Weed Technology

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Research Article

Cite this article: Osterholt MJ, Webster EP, Blouin DC, McKnight BM (2019) Quizalofop interactions when mixed with clomazone and pendimethalin in acetyl coenzyme A carboxylase–inhibiting herbicide-resistant rice. Weed Technol. **33**: 778–784. doi: 10.1017/wet.2019.59

Received: 5 April 2019
Revised: 7 June 2019
Accepted: 14 June 2019
First published online: 29 July 2019

Associate Editor:
Jason Bond, Mississippi State University

Nomenclature:
clomazone; pendimethalin; quizalofop; barnyardgrass; *Echinochloa crus-galli* (L.) P. Beauv.; red rice; *Oryza sativa* L; rice; O. *sativa* L.

Keywords:
mixtures; weed control

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Quizalofop interactions when mixed with clomazone and pendimethalin in acetyl coenzyme A carboxylase–inhibiting herbicide-resistant rice

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Abstract

A study was conducted in 2017 and 2018 at the H. Rouse Caffey Rice Research Station near Crowley, LA, to evaluate quizalofop at 120 g ai ha^{-1} applied independently or in a mixture with clomazone, pendimethalin, clomazone plus pendimethalin, or a prepackaged mixture of clomazone plus pendimethalin when PVLO1 rice reached the two- to three-leaf stage. A second application of quizalofop at 120 g ha^{-1} was applied 21 d after the initial application. At 7 days after treatment (DAT), antagonism of quizalofop occurred when mixed with clomazone at 334 g ai ha^{-1}, clomazone at 334 g ai ha^{-1} plus pendimethalin at 810 g ai ha^{-1}, or a prepackaged mixture of clomazone plus pendimethalin at 334 plus 810 g ai ha^{-1}, respectively, when applied to barnyardgrass. At 7 DAT, a neutral interaction occurred with a mixture of quizalofop plus pendimethalin at 810 g ha^{-1}. These data indicate the antagonism of quizalofop was overcome at 14, 28, and 42 DAT with a neutral interaction for barnyardgrass control, 94% to 98%, with all herbicide mixtures evaluated. A neutral interaction occurred for CL-111, CLXL-745, and red rice control when treated with all the herbicide mixtures evaluated across all evaluation dates. Rice yield decreased when not treated with the initial quizalofop application.

Introduction

Red rice is often considered one of the most problematic weeds hindering rice production in the southern United States (Carlson et al. 2011; Craigmiles 1978; Smith 1981). Smith (1968) reported that rice yield loss from season-long competition of dense populations of red rice could be as high as 82%. Red rice can also result in reductions in milling yields and grade (Webster 2014). Because of its genetic similarities to modern cultivated rice, red rice is difficult to control with traditional labeled herbicides (Carlson et al. 2011; Pellerin et al. 2003, 2004). However, with the commercialization of imidazolinone-resistant (IR) rice in 2002, producers finally had the means to manage red rice with a herbicide while producing a rice crop (Pellerin et al. 2003, 2004; Webster and Masson 2001). Hybrid IR rice was released in 2003 (RiceTec Inc., Alvin, TX). Acceptance of IR rice was quick, and by 2004, 27% of rice acreage in Louisiana was planted with IR rice (Shivrain et al. 2007).

The seeds of IR rice hybrids have a history of seed shattering and dormancy, which can become problematic during succeeding growing seasons as a volunteer weed (Rustom et al. 2018; Sudianto et al. 2013). Cultivated rice and red rice are sexually compatible, and IR rice can transfer the herbicide-resistant gene to red rice (Shivrain et al. 2007). Several researchers have reported this type of outcrossing (Chen et al. 2004; Shivrain et al. 2007; Song et al. 2003).

Barnyardgrass is another problematic weed that negatively affects rice production across the rice-producing areas of the United States (Smith 1974). Producers can expect up to a 79% yield reduction from barnyardgrass competition that occurs from rice emergence to maturity. Baltazar and Smith (1994) reported one of the first cases of barnyardgrass resistance to propanil. This was quickly succeeded by documented cases of barnyardgrass resistance to quinclorac in 1999, clomazone in 2007, and imazethapyr in 2008 (Dilpert et al. 2013; Malik et al. 2010).

After the development of IR weedy rice and several documented cases of barnyardgrass resistance to multiple modes of action, BASF launched an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide-resistant (ACCase-R) rice system (Provisia® Rice; BASF Corp., Research Triangle Park, NC). The ACCase-R rice technology uses quizalofop as the target herbicide applied at rates of 92 to 155 g ai ha^{-1}, and not to exceed 240 g ha^{-1} per year. Quizalofop provides

Table 1. Barnyardgrass control and interactions with quizalofop applied alone or mixed with residual herbicides, 2017 and 2018.[a]

		Quizalofop			
		0 g ha^{-1}	120 g ha^{-1}		
Mixture herbicide[b,c]	Rate	Observed	Expected	Observed[d]	P-value[e]
	g ha^{-1}	% control			
7 DAIT					
None	—	0	—	95	—
Clomazone	335	76	99	94 *	0.0031
Pendimethalin	810	54	99	96	0.1662
Clomazone + pendimethalin	335 + 810	74	99	94 *	0.0031
PP – Clomazone + pendimethalin[d]	1,145	77	99	95 *	0.0030
14 DAIT					
None	—	0	—	98	—
Clomazone	335	79	100	97	0.1630
Pendimethalin	810	49	99	98	0.4648
Clomazone + pendimethalin	335 + 810	78	100	97	0.1655
PP – Clomazone + pendimethalin	1,145	79	100	97	0.1571
28 DAIT[g]					
None	—	64	—	98	—
Clomazone	335	85	99	97	0.3568
Pendimethalin	810	71	98	98	0.8587
Clomazone + pendimethalin	335 + 810	88	99	97	0.2475
PP – Clomazone + pendimethalin	1,145	91	99	98	0.2322
42 DAIT					
None	—	98	—	96	—
Clomazone	335	96	94	96	0.6816
Pendimethalin	810	97	95	97	0.6701
Clomazone + pendimethalin	335 + 810	96	94	97	0.6250
PP – Clomazone + pendimethalin	1,145	96	93	97	0.5746

[a]Evaluated using Blouin's modified Colby's analysis.
[b]Evaluation dates for each respective herbicide mixture.
[c]Abbreviations: DAIT, days after initial treatment; PP, prepackaged mixture.
[d]Observed means followed by an asterisk are significantly different from Blouin's modified Colby's expected responses at the 5% level indicating an antagonistic response. No asterisk indicates a neutral response.
[e]$P < 0.05$ indicates an antagonistic response; $P > 0.05$ indicates a neutral response.
[f]RiceOne® contains 130 g ai L^{-1} clomazone plus 313 g ai L^{-1} pendimethalin in a dual-encapsulated suspension.
[g]Control observed for each mixture herbicide with an additional independent application of quizalofop applied at 120 h ai ha^{-1} 21 DAIT.

POST control of weedy rice and other annual and perennial grasses. The ACCase enzyme is responsible for catalyzing the first committed step of de novo fatty acid synthesis (Burton et al. 1989; Focke and Lichtenthaler 1987). Researchers in Mississippi recognized the utility of quizalofop applied at 70 to 280 g ha^{-1} to manage red rice populations in a soybean and rice rotation (Askew et al. 2000; Minton et al. 1989).

Mixing herbicides with differing sites of action (SOAs) in a single application is a cost-effective way for producers to apply herbicide programs. A simple application with multiple herbicides in a mixture reduces costs, saves time, reduces wear and tear on equipment, and may broaden the weed control spectrum (Carlson et al. 2012; Hydrick and Shaw 1995; Minton et al. 1989; Webster and Shaw 1997). Mixing herbicides can result in three different responses: synergism, antagonism, or an additive or neutral response (Berenbaum 1981; Blouin 2010; Colby 1967; Fish et al. 2015, 2016; Rustom et al. 2018, 2019). Antagonism was defined by Colby (1967) as an interaction of two or more agrichemicals such that the effect, when the chemicals are combined, is less than the predicted effect based on the activity of each chemical applied separately. ACCase-inhibiting herbicides can often be antagonized when mixed with other broadleaf herbicides (Barnwell and Cobb 1994; Rustom et al. 2018, 2019; Zhang et al. 2005). Rustom et al. (2018, 2019) observed antagonism of quizalofop in ACCase-R rice. Quizalofop activity was reduced when applied in a mixture with the acetolactate synthase–inhibiting herbicides bensulfuron, bispyribac, halosulfuron, imazosulfuron, orthosulfamuron plus halosulfuron, orthosulfamuron plus quinclorac, penoxsulam, and penoxsulam plus triclopyr in ACCase-R rice production (Rustom et al. 2018). Quizalofop activity was also antagonized by propanil, bentazon, and saflufenacil (Rustom et al. 2019).

In 2000, clomazone was labeled for use in rice production. Clomazone (Command®; FMC Corp., Philadelphia, PA) is a Group 3 diterpene synthesis–inhibiting herbicide that interferes with chloroplast development and reduces the accumulation of plastid pigments in susceptible weed species (Ferhatoglu and Barrett 2005). Clomazone applied PRE at 390 to 440 g ai ha^{-1} to rice on a coarse-textured soil controlled barnyardgrass 96% to 97%, and clomazone applied POST at 390 to 440 g ai ha^{-1} to barnyardgrass at the one- to two-leaf stage controlled barnyardgrass 85% (Willingham et al. 2008). The first reported confirmation of clomazone-resistant barnyardgrass occurred in Arkansas in 2008 (Norsworthy et al. 2008).

Pendimethalin (Prowl® H20; BASF Corp.) is a Group 3 dinitroaniline herbicide that disrupts mitotic cellular division through inhibition of microtubule proteins in susceptible weed species (Vaughn and Lehnen 1991). Pendimethalin is a soil-applied herbicide that is absorbed by germinating plant roots and coleoptiles, causing highly susceptible weed species not to emerge or to die soon after emergence. Pendimethalin is active on grass and small-seeded broadleaf weeds infesting rice when applied at different timings (Bond et al. 2009; Malik et al. 2010). RiceOne® (RiceCo LLC, Memphis, TN) is a prepackaged mixture of clomazone plus

https://doi.org/10.1017/wet.2019.59 Published online by Cambridge University Press

Table 2. CL-111 rice control and interactions with quizalofop applied alone or mixed with residual herbicides, 2017 and 2018.[a]

		Quizalofop			
		0 g ha^{-1}	120 g ha^{-1}		
Mixture herbicide[b,c]	Rate	Observed	Expected	Observed	P-value[d]
	g ha^{-1}	% of control			
7 DAIT					
None	—	0	—	89	—
Clomazone	335	0	89	90	0.6293
pendimethalin	810	0	89	88	0.6874
Clomazone + pendimethalin	335 + 810	0	89	89	0.6873
PP – Clomazone + pendimethalin[de]	1,145	0	89	89	0.9358
14 DAIT					
None	—	0	—	98	—
Clomazone	335	0	98	98	0.8112
Pendimethalin	810	0	98	97	0.5989
Clomazone + pendimethalin	335 + 810	0	98	98	0.7530
PP – Clomazone + pendimethalin	1,145	0	98	98	0.9355
28 DAIT[f]					
None	—	72	—	98	—
Clomazone	335	75	98	98	0.8974
Pendimethalin	810	71	98	97	0.6382
Clomazone + pendimethalin	335 + 810	71	98	98	0.8305
PP – Clomazone + pendimethalin	1,145	75	98	98	0.9827
42 DAIT					
None	—	97	—	97	—
Clomazone	335	97	97	97	0.7334
Pendimethalin	810	97	97	96	0.7724
Clomazone + pendimethalin	335 + 810	97	97	97	0.8939
PP – Clomazone + pendimethalin	1,145	97	96	97	0.8175

[a]Evaluated using Blouin's modified Colby's analysis.
[b]Evaluation dates for each respective herbicide mixture.
[c]Abbreviations: DAIT, days after initial treatment; PP, prepackaged mixture.
[d]$P < 0.05$ indicates an antagonistic response; $P > 0.05$ indicates a neutral response.
[e]RiceOne® contains 130 g ai L^{-1} of clomazone plus 313 g ai L^{-1} of pendimethalin in a dual-encapsulated suspension.
[f]Control observed for each mixture herbicide with an additional independent application of quizalofop applied at 120 h ai ha^{-1} 21 DAIT.

pendimethalin, 130 and 313 g ai L^{-1}, respectively, in a formulated, dual, aqueous capsule suspension; this herbicide was labeled for use in rice in 2017.

ACCase-R rice will help preserve the IR rice system by allowing rice producers to rotate between the two systems while providing a mechanism of control for weedy rice and troublesome grass species. However, it is important for producers to know what type of interaction will occur when mixing herbicides with quizalofop in ACCase-R rice production. The objective of this research was to determine whether an antagonistic, synergistic, or neutral interaction occurs when quizalofop is mixed with clomazone, pendimethalin, clomazone plus pendimethalin, or a prepackaged mixture of clomazone plus pendimethalin.

Materials and Methods

A study was conducted in 2017 and 2018 at the Louisiana State University Agricultural Center's H. Rouse Caffey Rice Research Station near Crowley, LA (30.177147°N, 92.3477430°W) to evaluate quizalofop applied independently or in a mixture with other herbicides with residual activity. The soil texture at the research station is a Crowley silt loam with a pH of 6.4 and 1.4% organic matter. Field preparation consisted of a fall and spring disking followed by two passes in opposite directions with a two-way bed conditioner consisting of rolling baskets and S-tine harrows set at a 6-cm depth. The research area received a preplant fertilizer application of 280 kg ha^{-1} 8-24-24 (N-P_2O_5-K_2O) fertilizer followed by an application of 280 kg ha^{-1} urea fertilizer 46-0-0 immediately before establishment of the permanent flood.

Long-grain ACCase-R rice cultivar 'PVL01' was drill seeded at 84 kg ha^{-1} on April 26 and April 12 in 2017 and 2018, respectively. Plot size was 5.1 m by 1.5 m, with eight 19.5-cm–wide rows. To simulate a weedy rice population, eight rows of IR 'CL-111' long-grain rice, 84 kg ha^{-1}, was drill seeded perpendicular to the PVL01 rice in the front third of each plot, and eight rows of IR 'CLXL-745' hybrid long-grain rice, 84 kg ha^{-1}, was drill seeded perpendicular to the ACCase-R rice in the back third of each plot. All drill-seeded rice was planted to a depth of 15 mm. Awnless red rice was broadcast across the study area at a rate of 50 kg ha^{-1} immediately before planting. The research area had a natural population of barnyardgrass. The research area was surface irrigated to a depth of 3 cm 24 h after planting.

The experimental design was two-factor factorial in a randomized complete block with four replications. Factor A consisted of quizalofop applied at 0 or 120 g ha^{-1}. Factor B consisted of no mixture herbicide, 335 g ai ha^{-1} clomazone, 810 g ha^{-1} pendimethalin, 335 g ha^{-1} clomazone mixed with 810 g ha^{-1} pendimethalin, and 1,145 g ha^{-1} prepackaged mix of clomazone plus pendimethalin. Clomazone and pendimethalin rates applied alone were equal to the rates found in the prepackaged mixture. To stay within the recommended BASF stewardship guidelines to prevent outcrossing with red rice and resistance development, a second application of quizalofop was applied to the entire research area at a rate of 120 g ha^{-1} at 21 d after the initial quizalofop treatment (DAIT) (Anonymous 2017). A crop oil concentrate (Agri-Dex®; Helena

Table 3. Hybrid CLXL-745 rice control and interactions with quizalofop applied alone or mixed with residual herbicides, 2017 and 2018.[a]

		Quizalofop			
		0 g ha^{-1}	120 g ha^{-1}		
Mixture herbicide[b,c]	Rate	Observed	Expected	Observed	P-value[d]
	g ha^{-1}	% of control			
7 DAIT					
None	—	0	—	90	—
Clomazone	335	0	90	90	0.6007
Pendimethalin	810	0	90	89	0.5420
Clomazone + pendimethalin	335 + 810	0	90	87	0.1232
PP – Clomazone + pendimethalin[de]	1,145	0	90	89	0.6626
14 DAIT					
None	—	0	—	99	—
Clomazone	335	0	98	98	0.7377
Pendimethalin	810	0	98	98	0.6819
Clomazone + pendimethalin	335 + 810	0	98	98	0.6306
PP – Clomazone + pendimethalin	1,145	0	98	98	0.8625
28 DAIT[f]					
None	—	74	—	98	—
Clomazone	335	71	98	98	0.9778
Pendimethalin	810	74	98	98	0.9303
Clomazone + pendimethalin	335 + 810	71	98	98	0.8454
PP – Clomazone + pendimethalin	1,145	71	98	98	0.8453
42 DAIT					
None	—	98	—	96	—
Clomazone	335	96	94	98	0.1661
Pendimethalin	810	97	96	97	0.6789
Clomazone + pendimethalin	335 + 810	97	96	97	0.4836
PP – Clomazone + pendimethalin	1,145	97	96	96	0.6759

[a]Evaluated using Blouin's modified Colby's analysis.
[b]Evaluation dates for each respective herbicide mixture.
[c]Abbreviations: DAIT, days after initial treatment; PP, prepackaged mixture.
[d]$P < 0.05$ indicates an antagonistic response; $P > 0.05$ indicates a neutral response.
[e]RiceOne® contains 130 g ai L^{-1} of clomazone plus 313 g ai L^{-1} of pendimethalin in a dual-encapsulated suspension.
[f]Control observed for each mixture herbicide with an additional independent application of quizalofop applied 21 DAIT.

Agri-Enterprises, Collierville, TN) was added to each herbicide treatment at 1% vol/vol.

Herbicide applications were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 190 kPa. The spray boom consisted of five flat-fan 110015 nozzles (AirMix Venturi® Flat Fan Nozzle; Greenleaf Technologies, Covington, LA) at 38-cm spacing. Each herbicide application was applied when PVLO1 rice was at the two- to three-leaf growth stage. Red rice, CL-111, and CLXL-745 were also at the two- to three-leaf stage and barnyardgrass was at the two- to four-leaf stage, with a population of 30 to 40 plants m^{-2}.

An activating 5-cm surface irrigation was applied to the entire research area within 5 d after the POST application in 2017 and 2018. The surface irrigation water was held for 24 h before draining. An 8-cm permanent flood was established when the rice reached the one- to two-tiller growth stage, 24 h after final quizalofop application, and maintained until 21 d before harvest.

Visual evaluations of crop injury and barnyardgrass, red rice, CL-111, and CLXL-745 control on a scale of 0% to 100%, where 0% indicates no injury or control and 100% indicates complete plant death, were recorded at 7, 14, 28, and 42 DAIT. Rice plant height was recorded immediately before harvest by measuring four plants in each plot from the ground to the tip of the extended panicle. The center four rows of each plot were harvested with a Mitsubishi VM3® (Mitsubishi Corp., Tokyo, Japan). Grain moisture was adjusted to 12%.

Control data were analyzed using the guidelines described the Blouin et al. (2010) augmented mixed model to determine synergistic, antagonistic, or neutral responses for herbicide mixtures by comparing an expected control calculated on the basis of the activity of each herbicide applied alone to an observed control (Fish et al. 2015, 2016; Rustom et al. 2018; Webster et al. 2012). Rough rice yield and plant height data were analyzed using the MIXED procedure of SAS (SAS 2013). The Tukey honestly significant difference test was used to separate yield means at the 5% probability level.

The fixed effects of the model were the herbicide treatments and evaluation timings. The random effects for the model were location by year and replications within location by year, and treatment by replication interactions. The dependent variables in the separate analyses were barnyardgrass, CL-111, CLXL-745, and red rice control, along with plant height and rough rice yield. The analyses for control were by DAT. Normality of effects over all DAT was checked using the UNIVARIATE procedure of SAS. Assumptions of normality were met (SAS 2013).

Results and Discussion

An antagonistic response was observed at 7 DAIT for barnyardgrass control when quizalofop was mixed with clomazone, clomazone plus pendimethalin, or the prepackaged mixture of clomazone plus pendimethalin, with observed controls of 94%, 94%, and 95%, respectively, compared with an expected control of 99% (Table 1). The data indicate the antagonism may be caused by the addition of clomazone, because pendimethalin applied alone with quizalofop resulted in neutral responses. Even though

Table 4. Red rice control and interactions with quizalofop applied alone or mixed with residual herbicides, 2017 and 2018.[a]

		Quizalofop			
		0 g ha^{-1}	120 g ha^{-1}		
Mixture herbicide[b,c]	Rate	Observed	Expected	Observed	P-value[d]
	g ha^{-1}	% of control			
7 DAIT					
None	—	0	—	85	—
Clomazone	335	0	85	82	0.2915
Pendimethalin	810	0	85	85	0.9187
Clomazone + pendimethalin	335 + 810	0	85	84	0.9593
PP – Clomazone + pendimethalin[de]	1,145	0	85	85	0.8383
14 DAIT					
None	—	0	—	99	—
Clomazone	335	0	99	99	0.9590
Pendimethalin	810	0	99	98	0.9590
Clomazone + pendimethalin	335 + 810	0	99	98	0.8439
PP – Clomazone + pendimethalin	1,145	0	99	99	0.9590
28 DAIT[f]					
None	—	72	—	99	—
Clomazone	335	74	99	98	0.7757
Pendimethalin	810	71	99	98	0.9694
Clomazone + pendimethalin	335 + 810	71	99	99	0.9496
PP – Clomazone + pendimethalin	1,145	72	99	98	0.9590
42 DAIT					
None	—	96	—	97	—
Clomazone	335	97	97	97	0.9596
Pendimethalin	810	97	97	96	0.8554
Clomazone + pendimethalin	335 + 810	97	97	97	0.9354
PP – Clomazone + pendimethalin	1,145	97	98	97	0.9094

[a]Evaluated using Blouin's modified Colby's analysis.
[b]Evaluation dates for each respective herbicide mixture.
[c]Abbreviations: DAIT, days after initial treatment; PP, prepackaged mixture.
[d]$P < 0.05$ indicates an antagonistic response; $P > 0.05$ indicates a neutral response.
[e]RiceOne® contains 130 g L^{-1} of clomazone plus 313 g L^{-1} of pendimethalin in a dual-encapsulated suspension.
[f]Control observed for each mixture herbicide with an additional independent application of quizalofop applied at 120 h ai ha^{-1} 21 DAIT.

antagonism occurred at 7 DAIT, control of barnyardgrass was 94% to 98% across all rating dates. These data indicate that the addition of one of the residuals can be mixed with quizalofop with little negative impact. At 14, 28, and 42 DAIT, no antagonism of quizalofop occurred for barnyardgrass, with observed control of 96% to 98%. The sequential application of quizalofop at 120 g ha^{-1} controlled the antagonized barnyardgrass observed at 7 DAIT and late-emerging barnyardgrass. However, a second application of quizalofop at 28 DAT did not overcome barnyardgrass antagonism when treated with an initial application of quizalofop plus penoxsulam (Rustom et al. 2018) or propanil (Rustom et al. 2019).

A neutral herbicide interaction occurred for CL-111 across all herbicide mixtures and evaluation dates (Table 2). At 7 DAIT, observed control of CL-111 was 88% to 90% when treated with either quizalofop plus any residual herbicide mixture evaluated, compared with an expected control of 89%. However, by 14, 28, and 42 DAIT, control increased to 96% to 98%. These results are similar to those of Minton et al. (1989), who reported increased red rice control: 91% with quizalofop at 21 DAT compared with 83% control at 7 DAT, indicating quizalofop takes longer than 7 d to control weedy rice.

A neutral herbicide interaction occurred for CLXL-745 across all herbicide mixtures and evaluation dates (Table 3). Similar results occurred for CL-111 (Table 2), and control of CLXL-745 was 87% to 90% at 7 DAIT when treated with either quizalofop plus any residual herbicide mixture evaluated (Table 3). However, at 14, 28, and 42 DAIT, control increased to 96% to 99%. These results are similar to those reported by Minton et al. (1989).

A neutral herbicide interaction occurred for red rice across all herbicide mixtures and evaluation dates (Table 4). At 7 DAIT, control of red rice was 82% to 85% across all herbicide mixtures; however, by 14, 28, and 42 DAIT, control increased to 96% to 99%. Red rice has been reported to have faster emergence, a higher tillering rate, taller growth habit, and to produce more straw material than cultivated rice (Diarra et al. 1985). These morphological features may be a factor in herbicide translocation by having more vegetative growth, making the herbicide translocate farther to the SOA, and ultimately lowering the control of red rice compared with CL-111 (Table 2) and CLXL-745 (Table 3) at 7 DAIT. A neutral interaction occurred when the prepackaged was mixed with quizalofop or the addition of the individual components of clomazone plus pendimethalin for control of CL-111 (Table 2), CLXL-745 (Table 3), and red rice (Table 4) across all evaluation dates.

Crop injury did not exceed 5% across all herbicide treatments and evaluation dates (data not shown). Rice plant height, 104 to 107 cm, was similar across all herbicide treatments (data not shown). A main affect occurred for rough rice yield over quizalofop rate (Table 5). Rice treated with an initial application of quizalofop yielded 5,440 kg ha^{-1}. Rice yield was 4,360 kg ha^{-1} when not treated with the initial application of quizalofop. The decrease in yield was likely due to the increased competition from the CL-111, CLXL-745, and red rice; however, the second application of quizalofop helped manage the weedy rice complex, resulting in a slight increase in rice yield.

In conclusion, the addition of a prepackaged mixture of clomazone plus pendimethalin in mixture with quizalofop resulted in a

https://doi.org/10.1017/wet.2019.59 Published online by Cambridge University Press

Table 5. Rough rice yield when treated with 0 or 120 g ha^{-1} of quizalofop, 2017 and 2018.[a]

Herbicide	Rate	Rough rice yield[ab]
	g ha^{-1}	kg ha^{-1}
No quizalofop[c]	0	4,360 b
Quizalofop	120	5,440 a

[a]Means followed by a common letter are not significantly different at P = 0.05 with the use of the Tukey honestly significant difference test.
[b]Yield data averaged over residual herbicide program.
[c]Rough rice yield with an additional independent blanket application of quizalofop at 120 g ai ha^{-1} applied at 21 d after the initial treatment across the entire research area.

neutral interaction for control of barnyardgrass (Table 1), CL-111 (Table 2), CLXL-754 (Table 3), and red rice (Table 4) at 14, 28, and 42 DAIT. Combining quizalofop with clomazone plus pendimethalin offers producers the ability to apply a POST herbicide to control already emerged grasses while providing residual activity for later in the growing season.

The addition of multiple herbicides with differing SOAs in a single mixture can help prevent or reduce the development of herbicide-resistant weeds as part of a full-season weed management program. These mixtures can also be part of a strategy to manage existing herbicide-resistant weeds (Norsworthy et al. 2012). Multiple weed species infest rice fields in Louisiana and rarely is there single monoculture of weed species (Webster 2014). The ACCase-R rice production system can be effective for controlling problem grasses found in Louisiana rice production. A prepackaged mixture of clomazone plus pendimethalin can be a useful residual herbicide in the ACCase-R rice production system. In addition, the application of multiple SOAs herbicide mixtures can be an excellent weed management tool (Carlson et al. 2011, 2012; Webster and Masson 2001; Norsworthy et al. 2007; Pellerin et al. 2004; Webster et al. 2012).

Acknowledgments. This report is published with the approval of the director of the Louisiana Agricultural Experiment Station and the Louisiana State University Agricultural Center, Baton Rouge, LA, under manuscript number 2019-306-33789. The authors would like to thank the staff of the Louisiana State University Agricultural Center's H. Rouse Caffey Rice Research Station. The Louisiana Rice Research Board provided partial funding for this project. No conflicts of interest have been declared.

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https://doi.org/10.1017/wet.2019.59 Published online by Cambridge University Press

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