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Glyphosate-Resistant Italian Ryegrass (*Lolium perenne* ssp. *multiflorum*) Control with Fall-Applied Residual Herbicides

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Dense populations of glyphosate-resistant (GR) Italian ryegrass are problematic for spring burndown herbicide programs and crop establishment in the midsouthern United States. Two field studies were conducted to evaluate fall-applied residual herbicides for control of GR Italian ryegrass and to identify the most effective application timing for these herbicides. Fall applications of clomazone at 0.84 and 1.12 kg ai ha^{-1}, pyroxasulfone at 0.16 kg ai ha^{-1}, and *S*-metolachlor at 1.79 kg ai ha^{-1} controlled GR Italian ryegrass $\geq$ 93% 180 d after application. Control from incorporated applications of pendimethalin at 1.59 kg ai ha^{-1} and trifluralin at 1.68 kg ai ha^{-1} and surface applications of *S*-metolachlor at 1.42 kg ha^{-1} provided control similar to the best treatments. Glyphosate-resistant Italian ryegrass control following clomazone, pyroxasulfone, *S*-metolachlor, or trifluralin applied in mid September, October, or November exceeded that from fall tillage by 19 to 56% at 90 and 140 d after the last treatment. Pyroxasulfone and *S*-metolachlor controlled more GR Italian ryegrass following October or November applications compared with those in September at both 90 and 140 d after the last application timing. However, the benefit of delaying clomazone application from October to November was not realized until the last evaluation (140 d after the last treatment). Clomazone, pyroxasulfone, and *S*-metolachlor offer growers the best opportunity for residual control of GR Italian ryegrass, and control is optimized when these herbicides are applied in November.

Nomenclature: Clomazone; glyphosate; pendimethalin; pyroxasulfone; *S*-metolachlor; trifluralin; Italian ryegrass, *Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot. LOLMU.

Key words: Application timing, herbicide resistance, incorporated applications, surface applications, tillage, weed control.

Poblaciones densas de *Lolium perenne* ssp. *multiflorum* resistente a glyphosate (GR) son problemáticas para los programas de eliminación de vegetación en la primavera y para el establecimiento de cultivos en el centro-sur de los Estados Unidos. Se realizaron dos estudios de campo para evaluar aplicaciones de herbicidas residuales en el otoño para el control de *L. perenne* GR y para identificar el momento de aplicación más efectivo para estos herbicidas. Aplicaciones en el otoño de clomazone a 0.84 y 1.12 kg ai ha^{-1}, pyroxasulfone a 0.16 kg ai ha^{-1}, y *S*-metolachlor a 1.79 kg ai ha^{-1} controlaron *L. perenne* GR $\geq$93%, 180 d después de la aplicación. El control a partir de aplicaciones incorporadas de pendimethalin a 1.59 kg ai ha^{-1} y trifluralin a 1.68 kg ai ha^{-1} y aplicaciones superficiales de *S*-metolachlor a 1.42 kg ha^{-1} brindaron un control similar a los mejores tratamientos. El control de *L. perenne* GR después de aplicaciones de clomazone, pyroxasulfone, *S*-metolachlor, o trifluralin, en la mitad de Septiembre, Octubre, o Noviembre, excedieron el control obtenido con labranza en el otoño en 19 a 56%, a 90 a 140 d después del tratamiento. Pyroxasulfone y *S*- metolachlor aplicados en Octubre o Noviembre controlaron *L. perenne* GR más que las aplicaciones en Septiembre a 90 y 140 d después del último momento de aplicación. Sin embargo, el beneficio de retrasar la aplicación de clomazone de Octubre a Noviembre no se vio sino hasta la última evaluación (140 d después del tratamiento). Clomazone, pyroxasulfone, y *S*-metolachlor ofrecen a los productores la mejor oportunidad de control residual de *L. perenne* GR, y el control se optimiza cuando estos herbicidas se aplican en Noviembre.

Italian ryegrass is a short, rhizomatous, annual or biennial bunchgrass that grows from 30 to 90 cm tall, often with erect stems exhibiting purple coloration at the base (Davies 1928). Seeds germinate when adequate moisture is available, and plants are tolerant to a wide range of daytime temperature fluctuations and light regimes. Germination occurs within 6 to 10 d when temperatures

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are between 10 and 30 C during the daytime (Hannaway et al. 1999). Plants grow vigorously in winter and early spring and are highly competitive for nutrients, water, and sunlight. Italian ryegrass establishes quickly, grows rapidly in a range of soil textures with pH levels from 5 to 7.9 and varied drainage regimes, and can withstand −22 C (Carey 1995; Hannaway et al. 1999; U.S. Department of Agriculture–Natural Resources Conservation Service [USDA-NRCS] 2013). Due to its rapid growth, Italian ryegrass generally dominates neighboring species and those with slower development (Davies 1928).

The United States grows approximately 1.2 million ha of annual ryegrass (*Lolium* spp.) with 90% used for winter pasture in the southeastern United States (USDA-NRCS 2013). Italian ryegrass is also used for soil stabilization. An extensive, shallow, and fibrous root system enables Italian ryegrass to establish quickly and prevent soil erosion while allowing slower-growing, longer-lived grass species become established (Hafenrichter et al. 1968; Hall 1992; Hannaway et al. 1999).

Cultivated ryegrass species and Italian ryegrass readily hybridize and escape cultivation, resulting in naturalization along roadsides (Carey 1995; Wilken 1993). Italian ryegrass has become a problematic weed along roadsides and in cereal, vegetable, and grass crops (Appleby et al. 1976; Bell 1995; Stanger et al. 1989; Taylor and Coats 1996). Italian ryegrass densities of 600 to 1,000 plants m^{-2} contributed to 100% yield loss in broccoli (*Brassica oleracea* var. *botrytis*) (Bell 1995). Italian ryegrass is highly competitive with winter wheat (*Triticum aestivum* L.) (Appleby and Brewster 1992), and competition reduced wheat yield up to 92% (Hashem et al. 1998).

Control of Italian ryegrass along roadsides and in crop production areas has historically been achieved with the use of herbicides. Italian ryegrass is one of the most common and problematic weeds of wheat in the southeastern United States (Webster 2012). Wheat producers have historically relied on diclofop for control of Italian ryegrass (Crooks et al. 2003), but control options in wheat are now limited because of diclofop resistance in the species (Grey and Bridges 2003). Cultural practices to control diclofop-resistant Italian ryegrass in wheat include increased tillage, delayed planting, increased seeding rate, narrow rows, and crop rotation (Justice et al. 1994). However, these practices were less effective than herbicides in controlling Italian ryegrass in Oklahoma.

In 1999, populations of Italian ryegrass with a two- to four-fold resistance to glyphosate were identified in two fruit orchards in Chile (Perez and Kogan 2003). A fivefold level of glyphosate resistance in Italian ryegrass was documented in a filbert (*Corylus avellana* L.) orchard in Oregon in 2003 (Perez-Jones et al. 2005). Nandula et al. (2007) documented the first GR Italian ryegrass populations in row crop production in the United States. Two separate Italian ryegrass populations from Mississippi survived glyphosate rates up to 0.84 and 1.68 kg ae ha^{-1}, representing a threefold resistance to glyphosate compared with the susceptible population (Nandula et al. 2007). Thirty-two counties in Mississippi now contain populations of GR Italian ryegrass. Populations of GR Italian ryegrass have also been confirmed in at least one county/parish in Arkansas, Louisiana, and North Carolina (JA Bond et al. 2011; Heap 2013).

Taylor and Coats (1996) documented two sulfometuron-resistant populations of Italian ryegrass from Mississippi. Italian ryegrass populations resistant to acetolactate synthase-inhibiting herbicides have also been identified in Arkansas, Georgia, and Idaho (Heap 2013). Italian ryegrass resistance to acetyl CoA carboxylase-inhibiting herbicides, primarily the aryloxyphenoxy propionate family, is also common across the United States (Heap 2013).

To reduce input costs, equipment use, soil erosion, and number of herbicide applications, growers have adopted GR crop technologies and have replaced conventional tillage practices with conservation or no tillage systems (Carpenter and Gianessi 1999; Cerderia and Duke 2006; Service 2007; Young 2006). Glyphosate is used as a preplant burndown herbicide, POST treatment, and sometimes as a harvest aid in Mississippi. Glyphosate-resistant Italian ryegrass in row crop production areas poses a challenge to producers utilizing conservation or no-tillage systems (Nandula et al. 2007). Heavy infestations of GR Italian ryegrass could compromise preplant burndown practices and weed control options. Ineffective control of Italian ryegrass prior to planting can result in significant Italian ryegrass residue, which impedes the planting process.

Christoffoleti et al. (2005) conducted field and greenhouse experiments to determine control of GR

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Table 1. Herbicide common and trade names, application rates and placement, and herbicide manufacturer information for treatments in a study conducted near Tribbett, MS, in 2006 to 2007 and 2007 to 2008 evaluating fall-applied residual herbicides for control of glyphosate-resistant Italian ryegrass.

Common name	Trade name	Rate	Herbicide placement[a]	Manufacturer
		kg ai ha^{-1}		
Clomazone	Command	0.56, 0.84, 1.12	Surface	FMC Corporation, Philadelphia, PA (www.fmc.com)
Flumioxazin	Valor SX	0.07	Surface	Valent U.S.A. Corporation, Walnut Creek, CA (www.valent.com)
Pendimethalin	Prowl H_2O	1.06, 1.59	Incorporated and surface	BASF Crop Protection, Research Triangle Park, NC (www.basf.com)
Pyroxasulfone	Zidua	0.04, 0.05, 0.16	Surface	BASF Crop Protection, Research Triangle Park, NC (www.basf.com)
S-metolachlor	Dual Magnum	1.06, 1.42, 1.79	Surface	Syngenta Crop Protection, Greensboro, NC (www.syngentacropprotection.com)
Trifluralin	Treflan	1.12, 1.68	Incorporated	Helena Chemical Company, Collierville, TN (www.helenachemical.com)

[a] Incorporated treatments were incorporated with the use of a rototiller to a depth of 7.6 cm. Surface treatments were applied to the soil surface.

Italian ryegrass with alternative herbicides at specific phenological stages and concluded that GR Italian ryegrass was more difficult to control with the use of glyphosate applied at advanced stages of growth. Clethodim was more effective than fluazifop or quizalofop for control of GR Italian ryegrass, and control was better following applications in January compared with those in November or March (RC Bond et al. 2011). The addition of metribuzin improved paraquat efficacy on GR Italian ryegrass (Eubank et al. 2011). However, neither clethodim nor paraquat provided complete control of GR Italian ryegrass (RC Bond et al. 2011; Eubank et al. 2011).

Fall applications of residual herbicides have been reported to provide excellent control of winter annual weeds (Hasty et al. 2004; Stougaard et al. 1984). Fall-applied residual herbicides are commonly recommended in Mississippi for management of GR horseweed [*Conyza canadensis* (L.) Cronq.] (Mississippi State University Extension Service [MSU-ES] 2013). Fall applications are advantageous because they target weeds in an earlier developmental stage when they are easier to control (Hasty et al. 2004). Because multiple resistance to POST herbicides in rigid ryegrass (*Lolium rigidum* Gaudin) is common throughout Australia (Broster and Pratley 2006; Owen et al. 2007), PRE herbicides have been widely used to control this weed (Walsh et al. 2011). The same concept may be useful for management of GR Italian ryegrass in the midsouthern United States.

Published research on control of GR Italian ryegrass in row crop production systems in the midsouthern United States is not readily available, and there are no reports on efficacy of fall-applied residual herbicides targeting this species. It is important to identify effective herbicides and application timings for control of GR Italian ryegrass to prevent competition and yield reduction in row crop production systems. The objectives of this research were to evaluate fall-applied residual herbicides for control of GR Italian ryegrass and identify the most effective timing for application of these herbicides.

Materials and Methods

Fall-Applied Residual Herbicide Evaluation. A study was conducted in 2006 to 2007 and 2007 and 2008 at an on-farm site near Tribbett, MS (33.36°N, 90.77°W), to evaluate fall applications of residual herbicides for control of GR Italian ryegrass. Soil at Tribbett was a Forrestdale silty clay loam (fine, smectitic, thermic Typic Endoaqualf) with a pH of 6.2 and 1% organic matter. Plots were established following no-tillage soybean [*Glycine max* (L.) Merr.] and were naturally infested with GR Italian ryegrass (Nandula et al. 2007). The experimental site was maintained fallow throughout the study.

Treatments were replicated four times within a randomized complete block experimental design. Herbicide treatments and application rates are listed in Table 1. Paraquat (Gramoxone Inteon, herbicide,

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Syngenta Crop Protection, 410 South Swing Rd., Greensboro, NC 27409) at 0.84 kg ai ha^{-1} plus crop oil concentrate (Agri-Dex®, a 99% crop oil concentrate, Helena Chemical Co., 5100 Poplar Ave., Memphis, TN 38137) at 1% (v/v) was included with all herbicide treatments to control emerged GR Italian ryegrass, which was 5 to 8 cm with one to two leaves, emerged at the time of application. A nontreated control was included for comparison.

All herbicide treatments were applied with the use of a CO_2-pressurized backpack sprayer and hand-held boom equipped with regular flat-fan nozzles (11003 flat-fan TeeJet nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189) calibrated to deliver 140 L ha^{-1} at 137 kPa. Herbicide incorporation for pendimethalin and trifluralin treatments (Table 1) was accomplished using a rototiller operated to a depth of 7.6 cm. Individual plots measured 2 m wide by 7.6 m long. Treatments were applied November 11, 2006, and November 8, 2007.

Glyphosate-resistant Italian ryegrass control was visually estimated at 100, 140, and 180 d after treatment (DAT) on a scale of 0 (no control) to 100% (complete control). Following the 180 DAT evaluation, aboveground shoot biomass of GR Italian ryegrass was collected from a 1-m^2 quadrat in each plot. Plants were cut at soil level, placed in paper bags, and allowed to dry under greenhouse conditions for 14 d. Dry weights of each sample were measured, and data were converted to a percent reduction from the nontreated control in each replication according to the equation:

$$\text{Percent reduction} = \{[\text{dry weight of nontreated(g)} - \text{dry weight of treated plot(g)}]/ \text{dry weight of nontreated(g)}\} \times 100. \quad [1]$$

The square roots of visual control estimates and dry weight reductions were arcsine transformed. The transformation did not improve homogeneity of variance based on visual inspection of plotted residuals; therefore, nontransformed data were used in analyses. Data from the nontreated control were deleted prior to analysis of visual control estimates to stabilize variance. Nontransformed data were subjected to the Mixed Procedure (SAS 2008), with year and replication (nested within year) as random effect parameters (Blouin et al. 2011). Type III Statistics were used to test the fixed effect of herbicide. Least-square means were calculated, and mean separation ($P \leq 0.05$) was produced with the use of PDMIX800 in SAS, which is a macro for converting mean separation output to letter groupings (Saxton 1998).

Fall-Applied Residual Herbicide Application Timing. A study to identify the most effective timing for fall-applied residual herbicides targeting GR Italian ryegrass was conducted once in 2009 to 2010 and twice in 2010 to 2011 at on-farm sites near Elizabeth, MS, known to be infested with GR Italian ryegrass (Nandula et al. 2007). Coordinates for the 2009 to 2010 site were 33.43°N, 90.87°W, and those for the 2010 to 2011 sites were 33.42°N, 90.87°W and 33.42°N, 90.89°W. Soil at all three sites was a Commerce silt loam (fine–silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) with pH ranging from 6.3 to 6.5 and 1 to 1.3% organic matter. Plots were established following no-tillage soybean each year and were maintained fallow for the duration of the study.

Treatments were replicated four times in a randomized complete block experimental design with a factorial arrangement of five treatments and three application timings. Herbicide treatments were identified based on results of the fall-applied residual herbicide evaluation described previously and other related, unpublished results. Treatments included clomazone at 0.84 kg ha^{-1}, pyroxasulfone at 0.16 kg ha^{-1}, *S*-metolachlor at 1.42 kg ha^{-1}, and trifluralin at 1.68 kg ha^{-1}. A tillage treatment consisting of two passes in opposite directions with a tandem disk set to operate at 7.6 cm was included at each application timing. Paraquat at 0.84 kg ha^{-1} plus crop oil concentrate at 1% (v/v) was included with all herbicide treatments to control emerged GR Italian ryegrass, which was 5 to 8 cm with one to two leaves. Trifluralin was incorporated within 4 hr of application with two passes in opposite directions with a tandem disk set to operate at 7.6 cm.

Treatments were originally prescribed to be applied at monthly intervals beginning in mid-September and terminating in mid-January. Because of inclement weather that persisted throughout fall and winter 2009, treatments were applied when soil moisture was conducive for tillage, but

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Table 2. Glyphosate-resistant Italian ryegrass control 100, 140, and 180 d following fall-applied residual herbicide applications at Tribbett, MS.[a]

Herbicide	Rate	Herbicide placement[b]	100 DAT[c]	140 DAT	180 DAT	Dry weight[d]
	kg ai ha^{-1}		%			
Clomazone	0.56	Surface	97 a	87 ab	76 bc	65 b
Clomazone	0.84	Surface	98 a	96 a	95 a	98 a
Clomazone	1.12	Surface	98 a	97 a	95 a	100 a
Flumioxazin	0.07	Surface	87 bc	81 b	64 cd	35 c
Pendimethalin	1.06	Incorporated	94 ab	82 b	75 bc	77 ab
Pendimethalin	1.59	Incorporated	95 a	90 ab	83 ab	80 ab
Pendimethalin	1.06	Surface	64 f	48 d	34 e	2 d
Pendimethalin	1.59	Surface	74 e	47 d	36 e	3 d
Pyroxasulfone	0.04	Surface	78 de	63 c	53 d	6 d
Pyroxasulfone	0.05	Surface	84 cd	68 c	55 d	37 c
Pyroxasulfone	0.16	Surface	96 a	95 a	93 a	99 a
S-metolachlor	1.06	Surface	96 a	88 ab	77 bc	82 ab
S-metolachlor	1.42	Surface	97 a	92 ab	89 ab	95 a
S-metolachlor	1.79	Surface	97 a	95 a	93 a	98 a
Trifluralin	1.12	Incorporated	95 a	85 ab	75 bc	75 ab
Trifluralin	1.68	Incorporated	97 a	89 ab	85 ab	88 ab

[a] Data averaged across two experiments. Means followed by same letter for each parameter are not significantly different at $P \leq 0.05$.

[b] Incorporated treatments were incorporated using a rototiller to a depth of 7.6 cm. Surface treatments were applied to the soil surface.

[c] Abbreviations: DAT, days after treatment.

[d] Data expressed as a percent reduction from the nontreated calculated using equation [1].

treatment interval was not < 19 or > 36 d. Wet conditions prevented mid December and January applications both years. Treatments were applied on September 26, October 15, and November 20 in 2009, and on September 17, October 11, and November 10 in 2010. All herbicide treatments were applied using a tractor-mounted, compressed-air boom equipped with regular flat-fan nozzles (8002 flat-fan TeeJet nozzles) calibrated to deliver 140 L ha^{-1} at 276 kPa. Individual plots measured 3 m wide by 10 m long.

Glyphosate-resistant Italian ryegrass control was visually estimated at 21, 90, and 140 d after the last treatment (applied in November) on the scale previously described. At 35 d following the final treatment, average GR Italian ryegrass density was calculated by counting all plants in two 1-m^2 quadrats in each plot. Following the evaluation at 140 d after the last treatment, dry weights of GR Italian ryegrass in each plot were determined as previously described. Glyphosate-resistant Italian ryegrass density and dry weight were converted to a percent reduction from the nontreated control with the use of equation [1]. Data analyses were as previously described for the fall-applied residual herbicide evaluation.

Results and Discussion

Fall-Applied Residual Herbicide Evaluation. Glyphosate-resistant Italian ryegrass control and dry weight reduction following fall-applied residual herbicides are presented in Table 2. All rates of clomazone, incorporated pendimethalin, *S*-metolachlor, and trifluralin and pyroxasulfone at 0.16 kg ha^{-1} controlled GR Italian ryegrass ≥ 94% 100 DAT. At the same evaluation, control from flumioxazin, surface applications of pendimethalin, and the two lowest rates of pyroxasulfone was ≤ 87%.

Pendimethalin has been widely researched for Italian ryegrass control in winter wheat; however, most published reports suggest that POST applications of other herbicides are required for adequate control following surface applications of pendimethalin (Barnes et al. 2001; Bond et al. 2005; Clemmer et al. 2004). This implies that surface applications of pendimethalin do not adequately control Italian ryegrass throughout the fall and

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winter months, which is similar to observations in the current research (Table 2).

Although most treatments adequately controlled GR Italian ryegrass 100 DAT, control was more variable 140 DAT (Table 2). Only the two highest rates of clomazone and the highest rate of pyroxasulfone or *S*-metolachlor controlled GR Italian ryegrass $\geq$ 95% 140 DAT. Incorporated applications of pendimethalin at 1.59 kg ha^{-1} or trifluralin (both rates) and surface applications of clomazone at 0.56 kg ha^{-1} or *S*-metolachlor at 1.06 and 1.42 kg ha^{-1} provided 85 to 90% control, which was similar to control from the best treatments. Control from flumioxazin and incorporated applications of the lower rate of pendimethalin was 81 to 82%, but no other treatment controlled GR Italian ryegrass $>$ 68% 140 DAT.

Pyroxasulfone is reported to control a similar weed spectrum to *S*-metolachlor (Geier et al. 2006; Mueller and Steckel 2011; Steele et al. 2005). Walsh et al. (2011) reported $>$ 90% control of rigid ryegrass with pyroxasulfone. Pyroxasulfone at 0.15 kg ha^{-1} controlled Italian ryegrass 90 to 100% approximately 4 mo after planting winter wheat, but control was only 63 to 78% with pyroxasulfone at 0.05 kg ha^{-1} (Hulting et al. 2012). *S*-metolachlor at 0.84 and 1.12 kg ha^{-1} controlled Italian ryegrass 92 to 100% in April following PRE applications to wheat in November (Ritter and Menbere 2002).

Similar to the 140 DAT evaluation, the two highest rates of clomazone and the highest rate of pyroxasulfone or *S*-metolachlor controlled GR Italian ryegrass $\geq$ 93% 180 DAT (Table 2). Control from incorporated applications of pendimethalin at 1.59 kg ha^{-1} and trifluralin at 1.68 kg ha^{-1} and surface applications of *S*-metolachlor at 1.42 kg ha^{-1} provided control similar to the best treatments. However, in contrast to 140 DAT evaluation, control from the lowest rate of clomazone or *S*-metolachlor was lower than that from higher rates of the same herbicides. Control was similar and ranged from 75 to 85% following both rates of trifluralin and incorporated applications of pendimethalin. Control with all other treatments was poor ($\leq$ 64%) 180 DAT.

Reductions in dry weight reflected trends reported for visual estimates of GR Italian ryegrass control 180 DAT (Table 2). Dry weights were reduced 95 to 100% following the two higher rates of clomazone and *S*-metolachlor and pyroxasulfone at 0.16 kg ha^{-1}. *S*-metolachlor at 2.24 kg ha^{-1} reduced Italian ryegrass density and dry weight 96 and 100%, respectively, in greenhouse experiments (Tharp and Kells 2000). Incorporated applications of both rates of pendimethalin and trifluralin and surface application of *S*-metolachlor at 1.06 kg ha^{-1} reduced GR Italian ryegrass dry weight 77 to 88%, which was similar to that following the best treatments. Although GR Italian ryegrass control following flumioxazin was 64% 180 DAT, dry weight reduction was only 35%. This may have resulted from surviving plants being larger (a function of time of emergence) following flumioxazin compared with other treatments.

Incorporated applications of pendimethalin at 1.59 kg ha^{-1} and trifluralin 1.68 kg ha^{-1} controlled GR Italian ryegrass 83 and 85%, respectively, 180 DAT. These two herbicides, if mechanically incorporated, should be considered options for control of GR Italian ryegrass. Trifluralin is widely used in Australia for managing herbicide-resistant rigid ryegrass (Chauhan et al. 2007). However, incorporation is a determining factor in the level of control with pendimethalin or trifluralin. In Mississippi corn (*Zea mays* L.) and soybean production, tillage is often performed soon after harvest of these crops, which can occur in early August. To utilize equipment and labor resources efficiently, pendimethalin or trifluralin would need to be applied and incorporated during these tillage operations. Unfortunately, these field operations do not coincide with germination and emergence of Italian ryegrass most years (Hannaway et al. 1999; RC Bond, unpublished data). Pendimethalin and trifluralin may be better options following cotton (*Gossypium hirsutum* L.) in Mississippi because the harvest window for cotton more closely coincides with emergence of Italian ryegrass. Clomazone at 0.84 kg ha^{-1}, pyroxasulfone at 0.16 kg ha^{-1}, and *S*-metolachlor at 1.42 kg ha^{-1} would be the best options for surface applications of fall-applied residual herbicides to control GR Italian ryegrass.

Fall-Applied Residual Herbicide Application Timing. Tillage performed in November controlled GR Italian ryegrass similar to residual herbicide treatments 21 d after the last treatment (Table 3). However, at the later evaluations, GR Italian ryegrass control following all herbicide treatments exceeded that from tillage by 19 to 56%.

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Table 3. Glyphosate-resistant Italian ryegrass control following residual herbicides applied at three application timings (September, October, November) near Elizabeth, MS, in 2009 to 2010 and 2010 to 2011.[a]

		Italian ryegrass control 21 d after November treatment			Italian ryegrass control 90 d after November treatment			Italian ryegrass control 140 d after November treatment		
Treatment	Rate	September	October	November	September	October	November	September	October	November
	kg ai ha^{-1}	%								
Clomazone	0.84	68 d	86 abc	97 a	57 d	85 ab	97 a	37 f	63 cd	86 a
Pyroxasulfone	0.165	68 d	85 bc	94 ab	55 d	76 bc	92 a	36 f	61 cd	82 ab
S-metolachlor	1.42	73 d	86 abc	94 ab	57 d	73 bc	93 a	36 f	52 de	77 ab
Trifluralin	1.68	73 d	77 cd	92 ab	61 cd	73 bc	87 ab	45 ef	51 de	72 bc
Tillage		22 f	36 e	89 ab	14 e	17 e	68 cd	10 g	13 g	35 f

[a] Data averaged across three experiments. Means followed by same letter for each evaluation interval are not significantly different at $P \leq 0.05$.

At 21 d after the last treatment, none of the residual herbicides applied in September controlled GR Italian ryegrass > 73% (Table 3). By 140 d after the last treatment, control was <50% following all herbicide treatments applied in September. Herbicide treatments applied in October controlled GR Italian ryegrass 77 to 86% 21 d after the last treatment. No differences in control were detected 90 d after the last treatment when the four residual herbicide treatments were applied in October. By 140 d after the last treatment, GR Italian ryegrass control with clomazone and pyroxasulfone exceeded that from *S*-metolachlor and trifluralin following applications in October; however, none of these treatments controlled GR Italian ryegrass > 63%.

Delaying application from October until November improved GR Italian ryegrass control with trifluralin at 21 and 140 d after the last treatment (Table 3). Pyroxasulfone and *S*-metolachlor controlled more GR Italian ryegrass following October or November applications compared with those in September at both 90 and 140 d after the last application timing. In contrast, the benefit of delaying clomazone application from October to November was not realized until the last evaluation (140 d after November treatment). At the last evaluation, November applications of clomazone controlled GR Italian ryegrass better than trifluralin applied the same day.

The research sites were infested with natural populations of GR Italian ryegrass. The density of the populations varied across the plots each site year, increasing the variability in GR Italian ryegrass density data. At 35 d after the last treatment, trifluralin applied in November reduced GR Italian ryegrass density compared with applications in September or October (Table 4). October and November applications of clomazone, pyroxasulfone,

Table 4. Italian ryegrass density and dry weight following residual herbicides applied at three application timings (September, October, November) near Elizabeth, MS, in 2009 to 2010 and 2010 to 2011.[a]

		Italian ryegrass density 35 d after November treatment			Italian ryegrass dry weight 140 d after November treatment		
Treatment	Rate	September	October	November	September	October	November
	kg ai ha^{-1}	% reduction from nontreated					
Clomazone	0.84	80 c	95 a	100 a	44 c	89 a	100 a
Pyroxasulfone	0.165	81 bc	92 ab	98 a	57 bc	79 ab	97 a
S-metolachlor	1.42	80 c	96 a	99 a	34 c	82 ab	99 a
Trifluralin	1.68	67 d	81 bc	95 a	74 ab	82 ab	94 a
Tillage		1 e	1 e	81 bc	2 d	3 d	83 ab

[a] Data averaged across three experiments. Means followed by same letter for each parameter are not significantly different at $P \leq 0.05$.

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and *S*-metolachlor produced similar reductions in GR Italian ryegrass density 35 d after the last treatment.

With the exception of trifluralin, GR Italian ryegrass dry weight reductions at 140 d after the last treatment followed a similar trend to density (Table 4). Dry weights of GR Italian ryegrass were similar following all applications of trifluralin, with reductions from the nontreated control ranging from 74 to 94%. October and November applications of clomazone, pyroxasulfone, and *S*-metolachlor produced similar reductions in GR Italian ryegrass dry weights 140 d after the last treatment.

Tillage performed in November reduced GR Italian ryegrass density 81% at 35 d after the last treatment and reduced GR Italian ryegrass dry weight similar to all herbicide treatments at 140 d after the last treatment (Table 4). Although GR Italian ryegrass control with tillage in November was only 35% at the last evaluation (Table 3), the plants were often smaller because most GR Italian ryegrass emerging during the fall flush was controlled by the tillage operation.

No treatment provided complete control at either of the last two evaluations, so all would require a POST herbicide application in the spring. Coverage is a major problem encountered with POST herbicide applications targeting GR Italian ryegrass (Eubank et al. 2011). Glyphosate-resistant Italian ryegrass plants surviving fall residual herbicides applied in October or November had fewer and smaller leaves at the last evaluation compared with those in the nontreated control. Therefore, coverage of POST herbicides in plots treated with fall residual herbicides in October or November would be better than in plots receiving no fall treatments or those treated in September.

None of the residual herbicides evaluated in the current research exhibit POST activity, so emerged GR Italian ryegrass must be controlled with aggressive tillage or a POST herbicide at the time the residual herbicide is applied. Paraquat was included in all fall-applied residual herbicide treatments. The cost of paraquat at 0.84 kg ha^{-1} is \$30 ha^{-1}, excluding adjuvant and application cost (Mississippi State University Department of Agricultural Economics [MSU-AE] 2012). This increases the cost of GR Italian ryegrass management programs. Most of the residual herbicides that are effective against GR Italian ryegrass are relatively expensive, with costs ranging from \$45 to \$85 ha^{-1} for the residual herbicide only (MSU-AE 2012). The additional cost of paraquat to an expensive fall residual herbicide will make this program difficult to afford for many growers.

Rainfall through the fall and winter can impact fall-applied residual herbicide treatments. It can also influence when Italian ryegrass emerges. Data from a related study also indicate that emergence of Italian ryegrass varies across the Mississippi Delta (RC Bond, unpublished data). Italian ryegrass emerges primarily in the fall (September to October) in some areas with little emergence in the spring. In contrast, a large portion of emergence occurs in spring in other areas of the Mississippi Delta. Data from the current research indicate that residual herbicides targeting GR Italian ryegrass can be applied too early in the fall. Clomazone, pyroxasulfone, and *S*-metolachlor offer growers the best opportunity for residual control of GR Italian ryegrass, and control is optimized when these herbicides are applied in November. Even when applications are delayed until November, POST applications in the spring will be required to control escapes.

Trifluralin resistance is common in rigid ryegrass in Australia (Chauhan et al 2007; McAllister et al. 1995). Resistance to clomazone was identified in Australian rigid ryegrass populations never exposed to clomazone (Tardiff and Powles 1999). Additionally, Rauch et al. (2010) reported that 12% of Italian ryegrass populations collected from 75 fields in the Palouse region of Idaho and Washington exhibited resistance to a prepackaged mixture of flufenacet plus metribuzin. *S*-metolachlor has a similar mode of action to flufenacet. Italian ryegrass is reported resistant to five unique herbicide modes of action in the United States (Heap 2013). Therefore, care should be taken that herbicide rotation using different modes of action is implemented when controlling Italian ryegrass in the midsouthern United States.

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