifen, application timings in closer proximity to the pinpoint flood may result in an increase in weed control. Increased soil moisture near the application timing plays a key role in conversion of this herbicide to its active form and ultimately the activity of the herbicide (Jeschkle 2015a; Epp et al. 2016; Miller and Norsworthy 2018b; Rustom 2020). There also appears to be an advantage to applying florpyrauxifen-benzyl to emerged weeds compared with the soil residual activity.

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Florpyrauxifen-benzyl should not be relied on as a PRE application but the soil activity can be beneficial for early season POST applications. Because halosulfuron plus prosulfuron has little to no activity on grass weed species, these results suggest that florpyrauxifen-benzyl may be a better POST application in water-seeded rice production; however, the presence of different weed species may drive herbicide decisions (Rustom 2020; Greer 2021). However, due to the residual activity from halosulfuron plus prosulfuron compared with florpyrauxifen-benzyl at the SURFACE timings, halosulfuron plus prosulfuron may be a more effective PRE option.

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Competing Interests

Competing interests: The authors declare none.

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Table 1. Source of materials.[a]

Active Ingredient	Trade Name	Form[a]	Rate	Manufacturer
			g ai ha^{-1}	
Florpyraxifen	Loyant®	EC	15, 29	Corteva Agriscience, Indianapolis, IN
Halosulfuron + prosulfuron	Gambit®	WDG	55, 83	Gowan Company, Yuma, AZ
MSO[b]	MSO®	L	-	Loveland Products, Loveland, CO

[a]Abbreviations: EC, emulsifiable concentrate; WDG, water dispersible granule; L, liquid.

[b]MSO was applied at 0.5% v v^{-1}

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Table 2. Significant main effect interactions for crop injury after rice was treated with florpyrauxifen applied at different timings, application rates, and d after treatment, and data were averaged over two locations in 2021.

Main effects[a]		Crop injury[b]	
		%[c]	
Application timing	SURFACE[d]	10	b
	SEED	19	a
	PEG	3	c
Rate (g ai ha^{-1})	15	8	b
	29	13	a
DAT	14	22	a
	21	8	b
	28	4	b

[a] Data for application timing is averaged over rate and DAT. Data for herbicide rate is averaged over application timing and DAT. Data for DAT is averaged over application timing and rate.

[b]Means for each main effect followed by a common letter do not significantly differ using Tukey-Kramer at $P<0.05$.

[c]Injury was visually measured using a scale of 0 = no injury or control and 100 = complete plant death.

[d]Abbreviations: SURFACE, surface application prior to seeding; SEED, following seeding; PEG, at pegging; DAT, d after treatment.

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Table 3. Barnyardgrass, Indian jointvetch, and rice flatsedge control when treated with florpyrauxifen at different application timings and rates, averaged across rating dates over both locations in 2021.[a,b]

Florpyrauxifen[c]		Control (%)					
Timing	Rate	Barnyardgrass		Indian jointvetch		Rice flatsedge	
	g ai ha^{-1}	%[d]					
SURFACE[e]	15	25	f	63	D	73	c
	29	35	e	75	C	78	c
SEED	15	65	d	83	B	86	b
	29	80	c	96	A	95	a
PEG	15	87	b	97	A	96	a
	29	92	a	97	A	97	a

[a]Means within columns followed by a common letter do not significantly differ using Tukey-Kramer at $P<0.05$.

[b]Ratings were recorded at 14, 21, and 28 d after treatment.

[c]Florpyrauxifen applied at 15 or 29 g ha^{-1} applied at SURFACE, SEED, and PEG.

[d]Barnyardgrass, Indian jointvetch, and rice flatsedge control was visually measured using a scale of 0 = no injury and 100 = complete plant death.

[e]Abbreviations: SURFACE, surface application prior to seeding; SEED, following seeding; PEG, at pegging; DAT, d after treatment.

Table 4. Rice plant heights taken immediately prior to harvest and rough rice yields averaged over two locations in 2021.[a]

Florpyrauxifen[b]		Rice plant height		Yield[d]	
Timing	Rate				
	g ai ha^{-1}	% of nontreated[c]		kg ha^{-1}	
—	0	—		4560	c
SURFACE[d]	15	100	d	4780	c
	29	99	d	5860	b
SEED	15	103	c	6140	b
	29	108	a	7000	a
PEG	15	105	b	6790	a
	29	106	b	7100	a

[a]Means within columns followed by a common letter do not significantly differ using Tukey-Kramer at $P<0.05$.

[b]Florpyrauxifen applied at 15 or 29 g ha^{-1} applied at SURFACE, SEED, and PEG.

[c]Expressed as a percent of the nontreated, 115 cm.

[d]Abbreviations: SURFACE, surface application prior to seeding; SEED, following seeding; PEG, at pegging; DAT, d after treatment.

[d]Rough rice yield was adjusted to 12% moisture.

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Table 5. Rice injury, Texasweed, Indian jointvetch, and rice flatsedge control when treated with halosulfuron plus prosulfuron, averaged across d after treatment over two locations in 2021.[a]

Halosulfuron + prosulfuron[b]		Crop injury		Control					
Timing	Rate			Texasweed		Indian jointvetch		Rice flatsedge	
	g ai ha^{-1}	%[c]							
SURFACE[d]	55	8	b	92	b	85	c	93	d
	83	7	b	95	a	94	ab	95	bc
SEED	55	4	b	94	ab	92	b	95	bc
	83	28	a	96	a	95	a	96	abc
PEG	55	3	b	97	a	94	ab	97	a
	83	4	b	96	a	96	a	97	a

[a]Means within columns followed by a common letter do not significantly differ using Tukey-Kramer at P<0.05.

[b]Halosulfuron plus prosulfuron applied at 55 or 83 g ha^{-1} applied at SURFACE, SEED, and PEG.

[c]Rice injury and barnyardgrass, Indian jointvetch, and rice flatsedge control was visually measured using a scale of 0 = no injury and 100 = complete plant death.

[d]Abbreviations: SURFACE, surface application prior to seeding; SEED, following seeding; PEG, at pegging; DAT, d after treatment.

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Table 6. Rice plant heights taken at harvest and rough rice yields when treated with halosulfuron plus prosulfuron, averaged over both locations in 2021.[a,b]

Halosulfuron + prosulfuron[c]		Rice plant height		Yield[d]	
Timing	Rate				
	g ai ha^{-1}	% of nontreated[e]		kg ha^{-1}	
—	0	—		4990	c
SURFACE[d]	55	100	ab	6350	ab
	83	99	bc	6620	ab
SEED	55	98	c	6710	ab
	83	100	ab	6340	b
PEG	55	101	a	6620	ab
	83	101	a	6780	a

[a]Means within columns followed by a common letter do not significantly differ using Tukey-Kramer at $P<0.05$.

[b]Abbreviations: SURFACE, surface application prior to seeding; SEED, following seeding; PEG, at pegging; DAT, d after treatment.

[c]Halosulfuron plus prosulfuron applied at 55 or 83 g ha^{-1} applied at SURFACE, SEED, and PEG.

[d]Rough rice yield was adjusted to 12% moisture.

[e]Expressed as percentages of the nontreated, 119 cm.

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