USE AND MANAGEMENT OF ACCASE-RESISTANT RICE TECHNOLOGY IN THE UNITED STATES*

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INTRODUCTION

A current weed management issue in rice-producing areas throughout the world is the management of weedy rice, more particularly, imidazolinone-resistant (IR) weedy rice (Rustom et al. 2018). IR rice technology, first commercialized in 2002, allowed producers to control red rice with a herbicide during cultivated rice production for the very first time (Webster et al. 2017). Weedy rice is taxonomically classified as the same species as cultivated rice but can include different phenotypic characteristics, such as various grain colors, medium-to-long grain size, awned or awnless seeds, light to dark green vegetation color, variable plant height, and pubescent to glabrous leaves. Weedy rice has greater height and tillering capabilities than does cultivated rice; therefore, it can compete for nutrients and light at a higher rate than cultivated rice.

IR hybrid rice seed has dormancy characteristics, and if these seed are allowed to germinate, emerge, and establish, the plants can become a weed in future growing seasons (Rustom et al. 2018). These offspring can segregate which can cause a serious weed problem with many different phenotypes, and can potentially be IR. Outcrossing between cultivated rice and its weedy and wild relatives has also been observed. Research has suggested that the technology used in IR rice can be transferred by natural outcrossing to produce IR red rice. The term weedy rice will refer to the entire complex of volunteer hybrids, outcrosses, and red rice.

Another weed management issue in rice-producing areas throughout the world is barnyardgrass. Barnyardgrass competing for nutrients and light can result in significant cultivated rice yield reductions. Barnyardgrass resistant to imazethapyr and imazamox has become a common issue in rice production throughout the southern United States, which further reduces the usefulness of IR rice. Historically, weed control programs in rice in the southern United States have included propanil for the control of annual grasses such as barnyardgrass. Propanil resistant barnyardgrass and other herbicide resistant weed biotypes have the potential to spread, and resistant biotypes must be managed to prevent future issues.

With rising concerns about IR weedy rice and barnyardgrass resistant to herbicides with different modes of action, BASF is currently developing a new herbicide-resistant rice to be sold under the trade name Provisia®. The herbicide targeted for use is quizalofop, which will also be sold under the trade name Provisia® (Anonymous 2017). Quizalofop is a Group 1 herbicide, with a mode of action that inhibits acetyl-coA carboxylase. Quizalofop provides postemergence control of annual and perennial grasses with little to no activity on broadleaf weeds and sedges. Quizalofop has been used to substantially reduce weedy rice infestations during soybean production and noncrop areas for annual or perennial grass control. The targeted single quizalofop application rate in ACCase-resistant (ACCase-R) rice production will be 92 to 155 g/ha, not to exceed 240 g/ha yr.

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MATERIAL AND METHODS

A study was conducted in 2015 and 2016 at the H. Rouse Caffey Rice Research Station (RRS) near Crowley, Louisiana to evaluate the activity of quizalofop applied independently or in a mixture with herbicides with the ALS mode of action or contact activity. The soil type at the RRS is a Crowley silt loam with a pH of 6,4 and 1,4% organic matter. Plot size was 5,1 by 2,2 m, with eight 19,5-cm-wide drill-seeded rows planted as follows: four center rows of ACCase-R 'PVL024B' long grain rice, two rows of IR 'CL-111' long grain rice, and two rows of IR 'CLXL-745' hybrid long grain rice. Rice was planted at a rate of 67 kg/ha. Awnless strawhull red rice was broadcast in the plot area prior to drill seeding at a rate of 50 kg/ha. The IR rice line, IR hybrid, and red rice were planted to represent a weedy rice population. The research area was naturally infested with barnyardgrass.

Each herbicide application was applied when ACCase-R rice was at the three- to four-leaf growth stage. Red rice, CL-111, and CLXL-745 were at the three- to four-leaf growth stage and barnyardgrass was at the two- to five-leaf growth stage with a population of 50 to 100 plants m^2 when the applications were applied. The study was a randomized complete block with a factorial arrangement of treatments with four replications. For the ALS study, factor A consisted of quizalofop applied at 120 g/ha or no quizalofop. Factor B consisted of penoxsulam at 40 g/ha ai, penoxsulam plus triclopyr at 352 g/ha ai, halosulfuron at 53 g/ha ai, bispyribac at 34 g/ha ai, orthosulfamuron plus halosulfuron at 94 g/ha ai, orthosulfamuron plus quinclorac at 491 g/ha ai, imazosulfuron at 211 g/ha ai, bensulfuron at 43 g/ha ai, or no mixture herbicide. In the contact study, factor A was quizalofop applied at 120 g/ha or no quizalofop. Factor B was bentazon at 1050 g/ha ai, carfentrazone at 18 g ai ha^{-1}, propanil at 3360 g ai ha^{-1}, saflufenacil at 25 g/ha ai, thiobencarb at 3360 g ai ha^{-1}, or no mixture herbicide. A second quizalofop application was applied to all treatments at a rate of 120 g ha^{-1} at 28 days after the initial quizalofop treatment (DAIT). This application was applied to evaluate quizalofop efficacy on weedy rice and barnyardgrass that escaped the initial application, potentially as a result of antagonism, and because it is recommended by the BASF stewardship program for managing resistance development for ACCase-R (Anonymous 2017). A crop oil concentrate was added to each herbicide application at a rate of 1% v v^{-1} except treatments containing thiobencarb or propanil.

A field study was established in 2013 to evaluate long-term rotations for control of weedy rice plants. The long-term rotation field is located near Esterwood, Louisiana with a similar soil type as the RRS. The field has a large population of both hybrid rice dormancy issues and possible red rice out-crosses with IR rice. The plants present have a red rice appearance from a distance, but closer evaluation indicates both smooth and pubescent leaf surfaces, pale green to dark-green to purple vegetation, and long- and medium-grain rice. It is apparent the field was close to being a total failure with a loss of profitability due to weedy rice competition and possible need for abandonment.

The four-year rotation study evaluated five rotations including the use of Provisia rice in 2014. The rotations used are: Rotation 1) glyphosate-resistant (GR) soybeans (2013) followed by (fb) ACCase-R rice (2014) fb GR soybeans (2015) fb IR hybrid rice (2016); Rotation 2) Fallow (2013) fb ACCase-R rice (2014) fb GR soybeans (2015) fb IR hybrid rice (2016); Rotation 3) IR hybrid rice (2013) fb glufosinate-resistant (Glu-R) soybeans (2014) fb ACCase-R rice (2015) fb IR hybrid rice (2016); Rotation 4) GR soybeans (2013) fb Glu-R soybeans (2014) fb GR soybeans (2015) fb IR hybrid rice (2016); Rotation 5) GR soybeans (2013) fb IR hybrid rice (2014) fb GR soybeans (2015) fb IR hybrid rice (2016).

RESULTS

ALS Mixture Study. Antagonistic responses were observed for red rice control at 14 DAIT when quizalofop was mixed with bispyribac or penoxsulam plus triclopyr. All other mixtures resulted in a neutral response on red rice at 14 DAIT. However, at 28 DAIT, all mixture herbicides evaluated antagonized quizalofop for red rice control. Penoxsulam, penoxsulam plus triclopyr, or bispyribac mixed with quizalofop reduced the expected control of 97% to an observed control of 59% to 67%. Halosulfuron, orthosulfamuron plus halosulfuron, orthosulfamuron plus quinclorac, imazosulfuron, or bensulfuron mixed with quizalofop reduced red rice control to an observed control of to 81% to 88%. Hybrid CLXL-745 rice was also treated with all mixtures evaluated for red rice control. At 14 DAIT, the addition of bispyribac or penoxsulam plus triclopyr antagonized quizalofop; however, the addition of penoxsulam alone,

halosulfuron, or orthosulfamuron plus quinclorac also antagonized quizalofop on CLXL-745. All ALS herbicides mixed with quizalofop proved to antagonize quizalofop on CLXL-745 at 28 DAIT. Antagonistic responses were observed at 14 DAIT for CL-111 when treated with quizalofop plus any ALS herbicide except bensulfuron, which indicated a neutral response. Bensulfuron was the only ALS herbicide that did not antagonize quizalofop activity on red rice, CLXL-745, or CL-111 evaluated at 14 DAIT, and this may indicate the potential as a mixture herbicide with quizalofop early in the growing season when weedy rice is present. At 14 DAIT, bispyribac and penoxsulam plus triclopyr antagonized quizalofop for barnyardgrass, red rice, CLXL-745, and CL-111 control. In addition, penoxsulam, orthosulfamuron plus halosulfuron, and orthosulfamuron plus quinclorac were also found to be antagonistic for barnyardgrass control at 14 DAIT. Any antagonism observed at 14 and 28 DAIT was overcome with a second application of quizalofop, except with penoxsulam-containing herbicides for barnyardgrass control.

Contact Mixture Study. Antagonistic responses were observed for red rice control when quizalofop was mixed with propanil at 14, 28, and 42 DAIT. At 42 DAIT, a slightly antagonistic response was indicated for red rice treated with quizalofop plus propanil. All other contact herbicides mixed with quizalofop resulted in a neutral response for red rice control at all evaluation dates, indicating the potential as mix partners with quizalofop for red rice control in ACCase-R rice production. Antagonistic mixtures for CLXL-745 control included quizalofop mixed with propanil, bentazon or saflufenacil at 14 DAIT. CL-111 responses were similar to CLXL-745, except a neutral response was observed for quizalofop mixed with saflufenacil at 14 DAIT. Similar to red rice, CLXL-745, and CL-111, propanil antagonized quizalofop activity on barnyardgrass at 14 and 28 DAIT. By 42 DAIT, the second quizalofop application at 28 DAIT could not overcome the antagonism observed at earlier evaluations 14 and 28 DAIT. In addition, quizalofop activity on barnyardgrass was antagonized by saflufenacil at 14 DAIT. Bentazon mixed with quizalofop resulted in a neutral response for barnyardgrass control at all evaluation dates. As with red rice, CLXL-745, and CL-111 at all DAIT, barnyardgrass treated with quizalofop plus carfentrazone or thiobencarb resulted in a neutral response, indicating the potential for use as a mixture in an ACCase-R rice production system for control of these weeds.

Long-term study. The entire research area reverted to the producer's rotational crop in 2016. The entire area was planted to CLXL 745 rice and treated with clomazone 336 g/ha plus penoxulam at 40 g/ha ai plus halosulfuron at 53 g/ha ai oz/A applied preemergence. The grower sprayed applications of imazethapyr at 70 g/ha ai at the one- to two-leaf stage fb 70 g/ha ai at the four-leaf to one-tiller stage. Rotation 4, which included 3 years of consecutive soybean reduced weedy rice to 50 plants/ha, and Rotation 1 employed a soybean-rice-soybean-rice rotation with ACCase-R rice planted the 2nd year, 2014, which resulted in a final count to 60 plants/ha in 2016. These populations were compared with the grower program in an adjacent area with 100 times more weedy rice plants in 2016.

CONCLUSIONS

In conclusion, it is important that one understand the compatibility between quizalofop when applied in mixture with other herbicides. These data suggest that the application of quizalofop mixed with common herbicides used in rice production can result in an antagonistic response resulting in yield reduction, thus potentially reducing economic returns. However, the long-term research indicates ACCAse-resistant rice can be a useful in reducing weedy rice infestations.

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