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WEED SCIENCE

Italian Ryegrass Control with Preplant Herbicides

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INTERPRETIVE SUMMARY

Effective control of weeds before planting cotton in reduced tillage systems is necessary for optimal stand establishment and early-season growth. Italian ryegrass is prevalent in many cotton-growing regions of the United States. Developing herbicide programs that control a wide variety of weeds, including Italian ryegrass, could lead to more efficient weed management in reduced tillage systems. Paraquat (Gramoxone Extra, Gramoxone Max) or glyphosate (Roundup D-PAK, Roundup Ultra) are often applied in reduced tillage systems for broad-spectrum control of weeds existing at the time of crop establishment. These herbicides can be applied in mixture with other herbicides to broaden the spectrum of control or to provide residual weed control. Glyphosate efficacy on certain weeds can be reduced when applied with other herbicides. Additionally, resistance of several weed species to glyphosate has been reported, and alternatives to glyphosate in preplant burndown herbicide programs may be needed. Paraquat controls Italian ryegrass, although weed size and coverage of foliage can influence efficacy. Determining the compatibility of glyphosate and paraquat with other herbicides and determining the efficacy of possible alternatives to glyphosate and paraquat for Italian ryegrass control may lead to more effective weed control in reduced tillage systems.

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Research was conducted to determine the effect of glyphosate and paraquat application timing on Italian ryegrass control. Additional research was conducted to determine the effect of cyanazine (Bladex, Cy-Pro), thifensulfuron plus tribenuron (Harmony Extra), cyanazine plus thifensulfuron plus tribenuron, oxyfluorfen (Goal), and 2,4-D (Weedar 64) on the efficacy of glyphosate and paraquat. In a final experiment, results of Italian ryegrass control by glyphosate, paraquat, and clethodim (Select) were compared. In one set of experiments, glyphosate controlled Italian ryegrass more effectively than paraquat when applied at growth stages ranging from two leaves to heading. However, in other experiments, glyphosate and paraquat controlled Italian ryegrass similarly. Oxyfluorfen, thifensulfuron plus tribenuron, and 2,4-D did not affect control by glyphosate or paraquat. Although cyanazine applied alone or with thifensulfuron plus tribenuron did not affect efficacy of paraquat, these herbicide treatments did reduce Italian ryegrass control by glyphosate. Clethodim controlled Italian ryegrass more effectively than glyphosate or paraquat in one of two experiments.

ABSTRACT

Successful weed control before planting cotton (*Gossypium hirsutum* L.) in reduced tillage systems minimizes early-season weed interference. Field experiments were conducted in 1994 and 1995 in Louisiana to compare Italian ryegrass control by glyphosate at 0.84 kg ae ha^{-1} or paraquat at 0.53 kg ai ha^{-1} applied at eight growth stages ranging from the two-leaf stage through heading. Applications were spaced 1 wk apart. In a second experiment conducted in Louisiana in 1995 and 1996, glyphosate (0.56 kg ha^{-1}) or paraquat (0.53 kg ha^{-1}) were applied alone or with oxyfluorfen (0.22 kg ai ha^{-1}), cyanazine (0.56 kg ai ha^{-1}), cyanazine plus commercial package mixture of thifensulfuron plus tribenuron (0.56 + 0.024 + 0.008 kg ai ha^{-1}), thifensulfuron plus tribenuron

(0.024 + 0.008 kg ha^{-1}), and 2,4-D (0.75 kg ai ha^{-1}). In a final experiment conducted in 2000 in North Carolina, glyphosate (0.84 kg ha^{-1}) and paraquat (0.53 kg ha^{-1}) efficacy was compared with efficacy of clethodim applied at 0.14, 0.21, and 0.28 kg ai ha^{-1}. Glyphosate was more effective in controlling Italian ryegrass than paraquat at most growth stages. However, when comparing efficacy of these herbicides in the tank mixture experiment or in the experiment comparing efficacy with clethodim, control by paraquat and glyphosate did not differ. Cyanazine and cyanazine plus thifensulfuron plus tribenuron reduced control by glyphosate but not control by paraquat. Oxyfluorfen, thifensulfuron plus tribenuron, and 2,4-D did not affect control by glyphosate or paraquat. Clethodim was more effective than glyphosate or paraquat in one of two experiments.

The shift from conventional tillage to reduced tillage practices has led to greater weed-management challenges before planting (Harman et al., 1989; Paxton et al., 1993). Stale seedbed crop production, sometimes referred to as a fallow bed system, is one form of reduced tillage that is widely accepted and practiced in most Mississippi Delta states (Brown and Whitwell, 1985; Heatherly et al., 1993; Lanie et al., 1994a,b). A diverse weed spectrum of winter and summer annual and perennial weed species can become well established before planting in fields that are left undisturbed.

Successful preplant weed control programs often use nonselective and residual herbicides (Brown and Whitwell, 1985; Oliver et al., 1993). Lanie et al. (1994a,b) reported higher soybean [*Glycine max* (L.) Merr.] yields when either paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) (Gramoxone Extra, Gramoxone Max) or glyphosate [*N*-(phosphonomethyl)glycine] (roundup D-PAK, Roundup Ultra) was applied before planting compared with a nontreated control. Wilson and Worsham (1988) noted that glyphosate applied alone or in combination with 2,4-D [(2,4-dichlorophenoxy)acetic acid] (formulation not listed) controlled many weeds in no-till soybean. Selecting effective herbicide programs for reduced tillage cotton production is one of the most important management decisions made by growers.

Several herbicides are registered for preplant and preemergence weed control in reduced tillage cotton. The commercial premix of thifensulfuron {3-[[[[(4methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid} plus tribenuron {2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid} (Harmony Extra) is applied to control broadleaf weeds in cereal crops. Thifensulfuron plus tribenuron enhanced control of Pennsylvania smartweed (*Polygonum pensylvanicum* L.), cutleaf eveningprimrose (*Oenothera laciniata* Hill), curly dock (*Rumex crispus* L.), and Carolina geranium (*Geranium carolinianum* L.) in stale seedbed cotton when applied with paraquat or glyphosate (Baughman et al., 1995). Since grasses are not controlled by thifensulfuron plus tribenuron, and because this commercial premix does not control all broadleaf weeds completely, application with glyphosate or paraquat is needed for broad-spectrum control. Oxyfluorfen [2-chloro-1-((3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene] (Goal), cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropionitrile} (Bladex, Cy-Pro), and 2,4-D (Weedar 64) often increase efficacy of glyphosate and paraquat, although the magnitude of enhancement depends upon the weed complex. Cutleaf eveningprimrose control was greater when glyphosate and paraquat were applied with 2,4-D compared with glyphosate or paraquat alone (Reynolds et al., 2000). Oxyfluorfen increased control of cutleaf eveningprimrose and horseweed [Conyza *canadensis* (L.) Cronq.] by glyphosate (McClelland et al., 1993; Reynolds et al., 2000). However, oxyfluorfen reduced efficacy of glyphosate on tall fescue (*Festuca arundinacea* Schreb.) (Weller and Carpenter, 1980). Cutleaf eveningprimrose control by paraquat increased when paraquat was applied with thifensulfuron + tribenuron or cyanazine (Reynolds et al., 2000).

Italian ryegrass is often present in reduced tillage fields. Glyphosate efficacy on Italian ryegrass often exceeds that by paraquat (Guy, 1995; Jordan and Sanders, 1999; Rhodes and Breeden, 2000; York and Culpepper, 2001). However, inconsistent control by glyphosate has been reported (Rankins et al., 1995). It was postulated that inconsistent control was associated with growth stage (Rankins et al., 1995). Weather conditions, especially temperature, can vary considerably in the spring when herbicides are applied preplant. Glyphosate would probably

perform more effectively at moderate to high temperatures compared with cooler temperatures. A combination of factors could be associated with the inconsistency of Italian ryegrass control by glyphosate.

Rigid ryegrass (*Lolium rigidum* Gaudin) resistance to glyphosate has been reported (Powles et al., 1998). Although no cases of Italian ryegrass resistance to glyphosate have been reported in the United States, developing control alternatives may be important in future resistance-management strategies. Selective graminicides control Italian ryegrass (Stritzke, 1992; Taylor and Coats, 1994). However, Hardcastle (1986) reported less control by selective graminicides when these herbicides were applied at flowering or early dough stages of Italian ryegrass when compared with glyphosate or paraquat applied at these timings.

Objectives of this research were (i) to compare Italian ryegrass control by glyphosate and paraquat applied at growth stages ranging from two leaves through heading, (ii) to determine if cyanazine, thifensulfuron plus tribenuron, cyanazine plus thifensulfuron plus tribenuron, oxyfluorfen, or 2,4-D affect Italian ryegrass control by glyphosate and paraquat, and (iii) to compare Italian ryegrass control by glyphosate and paraquat with that by clethodim {(E,E)-(+-)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}.

MATERIALS AND METHODS

Glyphosate and Paraquat Application Timing

The experiment was conducted at the Northeast Research Station located near St. Joseph, LA, on a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquerts) in 1994 and 1995. Seedbeds were prepared the previous fall, followed by seeding of Italian ryegrass (cultivar unknown) with a drill (19-cm spacing) at 80 kg ha^{-1} in mid-November of each year. Plot size was 2 by 4 m.

Treatments consisted of the isopropyl amine formulation of glyphosate (Roundup D-PAK) at 0.84 kg ha^{-1} and paraquat (Gramoxone Extra) at 0.53 kg ha^{-1} applied postemergence beginning in early February when Italian ryegrass had two leaves. Subsequent applications were made at weekly intervals for a total of eight applications (through heading). A nonionic surfactant at 1.0% (v/v) was included with glyphosate. The same nonionic surfactant at 0.25% (v/v) was included with paraquat. Herbicides were applied in 140 L ha^{-1} at pressures ranging from 205 to 240 kPa using a CO_2-pressurized backpack sprayer. A nontreated control was included.

Visual estimates of percent Italian ryegrass control were recorded 4 wk after treatment using a scale of 0 to 100% where 0 = no control and 100 = complete control. Foliar chlorosis and necrosis, stunting, and stand reduction were considered when making the visual estimates.

The experimental design was a randomized complete block with 4 replications. Data were subjected to analyses of variance with partitioning appropriate for a two (year) by two (glyphosate or paraquat) by eight (growth stage) factorial treatment arrangement. Means of significant main effects and interactions were separated using Fisher's Protected LSD Test at $P \leq 0.05$. Correlations of Italian ryegrass control for each herbicide and the 3-day average of high temperature (day before, day of, and day following herbicide application) were constructed.

Mixtures of Glyphosate and Paraquat with Other Herbicides

The experiment was conducted in 1995 and 1996 at the Northeast Research Station on the soil described previously. Seedbeds were established in the previous fall and herbicide applications were applied to naturally occurring Italian ryegrass 10 to 20 cm tall (tillering) in mid-February of each year. Plot size was 2 by 4 m.

Treatments consisted of postemergence applications of the isopropyl amine formulation of glyphosate (Roundup D-PAK) at 0.56 kg ha^{-1} and paraquat (Gramoxone Extra) at 0.53 kg ha^{-1}, alone or with oxyfluorfen (Goal) at 0.22 kg ai ha^{-1}; cyanazine (Bladex) at 0.56 kg ai ha^{-1}; cyanazine at 0.45 kg ha^{-1} plus the commercial package mixture of thifensulfuron plus tribenuron (Harmony Extra) at 0.024 + 0.008 kg ai ha^{-1}; thifensulfuron plus tribenuron at 0.024 + 0.008 kg ha^{-1}; 2,4-D (Weedar 64) at 0.75 kg ai ha^{-1}. Nonionic surfactant at 1.0 and 0.25% (v/v) was applied with glyphosate and

paraquat, respectively. A nontreated control was included. Herbicides were applied as described previously. Visual estimates of percent Italian ryegrass control were determined 4 wk after application using the scale described previously.

The experimental design was a randomized complete block with 4 replications. Data were subjected to a two (year) by two (glyphosate or paraquat) by 6 (tank mixture herbicide) factorial treatment arrangement. Means of significant main effects and interactions were separated using Fisher's protected LSD test at $P \leq 0.05$.

Comparison of Glyphosate, Paraquat, and Clethodim

The experiment was conducted in 2000 in adjacent fields at the Upper Coastal Plain Research Station located near Rocky Mount, North Carolina, on a Goldsboro loamy sand soil (fine-loamy, siliceous, subactive, thermic Aquic Paleudalts). Italian ryegrass was beginning to tiller at the time of herbicide application. Plot size was 2 by 4 m.

Treatments consisted of postemergence applications of glyphosate (Roundup Ultra) at 0.84 kg ha^{-1}; paraquat (Gramoxone Extra) at 0.53 kg ha^{-1}; and clethodim (Select) at 0.14, 0.21, and 0.28 kg ai ha^{-1}. Nonionic surfactant at 0.25% (v/v) was included with paraquat. No adjuvant was included with glyphosate. The formulation of glyphosate (Roundup Ultra) contained a proprietary surfactant. Crop oil concentrate at 1.0% (v/v) was included with clethodim. Herbicides were applied as described previously, and visual estimates of percent Italian ryegrass control were recorded 4 wk after treatment using the scale described previously.

The experimental design was a randomized complete block with 4 replications. Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$.

RESULTS AND DISCUSSION

The interaction of year by base herbicide (glyphosate or paraquat) by growth stage was significant for Italian ryegrass control. Additionally, the interaction of base herbicide by growth stage was significant during each year. With the exception of applications made at booting and early and late heading in 1994 and at early jointing in 1995, Italian ryegrass control by glyphosate exceeded that by paraquat (Table 1). Control by glyphosate was similar at most growth stages in 1994. However, control by glyphosate at early jointing was only 47% in 1995. In contrast, control ranged from 77 to 88% when applied at the other growth stages before heading. Control was at least 98% when applied at early and full heading. Italian ryegrass control by glyphosate was correlated with temperature in 1994 ($P = 0.0235$, $R = 0.35$) and 1995 ($P = 0.0001$, $R = 0.67$).

Table 1. Italian ryegrass control by glyphosate and paraquat applied at eight growth stages.†

	1994		1995	
Growth stage	Glyphosate	Paraquat	Glyphosate	Paraquat
	----------%----------			
2-leaf	95 a	80 b-e	88 ab	67 cd
4-leaf	77 cde	50 f	88 ab	60 de
Tillering	83 a-d	50 f	88 ab	50 ef
Early jointing	86 abc	72 de	47 f	52 ef
Jointing	94 a	69 e	80 b	54 ef
Booting	91 ab	78 b-e	77 bc	57 def
Early heading	85 a-d	84 a-d	98 a	60 de
Full heading	80 b-e	67 e	100 a	67 cd

† Means within a year followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$. Visual estimates of percent Italian ryegrass control taken 4 wk after treatment. Glyphosate and paraquat applied at 0.84 and 0.53 kg ha^{-1}, respectively.

Paraquat was less effective when applied during four-leaf and tillering stages of Italian ryegrass in 1994 compared with applications made to plants with two leaves or plants that were jointing, booting, or heading (Table 1). In 1995, control by paraquat was lower when applied during tillering and jointing compared with applications made to Italian ryegrass with two leaves or at full heading (Table 1). Italian ryegrass control was correlated with temperature in 1994 ($P = 0.036$, $R = 0.46$) but not in 1995 ($P = 0.84$, $R = 0.05$).

The interaction of year by base herbicide (glyphosate or paraquat) by complement herbicide was not significant for Italian ryegrass control. However, the interaction of base herbicide by complement herbicide was significant. When pooled over years, control by glyphosate alone or with oxyfluorfen, thifensulfuron plus tribenuron, and 2,4-D was similar to that by paraquat alone or when mixed with the other herbicides (Table 2). Control by

Table 2. Italian ryegrass control with glyphosate and paraquat applied alone or with cyanazine, cyanazine plus thifensulfuron plus tribenuron, oxyfluorfen, thifensulfuron plus tribenuron, or 2,4-D.†

Herbicides	Control
	%
Glyphosate	84 a
Glyphosate plus cyanazine	59 b
Glyphosate plus cyanazine plus thifensulfuron plus tribenuron	58 b
Glyphosate plus oxyfluorfen	88 a
Glyphosate plus thifensulfuron plus tribenuron	88 a
Glyphosate plus 2,4-D	80 a
Paraquat	87 a
Paraquat plus cyanazine	86 a
Paraquat plus cyanazine plus thifensulfuron plus tribenuron	89 a
Paraquat plus oxyfluorfen	92 a
Paraquat plus thifensulfuron plus tribenuron	88 a
Paraquat plus 2,4-D	92 a

† **Means followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$. Visual estimates of percent Italian ryegrass control taken 4 wk after treatment. Data are pooled over years. Glyphosate, paraquat, oxyfluorfen, 2,4-D, thifensulfuron plus tribenuron, and cyanazine were applied at 0.56, 0.53, 0.22, 0.75, 0.024 + 0.008, and 0.56 kg ha^{-1}, respectively.**

these herbicide treatments was 80 to 92%. Applying glyphosate with cyanazine or cyanazine plus thifensulfuron plus tribenuron resulted in lower Italian ryegrass control compared with all other herbicide treatments. Other research indicated that cyanazine, diuron [*N*'-(3,4-dichlorophenyl)-*N*,*N*-dimethylurea] (Karmex), and fluometuron {*N*,*N*-dimethyl-*N*'-[3-(trifluoromethyl)phenyl]urea} (Cotoran) reduced sicklepod [*Senna obtusifolia* (L.) Irwin and Barnaby] control by glyphosate, but improved control of this weed by paraquat (Webster and Shaw, 1997). Wicks and Hanson (1995) reported less barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] control when glyphosate was applied with atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] (several commercial formulations). Fomesafen {5-[chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide} (Reflex), a diphenyl ether herbicide like oxyfluorfen, and 2,4-D reduced barnyardgrass control by glyphosate (Starke and Oliver, 1998). McGee et al. (1992) reported no improvement in Italian ryegrass control when glyphosate or paraquat was applied with oxyfluorfen compared with the herbicides applied alone. Flint and Barrett (1989) reported less johnsongrass [*Sorghum halepense* (L.) Pers.] control when glyphosate was applied with dicamba (3,6-dichloro-2-methoxybenzoic acid) (Banvel) or 2,4-D when compared with glyphosate alone.

Italian ryegrass control by clethodim exceeded that by glyphosate or paraquat in one of two experiments, regardless of the clethodim rate (data not shown). In the first experiment, glyphosate and paraquat controlled Italian ryegrass 85 and 83%, respectively (data not presented). Control by clethodim was 100% with all rates (data not presented). In the second experiment, control by glyphosate, paraquat, and clethodim at all rates was similar and ranged from 95 to 100% (data not presented). Results from these experiments are consistent with those from the tank mixture experiments suggesting that glyphosate and paraquat control Italian ryegrass similarly. In that study, control by glyphosate and paraquat was 84 and 87%, respectively (Table 2). Other research (Stritzke, 1992) has documented effective Italian ryegrass control by sethoxydim {2-[1-(ethoxyimono)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} (Poast), a cyclohexanedione herbicide like clethodim.

The discrepancy in control between glyphosate and paraquat in the growth-stage experiment compared with the compatibility and clethodim experiments could not be easily explained. Glyphosate was more effective than paraquat at most timings of application in the growth-stage experiment. This is consistent with previous reports indicating that glyphosate is more effective in controlling Italian ryegrass than paraquat (Guy, 1995; Jordan and Sanders, 1999; Rhodes and Breeden, 2000; York and Culpepper, 2001). However, this was not the case in the tank mixture and clethodim studies, which indicated that glyphosate and paraquat controlled Italian ryegrass similarly. However, Baughman and Shaw (1995) reported similar Italian ryegrass control by glyphosate and paraquat.

Collectively, these data suggest that Italian ryegrass control by paraquat and glyphosate can be similar. These data also suggest that glyphosate and paraquat are compatible with 2,4-D, oxyfluorfen, and thifensulfuron plus tribenuron. While cyanazine did not affect efficacy of paraquat, Italian ryegrass

control was reduced when glyphosate was applied with cyanazine. Although registration of cyanazine was cancelled in 2000 in the United States, diuron can be used in preplant weed-management programs, and use of photosynthetic-inhibiting herbicides such as diuron may reduce glyphosate efficacy on Italian ryegrass. Results from these studies also suggest that clethodim would be a good alternative to glyphosate or paraquat for controlling Italian ryegrass.

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