The *Journal of Cotton Science 8:261–270 (2004)*
http://journal.cotton.org, © The Cotton Foundation 2004

WEED SCIENCE

Performance of Glyphosate-tolerant Cotton Cultivars in Official Cultivar Trials

Alan C. York*, A. Stanley Culpepper, Daryl T. Bowman, and O. L. May

ABSTRACT

All cultivars in official cultivar trials (OCT) typically receive a conventional herbicide program, and questions have arisen concerning the validity of glyphosate-tolerant (GT) cotton (*Gossypium hirsutum* L.) performance data under these conditions. Additionally, stagnant yields and declining fiber quality, concurrent with widespread planting of GT cultivars, have raised questions concerning the agronomic performance of these cultivars. The objectives of this study were to evaluate yield and fiber quality of GT cultivars treated with conventional or glyphosate-only herbicide systems and to compare performance of GT cultivars to a non-transgenic cultivar. Depending on the year, 8 to 19 GT cultivars were treated with either a conventional herbicide system or a glyphosate-only system in field studies in North Carolina during 1997 to 1999. Additionally, the GT cultivars were compared under a conventional herbicide system to Stoneville 474 (St 474), a non-transgenic cultivar with a history of good performance in North Carolina. The GT cultivar by herbicide system interaction was not significant for lint yield, fiber length, strength, micronaire, or uniformity index. Additionally, lint yield and fiber quality was not different between herbicide systems. These results imply that OCT with conventional and GT cultivars treated with a conventional herbicide program adequately indicate rank-order assessments among cultivars. Yield and fiber quality of GT cultivars, as a group, were not inferior in yield and fiber quality to ST 474 when a conventional herbicide system was used.

A. C. York and D. T. Bowman, Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695-7620 A. S. Culpepper and O. L. May, Department of Crop and Soil Sciences, University of Georgia, P. O. Box 1209, Tifton, GA 31793
*Corresponding author: alan_york@ncsu.edu

Weed management in cotton has traditionally relied on soil-applied herbicides, multiple applications of postemergence-directed herbicides, and cultivation (Wilcut et al., 1996; York and Culpepper, 2003). Soil-applied herbicides sometimes injure cotton (Corbin and Frans, 1991; Keeling and Abernathy, 1989; Snipes, 1991), and directing herbicides to small cotton is a slow, tedious task. Additionally, traditional weed management systems are not well suited to conservation tillage.

Glyphosate-tolerant (GT) cotton became commercially available in 1997, and it has since been readily accepted by growers across the southeastern USA. In 2003, glyphosate-tolerant cultivars were planted on 95, 98, 88, and 91% of the cotton acreage in North Carolina, South Carolina, Georgia, and Alabama, respectively (USDA-AMS, 2003). Widespread adoption of this technology is due in part to the potential benefits as follows: the opportunity to reduce or eliminate soil-applied herbicides and to reduce total herbicide use (Culpepper and York, 1998; 1999); more effective weed management in conservation tillage systems (Bradley, 2000); greater rotational crop flexibility (Bradley et al., 2001; Rogers et al., 1986; York, 1993); capability to control previously uncontrollable weeds (Byrd, 1995); and additional herbicide chemistry to use in resistance management programs (Shaw, 1995). The greatest benefit to growers is the broad-spectrum weed control and the convenience of postemergence (over-the-top) application to small cotton without crop injury (Wilcut et al., 1996).

Glyphosate-tolerant cotton was developed by insertion of a bacterial gene, along with a promoter, which encodes for a version of the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS, E.C.2.5.1.19) that has a greatly reduced affinity for glyphosate (Nida et al., 1996). Glyphosate-tolerant cultivars are produced through backcrossing the transformed line with parents from an established cultivar. Cultivars developed using the backcross method are expected to be similar, but not identical, to the parent cultivar (Fehr, 1987). When the genetic transformation is performed, all donor-DNA from the original non-transgenic line (usually the obsolete cultivar Coker 312) is not eliminated through backcrossing, particularly in chromosomal regions flanking the transgene (Falconer, 1989), and the resulting transgenic cultivar may suffer from linkage-drag effects on performance. Additionally, in a backcrossing program, there is little opportunity to make improvements in yield (Meredith, 2002).

An apparent decline in fiber quality that was concurrent with the widespread adoption of GT cotton was noted (Lewis, 2001). Growers have expressed concern over fiber quality of GT cultivars (Coley, 2000), and studies comparing commercially available conventional and transgenic cultivars have revealed shorter fiber length, reduced fiber strength, and greater micronaire in transgenic cultivars (Bourland and Johnson, 2003; Kerby et al., 2002; Meredith, 2002). This has led to speculation that a decline in fiber quality may be an unintended consequence of genetic transformation (Ethridge and Hequet, 2000). Verhalen et al. (2003) recently reported that the gene imparting resistance to glyphosate reduced cotton yield, fiber length, strength, and micronaire in some genetic backgrounds. Kerby et al. (2000) reported some differences in fiber quality between transgenic cultivars and their recurrent parents. These researchers noted that the differences were minor in magnitude and not consistent across cultivar families for the specific gene trait, so they concluded that the minor differences between a transgenic cultivar and its recurrent parent were due to variation in progeny selections from a parent.

Glyphosate-tolerant cotton cultivars were initially released in the USA with little to no public testing in official cultivar trials (OCT) or systems trials designed to evaluate these cultivars in the intended production system (May et al., 2000). Because OCT generally do not accommodate cultivar-specific production regimes, all cultivars are treated with the same conventional herbicides and without glyphosate (Bowman, 2003; Day et al., 2002), so validity of performance data for GT cultivars in OCT has been questioned (Hargett, 2000; May et al., 2000; Phipps et al., 2002).

This research was conducted to compare yield and fiber quality of GT cotton cultivars treated with conventional or glyphosate-only herbicide systems. The objective was to determine whether GT cultivars perform similarly under the two herbicide systems, which will determine the validity of results with GT cultivars included in standard OCT treated with conventional herbicides. An additional objective was to compare the agronomic performance of GT cultivars with a conventional cultivar with a record of good performance in North Carolina.

MATERIALS AND METHODS

The experiment was conducted at five locations in North Carolina as follows: the Upper Coastal Plain Research Station at Rocky Mount from 1997 through 1999; the Cherry Farm Unit at Goldsboro in 1997; the Central Crops Research Station at Clayton in 1998; a private farm at Woodland in 1998; and the Peanut Belt Research Station at Lewiston in 1999. Soils were a Norfolk sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) at Lewiston, Rocky Mount, and Woodland with organic matter ranging from 1.8 to 2.5% and pH ranging from 5.7 to 6.1. Soils at Goldsboro and Clayton were Norfolk loamy sand with 2.8% organic matter and pH of 5.6 and a Goldsboro sandy loam (fine-loamy, siliceous, subactive, thermic Aquic Paleudults) with 1.8% organic matter and pH of 5.8, respectively.

The experimental design was a split-plot with treatments replicated four times. Whole plots were herbicide systems (a conventional system and a glyphosate-only system) to eliminate concerns over herbicide drift. Subplots were cultivars randomized within whole plots and were two rows spaced 91 cm apart. Subplot length was 9 to 12 m, depending upon location. Glyphosate-tolerant cultivars varied among years, depending primarily on seed availability (Table 1). The non-transgenic cultivar Stoneville 474 (ST 474; Stoneville Pedigreed Seed; Memphis, TN) was included at each site as a standard. Cotton was planted into conventionally prepared seedbeds between 7 and 23 May each year. Seed were planted with a vacuum planter and placed 8 cm apart. Experiments were located in fields with light weed infestations and were maintained weed-free by the designated herbicide treatments, cultivation, and minimal hand weeding. Other cultural practices, including fertilization, plant growth management, and defoliation, were standard for North Carolina. Glyphosate-tolerant cultivars with and without the gene coding for the *Bacillus thuringiensis* endotoxin were present at several locations, and standard insect management practices for conventional cotton were followed.

The conventional herbicide system consisted of preplant incorporated, preemergence, postemergence,

Table 1. Lint yield of glyphosate-tolerant cultivars compared to the non-transgenic cultivar, Stoneville 474

Cultivars [y]	Lint yield (kg ha^{-1}) [x]					
	1997 [z]	1998			1999	
		Clayton	Rocky Mount	Woodland	Lewiston	Rocky Mount
DP 90 RR	1550	1220*		1330		
DP 409 B/RR					990	910
DP 422 B/RR					910	910
DP 425 RR		1270	1090	1400	920	780
DP 429 RR					990	910
DP 436 RR		1220*	1060	1440	880	940
DP 451 B/RR					950	940
DP 458 B/RR			1120		1050	990
DP 655 B/RR			980		1050	1030
DP 5415 RR	1510	1300	950	1540	960	920
DP 5690 RR	1560	1560	1020	1450	950	980
PM 1215 RR	1460	1560		1250		
PM 1218 BG/RR			1000		1080	990
PM 1220 RR	1280	1560	1060	1220	900	920
PM 1220 BG/RR			1140		1020	920
PM 1244 RR	1430	1680	1130	1230	1070	880
PM 1330 RR	1460	1230*		1400		
PM 1330 BG/RR					1010	1080
PM 1560 RR	1540	1380		1490		
PM 1560 BG/RR					1020	920
Sure-Grow 125RR					1070	1010
Sure-Grow 125BR					1100	970
Sure-Grow 501BR					1160	1030
ST 474	1360	1520	1080	1470	1100	890
MSD (P = 0.05)	270	290	170	280	NS	210

[x] All cultivars were treated with conventional herbicide program. Means were separated using Dunnett's minimum significant difference (MSD). Means followed by one asterisk (*) are less than the mean for ST 474; means followed by two asterisks (**) are greater than the mean for ST 474.

[y] ST 474 from Stoneville Pedigreed Seed Co., Memphis, TN; all other cultivars from Delta Pine and Land Co., Scott, MS.

[z] Data for 1997 averaged over Goldsboro and Rocky Mount locations.

and postemergence-directed herbicides as follows: trifluralin (Treflan, Dow AgroSciences; Indianapolis, IN) at 0.6 kg a.i. ha^{-1} plus norflurazon (Zorial Rapid 80, Syngenta Crop Protection; Greensboro, NC) at 1.1 kg a.i. ha^{-1} in 1997 and 1998 or trifluralin at 0.6 kg ha^{-1} in 1999 applied preplant and incorporated with a field cultivator; fluometuron (Cotoran, Griffin LLC; Valdosta, GA) at 1.4 kg a.i. ha^{-1} applied preemergence; pyrithiobac (Staple, E. I. du Pont de Nemours and Co.; Wilmington, DE) at 70 g a.i. ha^{-1} applied postemergence to 3- to 5-leaf cotton, and cyanazine (Bladex, E. I. du Pont de Nemours and Co.; Wilmington, DE) at 1.1 kg a.i. ha^{-1} plus MSMA (MSMA 6.6, Drexel Chemical Co.; Memphis, TN) at 2.2 kg a.i. ha^{-1} applied postemergence-directed when cotton had 8 to 12 leaves. The glyphosate-only system consisted of glyphosate isopropylamine salt (Roundup ULTRA, Monsanto Co.; St. Louis, MO) at 0.84 kg a.e. ha^{-1} applied postemergence to 1- to 3-leaf cotton followed by one (1997 and 1999) or two (1998) precision postemergence-directed applications of glyphosate at 0.63 kg ha^{-1}. The directed glyphosate was allowed to contact no higher than 5 cm on the cotton stalk.

Nonionic surfactant (Induce, Helena Chemical Co.; Memphis, TN) at 0.25% (v v^{-1}) was included with postemergence and postemergence-directed herbicides in the conventional system. The glyphosate formulation did not require additional surfactant. Preplant incorporated, preemergence, and postemergence herbicides were applied as broadcast sprays using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles spaced at 46 cm and delivering 160 L ha^{-1} at 170 kPa. Postemergence-directed herbicides were applied broadcast using a CO_2-pressurized backpack sprayer equipped with three evenly spaced flat-fan nozzles per row middle calibrated to deliver 240 L ha^{-1} at 170 kPa.

Plots were harvested once with a spindle picker modified for small-plot harvesting. A 200-g sample of mechanically harvested seed cotton was collected from each plot and used for lint percentage and fiber quality measurements. Seed cotton was ginned on a laboratory gin without lint cleaning. Cotton grades are not presented, since they would not be representative of cotton ginned commercially. Fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data were subjected to analysis of variance using the mixed model of the SAS (version 7.0, SAS Institute, Inc.; Cary, NC), with herbicide systems and years as fixed effects and cultivars and locations as random effects. Treatment sums of squares were partitioned to reflect the split-plot treatment design and location effects (McIntosh, 1983) when evaluating herbicide system effects on GT cotton. Although ST 474, a non-transgenic cultivar, was included in the split-plot design, glyphosate killed this cotton, so all data for ST 474 were removed prior to the split-plot analysis. An herbicide system by cultivar interaction was not observed for any variable. Means for significant main effects of herbicide systems were separated using Fisher's Protected LSD at $P = 0.05$. When all cultivars were treated with the conventional herbicide system, a second analysis of variance was conducted to compare GT cotton cultivars to ST 474. Cotton yield and fiber property means were separated using Dunnett's minimum significant difference (MSD) test at $P = 0.05$.

RESULTS AND DISCUSSION

All data in 1997 were pooled over Rocky Mount and Goldsboro locations because there was no location by treatment interaction. Data from all other locations are reported separately because of treatment by location interactions or variable cultivar selection.

Comparison of ST 474 and GT cultivars. ST 474 was chosen as the conventional cultivar for comparison to GT cultivars because it had the greatest 3-yr average yield in North Carolina's OCT during the period this experiment was conducted (Bowman, 1999). Under the conventional herbicide system, there was little evidence in this study to suggest that agronomic performance of GT cultivars as a group was inferior to ST 474. Based on the conservative Dunnett's procedure (Steel and Torrie, 1980), lint yield of GT cultivars was not different from the yield of ST 474 at 6 of 7 locations (Table 1). Three of 10 GT cultivars at Clayton in 1998 produced less yield than ST 474. Only one of those three cultivars, DP 436 RR, is still marketed (Anonymous, 2004a).

None of the GT cultivars produced fiber with significantly less strength than ST 474 (Table 2). Three of 8, 7 of 10, 6 of 10, 2 of 19, and 1 of 19 GT cultivars in 1997, at Clayton in 1998, Woodland in 1998, Lewiston in 1999, and Rocky Mount in 1999, respectively, had fiber strength greater than ST 474. The cultivars DP 90 RR, DP 655, DP 5415 RR, and DP 5690 RR had fiber strength greater than ST 474 at more than half of the locations where those cultivars were tested. In all cases where fiber strength of GT cultivars exceeded the strength of ST 474, the greater strength of the GT cultivars would have led to a greater market price based upon the 2003 Commodity Credit Corporation (CCC) loan schedule (NCC, 2004).

Upper half mean fiber length of 5 of 10 GT cultivars at Woodland in 1998 and 2 of 19 GT cultivars at Rocky Mount in 1999 exceeded ST 474 (Table 3). In each case, the GT cultivars had a greater market value than ST 474 (NCC, 2004). In contrast, two GT cultivars produced shorter fiber than ST 474 at Lewiston in 1999. Although PM 1220 BG/RR and PM 1244 RR produced shorter fiber with lower market value (NCC, 2004) than ST 474 at Lewiston in 1999,

Table 2. Fiber strength of glyphosate-tolerant cultivars compared with the non-transgenic cultivar Stoneville 474

Cultivars [y]	Fiber strength (kN m kg^{-1}) [x]					
	1997 [z]	1998			1999	
		Clayton	Rocky Mount	Woodland	Lewiston	Rocky Mount
DP 90 RR	325**	300**		323**		
DP 409 B/RR					309	281
DP 422 B/RR					282	277
DP 425 RR		277	280	285	286	293
DP 429 RR					321	291
DP 436 RR		273	290	280	303	296
DP 451 B/RR					299	287
DP 458 B/RR			279		317	297
DP 655 B/RR			263		340**	321**
DP 5415 RR	322**	290**	280	309**	321	310
DP 5690 RR	328**	312**	274	324**	345**	317
PM 1215 RR	311	290**		297		
PM 1218 BG/RR			294		298	273
PM 1220 RR	300	290**	290	304**	308	286
PM 1220 BG/RR			267		287	272
PM 1244 RR	297	285	267	288	308	293
PM 1330 RR	315	292**		304**		
PM 1330 BG/RR					300	287
PM 1560 RR	309	295**		303**		
PM 1560 BG/RR					309	292
Sure-Grow 125RR					274	274
Sure-Grow 125BR					277	271
Sure-Grow 501BR					294	291
ST 474	305	273	273	282	295	285
MSD (*P* = 0.05)	17	17	NS	19	40	35

[x] All cultivars were treated with conventional herbicide program. Means were separated using Dunnett's minimum significant difference (MSD). Means followed by one asterisk (*) are less than the mean for ST 474; means followed by two asterisks (**) are greater than the mean for ST 474.

[y] ST 474 from Stoneville Pedigreed Seed Co., Memphis, TN; all other cultivars from Delta Pine and Land Co., Scott, MS.

[z] Data for 1997 averaged over Goldsboro and Rocky Mount locations.

neither cultivar would have received a discounted price based upon fiber length. A difference in fiber length uniformity index between ST 474 and GT cultivars was noted only at Rocky Mount in 1999, where the indices for ST 474 and DP 409 B/RR were 84 and 81%, respectively (data not shown). Fiber with a uniformity index of 83% or greater receives a price premium, while fiber with uniformity index of 79% or less receives a discount (NCC, 2004). None of the other GT cultivars at Rocky Mount in 1999 had a uniformity index that differed significantly from that of ST 474.

Micronaire of GT cultivars were significantly different from that of ST 474 only in 1997. DP 90 RR, DP 5690 RR, PM 1330 RR, and PM 1560 RR had a micronaire reading of 4.2 compared with a reading of 4.7 for ST 474 (data not shown). Based on the 2003 CCC loan schedule (NCC, 2004), lint

Table 3. Upper half mean fiber length (UHM) of glyphosate-tolerant cultivars compared with the non-transgeniccultivar Stoneville 474

Cultivars [y]	Fiber length (UHM) (mm) [x]					
	1997 [z]	1998			1999	
		Clayton	Rocky Mount	Woodland	Lewiston	Rocky Mount
DP 90 RR	28.2	27.9		27.4		
DP 409 B/RR					29.1	27.3
DP 422 B/RR					29.4	27.7
DP 425 RR		27.9	27.7	27.4	29.1	27.9
DP 429 RR					30.1	28.0
DP 436 RR		28.6	27.8	27.9**	28.9	28.8**
DP 451 B/RR					30.1	28.7**
DP 458 B/RR			27.3		29.2	28.0
DP 655 B/RR			26.7		30.1	28.3
DP 5415 RR	28.6	27.9	27.8	27.8**	29.6	28.5
DP 5690 RR	28.9	27.9	26.3	27.8**	29.6	28.3
PM 1215 RR	28.3	27.9		27.8**		
PM 1218 BG/RR			28.3		27.9	27.4
PM 1220 RR	28.0	27.3	27.5	27.6	29.1	27.6
PM 1220 BG/RR			26.4		27.6*	27.8
PM 1244 RR	27.0	26.0	27.1	26.4	27.3*	26.9
PM 1330 RR	28.4	27.3		27.6		
PM 1330 BG/RR					29.1	27.8
PM 1560 RR	28.2	27.9		27.9**		
PM 1560 BG/RR					29.1	27.6
Sure-Grow 125RR					27.8	26.9
Sure-Grow 125BR					28.9	27.6
Sure-Grow 501BR					28.2	27.6
ST 474	28.1	27.9	26.9	26.6	29.5	27.5
MSD (P = 0.05)	1.2	NS	NS	1.1	1.9	1.2

[x] All cultivars were treated with conventional herbicide program. Means were separated using Dunnett's minimum significant difference (MSD). Means followed by one asterisk (*) are less than the mean for ST 474; means followed by two asterisks (**) are greater than the mean for ST 474.

[y] ST 474 from Stoneville Pedigreed Seed Co., Memphis, TN; all other cultivars from Delta Pine and Land Co., Scott, MS.

[z] Data for 1997 averaged over Goldsboro and Rocky Mount locations.

from these four GT cultivars with the lower micronaire would have received a greater price than lint from ST 474.

GT cultivar response to herbicide systems. In the split-plot analysis, a herbicide by cultivar interaction was not observed for any variable ($P > F$ ranged from 0.2855 to 0.9920); however, herbicide and cultivar main effects were often significant. Main effects of cultivars are not presented, since the results were very similar to those from the analysis comparing ST 474 and GT cultivars treated with the conventional herbicide program.

Averaged over GT cultivars, cotton yield was not different between the conventional herbicide program and the glyphosate-only program at any location (Table 4). Herbicide injury was not observed at 6 of 7 locations. At Lewiston in 1999, cotton seedlings exhibited minor stunting and leaf chlorosis

Table 4. Comparison of lint yield between glyphosate-tolerant cotton cultivars and the conventional cultivar as affected by herbicide systems

Herbicide system [y]	Lint yield ($g\ ha^{-1}$) [x]					
	1997 [z]	1998			1999	
		Clayton	Rocky Mount	Woodland	Lewiston	Rocky Mount
Conventional	1470	1400	1050	1370	1000	950
Glyphosate-only	1510	1400	1060	1360	1090	940
$P > F$	0.5108	0.9104	0.5000	0.5045	0.2059	0.5592

[x] Data averaged over 8 to 19 GT cultivars, depending on year and location.

[y] Conventional system consisted of trifluralin plus norflurazon (1997 and 1998) or trifluralin (1999) preplant incorporated, fluometuron preemergence, pyrithiobac postemergence, and cyanazine plus MSMA postemergence-directed. Glyphosate-only system consisted of glyphosate postemergence over-the-top followed by glyphosate postemergence-directed once (1997 and 1999) or twice (1998).

[z] Data averaged over Goldsboro and Rocky Mount locations in 1997.

typical of fluometuron injury. A heavy rainfall (3.3 cm) was received shortly after planting at Lewiston, which likely moved the herbicide into the root zone of the cotton (Savage and Ivy, 1973). The cotton visibly recovered, and there was no significant impact on yield. Herbicide systems had no effect on fiber length, fiber length uniformity, fiber strength, or micronaire at any location (data not shown).

In other experiments in North Carolina (Culpepper and York, 1998), lint yield or fiber quality of GT cotton were not different between conventional herbicide and glyphosate systems when weed control by the systems was similar. Researchers in Georgia (McGriff et al., 2000), Mississippi (Harrison et al., 2002), and Arkansas (Phipps et al., 2002) also reported similar yields with GT cotton treated with conventional and glyphosate-only herbicide systems. Greater yields of GT cotton were noted in a glyphosate-only system compared with a conventional herbicide system in South Carolina (May and Murdock, 2002). The response in South Carolina was likely due to injury by the conventional herbicides.

CONCLUSIONS

Cultivar selection is the foundation of a cotton production plan. Selection of the cultivar is a factor in determining the anticipated length of the production season, yield and quality goals, disease resistance, and other agronomic traits. Growers have historically used data from OCT, which document the relative agronomic performance of cultivars under local conditions, as an aid in cultivar selection. With transgenic cultivars that express pest management traits, such as tolerance to glyphosate, the pest management program is largely affected by cultivar selection, so cultivar selection may influence production costs and returns with transgenic cultivars to an even greater extent than it does with conventional cultivars. It follows, therefore, that cultivars would ideally be evaluated for yield, quality, and economic returns using pest management practices that are appropriate for the respective cultivars.

The question of how best to evaluate the agronomic performance of cultivars expressing pest management traits will continue as new transgenic technologies are commercialized. May et al. (2000) have recommended that cultivar trials that include both conventional and transgenic cultivars be conducted in a systems testing program that compounds treatments in a single-factor design. In this approach, treatments are the individual cultivars grown using their respective pest management programs. For the results from such a systems testing program to be most applicable to growers, the management systems used for both GT and conventional cultivars should be similar to those growers use on the respective cultivars, but there are several options in a glyphosate-based weed management system. For example, growers have the option of one or two postemergence applications of glyphosate before the fifth leaf stage (Anonymous, 2004b). They also have the option of using preplant-incorporated or preemergence herbicides in a glyphosate-based system. Depending upon the weed pressure, both the number of early glyphosate applications and soil-applied herbicides may impact yield (Askew and Wilcut, 1999; Culpepper and York, 1998; 1999). In some cases, a grower may mix another herbicide, such as pyrithiobac or metolachlor, with glyphosate applied postemergence to improve control of certain weeds or to provide residual weed control. This may also impact yield due to either improved weed control or crop injury (Culpepper and York, 2001; Everitt et al., 2001; York and Culpepper, 2002). Growers also have the option of directing glyphosate or conventional herbicides later in the season (Culpepper and York, 1998; 1999). Glyphosate applied in a manner contrary to the label may cause fruit abortion on glyphosate-tolerant cultivars (Jones, 1999; Pline et al., 2001). Similarly, growers have many weed management options in conventional cultivars (York and Culpepper, 2003). So, while there may be advantages from a systems testing program (May et al., 2000), this approach may not be practical considering the magnitude of treatments resulting from a typical number of cultivars each treated with several commonly used herbicide systems.

Cultivars and pest management programs can be field-tested independently. In this case, conventional and transgenic cultivars, such as GT cultivars, are evaluated under a conventional herbicide program to determine the relative performance of the cultivars under that single herbicide system. In separate experiments, commonly used conventional herbicide programs and glyphosate-based programs are compared on a common GT cultivar. Appropriate two-factor experiments must then be conducted to ascertain there are no interactions between cultivars and herbicide programs.

In the current experiment, cultivar by herbicide system interactions for cotton yield or fiber quality were not observed. Similarly, an interaction was not observed in other experiments (Harrison et al., 2002; May and Murdock, 2002; McGriff et al., 2000; Phipps et al., 2002). Lack of a cultivar by herbicide system interaction implies rank-order assessments from traditional cultivar trials comparing the agronomic performance of GT and conventional cultivars are valid. These agronomic performance data, along with information from experiments comparing efficacy and economic returns from conventional and glyphosate-based herbicide programs (Askew and Wilcut, 1999; Culpepper and York, 1998; 1999), can guide growers in selecting both their cultivar and their weed management system. Additionally, there was little to no evidence from the current experiment to indicate GT cultivars have inferior yield and fiber traits compared with a commonly planted conventional cultivar. While some exceptions occurred where specific GT cultivars were superior or inferior to ST 474 at some locations, GT cultivars as a group produced yield and fiber quality similar to this conventional cultivar that has historically performed well in North Carolina.

ACKNOWLEDGMENTS

Partial funding was provided by the cotton growers of North Carolina through the Cotton Incorporated State Support Program.

REFERENCES

Anonymous. 2004a. Delta and Pine Land Company cotton seed products. Available online at: http://www.deltaandpine.com/newsite/home001.asp (verified 19 Jan. 2004).

Anonymous. 2004b. Roundup WEATHERMAX herbicide label. Monsanto Co., St. Louis, MO. Available online at: http://www.cdms.net/ldat/ld5UJ000.pdf (verified 19 Jan. 2004).

Askew, S.D., and J.W. Wilcut. 1999. Cost and weed management with herbicide programs in glyphosate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 13:308-313.

Bourland, F.M., and J.T. Johnson. 2003. Transgenic vs. conventional varieties in Arkansas cotton variety tests, 1996-2002. p. 846. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 6-10 Jan. 2003. Natl. Cotton Counc. Am., Memphis, TN.

Bowman, D.T. 1999. North Carolina Measured Crop Performance - Soybean and Cotton. Crop Sci. Res. Rept. No. 182. North Carolina Agric. Res. Serv., Raleigh, NC.

Bowman, D.T. 2003. North Carolina Measured Crop Performance - Soybean and Cotton. Crop Sci. Res. Rept No. 209. North Carolina Agric. Res. Serv., Raleigh, NC.

Bradley, J.F. 2000. Economic comparison of weed control systems in conservation tillage systems. p. 1474-1476. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Bradley, A.L., A.C. York, F.H. Yelverton, A.S. Culpepper, and R.B. Batts. 2001. Fluometuron carryover to tobacco [Online]. J. Cotton Sci. 5:184-196. Available at http://www.cotton.org/journal/2001-05/3/184.cfm

Byrd, J.D., Jr. 1995. Herbicide-resistant crops: perspectives from an extension specialist. p. 37. *In* Proc. 48th South. Weed Sci. Soc., Memphis TN. 16-18 Jan. 1995. South. Weed Sci. Soc., Champaign, IL.

Coley, C.B. 2000. Seed selection: a southeastern grower's perspective. p. 26. *In* Proc. Beltwide Cotton Conf., San

Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Corbin, B.R., Jr., and R.E. Frans. 1991. Protecting cotton (*Gossypium hirsutum*) from fluometuron injury with seed protectants. Weed Sci. 39:408-411.

Culpepper, A.S., and A.C. York. 1998. Weed management in glyphosate-tolerant cotton [Online]. J. Cotton Sci. 2:174-185. Available at http://www.cotton.org/journal/1998-02/4/174.cfm

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.

Culpepper, A.S., and A.C. York. 2001. Comparing Roundup Ultra and Touchdown IQ in glyphosate-resistant cotton. p. 1232. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Day, J.L., A.E. Coy, W.D. Branch, O.L. May, S.S. Lahue, and L.G. Thompson. 2002. 2001 Peanut, Cotton, and Tobacco Performance Tests. College Agric. Environ. Sci. Res. Rpt. 677. University of Georgia, Athens, GA. Available online at: http://www.ces.uga.edu/es-pubs/RR677-contents.htm (verified 19 Jan. 2004).

Ethridge, M.D., and E.F. Hequet. 2000. Fiber properties and textile performance of transgenic cotton versus parent varieties. p. 488-494. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Everitt, J.D, J.W. Keeling, P.A. Dotray, and L.L. Lyon. 2001. Ivyleaf morningglory *(Ipomoea hederacea* (L.) Jacq.) management in Roundup Ready cotton. p. 3-4. In Proc. 54th South. Weed Sci. Soc., Biloxi, MS. 22-24 Jan. 2001. South. Weed Sci. Soc., Champaign, IL.

Falconer, D.S. 1989. Introduction to Quantitative Genetics. 3rd ed. John Wiley & Sons, Inc., New York, NY.

Fehr, W.R. 1987. Principles of Cultivar Development. Vol. 1. Theory and Technique. McGraw-Hill, Inc., New York, NY.

Hargett, J. 2000. Seed selection: a mid-south grower's perspective. p. 26. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Harrison, M.P., N.W. Beuhring, and R.R. Dobbs. 2002. B/RR-cotton performance in Roundup and conventional weed management systems. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 8-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. Available online at http://www.cotton.org/beltwide/proceedings/getPDF.cfm?year=2002&paper=M047.pdf (verified 19 Jan. 2004).

Jones, M. A. 1999. Tolerance of transgenic cotton to topical applications of glyphosate [Online]. J. Cotton Sci. 3:19-26. Available at http://www.cotton.org/journal/1999-03/1/19.cfm

Keeling, J.W., and J.R. Abernathy. 1989. Preemergence weed control in a conservation tillage cotton *(Gossypium hirsutum*) cropping system on sandy soils. Weed Technol. 3:182-185.

Kerby, T., D. Albers, K. Lege, and J. Burgess. 2002. Changes in yield and fiber quality due to variety grown. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 8-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. Available online at http://www.cotton.org/beltwide/proceedings/getPDF.cfm?year=2002&paper=G031.pdf. (verified 19 Jan. 2004).

Kerby, T., B. Hugie, K. Howard, M. Bates, J. Burgess, and J. Mahaffey. 2000. Fiber quality comparisons among varieties for conventional, Bollgard® and Roundup Ready® versions. p. 484-466. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Lewis, H. 2001. A review of yield and quality trends and components in American upland cotton. p. 1447-1453. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

May, L., S. Brown, B. Nichols, T. Kerby, S. Brown, and J. Silvertooth. 2000. Proposed guidelines for pre-commercial evaluation of transgenic and conventional cotton cultivars. p. 503-506. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-9 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

May, O.L., and E.C. Murdock. 2002. Yield ranks of glyphosate-resistant cotton cultivars are unaffected by herbicide system. Agron. J. 94:889-894.

McGriff, E.E., J.E. Hudgins, and A.S. Culpepper. 2000. Comparison of Roundup Ready (glyphosate-tolerant) varieties treated with either Roundup (glyphosate) or conventional herbicides. p. 1477-1478. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

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

Meredith, W.R., Jr. 2002. Factors that contribute to lack of genetic progress. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 8-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. Available online at http://www.cotton.org/beltwide/proceedings/getPDF.cfm?year=2002&paper=C002.pdf. Accessed Jan. 19, 2004.

National Cotton Council of America (NCC). 2004. National Cotton Council's EconCentral. Available online at http://www.econcentral.org/loan/grades.htm (verified 19 Jan. 2004).

Nida, D.L., K.H. Kolacz, R.E. Guehler, W.R. Deaton, W.R. Schuler, T.A. Armstrong, M.L. Taylor, C.C. Ebert, G.J. Rogan, S.R. Padgette, and R.L. Fuchs. 1996. Glyphosate-tolerant cotton: genetic characterization and protein expression. J. Agric. Food Chem. 44:1960-1966.

Phipps, B.J., N.R. Benson, F.M. Bourland, and C. Tingle. 2002. Are Roundup applications necessary for evaluaton of Roundup Ready cultivars? *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 8-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. Available online at http://www.cotton.org/beltwide/proceedings/getPDF.cfm?year=2002&paper=G034.pdf. (verified 19 Jan. 2004).

Pline, W. A., A. J. Price, J. W. Wilcut, K. L. Edmisten, and R. Wells. 2001. Absorption and translocation of glyphosate in glyphosate-resistant cotton as influenced by application method and growth stage. Weed Sci. 49:460-467.

Rogers, C.B., R. Talbert, and R. Frans. 1986. Effect of cotton (*Gossypium hirsutum*) herbicide carryover on subsequent crops. Weed Sci. 34:756-760.

Sasser, P.E. 1981. The basics of high volume instruments for fiber testing. p. 191-193. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-8 Jan. 1981. Natl. Cotton Counc. Am., Memphis, TN.

Savage, K.E., and H.W. Ivy. 1973. Fluometuron-disulfoton interactions in cotton as affected by soil properties. Weed Sci. 21:275-278.

Shaw, D.R. 1995. Herbicide-resistant crops and implications for herbicide resistant weeds. p. 38. *In* Proc. 48th South. Weed Sci. Soc., Memphis TN. 16-18 Jan. 1995. South. Weed Sci. Soc., Champaign, IL.

Snipes, C.E. 1991. Preemergence velvetleaf (*Abutilon theophrasti*) control in cotton (*Gossypium hirsutum*). Weed Technol. 142-146.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics: A biometrical approach. 2nd ed. McGraw-Hill, New York.

USDA-Agricultural Marketing Service (AMS). 2003. Cotton varieties planted - 2003 crop. USDA-AMS, Memphis, TN.

Verhalen, L.M., B.E. Greenhagen, and R.W. Thacker. 2003. Lint yield, lint percentage, and fiber quality response in Bollgard, Roundup Ready, and Bollgard/Roundup Ready cotton [Online]. J. Cotton Sci. 7:23-38. Available at http://www.cotton.org/journal/2003-07/2/23.cfm

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

York, A.C. 1993. Peanut response to fluometuron applied to a preceding cotton crop. Peanut Sci. 20:111-114.

York, A.C., and A.S. Culpepper. 2002. Dual/glyphosate combinations in Roundup Ready cotton. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 7-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. Available online at http://www.cotton.org/beltwide/proceedings/2002/abstracts/M028.cfm. (verified 19 Jan. 2004).

York, A.C., and A.S. Culpepper. 2003. Weed management in cotton. p. 77-123. *In* 2003 Cotton Information. Publ. AG-417. North Carolina Coop. Ext. Serv., Raleigh, NC.