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Florpyrauxifen-benzyl in rice

Impact of florpyrauxifen-benzyl on hybrid rice seeded at different densities

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Abstract

Florpyrauxifen-benzyl is a postemergence (POST) rice herbicide that has reduced rice yield in some situations, and producers are concerned that the impact could be even greater with low rice seeding densities. Therefore, research was conducted in Stoneville, MS, from 2019 to 2021 to evaluate the effect of florpyrauxifen-benzyl on rice yield when a hybrid was seeded at reduced densities. Hybrid rice ‘RT 7521 FP’ was seeded at 10, 17, 24, 30, and 37 kg ha^{-1}. At the four-leaf to one-tiller growth stage, florpyrauxifen-benzyl was applied at 0 or 59 g ai ha^{-1}. Rice injury following the application of florpyrauxifen-benzyl was ≤ 8% across all seeding rates and evaluation intervals. Application of florpyrauxifen-benzyl reduced plant heights by 14% across all seeding rates but did not result in delayed rice maturity. When florpyrauxifen-benzyl was not applied rice in the 10 and 17 kg ha^{-1} seeding rates, rice matured slower than when seeded at 24, 30, and 37 kg ha^{-1}. When florpyrauxifen-benzyl was applied, rough rice grain yields were reduced by 17 and 37 kg ha^{-1} but not at any other seeding rate. In conclusion, the application of florpyrauxifen-benzyl at a 2x rate can cause a loss of yield resulting from variation in rice densities.

Nomenclature: Florpyrauxifen-benzyl; rice, *Oryza sativa* L.; ‘RT 7521 FP’

Keywords: seeding rate, herbicide tolerance, maturity

Introduction

Rice is one of the most important food crops, providing 19% of the caloric intake for the world's population (McKenzie et al. 2014). In 2022, Mississippi produced 34,008 ha of rice, with an average yield of 8,264 kg ha^{-1} (USDA-NASS 2022). Rice production in Mississippi is almost completely limited to counties within the Mississippi-Yazoo Delta area, which consists of a 19-county area that borders the Mississippi River to the west. Bolivar and Tunica counties rank first and second in terms of harvested area with 8,947 and 7,773 rice ha during 2022, respectively, accounting for an average yield of 8,533 kg ha^{-1} and 8,130 kg ha^{-1} from the two respective counties (USDA-NASS 2022).

Weeds are one of the most limiting factors in rice production (Buehring 2008) and compete with rice for nutrients, water, space, and sunlight (Smith et al. 1977). The three most troublesome weeds in midsouthern U.S. rice production are *Cyperus* spp., *Echinochloa* spp., sprangletop spp., and red rice (*Oryza sativa*) biotypes (Van Wychen 2020). Barnyardgrass is a rice-mimicking weed that can cause substantial yield losses of up to 57% in severe cases (Dayan et al. 2012). One barnyardgrass plant per 40 cm^{-1} of row can reduce rice yield by up to 27% (Stauber 1991).

Herbicide-resistant weeds were not known to occur in U.S. rice prior to 1990 (Miller and Norsworthy 2018). Repeated use of herbicides with the same mode of action led to the selection and buildup of resistant plant populations (Carey et al. 1997; Retzinger and Mallory-Smith 1997). Propanil, a Group 7 herbicide, has been used extensively by rice producers since its introduction in 1959 (Smith 1961). However, the continued use of propanil led to the development of propanil-resistant barnyardgrass, which was first verified in Poinsett County, Arkansas, in 1989 (Smith 1993). The resistance mechanism of barnyardgrass was documented to be elevated metabolism of propanil by the enzyme aryl acylamidase (Carey et al 1997). Following the discovery of propanil-resistant barnyardgrass, quinclorac, a Group 4 herbicide, was introduced in 1992 and became the standard for barnyardgrass control (Talbert and Burgos 2007). However, in 1999, a barnyardgrass biotype from Arkansas was found to have multiple resistance to quinclorac and propanil (Lovelace et al. 2000). Since the initial observation of herbicide resistance in barnyardgrass, additional resistance to the chemicals developed to replace propanil has been observed. The development of barnyardgrass resistance to propanil, quinclorac, and herbicides in Group 2 including imazamox and imazethapyr has limited the herbicide options for controlling barnyardgrass (Carey et al. 1997; Lovelace et al. 2000, Norsworthy et al. 2013).

Florpyrauxifen-benzyl is a Group 4 POST herbicide belonging to the arylpicolinate family of synthetic auxins that was commercialized in 2018 by Corteva Agriscience (Corteva, 9330 Zionsville Road, Indianapolis, Indiana 46268). Florpyrauxifen-benzyl can control problematic weeds such as yellow nutsedge (*Cyperus esculentus* L.), hemp sesbania [*Sesbania exaltata* (Raf.) Cory], and barnyardgrass when applied at the labeled rate (Miller and Norsworthy 2018). Florpyrauxifen-benzyl has a site of action different from that of quinclorac, favoring the AFB5 IAA co-receptor instead of the TIRI co-receptor, which allows florpyrauxifen-benzyl to have activity on quinclorac-resistant barnyardgrass (Lee et al. 2014; Miller et al. 2018; Walsh et al. 2006). In rice production, florpyrauxifen-benzyl provides an alternate mode of action, which controls photosystem II-, synthetic auxin-, 1-deoxy-D-xylulose-5-phosphate (DOXP) synthase-, and acetolactate synthase (ALS)-resistant barnyardgrass (Epp et al. 2016).

Previous research has shown the propensity of florpyrauxifen-benzyl to control barnyardgrass greater than 96% (Miller et al. 2018). However, rice sensitivity to florpyrauxifen-benzyl application has been documented (Beesinger et al. 2022; Sanders et al. 2020; Wright et al. 2020). Rice cultivar selection and many environmental factors can influence rice injury following florpyrauxifen-benzyl application, such as extremely dry or saturated conditions, above-average temperatures, and cloudy conditions (Beesinger et al. 2022; Sanders et al. 2020). Beesinger et al. (2022) observed up to 36% injury following soil moisture conditions at 40% and 100%, indicating that both drought and saturated soils can increase injury symptoms. Wright et al. (2020) reported 34% injury 3 wk after florpyrauxifen-benzyl was applied 5 d apart on hybrid 'CLXL745', whereas injury for 'CL111' was < 10% 3 wk after sequential applications. Sanders et al. (2020) observed 6% greater injury following florpyrauxifen-benzyl applications on 'PVL01' compared to 'CLXL745', 'PVL013', and 'PVL081'. Injury following florpyrauxifen-benzyl application has been shown to be influenced by temperature, soil moisture conditions, and cultivar selection. Research has not focused on the impact florpyrauxifen-benzyl application can have on seeding rates in rice.

In the midsouthern U.S. rice-producing area, proper seeding rate is critical for stand establishment and producing high yields (Bond et al. 2005; Gravois and Helms 1992; Miller et al. 1991). Environmental conditions and management factors such as seeding method, cultivar, and tillage can cause the optimum seeding rate for rice in the midsouthern U.S. to fluctuate (Harrell and Blanche 2010). Rice has the capacity to overcome low plant populations by producing more reproductive tillers, which are culms that grow from the parent stem and produce panicles (Pinson et al. 2015). Gravois and Helms (1992) reported that rice seeding rates reduced by 66% produced yields comparable to those following greater seeding rates. When seeding rates are reduced, rice can compensate for the reductions and increase panicle density and filled grain per panicle (Counce 1987; Gravois and Helms 1992; Jones and Synder 1987; Ottis and Talbert 2005; Wells and Faw 1978; Yoshida and Parao 1972). Conversely, when rice seeding rates are increased, a decrease in panicles plant^{-1} is observed (Ottis and Talbert 2005). Counce et al. (1987) attributed the reduction in rice yield at excessive rice densities to be associated with population-dependent stressors such as water deficits, disease, and nutrient deficiencies.

Ottis and Talbert (2005) reported that increased seeding rates in rice resulted in poor emergence likely caused by intraspecific competition among neighboring plants. Alternatively, reduced seeding rates resulted in improved emergence from decreased intraspecific competition.

The advancement of breeding and genetic technologies has led to the development of more productive rice cultivars (Nalley et al. 2016). Introduction of hybrid rice began in 2000 in the midsouthern U.S. (Nalley et al. 2017). The overall number of hectares seeded to hybrid rice in the midsouthern U.S. increased from 15 to 40% between 2005 and 2013. Hybrid rice returned $0.16 more profit for every dollar invested than inbred cultivars. Research into the productivity of hybrid rice has shown 15-20% higher yield potential when compared to inbred cultivars under reduced and optimum growing conditions (Katsura et al. 2007; Yuan et al. 1994). Yuan et al. (1994) reported that inbred rice produced greater panicles m^{-2} and spikelets m^{-2} compared to hybrid rice but fewer spikelets per panicle and 1000 grain weight. Filled grain number per panicle has been the main yield component in support of the variability of yield between inbred and hybrids (Bueno and Lafarge 2009).

The development of hybrid rice, along with rice's natural ability to compensate for low densities, has led to a decrease in seeding rates. With florpyrauxifen-benzyl possessing the potential to reduce rice yield, producers are concerned that the negative impact could be even greater in field situations where reduced seeding densities are employed. Therefore, research

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was conducted to evaluate the effect of florpyrauxifen-benzyl on rice performance and yield when hybrid rice was seeded at reduced densities.

Materials and Methods

The research was conducted once in 2019 and twice in 2020 and 2021 at the Mississippi State University Delta Research Extension Center in Stoneville, MS, to determine the impacts of florpyrauxifen-benzyl applications on the growth and yield of hybrid rice seeded at different densities. Geographic coordinates and soil information from each site year are presented in Table 1. Rice was seeded using a small-plot grain drill (Great Plains 1520, Great Plains Mfg, Inc., 1525 East North St., Salina, KS 67401). Plots were 1.5 by 4.5 m, containing eight rows of rice spaced 20 cm apart, and separated by a fallow perpendicular alley 1.5 m in width. In all studies, glyphosate (Roundup PowerMax 4.5 L, 1,120 g ae ha^{-1}, Bayer Company, St. Louis, MO 63167), paraquat (Gramoxone 2.0 SL, 560 g ai ha^{-1}, Syngenta Crop Protection, Greensboro, NC 27409), and/or 2,4-D (2,4-D Amine 3.8 SL, 560 g ae ha^{-1}, Agri Star, Ankeny, IA 50021) were applied in late-March to early-April each site year to control emerged vegetation. Clomazone (Command 3 ME, 560 g ai ha^{-1}, FMC Corporation, Philadelphia, PA 19103) plus saflufenacil (Sharpen 2.85 SC, 50 g ai ha^{-1}, BASF Crop Protection, Research Triangle Park, NC 27709) were applied preemergence (PRE) each site year for residual weed control. Imazethapyr (Newpath 2 L, 105 g ai ha^{-1}, BASF Crop Protection, Research Triangle Park, NC 27709) plus quinclorac (Facet 1.5 L, 420 g ai ha^{-1}, BASF Crop Protection, Research Triangle Park, NC 27709) plus petroleum oil surfactant (Herbimax, 83% petroleum oil, Loveland Products, Greeley, CO 80632) at 1% (V/V) were applied at two-leaf rice (EPOST) stage to maintain experimental sites weed free.

The experimental design was a randomized complete block with a 2 (florpyrauxifen-benzyl treatment) by 5 (seeding rate) factorial arrangement of treatments and four replications. Factor A was florpyrauxifen-benzyl rate and included florpyrauxifen-benzyl (Corteva, 9330 Zionsville Road., Indianapolis, Indiana 46268) applied at 0 or 58 g ai ha^{-1} plus methylated seed oil surfactant (MSO Concentrate, 70% methylated seed oil of soybean Loveland Products, P.O. Box 1286, Greeley, CO 80632) at 0.83% (v/v) when rice reached the four-leaf to one-tiller growth stage. Applications of florpyrauxifen-benzyl were made at twice (2x) the labeled rate to evaluate herbicide tolerance (Wright et al. 2020; Sanders et al. 2020). Factor B was the seeding rate and included hybrid rice 'RT 7521 FP' (RiceTec Inc. P.O. Box 1305 Alvin, TX 77512) seeded at 10, 17, 24, 30, or 37 kg ha^{-1}. The seeding rates were percentages (120, 80, 56.67, and 33.3%) based on the recommended seeding rate of 30 kg ha^{-1} for RT 7521 FP (Harrell et al. 2021). Seeding rates in these experiments were chosen to cover a range of seeding rates from 25% higher than the maximum recommended seeding rate to 33% of the recommended seeding rate to simulate poor rice populations (Bond et al. 2005). Treatments were applied with a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (AM11002 nozzle, Greenleaf Technologies, 230 E Gibson St., Covington, LA 70433) set to deliver 140 L ha^{-1}.

Data collection included visible injury assessed on a scale of 0 to 100%, where 0 indicated no injury, and 100 indicated complete death at 7, 14, 21, and 28 d after application (DAA) (Frans and Talbert 1977). Rice plant height was recorded by measuring from the base of the plant to the tip of the uppermost leaf of five randomly selected plants on rows two and seven of each plot 14 DAA. Rice maturity was estimated as the number of days to 50% heading (when 50% of panicles in an individual plot had emerged from the leaf sheath) and recorded as days after emergence (DAE). Plots were mechanically harvested with a small-plot combine (Zürn Harvesting GmbH & Co. KG., Kapellenstr. 1 D 74214 Schöntal-Westernhausen, Germany) to obtain rough rice yield. Rough rice yields were recorded and adjusted to 12% moisture for uniform statistical analysis.

Data were regressed against the seeding rate, allowing for both linear and quadratic terms with coefficients depending on the seeding rate, and non-significant model terms were removed sequentially until a satisfactory model was obtained (Golden et al. 2006). Data that did not exhibit a significant trend were subjected to ANOVA using the PROC GLIMMIX procedure in SAS V 9.4 (SAS Institute Inc. 100 SAS Campus Drive Cary, NC 27513-2414, USA) with siteyear and replication (nested within siteyear) as random effects parameters (Blouin et al. 2011). Estimates of the Least Square Means at a 5% significance level were used for mean separation.

Results and Discussion

No biological trends in seeding rate were detected for rice injury across evaluations or rice maturity (P=0.0659 to 0.9166). Pooled across seeding rates, rice injury following florpyrauxifen-benzyl application was 4, 7, 6, and 5% at 7, 14, 21, and 28 DAA, respectively (data not presented). Wright et al. (2020) reported that in a field environment, 'CL111' was injured < 10% 3 wk after florpyrauxifen-benzyl application. Additionally, injury observed in a corresponding growth chamber trial never exceeded 9%. Sanders et al. (2020) reported injury among eight modern cultivars did not exceed 13%, 28 d after florpyrauxifen-benzyl application. Differential tolerance of certain rice cultivars to florpyrauxifen-benzyl application could be attributed to a lack of bioactivation, metabolic activity, or differences in receptor affinity at the site of action (Velásquez et al. 2021). Previous research has illustrated the impact environmental factors such as light, soil moisture, and temperature levels can have on florpyrauxifen-benzyl application on rice. Beesinger et al. (2022) reported that when florpyrauxifen-benzyl was applied to rice, the injury was 20% when subjected to high (24/35 C; night/day) temperatures and low (700 μmol m^{-2} s^{-1}) light levels. Furthermore, when soil moisture concentrations were 40 and 100%, injury from florpyrauxifen-benzyl application was 35 and 36%, respectively. Saturated moisture conditions found in a rice field can exacerbate injury following florpyrauxifen-benzyl application.

In the current research, rice plant height was reduced following exposure to florpyrauxifen-benzyl. Quadratic regression analysis indicated that the intercept for rice plant height when no florpyrauxifen-benzyl was applied (P=0.0475, R^2= 0.9524) was 62.20. When florpyrauxifen-benzyl was applied at 58 g ha, quadratic regression analysis indicated that the intercept for rice plant height was 56.41 (P=0.0775, R^2= 0.8735) (Table 2). Florpyrauxifen-benzyl reduced plant heights by 14% across all seeding rates. The greatest reduction in rice plant height between the two florpyrauxifen-benzyl treatments was 19% when rice was seeded at 37 kg ha^{-1}. Previous research has indicated that florpyrauxifen-benzyl can reduce plant height in certain cultivars by up to 20% (Beesinger et al. 2022; Sanders et al. 2020; Wright et al. 2020).

The main effect of the seeding rate was significant for rice maturity (P=<0.0001) (Table 3). Hybrid rice seeded at 10 and 17 kg ha^{-1} matured more slowly than that seeded at 24, 30, and 37 kg ha^{-1} (Table 3). Aklilu (2020) reported that rice planted at lower seeding rates had less competition for resources, resulting in delayed maturity. When florpyrauxifen-benzyl was applied, rice maturity was not affected (P=0.0588). Across eight different rice cultivars, no differences in rice maturity were detected when florpyrauxifen-benzyl was applied (Sanders et al. 2020).

Application of florpyrauxifen-benzyl reduced rough rice yield. Cubic and quadratic regression analysis indicated that the intercept for rough rice yield when no florpyrauxifen-

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benzyl was applied (P=0.0286, R^2=0.9995) and when florpyrauxifen-benzyl was applied at 58 g ha (P=0.0201, R^2=0.9798), was -1527.6688 and 8812.13, respectively (Table 4; Figure 1). When florpyrauxifen-benzyl was applied to 'RT 7521 FP' seeded at 17 and 37 kg ha^{-1}, rough rice yields were 10,406 and 10,500 kg ha^{-1}, compared to rough rice yields of 17 (11,758 kg ha^{-1}) and 37 (13,276 kg ha^{-1}) receiving no florpyrauxifen-benzyl, a 12 and 23% reduction was observed, respectively. Rough rice yield of the 10 kg ha^{-1} seeding rate was reduced by 27% when compared to the 37 kg ha^{-1} seeding rate. However, when florpyrauxifen-benzyl was applied, the rough rice yield of the 10 kg ha^{-1} seeding rate was reduced 5.9% when compared to the 37 kg ha^{-1} seeding rate. Sanders et al. (2020) reported that rough rice yield was reduced across eight cultivars when florpyrauxifen-benzyl was applied. Wright et al. (2020) reported that 'CL111' had no yield loss when the application of florpyrauxifen-benzyl occurred but significantly reduced the yield of the cultivar 'CLXL245'. In contrast to the current research, Velásquez et al. (2021) reported that while rice injury from florpyrauxifen-benzyl increased with rate, yield was not affected.

Practical Implications

This research demonstrates that florpyrauxifen-benzyl has the capacity to reduce rough rice yield of hybrid rice seeded at lower-than-recommended densities. Rice injury from florpyrauxifen-benzyl applied at a 2x rate was ≤ 8% across all hybrid seeding rates. Sanders et al. (2020) reported ≤ 10% injury on commercial and experimental rice cultivars 14 d after florpyrauxifen-benzyl applied at a 2x application rate. The injury was 11 and 13% greater when florpyrauxifen-benzyl was applied to the inbred cultivars 'CL163' and 'PVLO24-B', respectively, compared with the hybrid 'CL XL745' (Sanders et al. 2020). Rice cultivar differential tolerance to florpyrauxifen-benzyl has been attributed to varying crop metabolism rates among cultivars (Velásquez et al. 2021). In some cases, non-bioactivation of the florpyrauxifen-benzyl ester could be the cause of a lack of injury.

Similar to previous research, this study found application of florpyrauxifen-benzyl can result in reduced plant height. Wright et al (2020) observed that injury from florpyrauxifen-benzyl application may not always be visible, attributing injury to height and biomass reductions. Rice maturity was significantly affected by the seeding rate, as the 10 kg ha^{-1} seeding rate matured two days slower than the 37 kg ha^{-1}. Delaying rice maturity could potentially negatively impact rice producers in the mid-southern U.S. due to the tropical storm systems that are

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common during the harvest months of August and September. In the current study, florpyrauxifen-benzyl had no impact on rice maturity. Sanders et al. (2020) reported no delay in rice maturity when florpyrauxifen-benzyl was applied across multiple rice cultivars. Previous research has documented the ability of florpyrauxifen-benzyl to reduce rice yield across numerous different cultivars and environmental factors (Beesinger et al. 2022; Sanders et al. 2020; Wright et al. 2020). The current research indicates an application of florpyrauxifen-benzyl at a 2x rate can result in a loss of yield due to variation in rice densities. Rice producers should consider the impact of applying florpyrauxifen-benzyl to reduced or excessive rice plant populations. Growers should ensure that plant populations are at the recommended seeding rate of 30 kg ha^{-1} for ‘RT 7521 FP’ when applying florpyrauxifen-benzyl.

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Competing Interest

No competing interests have been declared.

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Table 1. Coordinates, soil series, and soil description from research evaluating rice hybrid response to seeding rates and postemergence applications of florpyrauxifen-benzyl from 2019 to 2021 at the Mississippi State Delta Research Extension Center Stoneville, MS.

Siteyear	Coordinates	Soil series	Description
2019	33°26'26.01"N, 90°55'54.33"W	Commerce very fine sandy loam	Silty over clay, mixed, superactive, nonacid, thermic, Fluvaquentic Endoaquepts
2020	33°26'26.42"N, 90°55'53.37"W	Commerce very fine sandy loam	Silty over clay, mixed, superactive, nonacid, thermic, Fluvaquentic Endoaquepts
2021-A	33°26'26.48"N, 90°55'54.15"W	Commerce very fine sandy loam	Silty over clay, mixed, superactive, nonacid, thermic, Fluvaquentic Endoaquepts
2021-B	33°25'25.61"N, 90°55'54.46"W	Tunica clay	Clayey over loamy, smectitic over mixed, superactive, nonacid, thermic Vertic Epiaquepts

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Table 2. Regression coefficients for rice plant height in research evaluating rice hybrid response to seeding rates and postemergence application of florpyrauxifen-benzyl from 2019 to 2021 at Stoneville, MS.

Parameter	Rate	Intercept	SE	Linear	SE	Quadratic	SE	Cubic	SE
	g ai ha^{-1}								
Rice plant height	0	62.2028	1.9271	0.8500	0.2039	-0.01587	0.0048	-	-
	58	56.4131	2.5219	0.8208	0.2668	-0.0211	0.0062	-	-

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Table 3. Influence of seeding rate on maturity research evaluating rice hybrid response to seeding rate and postemergence application of florpyrauxifen-benzyl from at Stoneville, MS, from 2019 to 2021.[a]

Seeding rate	Rice maturity[b]	
kg ha^{-1}	DAE	
10	75	a
17	75	a
24	74	b
30	74	b
37	73	b

[a] Data were pooled over two florpyrauxifen-benzyl rates and four studies. Means within a column followed by the same letter are not different at α=0.05

[b]Abbreviations: DAE; Days after emergence

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Table 4. Regression coefficients for rough rice yield in research evaluating rice hybrid response to seeding rates and postemergence application of florpyrauxifen-benzyl from 2019 to 2021 at Stoneville, MS.

Parameter	Rate	Intercept	SE	Linear	SE	Quadratic	SE	Cubic	SE
	g ai ha^{-1}								
Rough rice yield	0	-1527.6648	454.7881	2142.4931	78.4015	-110.6166	4.0400	1.7964	0.0638
	59	8812.1305	188.2147	147.7229	19.9177	-2.9122	0.4676	-	-

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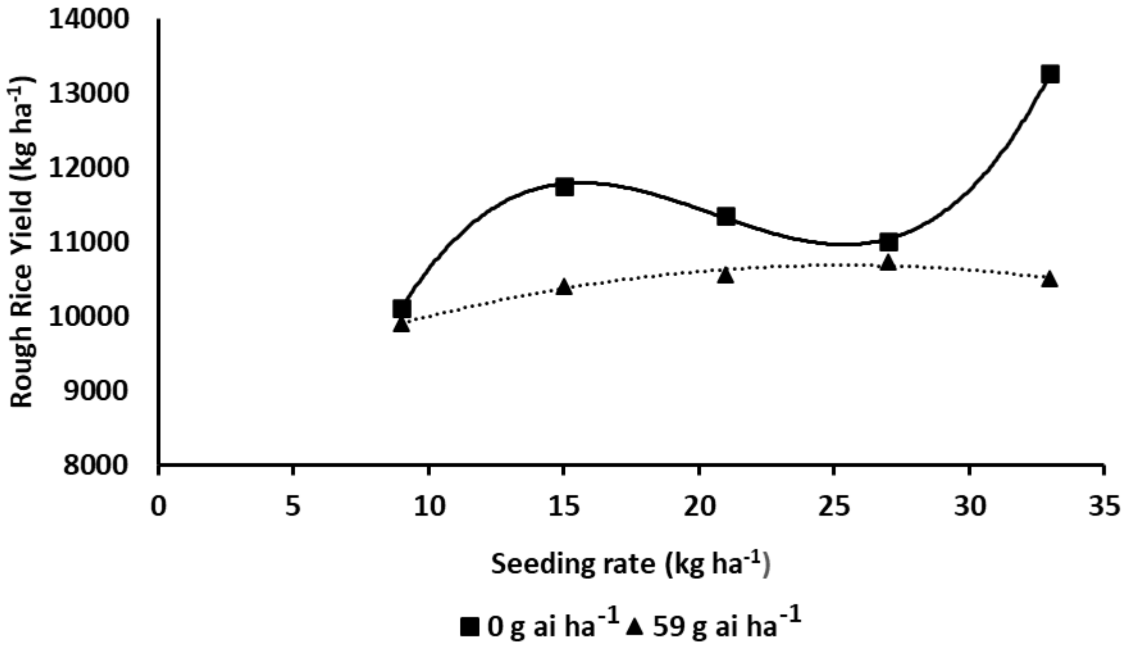
Figure 1. Rough rice grain yield following application of florpyrauxifen-benzyl for different Clearfield XL 7521 seeding rates from 2019-2021 at Stoneville, MS.



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