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Clomazone and Starter Nitrogen Fertilizer Effects on Growth and Yield of Hybrid and Inbred Rice Cultivars

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Cultivar and/or application of early-season (starter) nitrogen (N) fertilizer may influence rice tolerance to clomazone. Field studies were conducted to compare the response of hybrid and inbred rice cultivars to applications of clomazone and starter N fertilizer treatments. The inbred cultivar 'Cocodrie' and the hybrid cultivar 'XL723' were treated with clomazone at 0, 420, or 672 g ai ha^{-1} immediately after seeding, and starter N fertilizer was applied at 0 or 24 kg N ha^{-1} when rice reached the two-leaf growth stage. Pooled across clomazone rates and starter N fertilizer treatments, height of Cocodrie 1 week after emergence (WAE) was greater than that of XL723 in 1 of 3 yr. The difference in height between Cocodrie and XL723 resulted from greater clomazone injury 1 WAE on XL723 compared with Cocodrie. No differences in rice height 3 WAE were detected between Cocodrie and XL723 in 2 of 3 yr. when data were pooled across clomazone rates and starter N fertilizer treatments. Injury 3 WAE was similar for Cocodrie across the 3 yr., but injury on XL723 was greater in 1 of 3 yr. Rough rice yield was lower in plots treated with either rate of clomazone where no starter N fertilizer treatment was applied; however, in plots receiving a starter N fertilizer treatment, no effect of clomazone rate on rough rice yield was observed. Clomazone rate did not influence rough rice yield of Cocodrie in any single yr., but rough rice yields of XL723 were lower in plots receiving clomazone compared with plots that received no clomazone in 1 of 3 yr. Therefore, differential susceptibility to clomazone between Cocodrie and XL723 exists based on early-season response and rough rice yield. Starter N fertilizer treatments were beneficial for overcoming yield reductions due to clomazone injury.

Nomenclature: Clomazone, rice, *Oryza sativa* L.

Key words: Application rate, differential susceptibility, herbicide tolerance, seeding date.

El cultivar y/o la aplicación de fertilizante de nitrógeno (N) temprano en la temporada (inicial) podría influenciar la tolerancia del arroz a clomazone. Se realizaron estudios de campo para comparar la respuesta de cultivares de arroz híbridos y endógamos a aplicaciones de tratamientos con clomazone y fertilizante N inicial. El cultivar endógamo 'Cocodrie' y el cultivar híbrido 'XL723' fueron tratados con clomazone a 0, 420, ó 672 g ai ha^{-1} inmediatamente después de la siembra, y el fertilizante N inicial fue aplicado a 0 y 24 kg N ha^{-1} cuando el arroz alcanzó el estadio de crecimiento de dos hojas. Promediando las dosis de clomazone y los tratamientos de fertilizante inicial, la altura de Cocodrie 1 semana después de la emergencia (WAE) fue mayor que la de XL723 en 1 de 3 años. La diferencia en la altura entre Cocodrie y XL721 fue producto de un mayor daño 1 WAE en XL723 que con Cocodrie. No se detectaron diferencias en la altura del arroz 3 WAE entre Cocodrie y XL723 en 2 de 3 años cuando se promediaron las dosis de clomazone y los tratamientos de fertilizante N inicial. El daño 3 WAE fue similar para Cocodrie durante los tres años, pero el daño de XL723 fue mayor en 1 de 3 años. El rendimiento del arroz en granza fue menor en parcelas tratadas con cualquiera de las dosis de clomazone y donde no se aplicó fertilizante N inicial, mientras que en las parcelas que recibieron fertilizante N inicial no se vio ningún efecto de la dosis de clomazone sobre el rendimiento del arroz en granza. La dosis de clomazone no influenció el rendimiento del arroz en granza de Cocodrie en ninguno de los años, pero los rendimientos de arroz en granza de XL723 fueron más bajos en parcelas que recibieron clomazone cuando se compararon con parcelas que no recibieron clomazone en 1 de 3 años. Entonces, con base en la respuesta de la planta temprano durante la temporada de crecimiento y el rendimiento del arroz en granza, existe una susceptibilidad diferencial a clomazone entre Cocodrie y XL723. Los tratamientos con fertilizante N inicial fueron beneficiales para prevenir reducciones en el rendimiento producto del daño causado por clomazone.

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Clomazone has been a staple preemergence (PRE) herbicide for midsouthern US rice producers utilizing the direct-seeded, delayed-flood production system (Bond et al. 2016; Street and Bollich 2003). Residual grass herbicides common in direct-seeded, delayed-flood rice production include quinclorac, pendimethalin, and thiobencarb; however, none of these provide the same level of grass control as does clomazone (Baldwin 1995; Crawford and Jordan 1995; Jordan et al. 1998; Smith and Hill 1990; Street and Mueller 1993; Webster et al. 1999).

Clomazone is readily absorbed by roots and emerging shoots, with translocation occurring via xylem to the foliage (Shaner 2014). Clomazone inhibits 1-deoxy-D-xyulose 5-phosphate synthase (DOXP), causing an accumulation of plastid pigments. Inhibition of DOXP causes a bleaching symptomology in susceptible plants (Duke et al. 1991; Shaner 2014). Clomazone is labeled PRE in various crops including cotton (*Gossypium hirsutum* L.), pumpkin (*Cucurbita mixta* Pang.), soybean [*Glycine max* (L.) Merr.], sugarcane (*Saccharum officinarum* L.), tobacco (*Nicotiana tabacum* L.), and rice for controlling numerous broadleaf and grass weed species (Shaner 2014). Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] is the most troublesome weed in Mississippi rice (Webster 2012). Evolution of resistance to propanil and quinclorac in barnyardgrass biotypes has led to reliance on other herbicide mechanisms of action for barnyardgrass control (Baltazar and Smith 1994; Malik et al. 2010). Malik et al. (2010) reported 99% control of propanil-resistant barnyardgrass 56 d after emergence following clomazone applied PRE.

Differences in herbicide tolerance among rice cultivars are common. This has been widely reported for acetolactate synthase–inhibiting and auxin herbicides (Bond et al. 2007; Bond and Walker 2011, 2012; Pantone and Baker 1992; Zhang and Webster 2002). Although rice possesses an acceptable degree of tolerance to clomazone, rice injury can occur and may differ among cultivars (Mudge et al. 2005; O'Barr et al. 2007; Zhang et al. 2005). Zhang et al. (2004) reported differential tolerance to clomazone among inbred rice cultivars; however, most cultivars were able to overcome initial injury without reduction in grain yield.

Rice in Mississippi is ideally seeded between April 1 and May 20 (Buehring et al. 2008); however, rice injury from clomazone is of particular concern when rice is seeded outside optimum planting dates, especially prior to the optimal seeding window. O'Barr et al. (2007) concluded that rice injury at 16 to 22 d after treatment was greater when rice was seeded in March than it was when rice was seeded in April; however, rice injury declined to ≤4% 45 d after treatment with all treatments except clomazone at 560 g ha^{-1}. Jordan et al. (1998) suggested that clomazone injury to rice delayed grain maturity and development. Zhang et al. (2005) reported more severe rice injury with clomazone applied delayed-PRE, which is defined as delaying a residual herbicide application for 3 to 5 d after planting, after seeds have imbibed water for germination, compared with PRE; however, injury from clomazone rates ≥670 g ha^{-1} did not result in yield reduction.

Hybrid rice cultivars have been commercially grown since the mid-1970s in many Asian countries for their potential yield advantage over inbred cultivars (Tsuchiya et al. 2003; Virmani 2005, Yang et al. 2007). Hybrid rice production in the midsouthern United States has increased rapidly since RiceTec's release of 'XL6' rice hybrid in 2000 (Sha et al. 2009). Hybrid rice cultivars are utilized in midsouthern US rice production due to increased yield and disease resistance compared with inbred rice cultivars.

Starter nitrogen (N) fertilizer treatments applied during the early stages of vegetative growth are beneficial for increasing yield in numerous crops including cotton (Bednarz et al. 2000), corn (*Zea mays* L.) (Lamond and Gordon 2001), soybean (Osborne and Riedell 2006), and rice (Walker and Norman et al. 2008). Nitrogen fertilizer applied prior to rice tillering, i.e., preflood application, influences grain yield more than application at any other time; however, when starter N fertilizer was applied to two-leaf rice, grain yields increased ≥200 kg ha^{-1} compared with the yield achieved with no starter N (Walker and Bond et al. 2008). Walker and Norman et al. (2008) reported that starter N fertilizer applied to two-leaf rice not only increased grain yield, but also increased early-season plant height compared with a no-starter-N control. Increased early-season rice plant height can improve crop management by allowing earlier flooding, thereby potentially reducing herbicide applications (Walker and Norman et al. 2008).

Previous research suggests that there may be a positive response to starter N fertilizer applied to rice injured by clomazone. Furthermore, producers annually raise concerns over field observations of differential responses of rice cultivars (hybrid vs. inbred) to clomazone. However, no literature specifically addressing the response of different rice cultivars to starter N fertilizer treatments following application of clomazone was identified. Therefore, research was conducted to compare the responses of 'Cocodrie' and 'XL723' rice cultivars to applications of clomazone and to determine if starter N fertilizer treatment reduces clomazone injury on rice seeded early in the growing season. Our main goal was to determine if a differential response to clomazone exists between Cocodrie and XL723 rice cultivars and if starter N treatment would offset reductions in rice plant performance.

Materials and Methods

A study to evaluate rice response to clomazone and starter N fertilizer treatments was conducted in 2008 (33.43°N, 90.91°W), 2009 (33.44°N, 90.90°W), and 2010 (33.43°N, 90.91°W) at the Mississippi State University Delta Research and Extension Center in Stoneville, Mississippi. The soil was a Sharkey clay (very fine, smectitic, thermic Chromic Epiaquert) with a pH ranging from 8.0 to 8.3 and an organic matter content of approximately 2.0%. The experimental sites were in a 1:1 soybean to rice rotation. Field preparation each year consisted of fall disking and field cultivation in October. Experimental sites were left undisturbed following the last tillage pass until seeding each year. Emerged vegetation was controlled using glyphosate (Roundup® Weathermax® 4.5 L, Monsanto Company, 800 N. Lindburgh Blvd., St. Louis, MO 63167) at 1,120 g ae ha^{-1} prior to planting. Rice was drill-seeded to a depth of 2 cm on March 24 each year using a small-plot grain drill (Great Plains 1520, Great Plains Mfg, Inc., 1525 East North St., Salina, KS 67401) equipped with double-disk openers and press wheels spaced 20 cm apart. March 24 represents an early seeding date in Mississippi (Buehring 2008). Plots were kept weed-free by an application of quinclorac (Facet® 75 DF, BASF Crop Protection, 26 Davis Dr., Research Triangle Park, NC 27709) at 560 g ai ha^{-1} plus pendimethalin (Prowl® H_2O 3.8 CS, BASF Crop Protection) at 1,120 g ai ha^{-1} plus halosulfuron (Permit® 75 DF, Gowan Company LLC, 370 Main St. Yuma, AZ 85364) at 12 g ai ha^{-1} applied at the three- to four-leaf rice stage. Nitrogen fertilizer at 168 kg ha^{-1} as urea was applied immediately before flooding, when rice was in the one- to two-tiller stage. Direct-seeded, delayed-flood rice production typically produces maximal grain yields on clay-textured soil previously cropped to soybean when urea is applied at the one-tiller stage (i.e., preflood) at rates ranging from 168 to 235 kg N ha^{-1} (Buehring 2008). Standard agronomic and pest management practices were used during the growing season each year. The dates of several agronomic events are listed in Table 1. Ambient air temperature and solar radiation data were collected from seeding to harvest and are summarized in Table 2.

The study was designed as a randomized complete block with treatments defined by a factorial of two rice cultivars (Cocodrie and XL723), three clomazone (Command® 3ME, FMC Corporation, 1735 Market St., Philadelphia, PA 19103) rates (0, 420, or 672 g ha^{-1}), and two starter N fertilizer treatments (0 and 24 kg N ha^{-1}), with four replications. The long-grain rice cultivars Cocodrie (inbred) and XL723 (hybrid) were drill-seeded into randomly assigned plots at 95 kg ha^{-1} (400 to 450 seeds m^{-2}) for Cocodrie and 28 kg ha^{-1} (125 seeds m^{-2}) for XL723. Because of heterosis, a lower seeding rate is recommended by the hybrid rice manufacturer (Anonymous 2016). Each plot contained 8 rows of rice that were 5.5 m in length and spaced 20 cm apart. Plots were flooded to an approximate depth of 6 to 10 cm when rice reached the one- to two-tiller stage.

Immediately after seeding, clomazone treatments were applied to designated plots using a CO_2-pressurized backpack sprayer equipped with extended

Table 1. Rice seeding, emergence, flood, and harvest dates, and date of starter nitrogen fertilizer treatment application, in a study evaluating the rice cultivar response to clomazone and starter nitrogen treatments at Stoneville, MS from 2008 to 2010.

Year	Seeding date	Emergence date	Starter nitrogen treatment date	Flood date	Harvest date
2008	March 24	April 14	April 22	May 23	August 28
2009	March 24	April 15	April 23	May 22	August 24
2010	March 24	April 7	April 15	May 12	August 9

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Table 2. Air temperature and solar radiation for periods from seeding until flood establishment and from seeding until harvest at Stoneville, MS in 2008, 2009, and 2010.

Year	Air temperature				Solar radiation			
	Seeding to flood		Seeding to harvest		Seeding to flood		Seeding to harvest	
	Average maximum	Average minimum	Average maximum	Average minimum	Total	Average	Total	Average
	C				W m^{-2}	W m^{-2} d^{-1}	W m^{-2}	W m^{-2} d^{-1}
2008	25	12	30	18	13,949	229	38,951	247
2009	24	13	29	18	12,927	215	37,331	242
2010	26	12	31	19	12,821	257	36,926	266

range flat-fan nozzles (XR11002 TeeJet® nozzles, Spraying Systems Co., PO Box 7900, Wheaton, IL 60189) set to deliver 140 L ha^{-1} at 137 kPa. Approximately 1 wk after emergence (WAE), when rice reached the two-leaf growth stage, starter N fertilizer treatments in the form of ammonium sulfate were applied to designated plots.

Rice injury consistent with clomazone application was visually estimated 1 and 3 WAE on a scale of 0% (no injury) to 100% (rice death). Plant heights were determined by calculating the mean height of ten plants in each plot, measured from the soil surface to the tip of the extended leaf 1 and 3 WAE. Data collection intervals of 1 and 3 WAE corresponded to the day of and 2 wk after starter N fertilizer treatment, respectively. Rice density was calculated by counting all plants in two 1-m^2 quadrats in each plot prior to starter N fertilizer application. Rice was harvested with a small-plot combine (Wintersteiger Delta, Wintersteiger, Inc., 4705 W Amelia Earhart Drive, Salt Lake City, UT 84116) at a moisture content of approximately 20%. Grain weights and moisture contents were recorded and rough rice grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

All statistical analyses were conducted with the Mixed Procedure in SAS version 9.4 (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414). Type III statistics were used to test all possible fixed effects or interactions among the fixed effects. Data for all measurements were analyzed with year as a fixed effect. Year was designated a fixed effect because of differences in environmental conditions, particularly average daily solar radiation from planting until flooding, among the three years of the study (Table 2). For all measurements and analyses, block was considered a random effect, with cultivar, clomazone rate, starter N fertilizer treatment, and their potential interactions considered fixed effects and significant if $P \leq 0.05$. The square roots of visual injury data were acrsine transformed. The transformation did not improve homogeneity of variance based on visual inspection of plotted residuals; therefore, nontransformed data were used in analyses. Nontransformed data were used for rice density, height, and rough rice yield. Least-square means were calculated, and mean separation ($P \leq 0.05$) was produced using PDMIX800 in SAS, which is a macro for converting mean separation output letter groupings (Saxton 1998).

Results and Discussion

Early-Season Parameters. Environmental conditions across the three years of this experiment differed and had a direct impact on the results as each parameter measured was influenced by year (Table 3). Numerous publications have reported rice growth and development to vary greatly with environment (De Datta 1981; Moldenhauer and Gibbons 2003; Nemoto et al. 1995; Yoshida 1973). In the midsouthern United States, environmental conditions consistent with early seeding dates (prior to April 1) often result in delayed seedling development owing to low air temperature, abundant rainfall, and limited solar radiation. The duration between seedling emergence and flooding generally requires at least 25 d. In the current research, cool, wet conditions and delayed crop growth and were associated with greater rice injury from clomazone (Table 2). Furthermore, differences in rice density and height could partially be attributed to differences in environment (Table 3).

Rice density was only influenced by the main effects of year and cultivar (Table 3). Pooled across

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Table 3. Significance of the main effects of year (Yr), cultivar (Cult), clomazone rate (Clom), starter nitrogen fertilizer treatment (N), and interactions among the main effects, for rice density, height and injury determined 1 and 3 wk after emergence (WAE), and rough rice yield, in a study evaluating the rice cultivar response to clomazone and starter nitrogen fertilizer treatments.[a]

		Rice height		Rice injury		
Effect	Density	1 WAE	3 WAE	1 WAE	3 WAE	Rough rice yield
	P-value					
Yr	0.0226	0.0001	0.0001	0.0017	0.0166	0.0001
Cult	0.0001	0.0001	0.0424	0.0001	0.0001	0.0001
Clom	0.8328	0.8620	0.6468	0.0001	0.0001	0.0001
N	0.5271	0.0703	0.0094	0.1627	0.2516	0.0001
Yr*Cult	0.1171	0.0001	0.0001	0.0001	0.0040	0.0001
Yr*Clom	0.8971	0.9073	0.0691	0.0077	0.4107	0.0210
Yr*N	0.2715	0.4709	0.0836	0.2786	0.9614	0.0241
Cult*Clom	0.9998	0.3479	0.8568	0.6373	0.3911	0.0348
Cult*N	0.6731	0.8695	0.3384	0.3596	0.8672	0.3185
Clom*N	0.8553	0.1454	0.1861	0.7260	0.3727	0.0073
Yr*Cult*Clom	0.4884	0.2571	0.0821	0.8818	0.0658	0.0203
Yr*Cult*N	0.3420	0.4341	0.8208	0.1000	0.4298	0.2052
Yr*Clom*N	0.3634	0.2698	0.1358	0.6538	0.3819	0.6332
Cult*Clom*N	0.4844	0.9345	0.4051	0.3151	0.1215	0.7733
Yr*Cult*Clom*N	0.2915	0.0847	0.3436	0.5946	0.7141	0.2255

[a] Starter nitrogen fertilizer treatments had not been applied prior to the 1 WAE evaluation.

years, clomazone rates, and starter N fertilizer treatments, rice density 1 WAE for Cocodrie was 210 plants m^{-2} and greater ($P = 0.0001$) than the density for XL723, which was 69 plants m^{-2} (data not presented). Differences in rice density among cultivars were expected and resulted from the discrepancy in seeding rates between the inbred and hybrid cultivars (Anonymous 2016; Buehring et al. 2008). However, densities for both cultivars were within accepted ranges for optimal stand establishment. Mean rice density 1 WAE for each cultivar was greater in 2010 than it was in 2008, while rice density in 2009 was similar to that seen in the other two years (data not presented). Differences in rice density across the three years can be explained by the quantity of rainfall between planting and the date rice density was determined. Rainfall received from planting to 1 WAE was 8.3, 6.5, and 1.2 mm in 2008, 2009, and 2010, respectively. Early-season stress from cool, wet conditions hampered rice emergence, with average daily solar radiation accumulation limited during 2008 and 2009 compared with that accumulated during 2010 (Table 2).

The year by cultivar interaction affected rice height 1 WAE (Table 3). Averaged across clomazone rates and starter N fertilizer treatments, height of Cocodrie 1 WAE was greater than that of XL723 in 2010, but was not greater than that of XL723 in 2008 or 2009 (Table 4). Furthermore, for each cultivar, height 1 WAE was greater in 2010 compared with that in 2008 or 2009. Differences in height between Cocodrie and XL723 in 2010 were likely a result of greater clomazone injury in XL723 than in Cocodrie 1 WAE (Table 4). Injury was also greater in XL723 compared with that seen in Cocodrie in 2008, but heights were similar for the two cultivars in that year.

Similar to height recorded 1 WAE, rice height 3 WAE was influenced by the interaction of year and cultivar as well as the main effect of starter N fertilizer treatment (Table 3). Rice height 3 WAE averaged across years, cultivars, and clomazone rates was greater ($P = 0.0094$) in plots receiving 24 kg N ha^{-1} than it was in those receiving 0 kg N ha^{-1} starter fertilizer (data not presented). Walker and Norman et al. (2008) reported a similar response in rice height to starter N fertilizer treatments. No differences in height at 3 WAE were detected for Cocodrie in two of three years when data were pooled across clomazone rates and starter N fertilizer treatments (Table 4). Heights for XL723 differed at 3 WAE each year. The greatest height for each cultivar was recorded in 2009, while the shortest rice heights were measured in 2008. Furthermore, rice height 3 WAE across the three years fluctuated 55% and 73% for Cocodrie and XL723, respectively.

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Table 4. Rice height and injury 1 and 3 wk after emergence (WAE) influenced by year and cultivar in a study evaluating hybrid (XL723) and inbred (Cocodrie) rice cultivars' responses to clomazone and starter nitrogen fertilizer treatments at Stoneville, MS.[a]

	Height				Injury			
	1 WAE[b]		3 WAE		1 WAE[b]		3 WAE	
Year	Cocodrie	XL723	Cocodrie	XL723	Cocodrie	XL723	Cocodrie	XL723
	cm				%			
2008	8 c	7 c	11 c	11 c	8 c	30 a	4 b	7 a
2009	8 c	8 c	17 b	19 a	8 c	12 c	2 b	3 b
2010	13 a	11 b	16 b	16 b	10 c	24 b	2 b	9 a

[a] Data pooled over three clomazone rates and two starter nitrogen fertilizer treatments. Means followed by the same letter for each parameter and evaluation interval are not different at $P \leq 0.05$.

[b] Starter nitrogen fertilizer treatments had not been applied prior to evaluation.

Average solar radiation from seeding to flood was 12% greater in 2010 than it was in 2008 (Table 2). Yoshida (1981) reported that photosynthesis accounts for >84% of total carbohydrates in rice plants by the second week of growth and 100% of total carbohydrates by the second true leaf stage. Inconsistency in average solar radiation likely caused both the differences in height between cultivars in 2010 and the lack of differences in height between cultivars in 2008. Air temperatures have been shown to greatly impact rice growth rate in the first week after seeding (Yoshida 1973). Although average maximum temperatures in the current research fell within the optimal range for early-season plant growth, the average minimum temperatures were low. More recently, Deng et al. (2015) reported that average air temperature prior to panicle initiation was positively correlated with total aboveground biomass, plant height, and crop growth rate for rice grown in China.

Visual estimates of rice injury 1 WAE were influenced by year by cultivar and year by clomazone rate interactions (Table 3). Pooled across clomazone rates and starter N fertilizer treatments, injury was similar across years for Cocodrie, but different each year for XL723 (Table 4). The greatest injury (30%) was observed for XL723 in 2008. Across clomazone rates and N fertilizer, injury to XL723 in 2009 was similar to that seen in Cocodrie all three years (Table 4). Injury from clomazone was greater for XL723 in 2008 and 2010 compared with that for Cocodrie; however, severity of injury for XL723 varied across years.

Averaged over starter N fertilizer treatment and cultivar, rice injury 1 WAE differed among clomazone rates across years (Table 3). Within each year, injury increased as clomazone rate increased, and the greatest injury was observed following clomazone at 672 g ha^{-1} (Table 5). Injury was similar following clomazone at 420 and 672 g ha^{-1} in 2008 and 2010, and these injury levels were greater than those seen with either rate in 2009. Rice injury 1 WAE was similar across the three years for Cocodrie, but varied for XL723 (Table 4). Scherder et al. (2004) also reported differences in early-season clomazone injury among rice cultivars in different years. Differences in injury 1 WAE in XL723 were likely related to both average air temperatures and average solar radiation (Table 2). Average solar radiation between seeding and flood in 2009 was 6% and 16% lower compared with that in 2008 and 2010, respectively. Differences in injury have been documented in corn (Keifer 1989), rice (Mudge et al. 2005; Scherder et al. 2004; Zhang et. al. 2004), soybean (Ross et al. 2015), and sweet potato [*Ipomoea batatas* (L.) Lam.] (Harrison and Jackson 2011) cultivars following herbicide applications.

The year by cultivar interaction and the main effect of clomazone rate affected the level of injury 3 WAE (Table 3). Pooled over starter N fertilizer treatments and clomazone rates, injury was similar across years for

Table 5. Rice injury 1 wk after emergence influenced by year and clomazone rate in a study evaluating the rice cultivar response to clomazone and starter nitrogen fertilizer treatments at Stoneville, MS.[a]

Clomazone rate	2008	2009	2010
g ai ha^{-1}	%		
0	0 e	0 e	0 e
420	11 bc	6 d	9 c
672	27 a	13 b	25 a

[a] Data pooled over two cultivars and two starter nitrogen fertilizer treatments. Starter nitrogen fertilizer treatments had not been applied prior to evaluation. Means followed by the same letter are not different at $P \leq 0.05$.

Cocodrie. Alternatively, injury for XL723 was similar in two of three years (Table 4). Rice injury was greater for XL723 in 2008 and 2010 compared with that for Cocodrie in all 3 years or XL723 in 2009 (Table 4). Averaged over years, cultivars, and starter N fertilizer treatments, injury increased with increasing clomazone rate 3 WAE (data not presented). Injury was 7% following clomazone at 672 g ha^{-1} compared to 1% following clomazone at 420 g ha^{-1}, which was similar to the rate of injury seen in plots receiving no clomazone (data not presented).

Although similar to the 1 WAE evaluation in that the level of rice injury was greater for XL723 than it was for Cocodrie in 2008 and 2010, rice injury 3 WAE was <10% for all cultivar and year combinations (Table 4). Furthermore, injury 3 WAE was similar for Cocodrie across the three years, but injury on XL723 was greater in 2008 and 2010 than it was in 2009. Differences in response between hybrid and inbred rice cultivars has been reported. Zhang and Webster (2002) reported that rice tolerance to bispyribac-sodium was dependent on both cultivar and growth stage at application. Hybrid imidazolinone-resistant rice cultivars 'CLXL729' and 'CLXL745' were less tolerant to imazamox applications than was the inbred 'CL161' (Bond and Walker 2011). Bond and Walker (2012) reported variable tolerance among rice cultivars to postflood quinclorac applications, with rough rice yields of the inbred 'Cheniere' and the hybrid XL723 reduced more than those of the inbred cultivar 'Bowman'.

The reason for differences in rice height and injury were less obvious 3 WAE compared with 1 WAE. However, more noteworthy was that rice injury 1 and 3 WAE was similar across years for Cocodrie, but differences in injury varied by a factor of 2.5 to 3 across years for XL723. This observation alone indicates that, when seeded early in the season during times when environmental conditions are variable (Table 2), the inbred cultivar Cocodrie performs more consistently through the first 5 to 6 wk after seeding than does the hybrid cultivar XL723. This information is valuable for producers, as cultivar selection and seeding date decisions are critical for optimum production.

Rough Rice Yield. Rough rice yield was influenced by year by starter N fertilizer treatment, clomazone rate by starter N fertilizer treatment, and year by cultivar by clomazone rate interactions (Table 3).

Table 6. Rough rice yield influenced by year and starter nitrogen fertilizer treatment in a study evaluating the rice cultivar response to clomazone and starter nitrogen fertilizer treatments at Stoneville, MS.[a]

Starter nitrogen fertilizer rate	2008	2009	2010
kg ai ha^{-1}		kg ha^{-1}	
0	10,840 b	8,750 c	11,650 a
24	11,580 a	8,870 c	12,160 a

[a] Data pooled over two rice cultivars and three clomazone rates. Means followed by the same letter are not different at $P \leq 0.05$.

With data pooled over cultivars and clomazone rates, rough rice yield varied across the three years regardless of whether plots received a starter N fertilizer treatment (Table 6). Rough rice yield was lowest in 2009 and greatest in 2010, with no difference in rough rice yields across starter N fertilizer treatments in those years (Table 6). However, differences between starter N fertilizer treatments were observed in 2008, with rice receiving 24 kg N ha^{-1} producing the greatest rough rice yield. Rough rice yield following 24 kg N ha^{-1} in 2008 was greater than that for any treatment during 2009 and similar to that for starter N fertilizer treatments in 2010 (Table 6). Walker and Norman et al. (2008) reported similar mean rice grain yield when ammonium sulfate (244 kg ha^{-1}) or diammonium phosphate (198 kg ha^{-1}) was applied at 22 kg N ha^{-1} to two-leaf Cocodrie planted at an optimum seeding rate for Sharkey clay soils.

The influence of clomazone rate and starter N fertilizer treatment on rough rice yield pooled across years and cultivars is presented in Table 7. In the absence of a starter N fertilizer treatment (0 kg N ha^{-1}), rough rice yields were lower in plots treated with clomazone compared with those in plots receiving no

Table 7. Rough rice yield influenced by clomazone and starter nitrogen fertilizer treatment in a study evaluating the rice cultivar response to clomazone and starter nitrogen fertilizer treatments at Stoneville, MS, from 2008 to 2010.[a]

Clomazone rate	Starter nitrogen at 0 kg ai ha^{-1}	Starter nitrogen at 24 kg ai ha^{-1}
g ai ha^{-1}	kg ha^{-1}	
0	10,850 a	11,000 a
420	10,360 b	10,710 a
672	10,040 c	10,900 a

[a] Data pooled over two rice cultivars and three years. Means followed by the same letter are not different at $P \leq 0.05$.

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Table 8. Rough rice yield of one inbred (Cocodrie) and one hybrid (XL723) rice cultivar influenced by year and clomazone rate in a study evaluating the rice cultivar response to clomazone and starter nitrogen fertilizer treatments at Stoneville, MS.[a]

Clomazone rate	2008		2009		2010	
	Cocodrie	XL723	Cocodrie	XL723	Cocodrie	XL723
g ai ha^{-1}	kg ha^{-1}					
0	11,120 b-e	11,500 bc	7,690 g	11,020 b-e	10,710 de	13,580 a
420	10,780 cde	11,330 bcd	7,680 g	9,720 f	10,570 e	13,070 a
672	10,900 cde	11,650 b	7,420 g	9,340 f	10,580 e	12,920 a

[a] Data pooled over two nitrogen rates. Means followed by the same letter are not significantly different at $P \leq 0.05$.

clomazone. Additionally, rough rice yields were lower following clomazone at 672 g ha^{-1} compared with those following clomazone at 420 g ha^{-1}. In plots receiving a starter N fertilizer treatment (24 kg N ha^{-1}), no effect of clomazone rate on rough rice yield was observed. In the absence of clomazone, rough rice yields were not improved following starter N fertilizer treatment. Walker and Bond et al. (2008) hypothesized that starter N fertilizer applied to rice planted at below-optimum seeding rates would improve yield, and they reported that a starter N fertilizer rate of 22 kg ha^{-1} increased yield 200 kg ha^{-1} compared to the yield obtained when no starter N was applied. The low seeding rates in the work of Walker and Bond et al. (2008) were utilized to simulate suboptimal early-season conditions such as poor environment, pest pressure, seedling mortality, or herbicide injury. Although our data show no grain yield response to starter N fertilizer in the absence of clomazone, starter N fertilizer increased rice grain yield in the presence of clomazone at each application rate (Table 7).

Pooled across starter N fertilizer treatments, rough rice yield varied across years, cultivars, and clomazone rates (Table 8). Regardless of clomazone rate, rough rice yields of Cocodrie were similar in 2008 and 2010 but lower in 2009. Clomazone rate also did not influence rough rice yield of Cocodrie in any single year. Rough rice yield of XL723 was greatest in 2010 regardless of clomazone rate. In 2008 and 2010, rough rice yields of XL723 were not influenced by clomazone rate. The same trend was noted for Cocodrie across all three years.

The main goal of this research was to determine if a differential response to clomazone might exist between selected hybrid (XL723) and inbred (Cocodrie) rice cultivars, and if starter N fertilizer treatment would offset reductions in rice plant performance. In this research, clomazone injured the hybrid cultivar XL723 more than it injured the inbred cultivar Cocodrie. Additionally, in some years rough rice yields were lower for XL723 in plots where clomazone was applied than they were in plots where clomazone was not applied. This trend was not observed for Cocodrie. Therefore, early-season response and rough rice yield data suggest a differential susceptibility to clomazone between Cocodrie and XL723.

Positive early-season response to starter N fertilizer treatments was detected (height 3 WAE), and may shorten the time from emergence to flood. Starter N fertilizer may improve rough rice yields in some years, depending on environmental conditions, particularly average air temperature and solar radiation. The use of starter N fertilizer appears to be more beneficial to XL723 than it is to Cocodrie within the environmental constraints of this research. Ultimately, rice yield can be reduced by clomazone, but yield losses may be offset by the application of a starter N fertilizer.

These results are important as hectarage of hybrid rice in the midsouthern United States has increased and now accounts for >50% of rice production in the region. Clomazone is a foundation herbicide for direct-seeded, delayed-flood production systems and is recommended in weed management programs for barnyardgrass control. However, many producers express concern over injury following clomazone application. This research suggests that producers who choose to seed XL723 should apply a starter N fertilizer treatment to minimize the potential reduction in rough rice yield that may occur as a result of clomazone application.

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Literature Cited

Anonymous (2016) RiceTec Hybrid Rice Management Guidelines. http://www.ricetec.com/grower-resources/management-guidelines/. Accessed February 24, 2016

Baldwin FL (1995) A consolidated approach to weed management in rice (final report). Pages 32–37 *in* Wells BR ed. Rice Research Status 1994. Arkansas Agricultural Experiment Station Research Ser. 446. 251 p

Baltazar AM, Smith RJ (1994) Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Technol 8:576–581

Bednarz CW, Harris GH, Shurley WD (2000) Agronomic and economic analyses of cotton starter fertilizers. Agron J 92:766–771

Bond J, Golden B, Lawrence B (2016) Rice: weed response ratings for rice herbicides. Page 69 *in* Byrd JD Jr ed. Weed Control Guidelines for Mississippi. Mississippi State, MS: Mississippi State University Extension Service, Mississippi Agricultural and Forestry Experiment Station

Bond JA, Walker TW (2011) Differential tolerance of Clearfield® cultivars to imazamox. Weed Technol 25:192–197

Bond JA, Walker TW (2012) Effect of postflood quinclorac applications on commercial rice cultivars. Weed Technol 26:183–188

Bond JA, Walker TW, Webster EP, Buehring NW, Harrell DL (2007) Rice cultivar response to penoxsulam. Weed Technol 21:361–365

Buehring NW, Walker TW, Bond JA (2008) Rice stand establishment. Pages 9–15 *in* Miller T, ed. Mississippi's Rice Growers' Guide. http://msucares.com/pubs/publications/p2255.pdf. Accessed September 2, 2015

Crawford SH, Jordan DL (1995) Comparison of single and multiple applications of propanil and residual herbicides in dry-seeded rice (*Oryza sativa*). Weed Technol 9:153–157

De Datta SK (1981) Principles and Practices of Rice Production. New York, NY: Wiley and Sons

Deng N, Ling X, Sun Y, Zhang C, Fahad S, Peng S, Cui K, Nie HJ (2015) Influence of temperature and solar radiation on grain yield and quality in irrigated rice system. Europ J Agron 64:37–46

Duke SO, Paul RN, Becerril JM, Schmidt JH (1991) Clomazone causes accumulation of sesquiterpenoids in cotton (*Gossypium hirsutum* L.). Weed Sci 39:339–346

Harrison HF Jr, Jackson DM (2011) Greenhouse assessment of differences in clomazone tolerance among sweetpotato cultivars. Weed Technol 25:501–505

Jordan DL, Bollich PK, Burns AB, Walker DM (1998) Rice (*Oryza sativa*) response to clomazone. Weed Sci 46:374–380

Kiefer DW (1989) Tolerance of corn (*Zea mays*) line to clomazone. Weed Sci 37:622–628

Lamond RE, Gordon WB (2001) Developing more effective starter fertilizers for conservation tillage production systems. Fluid Forum Proc 18:132–137

Malik MS, Burgos NR, Talbert RE (2010) Confirmation and control of propanil-resistant and quinclorac-resistant barnyardgrass (*Echniochloa crus-galli*) in rice. Weed Technol 24:226–233

Moldenhauer KAK, Gibbons JH (2003) Rice morphology and development. Pages 103–127 *in* Smith CW & Dilday RH, eds. Rice: Origin, History, Technology, and Production. Hoboken, NJ: J Wiley & Sons

Mudge CR, Webster EP, Leon CT, Zhang W (2005) Rice (*Oryza sativa*) cultivar tolerance to clomazone in water-seeded production. Weed Technol 19:907–911

Nemoto K, Morita S, Baba T (1995) Shoot and root development in rice related to the phyllochron. Crop Sci 35:24–29

O'Barr JH, McCauley GN, Bovey RW, Sensman SA, Chandler JM (2007) Rice response to clomazone as influenced by application rate, soil type, and planting date. Weed Technol 21: 199–205

Osborne SL, Riedell WE (2006) Starter nitrogen fertilizer impact on soybean yield and quality in the northern Great Plains. Agron J 98:1569–1574

Pantone DJ, Baker JB (1992) Varietal tolerance of rice (*Oryza sativa*) to bromoxynil and triclopyr at different growth stages. Weed Technol 6:969–974

Ross J, Eubank T, Norsworthy J, Scott B (2015) Metribuzin Tolerance Testing of Soybean Varieties 2015. http://mssoy.org/wp-content/uploads/2014/12/2014-SOYBEAN-VARIETY-METRIBUZIN-SCREENING-UA1.pdf. Accessed November 11, 2016

Saxton AM (1998) A macro for converting mean separation output to letter groupings in Proc Mixed. Pages 1243–1246 *in* Proc. 23rd SAS Users Group International, SAS Inst., Cary, NC, Nashville, TN, March 22–25

Scherder EF, Talbert RE, Clark SD (2004) Rice (*Oryza sativa*) cultivar tolerance to clomazone. Weed Technol 18:140–144

Sha X, Linscombe SD, Blance SB, Groth DE (2009) Yield advantage of hybrid rice over conventional and Clearfield® long-grain rice in the southern United States. Page 687 *in* Xie F & Hardy B, eds. Accelerated Hybrid Rice Development. Los Banos (Philippines): International Rice Research Institute

Shaner DL, ed (2014) Herbicide Handbook. 10th edn. Lawrence, KS: Weed Science Society of America. 109 p

Smith RJ Jr, Hill JE (1990) Weed control technology in U.S. Pages 314–327 *in* Grayson BT, Green MB & Coping LD, eds. Pest Management in Rice. London: Elsevier

Street JE, Bollich RK (2003) Rice production. Page 284 *in* Smith CW & Dilday RH, eds. Rice Origin, History, Technology, and Production. Hoboken, NJ: John Wiley & Sons

Street JE, Mueller TC (1993) Rice (*Oryza sativa*) weed control with soil applications of quinclorac. Weed Technol 7:600–604

Tsuchiya T, Bastawisi A, Yan ZY, Moon HP, Ikehashi H (2003) Opportunities for and challenges to developing and using hybrid rice technology for temperate countries. Page 54 *in* Virmani SS, Mao CX & Hardy B, eds. Hybrid Rice for Food Security, Poverty Alleviation, and Environmental Protection. Los Banos (Philippines): International Rice Research Institute

Virmani SS (2005) Heterosis in rice for increasing yield, production efficiency, and rural employment opportunities. Pages 162–166 *in* Toriyama K, Heong KL & Hardy B, eds. Rice is Life: Scientific Perspective for the 21st Century. Proceedings of the World Rice Research Conference in Tokyo and Tsukuba, Japan, 4–7 November 2004. Los Banos (Philippines): International Rice Research Institute

Walker TW, Bond JA, Ottis BV, Harrell DL (2008). The effects of starter nitrogen to rice seeded at various densities. Crop Manag doi: 10.1094/CM-2008-0911-01-RS

Walker TW, Norman RJ, Ottis BV, Bond JA (2008) Starter fertilizer for delayed-flood rice – agronomic effects (North America). Better Crops 92:4–5

Webster EP, Baldwin FL, Dillion TL (1999) The potential for clomazone use in rice (*Oryza sativa*). Weed Technol 13:390–393

Webster TM (2012) Weed Survey-Southern States. Page 278 *in* Proceedings of the 65th Southern Weed Science Society. Las Cruces, NM: Southern Weed Science Society

Yang W, Peng SB, Laza RC, Visperas RM, Dionisio-Sese ML (2007) Grain yield and yield attributes of new plant type and hybrid rice. Crop Sci 47:1393–1400

Yoshida S (1973) Effects of temperature on growth of the rice plant (*Oryza sativa*) in a controlled environment. Soil Sci Plant Nut 19:299–310

Yoshida S (1981) Fundamentals of rice crop science. Manila, Philippines: IRRI

Zhang W, Webster EP (2002) Shoot and root growth of rice (*Oryza sativa*) in response to V-10029. Weed Technol 16: 769–772

Zhang W, Webster EP, Blouin DC (2005) Response of rice and barnyardgrass (*Echinochloa crus-galli*) to rates and timings of clomazone. Weed Technol 19:528–531

Zhang W, Webster EP, Blouin DC, Linscombe SD (2004) Differential tolerance of rice (*Oryza sativa*) varieties to clomazone. Weed Technol 18:73–76

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