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WEED SCIENCE

Cutleaf Eveningprimrose Control with Preplant Burndown Herbicide Combinations in Cotton

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INTERPRETIVE SUMMARY

Adequate preplant weed control is necessary to optimize cotton production in reduced tillage systems. A variety of winter and summer weeds infest cotton fields in the spring prior to planting, and choosing the best herbicide program to control weed complexes can be challenging. Control of cutleaf eveningprimrose can be difficult in reduced tillage systems; although a variety of herbicides including oxyfluorfen (Goal 2XL), cyanazine (Bladex 4L and other formulations), thifensulfuron + tribenuron (Harmony Extra), paraquat (Gramoxone Extra), and glyphosate (Roundup Ultra and other formulations) are applied for preplant weed control in cotton, these herbicides seldom control cutleaf eveningprimrose as well as 2,4-D (Weedar 64 and other formulations). However, potential crop injury from residues remaining in the soil after planting can limit utility of 2,4-D. Although product labels for 2,4-D vary with respect to intervals between herbicide application and planting, at least one month generally is needed to reduce risk of cotton stand loss and plant injury. Developing alternative herbicide options to 2,4-D that control cutleaf eveningprimrose when applied closer to planting cotton without crop injury would be advantageous.

Research was conducted to compare cutleaf eveningprimrose control by glyphosate or paraquat applied alone or with cyanazine, cyanazine + thifensulfuron + tribenuron, thifensulfuron + tribenuron, oxyfluorfen, or 2,4-D. A sequential application of glyphosate followed by paraquat also was included. Variable improvement in efficacy of glyphosate or paraquat by cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron was noted among experiments, and control by these combinations never exceeded control by glyphosate or paraquat applied with 2,4-D. This variation in control demonstrates the consistency of cutleaf eveningprimrose control by herbicide programs that include 2,4-D as well as the relative inconsistency of control offered by other commercially available herbicides. In situations where growers are reluctant to apply 2,4-D for fear of crop injury or damage to sensitive adjacent crops that have emerged, these data suggest that oxyfluorfen is a relatively good substitute for 2,4-D when applied with glyphosate. In contrast, thifensulfuron + tribenuron, either alone or with cyanazine, are the most effective complement herbicides with paraquat. Although sequential applications of glyphosate followed by paraquat were generally as effective as glyphosate or paraquat applied with 2,4-D, this approach requires two timely applications. Because cutleaf eveningprimrose is difficult to control with burndown herbicides other than 2,4-D and because concerns exist relative to injury from residues of 2,4-D as well as potential off-site movement, growers should consider applying 2,4-D alone in late winter or early spring to control this weed most effectively.

ABSTRACT

Successful elimination of vegetation prior to planting cotton (*Gossypium hirsutum* L.) in reduced tillage production is critical for adequate stand establishment, eliminating early-season weed interference, and maintaining yields. Cutleaf eveningprimrose (*Oenothera laciniata* Hill) often is prevalent in cotton fields in the spring prior to planting. Field experiments were conducted during 1995 and 1996 in Louisiana and in 1999 in North Carolina to compare cutleaf eveningprimrose control

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by glyphosate or paraquat applied alone or with cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, thifensulfuron + tribenuron, or 2,4-D. Combinations of glyphosate or paraquat with 2,4-D were generally more effective than glyphosate or paraquat applied alone or with other complement herbicides. Applying cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron with glyphosate was as effective as glyphosate applied with 2,4-D in two, one, four, or three of six experiments, respectively. In contrast, applying cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron was as effective as paraquat + 2,4-D in one, four, two, or four experiments, respectively. These data suggest that control by herbicide mixtures other than glyphosate or paraquat with 2,4-D are generally less effective. These data also suggest that oxyfluorfen is the most effective herbicide other than 2,4-D to apply with glyphosate to control cutleaf eveningprimrose while thifensulfuron + tribenuron, either alone or with cyanazine, are the most effective herbicides other than 2,4-D to apply with paraquat.

Reduced tillage crop production has increased dramatically during the past decade in the southern USA. Several factors have been suggested as the cause of this increase, among them are farm legislation requirements designed to minimize soil erosion; development of equipment capable of planting into crop residues; and availability of herbicides that control vegetation prior to crop establishment. Adoption of reduced tillage systems has increased the need to develop effective herbicide programs to manage winter vegetation and emerged summer weeds.

A variety of herbicides are available for use in reduced tillage cotton systems. Matching herbicides with the weed complex is important in obtaining adequate weed control, establishing an adequate crop stand, and preventing early-season weed interference. Glyphosate [*N*-(phosphonomethyl)glycine] and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) often are applied in reduced tillage systems to provide broad-spectrum weed control (Shaw, 1996). Use of one or both of these herbicides usually controls many but not all annual and perennial weeds. The commercial package mixture of the methyl ester of thifensulfuron methyl {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylate acid} + the methyl ester of tribenuron {methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoate acid} and amine salt or ester formulations of 2,4-D [2,4-dichlorophenoxyacetic acid] can be applied with glyphosate or paraquat to improve weed control. Substituted urea herbicides such as cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropionitrile} also are applied with glyphosate or paraquat to enhance control of emerged weeds and provide residual control early in the season (Baughman et al., 1995; Shaw, 1996).

Although 2,4-D can be applied in reduced tillage systems, product labels for 2,4-D are ambiguous. The label for the amine salt of 2,4-D (Weedar 64 herbicide, Rhone-Poulenc Ag. Co., Research Triangle Park, NC) states that cotton should not be planted into previous crop stubble for 3 mo after application or until chemical has dissipated from soil. Rainfall after application of 2,4-D but before crop planting is critical in determining if residues will exist when the crop emerges (Guy, 1995). Sensitive crops such as cotton can be injured when residues remain, regardless of the interval between herbicide application and planting. Most state recommendations suggest that 2,4-D not be applied within 45 d of planting cotton (Johnson and Kendig, 1997; York and Culpepper, 1998). Product labels for thifensulfuron + tribenuron (Harmony Extra herbicide, DuPont Agric. Products, Wilmington, DE) preclude planting rotation crops within 45 d of application. However, research suggests that thifensulfuron + tribenuron can be applied within this interval without injuring cotton, soybean [*Glycine max* (L.) Merr.], or rice (*Oryza sativa* L.) (Fairbanks et al., 1995; Guy, 1995; Jordan et al., 1997).

Oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene] (Goal 2XL herbicide, Rohm and Haas Co., Philadelphia, PA) can be applied 7 d or more before planting cotton, although the manufacturer suggests that minor tillage is needed following application and prior to planting to minimize potential for cotton injury. Cyanazine (Bladex 4L herbicide, DuPont) can be applied within 30 d of planting cotton, depending on application rate and soil characteristics. Shorter intervals between herbicide application and planting would increase flexibility of weed management strategies in reduced tillage production systems.

Cutleaf eveningprimrose can be difficult to control with herbicides other than 2,4-D in reduced tillage systems (Fairbanks et al., 1995; Guy, 1995). When the interval between herbicide application and planting cotton or rice is sufficiently long to prevent crop injury, 2,4-D is the most effective and economical herbicide available to control it (Guy, 1995; Johnson and Kendig, 1997; York and Culpepper, 1998). However, predicting when residues of 2,4-D have dissipated in relation to herbicide application and crop planting can be difficult.

Because oxyfluorfen and cyanazine can be applied closer to planting than 2,4-D and because research suggests that thifensulfuron + tribenuron are less injurious than 2,4-D to cotton seedlings, research was conducted to determine the effectiveness of mixtures of cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron with glyphosate and paraquat as alternatives to glyphosate or paraquat with 2,4-D for preplant control of cutleaf eveningprimrose.

MATERIALS AND METHODS

The experiment was conducted during 1995 and 1996 in early March in existing crop residue of cotton or soybean at the Northeast Research Station near St. Joseph, LA, on Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Aeric Fluvaquents) or Dundee silt loam (fine-silty, mixed, active, thermic Typic Endoaqualfs) soils with 0.5 to 0.8% organic matter and pH 5.2 to 5.8 or on Mhoon silt loam soil (fine-silty, mixed, nonacid, thermic Typic Fluvaquents) with 1.8% organic matter and pH 6.0.

The experiment also was conducted in corn (*Zea mays*, L.) stubble at the Upper Coastal Plain Research Station near Rocky Mount, NC, in 1999 on a Goldsboro loamy sand soil (fine-loamy, siliceous, subactive, thermic Aquic Paleudults) with 2.4% organic matter and pH 6.0. Cutleaf eveningprimrose density varied by location, ranging from 1 to 8 plants m^{-2} with plant diameters ranging from 7 to 20 cm, indicative of plant sizes typically noted in grower fields. Plot size was 3 by 6 m. Cotton was not planted in these experiments.

Glyphosate (Roundup Ultra or Roundup D-Pak herbicides, Monsanto Co., St. Louis, MO) at 0.56 kg ae ha^{-1} or paraquat (Gramoxone Extra herbicide, Zeneca Agric. Products, Wilmington, DE) at 0.53 kg ai ha^{-1} were applied alone or with cyanazine (Bladex 4L) at 0.56 kg ai ha^{-1}, cyanazine + commercial package mixture of thifensulfuron + tribenuron (Harmony Extra) at 0.56 + 0.016 + 0.008 kg ai ha^{-1}, oxyfluorfen at 0.22 kg ai ha^{-1}, thifensulfuron + tribenuron (0.016 + 0.008 kg ha^{-1}), or the ester (1995) or amine salt (1996 and 1999) of 2,4-D (Weedone LV or Weedar 64) at 0.75 kg ai ha^{-1}. A sequential application of glyphosate at 0.56 kg ha^{-1} followed by paraquat at 0.53 kg ha^{-1} 2 wk later was included in 1996 and 1999. An untreated control was also included. Glyphosate (Roundup D-Pak) was applied with a nonionic surfactant (Latron AG-98, Rohm and Haas Co., Philadelphia, PA) at 1.0% (v v^{-1}) in 1995. In 1996 and 1999, the glyphosate formulation (Roundup Ultra herbicide) contained a proprietary surfactant. Paraquat was applied with nonionic surfactant (Latron AG-98) at 0.25% (v v^{-1}). Herbicides were applied using CO_2-pressurized backpack sprayers calibrated to deliver 135 L ha^{-1} at 210 kPa.

Visual estimates of percent cutleaf eveningprimrose control were recorded 4 wk after application on a scale of 0 to 100% where 0 = no control and 100 = complete control. Necrosis, chlorosis, and plant stunting were used when making the visual estimates. The experimental design was a randomized complete block with three (1995 and 1996) or four (1999) replications. Data were subjected to analyses of variance with basic partitioning for a two (base herbicides, i.e. glyphosate or paraquat) by five (complement herbicides) factorial treatment arrangement. The sequential application of glyphosate followed by paraquat was not included in this analysis. However, experiment-by-treatment factor interactions as well as base-herbicide-by-complement-herbicide interactions were significant and prevented pooling data across experiments or treatment factors. Therefore, data are presented for each experiment with the sequential applications of glyphosate followed by paraquat included. Data were transformed to the arcsine square root. Means of nontransformed data were separated using Fisher's protected LSD test at $P = 0.05$ based on the transformed data.

RESULTS AND DISCUSSION

Cutleaf eveningprimrose control by glyphosate alone ranged from 42 to 60% in five of the six experiments (Table 1). In the remaining experiment (1999 in North Carolina), glyphosate alone gave 84% control of cutleaf eveningprimrose. Considerable variation in control by paraquat alone was noted among experiments. Paraquat alone controlled cutleaf eveningprimrose 24 to 52% in four experiments and 75 and 80% in the other two experiments (Table 1). Glyphosate or paraquat applied alone do not control cutleaf eveningprimrose completely (York and Culpepper, 1998). Differential control noted among experiments could not be easily explained by cutleaf eveningprimrose size (measured as diameter), plant stress, or air temperature. The range of plant size was approximately the same size at time of application and plants were not showing visible signs of moisture stress.

Although air temperature ranged from only 28 to 30 °C in 1996 and 1999, control by paraquat alone ranged from 24 to 75% (Table 1). In 1996, air temperature ranged from 18 to 20 °C with control by paraquat alone being 33 to 75%. No clear trend pertaining to relative humidity or cloud cover was noted that would explain variation in control by paraquat; however, these factors can influence efficacy of paraquat (Herbicide Handbook, 1994).

Applying 2,4-D with glyphosate or paraquat increased control in all but one experiment compared with glyphosate or paraquat applied alone (Table 1). Control by either glyphosate or paraquat applied with 2,4-D ranged from 80 to 100%. Cutleaf eveningprimrose is susceptible to 2,4-D (Johnson and Kendig, 1997; York and Culpepper, 1998).

Variable improvement in efficacy of glyphosate or paraquat by cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron was noted among experiments (Table 1). Mixing cyanazine with glyphosate increased control in only one experiment (Commerce silt loam in 1995). Applying cyanazine and thifensulfuron + tribenuron with glyphosate increased control when compared with glyphosate alone in the same experiment. In contrast, applying cyanazine + thifensulfuron + tribenuron with paraquat increased control in four experiments when compared with paraquat alone. Applying oxyfluorfen with glyphosate increased control in three experiments while in two experiments thifensulfuron + tribenuron increased control compared with glyphosate alone. Cutleaf eveningprimrose control by glyphosate or paraquat was not reduced by the other herbicides when applied in mixture.

When compared with cutleaf eveningprimrose control by paraquat alone, control increased in two experiments when cyanazine was applied with

Table 1. Cutleaf eveningprimrose control 4 wk after application of glyphosate and paraquat applied alone or with cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, thifensulfuron + tribenuron, or 2,4-D †,‡.

	1995		1996			1999
Herbicides §	**Commerce SL**	**Dundee SL**	**Mhoon SC**	**Commerce SL**	**Mhoon SC**	**Goldsboro LS**
	%					
Glyphosate	**57 f**	**60 cd**	**60 abc**	**55 ef**	**42 c**	**84 cde**
Glyphosate + cyanazine	**73 e**	**57 cde**	**58 bc**	**65 cde**	**60 abc**	**78 def**
Glyphosate + cyanazine + thifensulfuron + tribenuron	**73 e**	**60 cd**	**43 c**	**62 c-f**	**79 a**	**79 def**
Glyphosate + oxyfluorfen	**75 e**	**75 abc**	**60 abc**	**72 bcd**	**78 a**	**85 cd**
Glyphosate + thifensulfuron + tribenuron	**78 de**	**70 abc**	**75 ab**	**58 def**	**76 ab**	**84 cde**
Glyphosate + 2,4-D	**93 abc**	**88 a**	**83 ab**	**82 b**	**80 a**	**100 a**
Paraquat	**80 de**	**45 de**	**75 ab**	**52 ef**	**33 c**	**24 h**
Paraquat + cyanazine	**90 bc**	**62 bcd**	**62 abc**	**50 f**	**33 c**	**34 g**
Paraquat + cyanazine + thifensulfuron + tribenuron	**93 abc**	**80 ab**	**63 abc**	**63 c-f**	**73 ab**	**64 f**
Paraquat + oxyfluorfen	**85 cd**	**50 de**	**78 ab**	**63 c-f**	**55 abc**	**69 ef**
Paraquat + thifensulfuron + tribenuron	**97 ab**	**73 abc**	**73 abc**	**63 c-f**	**60 abc**	**31 gh**
Paraquat + 2,4-D	**100 a**	**88 a**	**90 a**	**96 a**	**83 a**	**97 ab**
Glyphosate followed by paraquat	**-**	**-**	**-**	**75 bc**	**73 ab**	**91 bc**

† Glyphosate, paraquat, oxyfluorfen, 2,4-D, thifensulfuron + 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.

‡ Means within an experiment followed by the same letter are not significantly different according to Fisher's protected LSD test at P = 0.05. Visual estimates of percent cutleaf eveningprimrose control taken 4 wk after treatment.

§ Abbreviations: SL, silt loam; SC, silty clay; LS, loamy sand.

paraquat (Table 1). Control also was increased in two experiments when paraquat was applied with thifensulfuron + tribenuron but in only one experiment when paraquat was applied with oxyfluorfen. The combination of paraquat with cyanazine and thifensulfuron + tribenuron was more effective than paraquat alone in four experiments.

Applying glyphosate with cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron controlled cutleaf eveningprimrose similar to glyphosate + 2,4-D in two, one, four, and three experiments, respectively (Table 1). When cyanazine, cyanazine + thifensulfuron + tribenuron, oxyfluorfen, or thifensulfuron + tribenuron were applied with paraquat, control by these respective herbicide mixtures was as effective as paraquat + 2,4-D in one, four, two, and four experiments. The combination of 2,4-D and glyphosate or paraquat controlled cutleaf eveningprimrose similarly in five of six experiments.

Sequential applications of glyphosate followed by paraquat were as effective as glyphosate + 2,4-D in the experiments where this treatment was included. Additionally, sequential applications of glyphosate followed by paraquat were as effective as paraquat + 2,4-D in two of three experiments. Although this approach to controlling cutleaf eveningprimrose requires two applications rather than one, it does increase planting flexibility because there is no risk of cotton injury from residues of 2,4-D.

These data suggest that combinations of glyphosate or paraquat with 2,4-D are the most effective herbicide combinations for controlling cutleaf eveningprimrose. Although 2,4-D alone would be a good alternative in controlling cutleaf eveningprimrose, it does not control other common weeds such as Italian ryegrass (*Lolium multiflorum* Lam.), little barley (*Hordeum brachyantherum* Nevski), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), sedges (*Cyperus* spp.), and several other important weeds (Johnson and Kendig, 1997; York and Culpepper, 1998). Applying a mixture of glyphosate or paraquat with complement herbicides often is considered the most effective weed management strategy for a broad complex of weeds.

In situations where growers are reluctant to apply 2,4-D, these data suggest that oxyfluorfen is a relatively good substitute for 2,4-D when applied with glyphosate. In contrast, thifensulfuron + tribenuron, either alone or with cyanazine, were the most effective complement herbicides with paraquat. While not addressed in these studies, growers should consider applying 2,4-D several months in advance of planting cotton to control cutleaf eveningprimrose in order to eliminate concerns about cotton injury from residues of 2,4-D and off-site movement of 2,4-D onto sensitive crops and other plants. Producers should consider the entire weed spectrum when developing a preplant herbicide programs for cotton. While cutleaf eveningprimrose is difficult to control, other winter weeds and emerged summer weeds that are present will determine the most effective burndown herbicide combination to apply.

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