Economic Comparison of Transgenic and Nontransgenic Cotton Production Systems in Georgia

P. Jost, D. Shurley, S. Culpepper, P. Roberts,* R. Nichols, J. Reeves, and S. Anthony

ABSTRACT

Transgenic cotton (*Gossypium hirsutum* L.) cultivars produce lint and seed and their propriety traits provide part of the crop's insect management and/or enable use of broad-spectrum herbicides for weed management. The standard procedures for conducting official cultivar trials utilize common pest management across all cultivars; whereas the pest management options and their associated potential for cost reductions are principal features of current transgenic cultivars. Field experiments were conducted to compare production systems utilizing cotton cultivars possessing different transgenic technologies managed in accordance with their respective genetic capabilities. In 2001 and 2002, selection of the Roundup Ready (RR) technology system resulted in reduced returns to the producer, while higher returns were attained from nontransgenic, Bollgard (B), and Bollgard/Roundup Ready (BR) technologies. In 2003, selection of the RR technology system or the Bollgard II/Roundup Ready (B2R) system reduced returns, while similar, higher returns were attained from nontransgenic, B, and BR technologies. In 2004, a nontransgenic system was superior to the BR, B2R, and Liberty Link (LL) systems in Tifton, but similar returns were achieved from nontransgenic, BR, and B2R technologies in Midville. Cultivar selection was important among the technology systems. Collectively these results indicate that profitability was most closely associated with yields and not the transgenic technologies.

Before the availability of transgenic technology, weed management in cotton was more difficult than in other agronomic crops such as corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.], and losses to insect pests, particularly to lepidoperous pests, were severe (Buchanan and Burns, 1970; Snipes and Mueller, 1992; Williams, 1995). Development of biological control technology by transferring genes between organisms that do not readily cross-fertilize has enabled breeders to develop crops with novel pest-managing traits (Dyer, 1996). The first transgenic cotton was introduced in 1995; BXN cultivars were resistant to the broad-leaf herbicide bromoxynil (Collins, 1996) (Table 1). At the rates permitted in BXN cotton, bromoxynil readily controlled cocklebur (*Xanthium strumarium* L.) and morningglories (*Ipomoea* spp.); whereas previously these weeds were difficult to manage using only cotton-selective herbicides and escapes were common (Culpepper and York, 1997). Since 1995, several new traits and combinations of traits have been developed and marketed in cotton cultivars. Cultivars expressing an endotoxin (Cry I Ac) produced by the bacterium *Bacillus thruringiensis* (Bt) were introduced in 1996 and marketed as Bollgard (B or BG) cotton (Begemann, 1996). Bollgard cultivars control such major lepidopteran pests of cotton as the tobacco budworm (*Heliothis virescens*) and the pink bollworm (*Pectinophora gossypiella*), and suppress populations of bollworm (*Helicoverpa zea*). Glyphosate resistant, or Roundup Ready (R or RR), cultivars were marketed the following year (Sherrick, 1996). Glyphosate is a herbicide with an extremely broad spectrum of activity (Jaworski, 1972; Spurrier, 1973). In 1998, cultivars possessing both the Cry I Ac Bt endotoxin and the RR technology, often referred to as *stacked gene* cultivars (BR, BGRR, or BG/RR), were introduced (Kerby and Voth, 1998); cultivars possessing both the Bt endotoxin and bromoxynil resistance were also introduced that same year (Panter et al., 1998).

There followed a period of 4 yr during which no new types of transgenic technologies were introduced for cotton (Table 1). In 2004, introductions of the so-called second generation of transgenic cultivars commenced. Cultivars were introduced that made improvements in both Bt and glyphosate resistance technologies. Bollgard II, a genetic technology whereby two Bt endotoxins are expressed by the cultivar, has an enhanced spectrum of control of lepidopteran insect pests compared with the single-gene B cultivars. Bollgard II technology was commercially released in 2004 in cultivars that also expressed the RR technology (BGII/RR or B2R)

P. Jost, 106 Corvina Dr., Clayton, NC 27520; D. Shurley, S. Culpepper, and P. Roberts, Univ. of Georgia, College of Agric. and Environ. Sci., P.O. Box 748, Tifton, GA 31794; R. Nichols and J. Reeves, Cotton Inc., 6399 Weston Pkwy., Cary, NC 27513; and S. Anthony, USDA-ARS Cotton Ginning Res. Unit, P.O. Box 256, Stoneville, MS 38776. Received 12 Sept. 2006. *Corresponding author (proberts@uga.edu).

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Abbreviations: B, Bollgard; BG, Bollgard; BGRR, Bollgard/Roundup Ready (also known as *stacked gene*); BG/RR, Bollgard/Roundup Ready (also known as *stacked gene*); BGII/RR, Bollgard II/Roundup Ready; BR, Bollgard/Roundup Ready (also known as *stacked gene*); BXN, bromoxynil resistant; B2LL, Bollgard II/Liberty Link; B2R, Bollgard II/Roundup Ready; B2RF, Bollgard II/Roundup Ready Flex; DAP, days after planting; HVI, high volume instrument testing; LDP, loan deficiency payment; PPI, preplant incorporated; PRE, pre-emergence; LL, Liberty Link; NT, nontransgenic; OCTs, official cultivar trials; R, Roundup Ready; RF, Roundup Ready Flex; RR, Roundup Ready; W, Widestrike; WR, Widestrike/Roundup Ready; WRF, Widestrike/Roundup Ready Flex.

(Albers and Shoemaker, 2004; Robinson, 2004). In that same year, LL cultivars, resistant to the herbicide glufosinate, were introduced (Becker et al., 2004). Glufosinate is also a broad spectrum herbicide; however, it must be used on relatively small weeds to be most effective (Corbett et al., 2004, Steckel et al., 1997). In 2005, another two gene Bt technology were released by Dow Agrosciences. Widestrike technology was released in cultivars that possess the insect-managing technology alone (W), or in conjunction with the RR technology (WR) (Thompson et al., 2005). In 2006, an enhanced version of the RR technology, Roundup Ready Flex (RF), was commercially available (Murdock, 2006). The genetic event conferring glyphosate resistance in the RR technology only fully protects cotton fruiting forms if glyphosate is applied to cotton foliage before the 4-leaf stage (Pline et al., 2002). Roundup Ready Flex technology permits application of glyphosate over the top of cotton throughout the period of fruit set. Roundup Ready Flex technology will be available in cultivars possessing that technology alone (RF), and with Bollgard II (B2RF) or with Widestrike (WRF). In 2006, Bollgard II technology in conjunction with LL technology (B2LL) was introduced (J. Ford, personal communication, 2006).

Table 1. Cotton cultivars and technology systems evaluated 2001 through 2004.

	Cultivar		
Technology	2001–2002	2003	2004
Nontransgenic (NT)	PEARL	PEARL	PEARL
	PSCGA161	PSCGA161	
	ST580	DP491	
	FM989		
Bollgard (B)	DP33B		
	DP448B		
Bollgard/Roundup Ready (BR)	DP555B/R	DP555B/R	DP555B/R
	DP458B/R	DP458B/R	DP444BR
	FM989BR	FM989BR	DP449BR
	ST4892BR	SG215B/R	FM960BR
		ST5599BR	FM991BR
			SG215B/R
			ST5242BR
			ST5599BR
Roundup Ready (RR)	SG521R	SG521R	
	ST4793R	ST4793R	
	FM989R	FM991RR	
		DP494R	
Bollgard II/Roundup Ready (B2R)		DP424B2R	DP424B2R
		ST4646B2R	ST4646B2R
			FM960B2R
			FM991B2R
			DP543B2R
Liberty Link (LL)		FM966LL	FM966LL
			FM981LL

Cotton producers planted transgenic cultivars on over 82% of U.S. hectares in 2005 (USDA-Agricultural Marketing Service, 2005). The management of key lepidopteran pests that is available with the Bt gene(s) combined with the broad-spectrum weed control available through the use of glyphosate (Culpepper and York, 1999) are the attributes that growers prefer in transgenic cultivars. Planting seed companies have stated that the increasing preference of growers for transgenic cultivars is the reason they are reducing the number of nontransgenic varieties they offer for sale.

Transgenic cotton cultivars are in essence dual-purpose products, providing seed and lint for producers to sell for profit, plus management of certain insect pests and/or the ability to apply herbicides that would otherwise kill or damage nontransgenic cotton (May et al., 2003). Growers face a steadily increasing selection of cultivars and pest management options as seed companies and biotechnology providers launch new cultivars and transgenic technologies. The costs of paying higher seed prices and technology fees in advance must be compared with relying on the traditional pesticide treatments used with nontransgenic cultivars (May et al., 2003). The high investment for the transgenic cultivars before any yield is realized is a predicament for growers. Cultivar performance data encompassing both yield and profitability are essential for growers to make critical comparisons (May et al., 2003).

The rapid development and availability of multiple transgenic cotton systems has outpaced the capability of OCTs to convey their agronomic merits and evaluate their pest management features. The limitations of OCTs to convey performance of transgenic cultivars and render unbiased yields among all cultivars when produced with insect and weed management intended for nontransgenic cultivars were summarized by May et al. (2003). These authors concluded that yields of Bt cultivars in OCTs can be biased upward from the additive effects of insecticide applications combined with the insect control attributed to Bt cotton. Another concern was the possibility of yield reduction imposed on glyphosate resistant cultivars when produced with high rates of soil-applied herbicides. The authors stated that OCTs still have value in defining general adaptation of new cultivars, but that cultivar choice could be facilitated by also considering data from trials where cultivars are produced according to their pest management capabilities.

A few studies report findings from agronomic and economic evaluations of transgenic and nontransgenic cultivars when pest management was tailored to each cultivar. Bryant et al. (2003) reported that cultivar profitability was most closely related to yield and secondarily to pest management costs under the pest pressure in their trials. The authors did not find an overall economic advantage with any transgenic production approach. The study conducted from 1998 through 2000 by Bryant et al. (2003) evaluated top performing cultivars in Arkansas possessing BXN, B, RR, and BR transgenic technologies. The objective of the current study was to evaluate the yield and returns of top performing grower-accepted cultivars in Georgia possessing B, RR, BR, B2R, and LL transgenic technology.

Table 2. Herbicide program for three weed pest management systems, Tifton, GA, 2001–2004, and Midville, GA, 2003–2004.†

Nontransgenic			Roundup Ready			Liberty Link		
Timing	Herbicide‡	Rate§	Timing	Herbicide	Rate	Timing	Herbicide	Rate
DAP		kg a.i./ha	DAP		kg a.i./ha	DAP		kg a.i./ha
2001–Tifton								
PPI	pendimethalin	0.84	PPI	pendimethalin	0.84		NA	
PRE	pyrithiobac	0.05¶	30	glyphosate	1.12			
PRE	fluometuron	1.12¶	60	prometryn	1.34			
30	cultivation	NA	60	MSMA	2.24			
30	MSMA	2.24#						
60	prometryn	1.34						
60	MSMA	2.24						
2002–Tifton								
PPI	pendimethalin	0.84	PPI	pendimethalin	0.84		NA	
PRE	pyrithiobac	0.05¶	30	glyphosate	1.12			
PRE	fluometuron	1.12¶	60	prometryn	1.12			
30	cultivation	NA	60	MSMA	2.24			
60	prometryn	1.14						
60	MSMA	2.24						
2003–Tifton								
PPI	pendimethalin	0.84	PPI	pendimethalin	0.84	PPI	pendimethalin	0.84
Preplant	glyphosate	1.12	Preplant	glyphosate	1.12	Preplant	glyphosate	1.12
PRE	pyrithiobac	0.05¶	30	glyphosate	1.12	30	glufosinate	0.46
PRE	fluometuron	1.12¶	60	diuron	1.34	60	diuron	1.34
30	cultivation	NA	60	MSMA	2.24	60	MSMA	2.24
60	diuron	1.34						
60	MSMA	2.24						
2003–Midville								
PPI	pendimethalin	0.84	PPI	pendimethalin	0.84	PPI	pendimethalin	
PRE	pyrithiobac	0.05	23	glyphosate	1.12	23	glufosinate	0.46
PRE	fluometuron	0.9	34	pyrithiobac	0.08	34	glufosinate	0.46
23	cultivation	NA	58	diuron	1.8	58	diuron	1.8
28	pyrithiobac	0.07	58	MSMA	2.24	58	MSMA	2.24
58	diuron	1.8						
58	MSMA	2.24						
2004–Tifton								
PPI	pendimethalin	0.92	PPI	pendimethalin	0.92	PPI	pendimethalin	0.92
PRE	fluometuron	1.12¶	20	glyphosate	0.77	PRE	fluometuron	1.12¶
PRE	pyrithiobac	0.05¶	30	glyphosate	0.77	30	cultivation	NA
30	cultivation	NA	60	diuron	0.56	60	diuron	0.56
60	diuron	0.56	60	MSMA	2.1	60	MSMA	2.1
60	MSMA	2.1	60	linuron	0.56	60	linuron	0.56
60	Linuron	0.56						
2004–Midville								
PPI	pendimethalin	0.93	PPI	pendimethalin	0.93	PPI	pendimethalin	0.93
PRE	fluometuron	1.12	21	glyphosate	1.06	21	glufosinate	0.5
PRE	pyrithiobac	0.05	30	glyphosate	1.06	30	glufosinate	0.5
17	pyrithiobac	0.075	38	MSMA	2.5	38	MSMA	2.5
21	cultivation	NA	38	fluometuron	1.8	38	fluometuron	1.8
30	trifloxysulfuron	0.005						
38	MSMA	2.5						
38	fluometuron	1.8						

† DAP = days after planting; NA, not available;PPI = preplant incorporated; PRE = preemergence at planting; Preplant = broadcast before planting.

‡ Pendimethalin: N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine; pyrithiobac: 2-chloro-6-[(4,6-dimethoxy-2-pyrimidinyl)thio] benzoic acid; fluometuron: N,N-dimethyl-N'-[3-(trifluoromethyl)phenyl] urea; MSMA: monosodium salt of methylarsonic acid; prometryn: N,N'-bis(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine; glyphosate: N-(phosphonomethyl) glycine; diuron: N'-(3,4-dichlorophenyl)-N,N-dimethylurea; linuron: N-[[(4,6-dimethoxy-2-pyridiminyl)amino]carbonyl]-3-(2,2,2-trifluoroethoxy)-,monosodium salt; monohydrate glufosinate: 2-amino-4-(hydroxymethylphosphinyl) butanoic acid.

§ Herbicides were broadcast unless otherwise noted.

¶ Applied in a band over the row.

Applied post direct on a band.

MATERIALS AND METHODS

Field experiments were conducted from 2001 through 2004 to compare cotton production systems utilizing cotton cultivars possessing differing transgenic technologies. Treatments consisted of cotton cultivars possessing no pest management system, an insect management system, a weed management system, or a combination of both and were managed in accordance. Experiments were conducted at the Coastal Plain Experiment Station in Tifton, GA, in 2001 through 2004, and at the Southeast Research and Education Center in Midville, GA, in 2003 and 2004. In the years, 2001 and 2002, 2003, and 2004, 13, 15, or 16 cultivars, respectively, were evaluated (Table 1). Cultivar and transgenic system selection in each year was based on performance in the University of Georgia OCTs, adoption by Georgia growers, and cultivars that were offered by their respective planting seed companies as representative of new technologies (May et al., 2003). In each test, cultivars were arranged in a randomized complete block design with four replications. Planting occurred during the first 2 wk of May in all years in both locations. Plots were 12.2 m long by six 0.9-m rows wide in Tifton, GA, and six 0.96-m rows wide in Midville, GA.

Each cultivar was managed to maximize profit, consistent with practices recommended by the University of Georgia Extension Service (Jost et al., 2006), and administered by the authors. Fertilization, irrigation, and plant growth regulator and harvest-aid applications were held consistent across all cultivars in a given location or year.

The pest management program for each cultivar was selected based on the pest management traits possessed by each cultivar. Thus, the insect and weed management programs were unique to each transgenic system. These inputs varied by location and year and were dictated by pest pressure. Plots were scouted at least weekly for insect pests. Insecticide treatments were based on thresholds determined for each insect pest management system possessed by the cultivars. Once a weed or insect threshold was reached within an individual transgenic system, all cultivars possessing that technology were treated identically.

Herbicide programs utilized in each trial are listed in Table 2. The transgenic and nontransgenic weed management systems were similar. All systems received full tillage and preplant incorporated (PPI) applications of pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzeneamine]. In the Coastal Plain, pre-emergence control with a dinitroaniline herbicide is essential for control of Florida pusley (*Richardia scabra*). The nontransgenic systems received pre-emergence treatments at planting and cultivation at about 30 days after planting (DAP); in contrast, the transgenic systems received one or two applications of broad-spectrum herbicide, consistent with respective tolerances of the cultivars, as needed. All treatments received lay-by applications to provide burn-down of escapes and soil-residual control of late-emerging weeds. Heliothine insect pressure was light in 2001 and 2002, and moderate in 2003 and 2004 (Table 3). In Tifton, the Bt cultivars were not treated with insecticides in 2001 or 2002, and treated once and twice in 2003 and 2004, respectively. The non-Bt cultivars were either not treated or treated twice, four times, and three times with insecticides in the 4 yr, respectively. The Bt and non-Bt cultivars were treated one and two times, respectively, with insecticides in 2003 and 2004 in Midville. There were no differences in the insect control programs between

Table 3. Insecticide program for Bt and non-Bt cotton cultivars, Tifton, GA, 2001–2004, Midville, GA, 2003–2004.

Bt†			Non-Bt		
Timing	**Product‡**	**Rate**	**Timing**	**Product‡**	**Rate**
DAP		kg a.i./ha	DAP		kg a.i./ha
2001–Tifton					
NA	none		NA	None	
2002–Tifton					
NA	none		80	spinosad	0.052
			80	cypermethrin	0.067
			92	cyhalothrin	0.034
			92	spinosad	0.052
2003–Tifton					
80	bifenthrin	0.078	56	cyhalothrin	0.034
			65	cyhalothrin	0.034
			72	spinosad	0.069
			80	bifenthrin	0.056
			80	spinosad	0.049
2003–Midville					
			47	esfenvalerate	0.045
83	cyhalothrin	0.045	83	cyhalothrin	0.045
83	spinosad	0.099	83	spinosad	0.099
2004–Tifton					
85	zeta-cypermethrin	0.022	79	spinosad	0.052
85	acetamiprid	0.083	79	zeta-cypermethrin	0.022
96	pyriproxyfen	0.06	85	zeta-cypermethrin	0.022
			85	acetamiprid	0.083
			96	pyriproxyfen	0.06
2004–Midville					
72	zeta-cypermethrin	0.021	57	spinosad	0.07
			72	zeta-cypermethrin	0.021

† The BR and B2R cultivars were treated identically in all locations in all years, differential insect control was not necessitated.

‡ Bifenthrin: (2-methyl{1,1'-biphenyl}-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate; cyhalothrin: (R+S)-alpha-cyano-3-phenoxybenzyl (1S+1R)-cis-3-(Z-2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate; spinosad: 2-{(6-deoxy-2,3,4-tri-O-methyl-alpha-L-mannopyranosyl)oxy}-13-{{5-(dimethylamino)tetrahydro-6-methyl-2H-pyran-2-yl}oxy}-9-ethyl; zeta-cypermethrin: cyano(3-phenoxyphenyl) methyl (±)-cis/trans-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate; acetamiprid: (E)-N-?(6-chloro-3-pyridyl)methylU-N'-cyano-N-methyl acetamidine; pyriproxyfen: 2-(1-methyl-2-(4-phenoxyphenoxy)ethoxy)pyridine; esfenvalerate: (S)-alpha-cyano-3-phenoxybenzyl (S)-2-(4-chlorophenyl)-3-methylbutyrate.

Table 4. Lint yield, price, seed income, seed costs, herbicide costs, insecticide costs, application costs, and returns for cotton cultivars, and contrast of returns by technology system, Tifton, 2001 and 2002.

Cultivar	Lint	Price†	Seed income‡	Costs					Return#
					Weed control		Pest management		
				Seed§	Herbicide	Application	Insecticide	Application¶	
	kg/ha	c/kg	$/ha						
FM989	1241.54ab††	136.66	152.96	28.35	70.88	80.83	30.50	4.33	1637.55a
DP555B/R	1282.77a	131.56	138.95	123.04	58.59	71.34	0.00	0.00	1584.95ab
DP458B/R	1185.49abcd	133.23	147.29	111.08	58.59	71.34	0.00	0.00	1497.79abc
PHGA161	1146.21bcde	134.93	155.42	24.51	70.88	80.83	30.50	4.33	1494.64abc
ST4892BR	1223.97abc	127.57	148.56	119.15	58.59	71.34	0.00	0.00	1483.82abc
PEARL	1140.37bcde	131.96	134.12	23.01	70.88	80.83	30.50	4.33	1439.95bcd
DP33B	1152.32bcde	129.55	152.46	91.30	70.88	80.83	0.00	0.00	1422.94bcd
DP448B	1118.53cde	134.58	143.02	92.04	70.88	80.83	0.00	0.00	1408.92bcd
FM989BR	1123.49bcde	133.46	144.26	119.37	58.59	71.34	0.00	0.00	1405.57bcd
ST580	1098.26de	126.83	140.79	26.01	70.88	80.83	30.50	4.33	1341.92cde
FM989R	1068.01de	132.80	128.20	52.40	58.59	71.34	30.50	4.33	1337.77cde
SG521R	1042.87e	127.90	132.12	50.41	58.59	71.34	30.50	4.33	1261.31de
ST4793R	1050.05e	121.89	124.15	47.96	58.59	71.34	30.50	4.33	1215.36e

Var.	*P* > *F*
Year	<0.0001
C	0.0200
C × Year	0.6479

Contrast of returns by system

Comparison	Returns	*P* > *F*
NT vs. B	1478.51 vs. 1415.93	0.2480
NT vs. RR	1478.51 vs. 1271.48	0.0007
NT vs. BR	1478.51 vs. 1493.03	0.7361
B vs. RR	1415.93 vs. 1271.48	0.0208
B vs. BR	1415.93 vs. 1493.03	0.1605
RR vs. BR	1271.48 vs. 1493.03	0.0004

Var.	*P* > *F*
Year	<0.0001
C	0.0115
C × Year	0.6547

† Price/kg of lint is the November avg. Georgia price/kg adjusted for quality (includes LDP).

‡ Calculated by multiplying the kilograms of seed produced/ha by the November avg. Georgia price received for cottonseed.

§ Seed costs include technology fee assuming a 9.8 seed/m seeding rate.

¶ Application costs for insecticides assume one insect application was made with a plant growth regulator application thus incurring no additional cost.

Net return (R_{xy}) = ($Y_x \times LP_{qx}$) + ($C_x \times SP$) - S_{xy} - H_y - I_y - A_y, where R = the return above system costs for variety x, technology y; Y = lint yield (kg/ha) for variety x; LP = the November avg. Georgia price/kg adjusted for quality ***q*** for variety ***x*** (includes LDP); C = the cottonseed yield for variety x; SP = the November avg. Georgia price received for cottonseed; S = seed cost/ha for variety ***x***, technology ***y***; H = herbicide costs/ha for technology ***y***; I = insecticide costs/ha for technology ***y***; A = herbicide and insecticide application costs/ha for technology ***y***.

†† Means in a column followed by the same letter are not significantly different (***P*** = 0.05).

the BR and B2R systems. Therefore, these technologies are referred to collectively as the Bt system.

Yields were measured by machine harvesting the center four rows of each plot. In each year and location, seed cotton harvested from the first and third replications and the second and fourth replications were combined to create two samples for each cultivar that were large enough to be processed at the USDA-ARS Cotton Ginning Laboratory in Stoneville, MS, for ginning and lint turn-out determinations. Seed cotton yields for each replication of a cultivar were multiplied by lint turnout obtained from corresponding gin samples to obtain the lint yield. Seed turnout for each plot was calculated as the portion of the sample that was not attributed to lint. Fiber properties were measured on lint of each ginned sample by High Volume Instrument (HVI) testing (Uster Technologies Inc.) at the Textile Service Laboratory at Cotton Incorporated in Cary, NC. For each graded sample, the value of lint was determined. The price/kg of lint for each sample was calculated by adjusting the average November Georgia price for quality (including loan deficiency payment [LDP]) for each year. Lint income for each replication of a cultivar was determined by multiplying lint yield by the price/kg of lint from corresponding gin samples. Seed income was determined by multiplying the seed yield by the average November Georgia price for each year. Although used to calculate net returns of a cultivar, the combining of replications for ginning purposes precluded the statistical analysis of lint turn-out, lint quality, and price received/kg of lint.

Seed costs, including seed and technology fee, were calculated for each cultivar based on local prices in each year. Technology fees are charged per bag of seed, and were calculated based on a seeding rate of 9.8 seed/m of row. Herbicide and insecticide costs were determined in each year by averaging several locally obtained prices. Application costs are those associated with specific applications for each cultivar in each year and location (Shurley, 2006).

For each cultivar, the return above system cost was calculated. System costs include seed and technology fee, herbicides, insecticides, and application. All other inputs and costs (ginning costs were not accounted for) were the same regardless of technology. The Return above system cost was calculated as:

$$R_{xy} = (Y_x \times LP_{qx}) + (C_x \times SP) - S_{xy} - H_y - I_y - A_y$$

Table 5. Lint yield, price, seed income, and seed costs, herbicide costs, insecticide costs, application costs, and returns for cotton cultivars, and contrast of returns by technology system, Midville and Tifton, 2003.

Cultivar	Lint	Price†	Seed income‡	Costs: Seed§	Weed control: Herbicide	Weed control: Application	Pest management: Insecticide	Pest management: Application¶	Return#
	kg/ha	c/kg				$/ha			
DP491	1348.35a††	155.47	174.64	30.78	102.84	65.41	80.73	17.40	1974.60a
DP555B/R	1344.50a	151.67	170.49	130.59	88.41	52.38	41.06	0.00	1900.30ab
FM966LL	1291.47ab	152.09	186.78	69.86	76.32	52.38	80.73	17.40	1856.70abc
FM989BR	1263.71ab	152.66	189.52	125.17	88.41	52.38	41.06	0.00	1813.20abc
ST5599BR	1297.29ab	149.29	174.85	125.80	88.41	52.38	41.06	0.00	1807.20abc
DP494R	1243.53ab	153.30	169.54	77.53	88.41	52.38	80.73	17.40	1758.30abcd
PEARL	1165.97abcd	153.13	161.38	26.58	102.84	65.41	80.73	17.40	1656.10bcde
SG215B/R	1230.25abc	141.03	188.42	123.76	88.41	52.38	41.06	0.00	1618.80bcde
PHGA161	1109.59bcd	153.23	179.06	25.24	102.84	65.41	80.73	17.40	1586.50cde
DP424B2R	1163.64abcd	145.75	192.49	138.10	88.41	52.38	41.06	0.00	1573.90cde
SG521R	1126.79bcd	140.40	169.81	55.38	88.41	52.38	80.73	17.40	1456.70de
ST4646B2R	1119.03bcd	143.86	172.64	164.52	88.41	52.38	41.06	0.00	1440.00e
FM991RR	1021.61d	152.44	156.74	56.00	88.41	52.38	80.73	17.40	1417.00e
DP458B/R	1015.54d	149.61	152.43	117.27	88.41	52.38	41.06	0.00	1376.70e
ST4793R	1048.50cd	143.79	151.62	59.00	88.41	52.38	80.73	17.40	1360.30e

Var.	P > F
Loc	0.0046
C	0.0225
C × Loc	0.0793

Contrast of returns by system

Comparison	Returns	P > F
NT vs. RR	1727.29 vs. 1498.07	0.0052
NT vs. BR	1727.29 vs. 1703.25	0.5113
NT vs. B2R	1727.29 vs. 1506.95	0.0210
NT vs. LL	1727.29 vs. 1856.73	0.4451
RR vs. BR	1498.07 vs. 1703.25	0.0077
RR vs. B2R	1498.07 vs. 1506.95	0.8441
RR vs. LL	1498.07 vs. 1856.73	0.0072
BR vs. B2R	1703.25 vs. 1506.95	0.0383
BR vs. LL	1703.25 vs. 1856.73	0.2139
B2R vs. LL	1506.95 vs. 1856.73	0.0164

Var.	P > F
Loc	0.0453
C	<0.0001
C × Loc	0.0888

† Price/kg of lint is the November avg. Georgia price/kg adjusted for quality (includes LDP).

‡ Calculated by multiplying the kilograms of seed produced/ha by the November avg. Georgia price received for cottonseed.

§ Seed costs include technology fee assuming a 9.8 seed/m seeding rate.

¶ Application costs for insecticides assume one insect application was made with a plant growth regulator application thus incurring no additional cost.

Net return (R_{xy}) = ($Y_x \times LP_{qx}$) + ($C_x \times SP$) − S_{xy} − H_y − I_y − A_y, where R = the return above system costs for variety x, technology y; Y = lint yield (kg/ha) for variety x; LP = the November avg. Georgia price/kg adjusted for quality q for variety x (includes LDP); C = the cottonseed yield for variety x; SP = the November avg. Georgia price received for cottonseed; S = seed cost/ha for variety x, technology y; H = herbicide costs/ha for technology y; I = insecticide costs/ha for technology y; A = herbicide and insecticide application costs/ha for technology y.

†† Means in a column followed by the same letter are not significantly different (***P*** = 0.05).

R = the return above system costs for variety *x*, technology *y*; Y = lint yield (kg/ha) for variety *x*; LP = the November average Georgia price/kg adjusted for quality *q* for variety *x* (includes LDP); C = the cottonseed yield for variety *x*; SP = the November average Georgia price received for cottonseed; S = seed cost/ha for variety *x*, technology *y*; H = herbicide costs/ha for technology *y*; I = insecticide costs/ha for technology *y*; A = herbicide and insecticide application costs/ha for technology *y*.

Lint yield and returns above system costs were analyzed using the PROC GLM procedure in the SAS version 9.1.3 statistical software (SAS Institute, Cary, NC). Yield and return data were combined across years and locations where like cultivars were evaluated and no significant cultivar by year or location interaction was observed. In addition, for all situations where data were combined across sites and/or years, a homogeneity of error variance test was conducted (Gomez and Gomez, 1984). When this test was not significant, the overall error term was used to evaluate cultivar differences; if this test indicated a significant difference in error variance between years or locations, the cultivar by year or location term was used to test cultivar differences. In the presence of a significant cultivar by year or location interaction, data are presented separately by year or location. Cultivar means were separated using Fisher's Protected LSD at a $P = 0.05$. Selected contrasts were employed to evaluate net returns of a technology system as a whole (Gomez and Gomez, 1984).

Multiple regression was performed with returns of a cultivar as the dependent variable and lint yield, price received, seed income, seed cost, herbicide cost, insecticide cost, and application costs as the independent variables. The standardized regression coefficients were calculated for each of the independent variables to quantify the magnitude of influence

Table 6. Lint yield, price, seed income, and seed costs, herbicide costs, insecticide costs, application costs, and returns for cotton cultivars, and contrast of returns by technology system, Tifton, 2004.

				Costs					
					Weed control		Pest management		
Cultivar	Lint	Price†	Seed income‡	Seed§	Herbicide	Application	Insecticide	Application¶	Return#
	kg/ha	c/kg	$/kg						
DP555B/R	1188.61a††	131.94	127.90	156.70	84.80	56.93	109.90	9.17	1278.40a
PEARL	1104.36ab	133.94	132.53	43.00	69.88	59.33	143.80	18.33	1274.80a
DP543B2R	1000.17bc	133.36	120.03	168.90	84.80	56.93	109.90	9.17	1026.30b
FM960B2R	929.33cd	134.82	114.65	160.00	84.80	56.93	109.90	9.17	946.50bc
FM966LL	837.81def	135.63	107.60	71.70	55.23	59.33	143.80	18.33	894.70bcd
FM960BR	880.17cde	134.41	117.95	145.80	84.80	56.93	109.90	9.17	891.00bcd
SG215B/R	880.21cde	132.11	115.36	141.60	84.80	56.93	109.90	9.17	875.60bcde
FM981LL	816.05defg	134.23	112.50	70.10	55.23	59.33	143.80	18.33	857.60bcde
DP449BR	822.78def	134.27	110.77	152.40	84.80	56.93	109.90	9.17	804.50bcde
ST5599BR	841.74def	133.13	97.90	152.40	84.80	56.93	109.90	9.17	801.10bcde
FM991BR	801.51defgh	135.37	112.56	143.80	84.80	56.93	109.90	9.17	792.80cde
ST5242BR	788.62defgh	132.28	92.12	152.40	84.80	56.93	109.90	9.17	722.30cdef
DP444BR	774.01efgh	132.44	93.16	152.40	84.80	56.93	109.90	9.17	704.10def
FM991B2R	725.92fgh	134.38	101.34	159.00	84.80	56.93	109.90	9.17	653.20ef
DP424B2R	673.66gh	132.62	99.84	168.90	84.80	56.93	109.90	9.17	563.30f
ST4646B2R	660.42h	127.35	87.13	169.00	84.80	56.93	109.90	9.17	497.60f

Var.	$P > F$
C	<0.0001

Contrast of returns by system

Comparison	Returns	$P > F$
NT vs. BR	1274.81 vs. 858.73	0.0001
NT vs. B2R	1274.81 vs. 737.41	0.0001
NT vs. LL	1274.81 vs. 876.14	0.0002
BR vs. B2R	858.73 vs. 858.73	0.0108
BR vs. LL	858.73 vs. 876.14	0.7805
B2R vs. LL	737.41 vs. 876.14	0.0423

Var.	$P > F$
C	<0.0001

† Price/kg of lint is the November avg. Georgia price/kg adjusted for quality (includes LDP).

‡ Calculated by multiplying the kilograms of seed produced/ha by the November avg. Georgia price received for cottonseed.

§ Seed costs include technology fee assuming a 9.8 seed/m seeding rate.

¶ Application costs for insecticides assume one insect application was made with a plant growth regulator application thus incurring no additional cost.

Net return (R_{xy}) = ($Y_x \times LP_{qx}$) + ($C_x \times SP$) - S_{xy} - H_y - I_y - A_y, where R = the return above system costs for variety x, technology y; Y = lint yield (kg/ha) for variety x; LP = the November avg. Georgia price/kg adjusted for quality q for variety x (includes LDP); C = the cottonseed yield for variety x; SP = the November avg. Georgia price received for cottonseed; S = seed cost/ha for variety x, technology y; H = herbicide costs/ha for technology y; I = insecticide costs/ha for technology y; A = herbicide and insecticide application costs/ha for technology y.

†† Means in a column followed by the same letter are not significantly different (P = 0.05).

of each on net return of a variety (Neter et al., 1996). A variable was dropped from certain analyses to alleviate multicollinearity using standard procedures.

RESULTS AND DISCUSSION

No year by cultivar interactions were noted for yields or returns for the cultivars evaluated in Tifton in 2001 and 2002. Thus the data are presented as a combined analysis for these 2 yr with cultivars listed in order of returns (Table 4). With few exceptions, the rank order of the lint yield and those for returns were the same. Contrast analysis of the systems indicated that the nontransgenic, B, and BR systems provided greater returns than did the RR system. This outcome is consistent with the reduced yields observed with the RR cultivars. There was no difference in returns between the nontransgenic, B, and BR systems. Thus, the B and BR technologies systems reduced production costs only enough to compensate for their respective technology fees. When returns were examined within a system, significant differences were observed between nontransgenic cultivars, but no cultivar differentiations were noted within the B, BR, or RR technologies. The 2001 and 2002 data suggest that selection of an RR technology system would result in reduced returns to the producer. Similar returns, higher than those produced with RR cultivars, could be attained from nontransgenic, B, and BR technologies. However, cultivar selection was important among the nontransgenic cultivars.

No location by cultivar interactions were noted for yields or returns for the cultivars evaluated in Tifton and Midville in 2003. Thus data are presented as a combined analysis for these two locations (Table 5). Cultivars are listed in order of returns. Again, lint yields generally followed returns. Contrast analysis of the systems as a whole indicated that no technology system provided significantly greater returns than did the nontransgenic system. The nontransgenic system provided greater returns than did the RR and B2R technology systems, indicating production costs in these systems were not reduced to levels that could compensate for associated technology fees and differences in yields among production systems. There were no differences in returns between the

Table 7. Lint yield, price, seed income, and seed costs, herbicide costs, insecticide costs, application costs, and returns for cotton cultivars, and contrast of returns by technology system, Midville, 2004.

				Costs					
					Weed control		Pest management		
Cultivar	Lint	Price†	Seed income‡	Seed§	Herbicide	Application	Insecticide	Application¶	Return#
	mg/ha	c/kg	$/kg						
DP555B/R	1791.70a††	134.57	243.20	148.40	128.40	56.46	12.86	0.00	2307.50a
DP449BR	1641.18ab	134.27	273.26	144.40	128.40	56.46	12.86	0.00	2134.50ab
FM960BR	1600.54abc	135.26	276.70	138.10	128.40	56.46	12.86	0.00	2105.50abc
DP424B2R	1527.61bcd	133.98	254.75	160.10	128.40	56.46	12.86	0.00	1945.00bcd
DP543B2R	1462.31bcd	134.27	238.78	160.10	128.40	56.46	12.86	0.00	1844.20bcde
FM960B2R	1436.45cd	135.41	248.08	151.60	128.40	56.46	12.86	0.00	1843.50bcde
FM991BR	1409.65cde	134.30	239.51	136.20	128.40	56.46	12.86	0.00	1798.80cdef
ST5599BR	1461.30bcd	127.27	234.52	144.40	128.40	56.46	12.86	0.00	1763.00defg
PEARL	1402.66cde	134.27	227.58	40.80	186.40	76.77	40.85	9.17	1757.60defgh
FM991B2R	1329.11def	128.63	242.68	150.70	128.40	56.46	12.86	0.00	1605.10efghi
ST5242BR	1206.13efg	134.53	205.56	144.40	128.40	56.46	12.86	0.00	1486.20fghi
ST4646B2R	1223.19efg	132.78	208.99	160.10	128.40	56.46	12.86	0.00	1476.00ghi
SG215B/R	1176.32fg	133.06	203.37	134.20	128.40	56.46	12.86	0.00	1436.50hij
FM966LL	1099.05gh	132.75	193.58	68.00	101.00	56.46	40.85	9.17	1375.90ij
FM981LL	1054.86gh	135.26	200.56	66.40	101.00	56.46	40.85	9.17	1353.30ij
DP444BR	971.61h	135.37	157.53	144.40	128.40	56.46	12.86	0.00	1130.70j

Var.	*P* > *F*
C	<0.0001

Contrast of returns by system

Comparison	Returns	*P* > *F*
NT vs. BR	1757.59 vs. 1754.14	0.8330
NT vs. B2R	1757.59 vs. 1761.82	0.8786
NT vs. LL	1757.59 vs. 1366.90	0.0166
BR vs. B2R	1754.14 vs. 1761.82	0.5141
BR vs. LL	1754.14 vs. 1366.90	0.0005
B2R vs. LL	1761.82 vs. 1366.90	0.0025

Var.	*P* > *F*
C	<0.0001

† Price/kg of lint is the November avg. Georgia price/kg adjusted for quality (includes LDP).

‡ Calculated by multiplying the kilograms of seed produced/ha by the November avg. Georgia price received for cottonseed.

§ Seed costs include technology fee assuming a 9.8 seed/m seeding rate.

¶ Application costs for insecticides assume one insect application was made with a plant growth regulator application thus incurring no additional cost.

\# Net return $(R_{xy}) = (Y_x \times LP_{qx}) + (C_x \times SP) - S_{xy} - H_y - I_y - A_y$, where R = the return above system costs for variety ***x***, technology ***y***; Y = lint yield (kg/ha) for variety ***x***; LP = the November avg. Georgia price/kg adjusted for quality ***q*** for variety ***x*** (includes LDP); C = the cottonseed yield for variety ***x***; SP = the November avg. Georgia price received for cottonseed; S = seed cost/ha for variety ***x***, technology ***y***; H = herbicide costs/ha for technology ***y***; I = insecticide costs/ha for technology ***y***; A = herbicide and insecticide application costs/ha for technology ***y***.

†† Means in a column followed by the same letter are not significantly different (***P*** = 0.05).

nontransgenic, BR, and LL systems. Significant differences were noted for cultivars within the nontransgenic, RR, and BR technology systems. Returns were not different between the two B2R cultivars and only one LL cultivar was evaluated. The 2003 data indicate again that selection of an RR technology system as well as a B2R system would result in reduced returns to the producer. Similar returns could be attained from nontransgenic, B, and BR technologies. However, cultivar selection was important for the nontransgenic and BR cultivars.

In 2004, a significant location by cultivar interaction was noted for both yields and returns, therefore the data from Tifton and Midville are presented in Tables 6 and 7, respectively. In each of these tables, cultivars are listed in order of returns. At both locations, lint yields generally followed return trends. At Tifton, the nontransgenic system provided greater returns than did any other technology system. The B2R system provided lower returns than did the other systems. Returns for the BR and LL systems were intermediate and did not differ. In Midville, there were no differences between the nontransgenic, BR, and B2R systems, and these three systems provided greater returns than did the LL system. Yields with the LL cultivars were low. Significant cultivar differences were noted within the BR and B2R systems in both locations. No differences were noted between the two LL cultivars evaluated in either location, and only one nontransgenic variety was tested. The 2004 data indicate that a nontransgenic cultivar was the superior choice in Tifton, but that similar returns could be attained from nontransgenic, BR, and B2R technologies in Midville. However, cultivar selection was important for the BR and B2R cultivars.

Multiple regression analysis indicated that as lint yield, price, and seed income increased, net returns were positively influenced in all studies (Table 8). As costs associated with seed increased, net returns were negatively influenced. The fact that seed cost, which increases dramatically with trait-enhanced cultivars, did not positively influence returns, suggests that technology system per se did not provide greater returns. The standardized coefficients of these variables indicate that lint yield was the

Table 8. Multiple regression of lint yield, lint price, seed income, seed cost, herbicide cost and application, and insecticide cost and application on net return of a variety.

Variable	Estimate	Prob > |t|	Standardized coefficient
Tifton, 2001 and 2002			
Lint yield	1.32790	<0.0001	0.77271
Lint price	8.74270	<0.0001	0.13913
Seed income	1.04916	<0.0001	0.08764
Seed cost	−0.88985	<0.0001	−0.07552
Herbicide cost	−1.42501	<0.0001	−0.01971
Herbicide application	0.13042	0.6332	0.00297
Insecticide cost	−0.93108	<0.0001	−0.05489
Insecticide application	NA†	NA	NA
Midville and Tifton, 2003			
Lint yield	1.51269	<0.0001	0.89079
Lint price	11.94624	<0.0001	0.22245
Seed income	0.88806	<0.0001	0.09842
Seed cost	−1.05177	<0.0001	−0.15150
Herbicide cost	−0.79154	<0.0001	−0.04822
Herbicide application	−1.62462	<0.0001	−0.02661
Insecticide cost	−1.15119	<0.0001	−0.09633
Insecticide application	−0.76497	0.0997	−0.02797
Tifton, 2004			
Lint yield	1.31703	<0.0001	0.90094
Lint price	8.02788	<0.0001	0.03648
Seed income	1.14824	<0.0001	0.09170
Seed cost	−0.80876	<0.0001	−0.06577
Herbicide cost	−0.48424	0.2635	−0.01046
Herbicide application	−6.71758	0.4319	−0.01347
Insecticide cost	NA	NA	NA
Insecticide application	NA	NA	NA
Midville, 2004			
Lint yield	1.34648	<0.0001	0.92095
Lint price	12.86266	<0.0001	0.09450
Seed income	0.98772	<0.0001	0.09562
Seed cost	−1.01400	<0.0001	−0.09691
Herbicide cost	0.37547	0.18719	0.01770
Herbicide application	−6.81457	0.85625	−0.09276
Insecticide cost	NA	NA	NA
Insecticide application	NA	NA	NA

† NA indicates that either multicollinearity or a biased estimate of this parameter precluded use of the variable in the analysis.

parameter having the greatest impact on net returns of a cultivar.

CONCLUSIONS

Lint and seed yield were consistently linked with increasing profitability in the six systems trials conducted in Georgia. Fiber quality of the lint, quantified as price received per kg of lint, was important in certain years and locations but not to the same degree as yield of lint and seed. Therefore, under current pricing structures, yield potential should be the primary factor evaluated when considering profit potential of a specific cultivar.

When considered as a whole, no transgenic technology system provided greater returns than a nontransgenic system in any year or location. The predictability of pest management and the convenience that growers attribute to the transgenic cultivars implies that they save management time and therefore labor not accounted for in the application costs of insecticides and herbicides. Thus, general use of transgenic cultivars could create savings at a farm enterprise level. One benefit often attributed to transgenic production systems is the ability to farm more hectares with the same number of personnel or farm the same number of hectares with fewer personnel.

The RR system was consistently the worst performer in terms of returns in all years and locations evaluated. Generally, these cultivars expressed lower yields than cultivars from other systems. These data contrast with the observation made by Bryant et al. (2003), who found that high yields and returns could be realized by carefully selecting for yields among the cultivars in all technology systems evaluated. A mixed response was noted for the B2R and LL systems. Differences in yields were found among nontransgenic cultivars and among those possessing the BR and B2R technologies. Cultivars expressing technologies that were recently registered, such as the LL and B2R cultivars, tended to have low yields relative to technologies that had been registered for several years.

Collectively, these results indicated that profitability was most closely associated with yield and not with technology. Similar to the conclusions of Bryant et al. (2003), cultivar selection for profitability must focus on yield potential.

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