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WEED SCIENCE

Pre-plant Control of Cutleaf Eveningprimrose *(Oenothera laciniata* Hill) and Wild Radish (*Raphanus raphanistrum* L.) in Conservation Tillage Cotton (*Gossypium hirsutum* L.)

A. Stanley Culpepper*, D. Scott Carlson, and Alan C. York

ABSTRACT

Cutleaf eveningprimrose and wild radish are problematic winter annual weeds in cotton conservation tillage systems. Neither weed is adequately controlled by glyphosate nor paraquat applied alone, so combinations with other herbicides are needed to control these weeds prior to planting. Field experiments in Georgia during 2001 and 2002 compared cutleaf eveningprimrose and wild radish control by glyphosate or paraquat applied alone or mixed with 2,4-D, carfentrazone, dicamba, diuron, flumiclorac, flumioxazin, prometryn, tribenuron, or tribenuron plus thifensulfuron. Several combinations were effective on wild radish. Glyphosate and paraquat alone controlled wild radish only 80 to 81% at 28 d after treatment (DAT), but glyphosate or paraquat plus 2,4-D, dicamba, tribenuron, or tribenuron plus thifensulfuron and paraquat plus diuron provided 92 to 97% control. Cutleaf eveningprimrose was more difficult to control, and glyphosate or paraquat alone controlled eveningprimrose only 56 to 60% at 28 DAT. Glyphosate plus dicamba, glyphosate plus 2,4-D, and paraquat plus 2,4-D controlled cutleaf eveningprimrose 94 to 97%, and paraquat plus dicamba and glyphosate plus flumioxazin provided 83% control. Control by other combinations was 75% or less. Cutleaf eveningprimrose and wild radish can be managed most effectively and economically by 2,4-D as part of a pre-plant weed control program. For wild radish, tribenuron, and tribenuron plus thifensulfuron are effective and economical alternatives to 2,4-D or dicamba.

A. Stanley Culpepper, Department of Crop and Soil Sciences, University of Georgia, P.O. Box 1209, Tifton, GA 31793; D. Scott Carlson, University of Georgia Cooperative Extension Service, P.O. Box 630, Fitzgerald, GA 31750; Alan C. York Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695-7620
*Corresponding author: stanley@arches.uga.edu

In Georgia, less than 7% of the cotton crop was grown using conservation tillage practices in 1996, compared with 11, 19, 31, and 40% in 1998, 2000, 2002, and 2004, respectively (CTIC, 2004). Several factors, including farm legislation, have influenced the increased adoption of conservation tillage cotton (Crozier et al., 2005). In addition to being the most practical means to meet conservation compliance requirements and to reduce soil erosion, conservation tillage practices offer other benefits, such as moisture conservation, protection of young cotton seedlings from sand-blasting, improved soil tilth, reduced soil crusting, more rapid water infiltration, protection of water quality, and reduced equipment, labor, and time requirements (Naderman, 1993; Wilcut et al., 1993). Although all of these factors have played a significant role in this adoption, commercialization of herbicide-resistant cultivars is the primary factor that facilitated the expansion of conservation tillage (CTIC, 2004; Fawcett and Towery, 2002).

Preplant burndown herbicides, primarily glyphosate and paraquat, replace primary tillage in conservation tillage systems. Most winter annual weeds typically encountered in conservation tillage systems in Georgia are controlled by one or both of these herbicides. Notable exceptions include cutleaf eveningprimrose and wild radish, which are usually not adequately controlled by either glyphosate or paraquat applied alone (Culpepper et al., 2002; York and Culpepper, 2005a). Since the rapid adoption of conservation tillage, these weed species have become more common and problematic across the southeastern USA in conservation tillage production systems.

Research in several southern states has shown that cutleaf eveningprimrose is most effectively, consistently, and economically controlled by 2,4-D applied at 430 to 750 g a.e. ha^{-1} alone or in combination with glyphosate or paraquat (Culpepper et al., 2002; Kelly et al., 2002; Reynolds et al., 2000; Smith et al., 1996). Recent research in Georgia and North Carolina has shown excellent control with 2,4-D at rates as low as 134 g ha^{-1} (York and Culpepper, 2005b). Others have also noted excellent cutleaf eveningprimrose control by dicamba mixed with glyphosate or paraquat (Ferguson, 1996; Guy and Ashcraft, 1996; Smith et al., 1996). Less research has been conducted to determine the most effective burndown treatment for wild radish, but research in small grains has shown that 2,4-D effectively controls wild radish (Schroeder, 1989).

Although 2,4-D and dicamba formulations labeled for pre-plant application in conservation tillage cotton systems are effective tools to manage troublesome weeds, both herbicides have limitations. Certain dicamba product labels specify that cotton planting must be delayed at least 21 d after herbicide application and after the accumulation of 2.5 cm or more of rainfall or overhead irrigation (Anonymous, 2005b). Labels for most 2,4-D products are ambiguous concerning preplant application to cotton. Many labels generally state that cotton can be planted 3 mo after 2,4-D application or when the herbicide has dissipated from the soil (Anonymous, 2005e; 2005f), but labels for certain 2,4-D products have been amended to allow application 30 d prior to planting of cotton (Anonymous, 2005a; 2005c; 2005d). These labels do not specify a rainfall or irrigation requirement but do warn of potential injury to the crop under conditions not conducive to herbicide degradation. In research in Georgia and North Carolina (York et al., 2004), 2,4-D dimethylamine salt at 1060 g ha^{-1} applied 21 d prior to planting did not adversely affect cotton. This rate of 2,4-D is greater than is necessary to control cutleaf eveningprimrose (York and Culpepper, 2005b). Dicamba applied pre-plant is potentially more injurious to cotton than 2,4-D (York et al., 2004). The ability to decontaminate spray equipment after application of 2,4-D and dicamba, and the potential that drift of these products may injure nearby sensitive plants are concerns. These concerns limit adoption of 2,4-D or dicamba as part of a burndown program for troublesome weeds, such as cutleaf eveningprimrose and wild radish, in conservation tillage cotton production systems. Several other herbicides, without these issues, are currently available and can be mixed with glyphosate or paraquat to potentially improve control of troublesome weeds. Several studies have evaluated cutleaf eveningprimrose response to pre-plant weed control options; however, new herbicides, such as carfentrazone, flumiclorac, and flumioxazin, have received pre-plant application labels since much of this work was published. Additionally, there is little to no available information on the response of wild radish to pre-plant weed control options. Therefore, an experiment was conducted to compare 22 herbicide pre-plant weed control options for the most effective and affordable control of cutleaf eveningprimrose and wild radish in conservation tillage cotton production.

MATERIALS AND METHODS

The experiment was conducted at two locations in 2001 and 2002 on privately owned farms located in Tift or Worth counties in southern Georgia. One location each year was infested with a natural population of cutleaf eveningprimrose, and the other location was infested with natural populations of wild radish. Cutleaf eveningprimrose and wild radish densities were at least 10 plants per m^2 and few additional weeds were present. Heavy populations of each species were specifically selected for enhanced validity of treatment comparisons. Soils were Tifton loamy sands (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with pH ranging from 5.7 to 6.2 and organic matter ranging from 0.7 to 1.1%.

The experimental design was a randomized complete block containing a two-factor factorial treatment arrangement including either glyphosate isopropylamine salt (Roundup UltraMax; Monsanto Co.; St. Louis, MO) at 840 g a.e. ha^{-1} or paraquat (Gramoxone Max; Syngenta Crop Protection, Inc.; Greensboro, NC) at 700 g a.i. ha^{-1} applied alone or in combination with the following herbicides: 1) 2,4-D dimethylamine salt (Weedar 64; Nufarm Inc.; Burr Ridge, IL) at 560 g ha^{-1}, 2) flumiclorac (Resource; Valent U.S.A. Corp.; Walnut Creek, CA) at 30 g a.i. ha^{-1}, 3) flumioxazin (Valor; Valent U.S.A. Corp.) at 36 g a.i. ha^{-1} or 4) 71 g ha^{-1}, 5) carfentrazone (Aim 2 EC; FMC Corp.; Philadelphia, PA) at 18 g a.i. ha^{-1}, 6) tribenuron (Express; E. I. DuPont deNemours and Co.; Wilmington, DE) at 17 g ha^{-1}, 7) tribenuron plus thifensulfuron (Harmony Extra; E. I. DuPont deNemours and Co.) at 9 plus 17 g a.i. ha^{-1}, 8) diuron (Direx; E. I. DuPont deNemours and Co.) at 560 g a.i. ha^{-1}, 9) prometryn (Caparol; Syngenta Crop Protection, Inc.; Greensboro, NC) at 560 g a.i. ha^{-1}, or 10) dicamba diglycolamine salt (Clarity; BASF Corp.; Research Triangle Park, NC) at 280 g a.e. ha^{-1}. A non-treated check was also included for comparison purposes. No additional adjuvant was added with glyphosate mixtures, but a crop oil concentrate (Agri-Dex; Helena Chemical Co.; Memphis, TN) at 1% by volume was included with all paraquat applications. Herbicides were applied with a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles delivering 140 L ha^{-1} at 166 kPa. Applications were made between 25 March and 4 April of each year. At the time of treatment, wild radish was in the full-bloom stage of growth and was 40 to 60 cm in height, while cutleaf eveningprimrose had just begun to bloom and was 30 to 40 cm in diameter.

Visual estimates of weed control were determined 7, 14, and 28 DAT using a 0 to 100% scale, where 0% = no weed control and 100% = complete weed control. Data were subjected to analysis of variance using the general linear models procedure of the Statistical Analysis System (version 8.02; SAS Institute Inc.; Cary, NC) with the treatment sums of squares partitioned to reflect the factorial treatment arrangement. The non-treated check was not included in the analysis, and data transformation was not needed. Data for each weed species could be pooled over years, and an interaction of glyphosate or paraquat by tank-mix partners was noted for each species. Trends in control at 7 and 14 DAT were similar, so results from only the 14 and 28 DAT evaluations are reported.

RESULTS AND DISCUSSION

Cutleaf eveningprimrose control. Glyphosate and paraquat controlled cutleaf eveningprimrose 56 and 71% at14 DAT, respectively, and no greater than 60% control at 28 DAT (Table 1). Other researchers have also reported inadequate control of this weed with glyphosate and paraquat (Kelly et al., 2002; Johnson et al., 2000; Reynolds et al., 2000). Compared to glyphosate alone (56%), mixing 2,4-D, dicamba, or flumioxazin at 71 g ha^{-1} with glyphosate increased control to 86 to 92% at 14 DAT. Flumioxazin at 71 g ha^{-1} was 11% more effective than half that rate when mixed with glyphosate. Carfentrazone, diuron, flumiclorac, or prometryn mixed with glyphosate improved control 9 to 20% compared with glyphosate alone, but these combinations were less effective than glyphosate plus 2,4-D, dicamba, or flumioxazin at 71 g ha^{-1}. Tribenuron or tribenuron plus thifensulfuron mixed with glyphosate did not improve control (59%). Dicamba, 2,4-D, diuron, or flumioxazin mixed with glyphosate improved control of cutleaf eveningprimrose in other studies (Kelly et al., 2002).

Only four glyphosate tank mixtures were more effective at 28 DAT than glyphosate applied alone. Flumioxazin at 36 and 71 g ha^{-1} mixed with glyphosate controlled cutleaf eveningprimrose 74 to 83% compared with 60% control by glyphosate alone (Table 1). Dicamba and 2,4-D mixed with glyphosate increased control to 94 and 97%, respectively. Carfentrazone, diuron, flumiclorac, prometryn, tribenuron, and tribenuron plus thifensulfuron mixed with glyphosate did not improve cutleaf

Table 1. Cutleaf eveningprimrose control by glyphosate or paraquat applied alone and in mixtures at 14 and 28 days after treatment (DAT)

Tank mix partner and rate (g ha^{-1})	Control (%)[z]			
	14 DAT		28 DAT	
	Glyphosate	Paraquat	Glyphosate	Paraquat
None	56 k	71 g-i	60 fgh	56 gh
2,4-D (560)	86 abc	94 a	97 a	97 a
Carfentrazone (18)	68 hi	77 d-g	64 d-g	65 c-g
Dicamba (280)	87 abc	86 abc	94 a	83 b
Diuron (560)	76 e-h	87 abc	70 c-f	75 bc
Flumiclorac (30)	70 g-i	73 f-i	67 c-f	51 h
Flumioxazin (36)	81 c-f	81 c-f	74 bcd	71 c-e
Flumioxazin (71)	92 ab	84 b-e	83 b	70 c-f
Prometryn (560)	65 ij	76 e-h	69 c-f	68 c-f
Tribenuron (17)	59 jk	82 b-e	66 c-g	73 b-e
Tribenuron + thifensulfuron (9 + 17)	59 jk	85 bcd	63 e-g	75 bc

[z]Glyphosate was applied at 840 g ha^{-1}. Paraquat was applied at 700 g ha^{-1}. Crop oil concentrate at 1% by volume was included with all paraquat applications. Means within an evaluation date followed by the same letter are not significantly different according to Fisher's Protected LSD at $P = 0.05$.

eveningprimrose control at 28 DAT (63 to 70%). Other researchers have shown that products, such as carfentrazone, mixed with glyphosate will initially improve control because of visual plant dessication, but by several weeks after application, control with the mixture is no greater than control by glyphosate applied alone (Kelly et al., 2002).

Paraquat applied alone controlled cutleaf eveningprimrose 71% at 14 DAT (Table 1). Dicamba, diuron, flumioxazin, tribenuron, and tribenuron plus thifensulfuron mixed with paraquat increased control 10 to 16%. Although control by paraquat plus 2,4-D, dicamba, or diuron was similar, paraquat plus 2,4-D was the only treatment that controlled the weed greater than 90%. Cutleaf eveningprimrose control by paraquat applied alone decreased to 56% at 28 DAT. Other researchers have also noted fair initial cutleaf eveningprimrose control by paraquat but decreasing control over time due to regrowth (Kelly et al., 2002). Regrowth was also noted with several paraquat mixtures, including those with carfentrazone, diuron, flumiclorac, flumioxazin, prometryn, tribenuron, and tribenuron plus thifensulfuron. Cutleaf eveningprimrose was controlled 75% or less by these mixtures at 28 DAT. Regrowth after application of paraquat mixtures was most likely due to the cutleaf eveningprimrose being predominately in the pre-bloom stage of growth at time of treatment. The authors are currently experimenting with paraquat mixtures applied to pre-bloom and post-bloom cutleaf eveningprimrose. Results from these studies, conducted in both Georgia and North Carolina, show paraquat mixed with diuron or prometryn is much more effective when applied post-bloom to mature cutleaf eveningprimrose (York and Culpepper, 2005b). Of the paraquat mixtures, the only two that eliminated regrowth were paraquat plus dicamba and paraquat plus 2,4-D. Paraquat plus 2,4-D controlled cutleaf eveningprimrose 97% at 28 DAT, which was the only paraquat-containing treatment that controlled the weed greater than 83%.

Wild radish control. Little to no published data are available on control of wild radish in a conservation tillage cotton burndown program. Research in small grains has shown that 2,4-D or tribenuron plus thifensulfuron control small wild radish, but control by dicamba is poor (Fischer et al., 1999; Schroeder, 1989). In the current study, wild radish was more sensitive to most burndown treatments than cutleaf eveningprimrose. Wild radish was controlled 80 to 84% by glyphosate or paraquat applied alone (Table 2). Dicamba, diuron, or 2,4-D mixed with paraquat, flumioxazin mixed with glyphosate, and tribenuron or tribenuron plus thifensulfuron mixed with either glyphosate or paraquat increased control at 14 DAT to at least 90%. At 28 DAT, the most effective treat-

Table 2. Wild radish control by glyphosate or paraquat applied alone and in mixtures at 14 and 28 days after treatment (DAT)

Tank mix partner and rate (g ha^{-1})	Control (%)^z			
	14 DAT		28 DAT	
	Glyphosate	Paraquat	Glyphosate	Paraquat
None	81 ef	84 de	80 e-h	81 e-h
2,4-D (560)	80 ef	95 ab	97 a	96 a
Carfentrazone (18)	84 de	80 ef	84 c-f	80 e-h
Dicamba (280)	82 ef	95 ab	94 a	96 a
Diuron (560)	81 ef	90 bc	88 bc	92 ab
Flumiclorac (30)	81 ef	84 de	82 d-g	78 gh
Flumioxazin (36)	93 ab	87 cd	87 bcd	79 fgh
Flumioxazin (71)	92 abc	82 ef	85 cde	76 h
Prometryn (560)	78 f	82 ef	79 fgh	82 d-g
Tribenuron (17)	91 bc	97 a	97 a	97 a
Tribenuron + thifensulfuron (9 + 17)	91 bc	97 a	97 a	97 a

^{z}Glyphosate was applied at 840 g ha^{-1}. Paraquat was applied at 700 g ha^{-1}. Crop oil concentrate at 1% by volume was included with all paraquat applications. Means within an evaluation date followed by the same letter are not significantly different according to Fisher's Protected LSD at $P = 0.05$.

ments included paraquat plus diuron and paraquat or glyphosate plus 2,4-D, dicamba, tribenuron, or tribenuron plus thifensulfuron. Each of these treatments controlled wild radish at least 92%.

CONCLUSIONS

The cost per hectare for the 10 tank-mix partners used in this study, based on the rates applied and an average of prices quoted by three distributors in Georgia in February 2005, were as follows: 2,4-D, $3.56; diuron, $4.94; prometryn, $8.96; flumioxazin 36 g ha^{-1}, $9.88; carfentrazone, $12.86; flumiclorac, $11.95; dicamba, $13.43; tribenuron, $14.25; tribenuron plus thifensulfuron, $14.52 and flumioxazin 71 g ha^{-1}, $19.76. These results show that of the formulations tested, 2,4-D is the most economical and effective herbicide to mix with glyphosate or paraquat to improve control of both cutleaf eveningprimrose and wild radish. Dicamba was as effective as 2,4-D on wild radish when mixed with either glyphosate or paraquat, and dicamba was as effective as 2,4-D on cutleaf eveningprimrose when mixed with glyphosate. Dicamba, however, is more costly than 2,4-D, and dicamba is potentially more injurious than 2,4-D on cotton (York et al., 2004). In situations where growers are reluctant to apply 2,4-D or dicamba because of concerns over drift or sprayer contamination, these results show that flumioxazin at 71 g ha^{-1} plus glyphosate is the best option for cutleaf eveningprimrose. Although less effective and more expensive than 2,4-D, this combination controlled cutleaf eveningprimrose 83% at 28 DAT, a level of control that should protect cotton from yield loss (Burton and York, 2005). All other combinations not containing 2,4-D or dicamba controlled cutleaf eveningprimrose less than 80%. Growers have more options to control wild radish compared to cutleaf eveningprimrose. Although those options are somewhat more expensive than 2,4-D, at least 92% control at 28 DAT was obtained with tribenuron or tribenuron plus thifensulfuron mixed with glyphosate or paraquat and with diuron mixed with paraquat.

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