Weed Technology. 2004. Volume 18:432–436

Tropical Spiderwort (*Commelina benghalensis*) Control in Glyphosate-Resistant Cotton[1]

A. STANLEY CULPEPPER, J. T. FLANDERS, ALAN C. YORK, and THEODORE M. WEBSTER[2]

Abstract: Tropical spiderwort has recently become the most troublesome weed in Georgia cotton. Most of Georgia's cotton is glyphosate resistant (GR), and glyphosate is only marginally effective on tropical spiderwort. An experiment was conducted at four locations to determine tropical spiderwort control in GR cotton by 27 herbicide systems. Treatments consisted of three early-postemergence over-the-top (POT) herbicide options and nine late–postemergence-directed (LPD) options arranged factorially. Glyphosate POT controlled tropical spiderwort only 53% 21 d after treatment (DAT). Glyphosate plus pyrithiobac or S-metolachlor controlled tropical spiderwort 60 and 80%, respectively. Pyrithiobac improved control of emerged spiderwort, whereas S-metolachlor provided residual control. Pooled over POT treatments, glyphosate LPD controlled tropical spiderwort 70% 21 DAT. Dimethipin mixed with glyphosate did not improve control. Carfentrazone, diuron, or flumioxazin mixed with glyphosate LPD improved control 9 to 15%. MSMA and MSMA plus flumioxazin were 8 and 19% more effective than glyphosate LPD. At time of cotton harvest, systems without residual herbicides at LPD controlled tropical spiderwort 42 to 45% compared with 64 to 76% with LPD treatments that included diuron or flumioxazin.

Nomenclature: Carfentrazone; dimethipin; diuron; flumioxazin; glyphosate; MSMA; pyrithiobac; S-metolachlor; tropical spiderwort, *Commelina benghalensis* L.; cotton, *Gossypium hirsutum* L. 'DP 458 B/RR', 'FM 989 B/RR', 'ST 4793 BR'.

Additional index words: Invasive weed, noxious weed, weed shift.

Abbreviations: DAP, days after planting; DAT, days after treatment; GR, glyphosate resistant; LPD, late postemergence directed; POT, postemergence over-the-top.

INTRODUCTION

Since commercial introduction in 1997, glyphosate-resistant (GR) cotton has readily been accepted by growers across the southeastern United States. Greater than 89% of the cotton planted in Alabama, Florida, Georgia, North Carolina, and South Carolina is GR (USDA-AMS 2002; USDA-ERS 2003). Reasons for the widespread use of this technology have been reviewed by Culpepper and York (1999). The technology has allowed growers to reduce or eliminate soil-applied herbicides and to abandon cultivation. It also has allowed a shift to conservation tillage. At least one-third of the cotton in Georgia and several other southeastern states is produced using either no-tillage or strip-tillage techniques (S. M. Brown, personal communication). Herbicides are now the primary, and often only, method used for weed control. Glyphosate is applied two to four times on most fields, and it is often the only herbicide used.

Glyphosate is a highly effective and environmentally benign herbicide that controls a broad spectrum of annual and perennial grass and broadleaf weeds (Culpepper and York 1998; Franz et al. 1997; Wilcut et al. 1996). However, there are some species that are often not adequately controlled by glyphosate programs, and heavy dependence on glyphosate, coupled with increased adoption of reduced tillage practices, is resulting in changes in weed species composition. Most notable and of greatest concern for Georgia producers is tropical spiderwort.

Tropical spiderwort is among the world's worst weeds, and it is considered a weed in 25 crops in 29 countries (Holm et al. 1977). In 1983, the U.S. Department of Agriculture designated tropical spiderwort as a federal noxious weed (USDA-APHIS 2000). This weed was first observed in the continental United States in 1928 and was reported to be common through Florida by the mid-

[1] Received for publication July 2, 2003, and in revised form September 8, 2003.

[2] Assistant Professor and Grady County Extension Coordinator, Department of Crop and Soil Sciences, University of Georgia, P.O. Box 1209, Tifton, GA 31794; William Neal Reynolds Professor, Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695; Research Agronomist, Crop Protection and Management Research Unit, United States Department of Agriculture, Agricultural Research Service, Coastal Plain Experiment Station, Tifton, GA 31794. Corresponding author's E-mail: stanley@arches.uga.edu.

1930s (Faden 1993). In 1998, tropical spiderwort was present in Georgia but not considered a serious pest infesting cotton (Webster and MacDonald 2001). However, by 2001, it had quickly become very problematic and was ranked as the ninth most troublesome weed (Webster 2001). By 2002, tropical spiderwort was clearly the most troublesome weed facing Georgia producers in several southern counties (A. S. Culpepper, personal observation). A recent survey of county extension agents in Georgia (Prostko et al. 2003) determined that tropical spiderwort is present in 41 counties and is a moderate or severe pest in 17 counties. Tropical spiderwort also has recently been discovered in North Carolina (Krings et al. 2002).

Tropical spiderwort is an exotic, invasive herbaceous perennial of tropical climates, which grows as an annual in temperate climates (Holm et al. 1977). Tropical spiderwort is a monocot and possesses the unique ability to produce both aerial and subterranean flowers (Maheshwari and Maheshwari 1955; Walker and Evenson 1985). Aerial flowers are chasmogamous (typical, open flowers), lilac or blue, and capable of self-pollination. Subterranean flowers develop on the rhizomes and are cleistogamous (flowers are self-pollinated and do not open). Walker and Evenson (1985) reported that subterranean flower formation begins by 6 wk after plant emergence, whereas aerial flowers form 8 to 10 wk after emergence. In North Carolina, however, two-leaf seedlings of tropical spiderwort have been observed to have subterranean flowers (M. G. Burton, personal communication). Plants are capable of producing up to 12,000 seeds/m^2 (Walker and Evenson 1985). In addition, broken vegetative cuttings of stems are capable of rooting and reestablishing themselves after cultivation (Budd et al. 1979).

Preliminary data show that optimum temperatures for tropical spiderwort growth range from 30 to 35 C, indicating that the southeastern United States could provide an adequate environment for rapid growth and reproduction of this species (Burton et al. 2003). This, along with widespread planting of GR cotton and the heavy dependence on glyphosate for weed management, suggests that this problem is likely to increase across the region. There have been no published studies evaluating control of tropical spiderwort in agronomic crops in the United States, or in cotton throughout the world. The objective of our study was to evaluate response of tropical spiderwort to weed management systems in GR cotton.

MATERIALS AND METHODS

Studies were conducted in grower fields during 2001 and 2002 with naturalized populations of tropical spiderwort in Cairo, GA, and Pine Level, GA. Soils were Tifton loamy sands (thermic Plinthic Kandiudults), with organic matter ranging from 0.7 to 1.4% and pH ranging from 5.2 to 6.2. Plots consisted of three 76-cm rows 7.5 m in length. In Cairo during 2001, glyphosate isopropylamine salt[3] (840 g ae/ha) was applied 1 wk before strip-tillage, whereas land at all other locations was conventionally prepared by disking and then forming beds with a ripper-bedder. Pendimethalin[4] (930 g ai/ha) was applied preplant incorporated at the three conventionally prepared locations and applied preemergence at the strip-tillage location. GR 'DP 458 B/RR' cotton was planted in 2001, whereas 'FM 989 B/RR' and 'ST 4793 BR' cotton were planted in Cairo and Pine Level, respectively, in 2002. Cotton was planted between May 17 and 26 using a vacuum planter spacing seed 10 cm apart. No cultivation was performed after planting. Other cultural practices, including fertilization, insect management, and plant growth management, were standard for Georgia (Jost et al. 2003).

The experimental design was a randomized complete block, with each block replicated four times. A split-plot treatment arrangement was used, with the main plots being glyphosate[3] (840 g/ha) applied early-postemergence over-the-top (POT) alone or mixed with pyrithiobac[5] (36 g ai/ha) or S-metolachlor[6] (1,100 g ai/ha). Subplots consisted of the following nine late–postemergence-directed (LPD) options: glyphosate[3] (840 g/ha) applied alone or mixed with carfentrazone[7] (18 g ai/ha), diuron[8] (700 g ai/ha), dimethipin[9] (340 g ai/ha) plus a crop oil concentrate[10] (0.9% v/v), or flumioxazin[11] (36 g ai/ha); MSMA[12] (2,240 g ai/ha) applied alone or mixed with diuron

[3] Roundup UltraMax® herbicide, Monsanto Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167.

[4] Prowl® 3.3 EC herbicide, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709.

[5] Staple® herbicide, E. I. du Pont de Nemours and Company, Walker's Mill, Barley Mill Plaza, Wilmington, DE 19898.

[6] Dual Magnum® herbicide, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419.

[7] Aim® herbicide, FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

[8] Direx® herbicide, Griffin L.L.C., 2509 Rocky Ford Road, Valdosta, GA 31601.

[9] Harvade® herbicide, Crompton Uniroyal Chemical, 199 Benson Road, Middlebury, CT 06749.

[10] Agridex®, a mixture of 83% paraffinic mineral oil and 17% polyoxyethylene sorbitan fatty acid ester, Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 8137.

[11] Valor® herbicide, Valent Crop Protection, 1333 North California Boulevard, Walnut Creek, CA 94596.

[12] MSMA Plus H.C.® herbicide, Helena Chemical Company, 225 Schilling Boulevard, Collierville, TN 38017.

(1,120 g/ha) or flumioxazin (72 g/ha); and no LPD treatment. A nontreated control was included for treatment comparison.

Tropical spiderwort emergence began between the cotyledonary and two-leaf stage of cotton development at each location, and densities ranged from 30 to 90 plants/m^2 at time of the POT application. Populations at time of the LPD application varied depending on POT treatment; however, when nonresidual herbicides were applied POT, tropical spiderwort populations ranged from 200 to 300 plants/m^2 at time of LPD application. Tropical spiderwort had one to five leaves and was 3 to 10 cm tall at time of each application. Cotton was 8 to 13 cm tall with four to five leaves at time of the POT application and 40 to 56 cm tall with 10 to 13 leaves at time of the LPD application. Treatments were applied using a CO_2-pressurized backpack sprayer equipped with extended range flat-fan nozzles calibrated to deliver 140 L/ha at 152 kPa. LPD applications were applied 8 to 12 cm up the cotton stem. Visual estimates of crop injury were taken 5, 10, and 21 d after each application. Visual estimates of tropical spiderwort control were taken 21 d after each application and again at harvest (120 to 140 d after planting [DAP], hereafter referred to as 130 DAP). Visual estimates were based on a scale of 0 to 100, where 0 = no weed control or cotton injury and 100 = complete weed control or cotton death. The center cotton row was harvested by hand to determine seed cotton yield at both locations in 2002.

Data were subjected to ANOVA, and treatment sums of squares were partitioned to reflect the split-plot treatment design and year–location effects (McIntosh 1983). Year and location effects were not significant, and data were pooled. Main plot by subplot treatment interactions were not significant, and main effect means are reported where significant ($P \leq 0.05$). Means were separated using Fisher's protected LSD at $P = 0.05$. Arcsine transformation of data was not used because the transformation did not change data interpretation.

RESULTS AND DISCUSSION

Tropical Spiderwort Control. At 21 d after treatment (DAT), glyphosate applied POT controlled tropical spiderwort only 53% (Table 1). Poor control 21 DAT with glyphosate was attributed to both newly emerged plants and presence of plants only suppressed by glyphosate. Plants less than 6 cm in height were completely controlled by glyphosate, but plants ranging from 6 to 10 cm in height were only suppressed. However, there was little to no visible growth for 3 to 4 wk on larger plants treated with glyphosate. Once regrowth began, tropical spiderwort plants treated with glyphosate appeared to grow more slowly than those not treated with glyphosate. In addition to glyphosate only reducing growth of the larger plants, tropical spiderwort continued to emerge throughout the season.

Table 1. Tropical spiderwort control by herbicides applied topically to GR cotton.[a,b]

Treatments		Control	
Herbicides	Application rates	21 DAT	130 DAP
	g/ha	%	
Glyphosate	840	53 c	49 b
Glyphosate + pyrithiobac	840 + 36	60 b	48 b
Glyphosate + S-metolachlor	840 + 1,100	80 a	69 a

[a] Abbreviations: GR, glyphosate resistant; DAT, days after treatment; DAP, days after planting.

[b] Data pooled over subplot factors and four locations. Means separated using Fisher's protected LSD at $P = 0.05$.

Pyrithiobac added to glyphosate POT increased tropical spiderwort control by only 7% 21 DAT (Table 1). The increase in control compared with glyphosate alone was because of better control or suppression of plants emerged at time of application. It was noted that pyrithiobac offered little to no residual control of plants emerging after application. S-Metolachlor mixed with glyphosate increased control by 27%. S-Metolachlor did not increase control of emerged tropical spiderwort but provided residual control of seedlings emerging after application. In another trial conducted at two Georgia locations, S-metolachlor applied before tropical spiderwort emergence controlled the weed 99 and 85% at 25 and 55 DAT, respectively (A. S. Culpepper, unpublished data). Rainfall or irrigation shortly after S-metolachlor application is critical for good control, and at least 1.25 cm of rainfall was received at each location within 7 d after S-metolachlor application in the present study. At 130 DAP, tropical spiderwort control by glyphosate plus S-metolachlor applied POT was still 20% greater than control by glyphosate alone (Table 1). Pyrithiobac mixed with glyphosate had no effect on tropical spiderwort control 130 DAP.

Pooled over POT treatments, glyphosate applied LPD controlled tropical spiderwort 70% at 21 DAT (Table 2). Dimethipin mixed with glyphosate did not improve control. However, carfentrazone, diuron, or flumioxazin mixed with glyphosate increased control by 9 to 15%. MSMA applied LPD controlled tropical spiderwort 78% compared with 70% control by glyphosate. Diuron mixed with MSMA did not improve control. However,

Table 2. Tropical spiderwort control by herbicides directed to GR cotton.[a,b]

Treatments		Control	
Herbicides	Application rates	21 DAT	130 DAP
	g/ha	%	
Glyphosate	840	70 e	44 c
Glyphosate + carfentrazone	840 + 18	80 bcd	42 c
Glyphosate + flumioxazin	840 + 36	85 ab	64 b
Glyphosate + dimethipin[c]	840 + 340	75 de	43 c
Glyphosate + diuron	840 + 700	79 bcd	57 b
MSMA	840 + 2,240	78 cd	45 c
MSMA + diuron	840 + 1,120	83 abc	64 b
MSMA + flumioxazin	840 + 72	89 a	76 a
None	—	27 f	17 d

[a] Abbreviations: GR, glyphosate resistant; DAT, days after treatment; DAP, days after planting.

[b] Data pooled over main plot factors and four locations. Means separated using Fisher's protected LSD at P = 0.05.

[c] Crop oil concentrate (0.9% v/v) was included.

flumioxazin mixed with MSMA improved control by 11%.

Because of season-long emergence of tropical spiderwort, control by LPD treatments was less than desired by 130 DAP, or at cotton harvest. Pooled over POT treatments, MSMA and glyphosate alone or glyphosate mixed with carfentrazone or dimethipin controlled tropical spiderwort only 42 to 45% (Table 2). Although these herbicides applied LPD initially controlled emerged tropical spiderwort 70% or greater, they did not provide residual control. With season-long emergence, residual herbicide activity appears to be the most important component of a tropical spiderwort management system in cotton. Benefits from residual control by flumioxazin or diuron mixed with glyphosate or MSMA were evident, where late-season control was increased by 13 to 31%. The most effective treatment applied LPD was MSMA plus flumioxazin. Although postemergence control of tropical spiderwort at 21 DAT was similar with glyphosate plus 36 g/ha of flumioxazin and MSMA plus 72 g/ha of flumioxazin, greater late-season control was noted with MSMA plus flumioxazin at 72 g/ha because flumioxazin at the higher rate provided greater residual control.

Cotton Response. Glyphosate did not visually injure GR cotton (data not shown). Pyrithiobac mixed with glyphosate injured cotton 12% at 5 DAT. The injury was expressed as chlorosis. Minor injury from pyrithiobac applied topically to cotton has been previously observed (Jennings et al. 1999). Cotton was injured 5% when treated with S-metolachlor plus glyphosate. Injury was expressed as necrotic speckling on leaves contacted by the spray solution. Cotton leaves developing after S-metolachlor plus glyphosate application were not affected. Similar results have been observed with this mixture in North Carolina (York and Culpepper 2002). No cotton injury was detected by 21 DAT regardless of treatment. LPD treatments were applied to cotton stems that had developed bark. Injury from LPD applications caused less than 6% stem necrosis at 5 DAT. By 10 DAT, no visual cotton injury was detected.

Cotton Yield. The nontreated control plots did not produce cotton at either location in 2002. Seed cotton yields from all herbicide systems were similar and averaged 1,680 and 1,320 kg/ha at Cairo and Pine Level, respectively (data not shown). The lack of difference in cotton yield among the herbicide systems may reflect the impact each system had in reducing the competitiveness of tropical spiderwort. At each location, cotton emerged 10 to 17 d before tropical spiderwort emergence. At the four- to five-leaf stage, cotton in each herbicide system received glyphosate or a glyphosate mixture, which controlled tropical spiderwort at least 50% and suppressed growth of plants that were not killed. This most likely limited the early-season weed competition. No data are available to suggest how competitive this weed is with cotton. One factor that was not accounted for in this study, because of hand-harvesting, was the effect of tropical spiderwort present at harvest on cotton lint quality. Mechanical harvesting of cotton with high densities of tropical spiderwort could have a negative impact on lint quality and could slow the harvesting operation.

Results from this experiment confirm grower observations of inadequate tropical spiderwort control when depending heavily on glyphosate and help explain the rapid buildup of this weed in GR cotton fields. In addition, the results demonstrated the need for management programs that include herbicides with residual activity. Of the programs evaluated, the best late-season control (80%) of tropical spiderwort was obtained by glyphosate plus S-metolachlor applied POT and followed by MSMA plus flumioxazin applied LPD. Additional experiments are underway in Georgia and North Carolina to further evaluate management systems for tropical spiderwort in cotton and other crops and also to better understand the biology of this weed and its interaction with crops.

LITERATURE CITED

Budd, G. D., P.E.L. Thomas, and J.C.S. Allison. 1979. Vegetative regeneration, depth of germination and seed dormancy in *Commelina benghalensis* L. Rhod. J. Agric. Res. 17:151–153.

Burton, M. G., T. M. Webster, E. P. Prostko, A. S. Culpepper, A. C. York, and S. Sermons. 2003. Rapid increase of tropical spiderwort (*Commelina* *benghalensis* L.) in herbicide-resistant crops of southeastern USA agroecosystems. Abstracts of the Ecol. Soc. Am. 88:51–52.

Culpepper, A. S. and A. C. York. 1998. Weed management in glyphosate-tolerant cotton. J. Cotton Sci. 2:174–185.

Culpepper, A. S. and A. C. York. 1999. Weed management and net returns with transgenic, herbicide-resistant, and non-transgenic cotton (*Gossypium hirsutum* L.). Weed Technol. 13:411–420.

Faden, R. B. 1993. The misconstrued and rare species of *Commelina* (Commelinacea) in the eastern United States. Ann. Mo. Bot. Gard. 80:208–218.

Franz, J. E., M. K. Mao, and J. A. Sikorski. 1997. Toxicology and environmental properties of glyphosate. *In* Glyphosate: A Unique Global Herbicide. American Chemical Society Monograph 189. Washington, D.C.: American Chemical Society. Pp. 103–141.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI: University Press of Hawaii. 609 p.

Jennings, K. M., A. S. Culpepper, and A. C. York. 1999. Cotton response to temperature and pyrithiobac. J. Cotton Sci. 3:132–138.

Jost, P. J., S. M. Brown, S. Culpepper, G. Harris, B. Kemerait, P. Roberts, D. Shurley, and J. Willams. 2003. 2003 Georgia Cotton Production Guide. Publication No. CSS-03-01. Tifton, GA: University of Georgia Cooperative Extension Service. 98 p.

Krings, A., M. G. Burton, and A. C. York. 2002. *Commelina benghalensis* (Commelinacea) new to North Carolina and an updated key to Carolina congeners. Sida 20:419–422.

Maheshwari, P. and J. K. Maheshwari. 1955. Floral dimorphism in *Commelina forskalaei* Vahl. and *C. benghalensis* L. Phytomorphology 5:413–422.

McIntosh, M. S. 1983. Analysis of combined experiments. Agron. J. 75:153–155.

Prostko, E. P., A. S. Culpepper, T. M. Webster, and J. T. Flanders. 2004. Tropical Spiderwort Identification and Control in Cotton and Peanut. Tifton, GA: University of Georgia Cooperative Extension Service Bulletin. In press.

[USDA-AMS] United States Department of Agriculture, Agricultural Marketing Service—Cotton Program. 2002. Cotton Varieties Planted 2002 Crop. Memphis, TN: USDA-AMS.

[USDA-APHIS] United States Department of Agriculture, APHIS. 2000. Federal Noxious Weed List: Web page: http://www.aphis.usda.gov/ppq/permits/fnwsbycat-e.PDF. Accessed: May 3, 2004.

[USDA-ERS] United States Department of Agriculture, Economic Research Service. 2003. The Extent of Adoption of Bioengineered Crops: Web page: http://www.ers.usda.gov/publications/aer810/aer810d.pdf. Accessed: May 3, 2004.

Walker, S. R. and J. P. Evenson. 1985. Biology of *Commelina benghalensis* L. in south-eastern Queensland. Growth, development, and seed production. Weed Res. 25:239–244.

Webster, T. M. 2001. Weed survey—southern states. Proc. South. Weed Sci. Soc. 54:244–248.

Webster, T. M. and G. E. MacDonald. 2001. A survey of weeds in various crops in Georgia. Weed Technol. 15:771–790.

Wilcut, J. W., H. D. Coble, A. C. York, and D. W. Monks. 1996. The niche for herbicide-resistant crops in U.S. agriculture. *In* S. O. Duke, ed. Herbicide-Resistant Crops: Agricultural, Environmental, Economic, Regulatory, and Technical Aspects. Boca Raton, FL: CRC. Pp. 213–230.

York, A. C. and A. S. Culpepper. 2002. Dual/glyphosate combinations in Roundup Ready cotton. *In* J. McRae and D. A. Richter, eds. Proceedings of Beltwide Cotton Conference; 2002 January 8–13; Atlanta, GA. Memphis, TN: National Cotton Council of America.