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AGRONOMY AND SOILS

Growth and Agronomic Performance of Cotton When Grown in Rotation with Soybean

W.T. Pettigrew*, H.A. Bruns and K.N. Reddy

ABSTRACT

Mid-South United States (US) cotton producers are now rotating cotton (*Gossypium hirsutum* L.) with other crops such as corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.] , in response to economic conditions, rather than growing cotton continuously as was the tradition. This research investigated cotton growth and development, lint yield, and fiber quality when cotton was grown following soybean compared to following cotton. Cotton and soybean were grown in six rotational sequences (CCCC, SSSS, CSCS, CSSC, SCSC, and SCCS) during 2012-2015 at Stoneville, MS. These rotations were imposed in production systems utilizing either transgenic or conventional cultivars, with or without glyphosate in the herbicide regime. Dry matter partitioning, leaf chlorophyll (Chl) concentration, lint yield, and fiber quality data were collected. Years when cotton was grown following soybean, produced cotton plants that were on average 13% taller, intercepted on average 6% more sunlight, and contained 13% greater leaf Chl concentrations compared to plants in continuous cotton. Cotton grown following soybean produced increased yields one of the two years. Fiber quality was not impacted by the different rotation sequences. Cotton grown in a conventional production system was competitive with that grown in a transgenic production system. The yield increase observed when growing cotton in rotation with soybean is possibly due to increased soil N via N-fixation from the prior soybean crop and/or due to altered soil microbial populations favorable to the subsequent cotton crop.

Fluctuating commodity prices and changes in farm program regulations have made it easier and often desirable to shift the planting acreage among different crops in response to changing market conditions. Many traditional Mid-South cotton (*Gossypium hirsutum* L.) hectares have shifted into corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.] production in recent years in response to more favorable market prices for those commodities. Mississippi cotton production has thus declined from nearly 650,000 ha in 2001 ($0.32 per pound lint) to slightly more than 129,000 ha in 2015 ($0.62 per pound lint) (USDA, NASS, 2015). Soybean production in Mississippi increased from 450,000 ha in 2001 to 931,000 ha in 2015 due in part to higher prices paid for harvested seed [($4.39 per bushel ($161 per metric ton) in 2001 to $10.06 per bushel in 2015 ($370 per metric ton)] (USDA, NASS, 2015). The cyclical nature of commodity prices undoubtedly will lead to some of that land shifting back into cotton production in the future.

Evaluating rotations involving multiple crops is not a new concept. Recent studies have documented the impacts of rotating cotton with corn on subsequent crop productivity (Bruns et al., 2007; Pettigrew et al., 2006; Reddy et al., 2006). The rotational yield responses were impacted by shifts in weed populations (Reddy et al., 2006) and suppression of reniform nematode (*Rotylenchulus reniformis* Linford and Oliveira) populations (Stetina et al., 2007) when cotton was grown following corn. These and similar other studies have demonstrated the agronomic benefits derived from implementing some form of rotation with cotton and corn for a particular field.

Similar projects have also been conducted with cotton grown in rotation with soybean, although not as extensive as with corn, grain sorghum (Wesley et al., 2001) or peanuts (Johnson et al., 2001). Inconsistent yield responses have been reported when cotton has been grown following soybean (Bryson et al., 2003; Davis et al., 2003; Mitchell et al., 2008; Rochester et al., 2001; Westphal and Scott, 2005). Rochester et al. (2001) were able to document how N fixed by a prior crop of the leguminous soybean was able to partially fulfill the N needs of a subsequent cotton crop. Certain soybean genotypes are partially resistant to the reniform nematode while other genotypes are susceptible (Westphal and Scott,

W.T. Pettigrew, H.A. Burns, and K.N. Reddy. USDA-ARS, Crop Production Systems Research Unit. P.O. Box 350, Stoneville, MS 38776
*Corresponding author: bill.pettigrew@ars.usda.gov

2005). When cotton was grown following a nematode resistant soybean, the yields were sometimes increased compared to continuous cotton (Davis et al., 2003; Westphal and Scott, 2005) but when cotton followed a susceptible soybean genotype, lint yields were unaffected compared to continuous cotton (Davis et al. 2003). In contrast, cotton grown after grain sorghum or fallow conditions produced yields greater than cotton grown following a susceptible soybean line (Westphal and Scott, 2005). Few of these research efforts have addressed how growth, development, and various physiological components were impacted beyond just how the agronomic yield was affected when cotton is grown after a prior soybean crop.

Although the glyphosate resistance trait in crop plants has been widely adapted by many producers, the development of glyphosate-resistant weeds has made this trait less valuable to many Mid-South producers. About 10 of 35 weeds resistant to glyphosate globally are distributed widely in the mid-southern US. Palmer amaranth (*Amaranthus palmeri* S. Wats.), horseweed [*Conyza canadensis (L.) Cronq.*], and Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] in recent years have become major problems for row crop production across the mid-southern US. Some Mid-south producers are considering planting conventional (non-transgenic) varieties to avoid having to pay a technology fee for a herbicide resistance trait that is ineffective on glyphosate-resistant weeds.

Due to the fact that current soybean acreage could shift back into cotton production during years when market conditions suggest producing cotton would be a more viable and profitable venture, it is important to understand how a cotton plant's growth, physiological development, agronomic yield, and fiber quality are impacted when cotton is grown following soybean. Therefore, the objectives of this research were to examine the growth and development, dry matter partitioning, canopy light interception, leaf chlorophyll concentration, lint yield, yield components, and fiber quality response for cotton when it is grown following a year or two of soybean production. In addition, these cotton-soybean rotation scenarios will be evaluated under both a conventional production system (non-transgenic cultivar and no glyphosate in the herbicide regime) and a transgenic production system (transgenic glyphosate resistant cultivar with glyphosate in the herbicide regime).

MATERIALS AND METHODS

A four-yr cotton-soybean rotation study was conducted from 2012 through 2015 at the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) Crop Production Systems Research Unit farm, Stoneville, MS. The soil is a Dundee silt loam (fine-silty, mixed active, thermic Typic Ochraqualf) and the area was planted to glyphosate-resistant corn in 2011. There were six crop rotation sequences for each glyphosate-resistant (GR) cultivar and non-GR cultivar initiated in the spring of 2012. The rotation sequences were cotton grown continuously for four years (CCCC); soybean grown continuously for four years (SSSS); cotton was grown followed by soybean, followed by cotton, followed by soybean (CSCS); cotton was grown followed by two years of soybean followed by cotton (CSSC); soybean was grown followed by cotton, followed by soybean, followed by cotton (SCSC); and soybean was grown followed by two years of cotton, followed by soybean (SCCS). These rotations were grown under two production systems (conventional and transgenic). Under the conventional production system, conventional (non-transgenic) varieties were grown and glyphosate was not part of the herbicide regime. Under the transgenic production system, transgenic (glyphosate-resistant) varieties were grown and glyphosate was part of the herbicide regime. The transgenic cotton cultivar was DP 1252B2RF (Monsanto Co., St. Louis, MO) and the conventional cultivar was MD 25ne (Meredith and Nokes, 2011). Agronomic information regarding the two cotton cultivars can be found in the 2009 (MD 25ne) and 2012 (DP 1252B2RF) National Cotton Variety Trials (USDA-ARS, 2009 and 2012) Data on DP 1252B2RF were also found in the 2011 Mississippi Cotton Variety Trials (Golden et al., 2012). The soybean cultivar was DK 4744RR (Monsanto Co., St. Louis, MO). Although this was a glyphosate resistant cultivar, it was utilized in both the transgenic and conventional production systems because we were not able to obtain a conventional soybean cultivar. However, in the conventional soybean system, it was treated as a non-transgenic cultivar and the herbicide regime applied to those plots did not contain glyphosate.

Cotton and soybean were planted on 24 April in 2012, 30 April in 2013, 5 May in 2014, and 30 April in 2015. The plots consisted of eight rows with a one-m row spacing and 21.3 m in length. Cotton was seeded at a rate of approximately 110,000 plants ha^{-1}. Nitrogen was applied to the cotton plots shortly after planting at a rate of 112 kg N ha^{-1} each year in 2012, 2013, and 2015. In the year 2014, N application was omitted inadvertently, therefore data from that year will not be presented. Plots were irrigated as needed each year to minimize moisture deficit stress. Approximately 2.5 cm of water was applied with each irrigation event. Two irrigations were applied in 2012, 3 in 2013, 2 in 2014, and 4 in 2015. The plant growth regulator mepiquat chloride was applied at 61 g a.i. ha^{-1} in 2012; 252 g a.i. ha^{-1} in 2013; 98 g a.i. ha^{-1} in 2014; and 196 g a.i. ha^{-1} in 2015 to control plant height and excessive vegetative growth. Insecticides were applied as needed to control any predatory insect infestations that developed.

The experimental area was treated with paraquat at 1.1 kg ai ha^{-1} during the week prior to planting cotton and soybean to kill existing vegetation. Weed management consisted of glyphosate-based program for the transgenic cultivars and a non-glyphosate herbicide-based program for the conventional cultivars. In both crops, pre-emergence herbicides were applied immediately after planting, early post-emergence herbicides were applied four to six weeks after planting, and late post-emergence herbicides were applied six to eight weeks after planting. In both transgenic and conventional cotton, pre-emergence herbicides were fluometuron at 1.12 kg ai ha^{-1} and pendimethalin at 1.12 kg ai ha^{-1}. In transgenic cotton, glyphosate at 0.87 kg ae ha^{-1} followed by glyphosate at 0.87 kg ae ha^{-1} were applied early and late post-emergence, respectively. In conventional cotton, pyrithiobac at 107 g ai ha^{-1} was applied as an early post-emergence and this was followed by trifloxysulfuron at 11.7 g ai ha^{-1} plus prometryn at 1.33 kg ai ha^{-1} or trifloxysulfuron alone at 7.7 g ai ha^{-1} was applied as a late post-emergence treatment. Aside from herbicides, inter-rows of cotton were cultivated on an as needed-basis. In both transgenic and conventional soybean, pre-emergence herbicides were *S*-metolachlor at 1.12 kg ai ha^{-1} and pendimethalin at 1.12 kg ai ha^{-1}. In GR soybean, glyphosate at 0.87 kg ae ha^{-1} was applied as an early post-emergence followed by glyphosate at 0.87 kg ae ha^{-1} as late post-emergence, on an as needed-basis. In conventional soybean, *S*-metolachlor at 1.21 kg ai ha^{-1} plus fomesafen 0.27 kg ai ha^{-1} were applied as early post-emergence. This was followed by chlorimuron at 13.2 g ai ha^{-1} applied as a late post-emergence treatment. Overall, control of weeds by these weed management programs was sufficient to support cotton and soybean production.

Plant dry matter harvests were collected from each cotton plot approximately during the cutout growth phase (slowing or cessation of vegetative growth due to competition for assimilates from reproductive growth) each year. Dry matter harvests were conducted from 83-84 days after planting (DAP) in 2012, 90-92 DAP in 2013, 84-86 DAP in 2014, and 88-90 DAP in 2015. The above ground portion of plants from a 30 cm section of row was harvested from one of the outer plot row avoiding the ends of the row. Plant height and the number of main stem nodes was recorded for each plant. Plants were then separated into leaves, stems and petioles, squares, and blooms and bolls. Leaves were passed through a LI-3100 leaf area meter (LI-COR, Lincoln, NE) to determine leaf area index. The plant component parts were then dried at 60°C for at least 48 h, and the dry weights recorded. Dry weights and leaf area of the leaf samples were used to calculate specific leaf weight (SLW). Harvest index was calculated as follows: reproductive dry weight (squares, blooms, and bolls) / total above ground dry weight.

The percent incoming photosynthetic photon flux density (PPFD) intercepted by the cotton canopies was determined during the same periods as when the dry matter harvests were taken each year. The incoming PPFD intercepted was determined using a LI-190SB point quantum sensor (LI-COR, Lincoln, NE) positioned above the canopy coupled with readings from a LI-191SB line quantum sensor (LI-COR, Lincoln, NE) positioned on the ground perpendicular to and centered on the row. Measurements were collected from two different locations within each plot avoiding the ends of the plot and outside rows, with the average to those two measurements used for all statistical analyses. All measurements were collected between 1230 h and 1500 h CDT with all the above canopy readings $\geq$ 1600 μmol m^{-2} s^{-1}.

Leaf chlorophyll (Chl) concentration was determined for all the cotton plots in 2015 during the period 81 to 86 DAP. Two leaf disks (0.4 cm^{-2} each) were cut from two of the youngest fully expanded, disease-free, fully sunlit leaves per plot. Chlorophyll was extracted from these four leaf disks per plot over a 24 h period in darkness at 30°C in 10 mL of 950 mL L^{-1} ethanol. The Chl concentration in the extract was then quantified spectrophotometrically according to the methods of Holden (1976).

The cotton plots were defoliated during early- to- mid September each year, when approximately 60% of the bolls had already opened. A two-step defoliation process was employed where the first step involved applying a mixture of 0.035 kg thidiazuron ha^{-1} and 0.0175 kg diuron ha^{-1} to the canopy. One week later a second application consisting of 0.035 kg thidiazuron ha^{-1}, 0.0175 kg diuron ha^{-1}, and 1.68 kg ethephon ha^{-1} was made to complete the defoliation and also to open most of the remaining unopened bolls. Approximately two weeks following the second defoliant application, two of the inner plot rows were mechanically harvested with a spindle picker equipped with an automated weighing system. After defoliation, but prior to mechanical harvest, a 50-boll sample was hand harvested from each plot for use in determining the yield components. These boll samples were subsequently ginned on a 10-saw laboratory gin with the lint and seed samples weighed and saved. The lint percentage was determined from these ginned samples and used to calculate the total plot lint yield derived from the combined total of the mechanically harvested and hand harvested seed cotton. Boll mass was calculated from the 50-boll sample by dividing the seed cotton weight of the sample by the number of bolls harvested. The boll mass and total seed cotton weights were used to calculate the number of bolls produced per unit ground area. Average seed mass was determined from 100 non-delinted seeds and reported as weight per individual seed. Lint from each plot was sent to Starlab Inc. (Knoxville, TN) in 2012 and Louisiana State University (LSU) Cotton Fiber Testing Laboratory (Baton Rouge, LA) from 2013 to 2015 for High volume instrument (HVI) fiber quality determination.

The experimental design utilized in the study was a randomized complete block design with a split-plot treatment arrangement. The two production systems were the main plots and the six rotation schemes were the split plots. There were six replicates. Treatments were randomly assigned to the plots the first year of the study (2012) and then the treatments stayed in this original plot location throughout the duration of the study (2013-2015). Statistical analyses were performed by analysis of variance. Means were presented by years because the different rotational schemes meant different crops were grown in individual plots depending upon the year. When statistically significant interactions were not detected, rotational scheme means were averaged across production systems and production system means were averaged across rotational schemes. Overall production systems or rotation scheme means were separated by use of a LSD $P \leq 0.05$.

RESULTS AND DISCUSSION

Climatic conditions varied considerably throughout the duration of this study, resulting in four distinct growing seasons (Table 1). The 2012 growing season was characterized by a drier and warmer planting period whereas 2013 through 2015 exhibited a cooler and wetter planting period. The boll filling periods of July and August were drier in 2013 and 2015 than the other two years. Temperatures were warmer during the boll filling period for 2012 and 2015 compared to 2013 and 2014. Sunlight during the 2012 boll filling period was lower compared to the other three years.

Table 1. Monthly weather summary for 2009 to 2012 at Stoneville, MS.[z]

Month	2012	2013	2014	2015
		Precipitation (cm)		
April	10.6	16.8	24.9	16.1
May	5.2	14.5	15.8	17.7
June	16.2	9.3	14.6	6.5
July	11.6	4.9	12.2	8.1
August	10.9	5.1	7.7	1.9
September	8.3	13.0	2.6	2.0
October	14.7	18.1	17.0	13.9
		Thermal Units[y]		
April	137	73	85	122
May	293	185	205	244
June	316	306	331	349
July	409	324	313	413
August	370	374	350	360
September	264	303	285	309
October	68	114	147	128
		Solar Radiation ($MJ\ m^{-2}$)		
April	638	-	-	481
May	688	635	585	620
June	751	676	671	720
July	700	725	726	721
August	634	695	641	718
September	528	583	549	588
October	462	405	479	478

[z] All observations made by NOAA, Mid-South Agric. Weather Service, and Delta Research and Extension Center Weather, Stoneville, MS.

[y] [(Max. temp + Min. temp.)/2] – 15.

Because corn was grown in the experimental area in 2011 and the study was initiated in 2012, that year was the first year for any of the cotton-soybean rotational schemes to be in place. Therefore, there was no rotation effect measured for any of the dry matter partitioning traits measured in 2012 (Table 2). The minor differences seen in the number of main stem nodes that year were more than likely noise associated with random experimental error that was incurred. In 2013, the rotational schemes that had cotton being grown following soybeans produced bigger cotton plants. On average, the SCSC and SCCS rotational schemes were 13% taller with an 11% greater height to node ratio than the continuous cotton (CCCC). They also intercepted 5% more of the incoming solar radiation that year. Because 2014 was the year when N was inadvertently not applied to the plots, no dry matter partitioning data, or data for the other traits will be presented for that year. Similar results were obtained in 2015. Rotations where cotton grown following soybean the prior year (CSSC and SCSC) were on average 12% taller, with 9% greater height to node ratio, and intercepted 6% more of the incoming solar radiation. It did not matter for these dry matter partitioning traits whether the cotton was grown following one or two years of soybean; the effect was the same.

Differences in growth habit between the two production systems were obvious most years of the study (Table 3). In general, the transgenic production system featuring DP 1252B2RF was more vegetative than the conventional system with MD 25ne, although this was not consistent for all traits and all years. Two of the three years, plant height did not differ between production systems although the transgenic was 17% taller in 2013. In contrast, plants in the transgenic system produced on average 9 % fewer main stem nodes than the conventional system during 2012-2013. The height to node ratio and leaf area index (LAI) were only different in 2013 when the transgenic had 29% and 33% greater values relative to the conventional. The specific leaf weight (SLW) was 9% lower for the transgenic system in 2013 compared to the conventional system, probably due to the increased LAI seen in the transgenic plots that year. Harvest index was the most fairly consistently affected trait by the production systems, with the transgenic plots producing on average a 65% lower harvest index compared to the conventional system for two out of the three years. This reduced harvest index is indicative of the reduced reproductive growth from the transgenic system at that time. We speculate that these production system differences in dry matter partitioning were most likely reflective of true genetic differences and not impacted very much by the different herbicide regimes employed for the two different production systems.

Table 2. Cotton dry matter partitioning and canopy light interception as affected by various crop rotational sequences involving cotton (C) and soybean (S) when grown at Stoneville, MS during the 2012, 2013, and 2015 growing seasons

Year	Rotation Scheme [z]	Plant Height	Main Stem Nodes	Height:Node Ratio	Leaf Area Index	Specific Leaf Weight	Total Dry Weight	Harvest Index [y]	Canopy Light Interception
		cm	nodes plant^{-1}	cm node^{-1}		g m^{-2}	g m^{-2}		%
2012	CCCC	125	21.1	5.93	4.88	45.6	600	0.0583	98.9
	CSCS	133	22.6	5.89	5.57	45.4	668	0.0534	99.1
	CSSC	129	22.6	5.71	6.03	48.1	758	0.0440	99.2
	LSD 0.05	8 (ns) [x]	1.1	0.28 (ns)	1.74 (ns)	5.2 (ns)	175 (ns)	0.0309 (ns)	0.6 (ns)
2013	CCCC	99	19.4	5.16	4.22	53.0	552	0.0261	91.7
	SCSC	115	19.7	5.84	4.81	50.2	624	0.0240	95.7
	SCCS	108	19.2	5.64	4.61	51.7	597	0.0224	96.6
	LSD 0.05	8	0.8 (ns)	0.32	0.81 (ns)	4.2 (ns)	123 (ns)	0.0125 (ns)	3.4
2015	CCCC	90	19.9	4.53	3.91	53.7	629	0.0806	91.4
	SCSC	101	20.6	4.90	4.63	52.4	697	0.0782	97.1
	CSSC	100	20.0	4.98	3.90	51.6	600	0.0729	97.0
	LSD 0.05	10	1.3 (ns)	0.28	0.91 (ns)	4.9 (ns)	120 (ns)	0.0176 (ns)	2.1

[z] Bold letters indicate the crop of a particular rotation sequence for any given year.

[y] Harvest index = Reproductive dry weight / total dry weight.

[x] Not different at the 0.05 level of significance.

Table 3. Cotton dry matter partitioning and canopy light interception as affected by production systems utilizing transgenic or conventional cultivars, with or without glyphosate in the herbicide regime, when grown at Stoneville, MS during the 2012, 2013, and 2015 growing seasons

Year	Production System	Plant Height	Main Stem Nodes	Height:Node Ratio	Leaf Area Index	Specific Leaf Weight	Total Dry Weight	Harvest Index [z]	Canopy Light Interception
		cm	nodes plant^{-1}	cm node^{-1}		g m^{-2}	g m^{-2}		%
2012	Conventional	131	23.1	5.69	4.95	45.7	630	0.0232	98.9
	Transgenic	126	21.0	6.00	6.04	47.1	721	0.0090	99.2
	LSD 0.05	10 (ns) [y]	1.6	0.35 (ns)	1.41 (ns)	4.3 (ns)	186 (ns)	0.0109	0.8 (ns)
2013	Conventional	99	20.4	4.84	3.90	54.1	549	0.0329	93.1
	Transgenic	116	18.5	6.25	5.20	49.1	634	0.0154	96.2
	LSD 0.05	11	0.8	0.40	0.98	3.4	140 (ns)	0.0168	3.2 (ns)
2015	Conventional	99	20.8	4.76	3.91	52.2	683	0.0969	95.3
	Transgenic	95	19.5	4.84	4.38	53.0	601	0.0575	95.0
	LSD 0.05	13 (ns)	1.5 (ns)	0.34 (ns)	0.88 (ns)	7.5 (ns)	130 (ns)	0.0435 (ns)	2.2 (ns)

[z] Harvest index = Reproductive dry weight / total dry weight.

[y] Not different at the 0.05 level of significance.

Leaf chlorophyll (Chl) concentration was only measured in 2015, but it nonetheless revealed some useful information relative to the research (Table 4). The rotational sequence that had cotton grown following two years of soybean (CSSC) had a 13% greater leaf Chl concentration compared to the continuous cotton (CCCC). Cotton grown following one year of soybean had a somewhat intermediate Chl concentration. The increased Chl concentration came from both Chl A and Chl B molecules as there were no rotation scheme differences in the Chl A:B ratios. Neither leaf Chl concentration nor Chl A:B ratios were impacted by varying the production system.

Table 4 Cotton leaf chlorophyll concentration and chlorophyll A:B ratios as affected by various crop rotational sequences involving cotton (C) and soybean (S) when grown at Stoneville, MS during the 2015 growing season

Rotation Scheme [z]	Production System	Chlorophyll Concentration	Chlorophyll A:B Ratio
		mg m^{-2}	
CCCC		390	3.61
SCSC		427	3.60
CSSC		440	3.67
LSD 0.05		38	0.12 (ns) [y]
	Conventional	442	3.72
	Transgenic	396	3.59
	LSD 0.05	83 (ns)	0.22 (ns)

[z] Bold letters indicate the crop of a particular rotation sequence for 2015.

[y] Not different at the 0.05 level of significance.

Lint yields and yield components did not differ among the rotation schemes in 2012, as was expected because all the rotational sequences were in their initial year and each plot was following a corn crop that was grown the prior year (Table 5). Mild weather and light insect infestations in 2013 resulted in exceptional yields that year. There was a significant rotation effect that year. On average, the two rotational sequences where cotton was grown following soybean (SCSC and SCCS) produced yields that were 19% greater than the continuous cotton. An average 26% increase in the number of bolls produced by these rotations was the yield component primarily responsible for the observed yield increase. In contrast, the lint percentage for the rotations SCSC and SCCS was 2% lower than that of the continuous cotton. No significant differences were detected among the rotational sequences for lint yield or any of the yield components in 2015, however.

Production systems produced fairly consistent yield differences throughout the duration of the study (Table 6). For two out of the three years, the conventional production system had lint yields on average about 41% greater than the transgenic production system due to the production of about 28% more bolls compared to the transgenic system. The boll mass, seed mass, and number of seeds per bolls were increased 28%, 20%, and 17%, respectively in the conventional production system contributing to the yield increase observed with the conventional system. In contrast, the lint percentage was decreased 13% and the lint index was 5% lower for the conventional system compared to the transgenic. Similar to the production systems differences in dry matter production, we speculate these differences in lint yield and yield components most likely represent true genetic differences in yield production between the two cultivars, with the differences in herbicide regimes contributing little to the productions system differences.

Table 5. Cotton lint yield and yield components as affected by various crop rotational sequences involving cotton (C) and soybean (S) when grown at Stoneville, MS during the 2012, 2013, and 2015 growing seasons.

Year	Rotation Scheme [z]	Lint Yield	Boll Number	Lint Percentage	Boll Mass	Seed Mass	Seed number	Lint Index
		kg ha^{-1}	bolls m^{-2}	%	g boll^{-1}	mg seed^{-1}	seed boll^{-1}	mg seed^{-1}
2012	CCCC	1103	77.2	41.7	4.00	91	25.5	65
	CSCS	1111	81.7	42.5	3.78	87	24.8	64
	CSSC	1223	81.1	42.7	4.06	94	24.8	70
	LSD 0.05	177 (ns) [y]	13.7 (ns)	1.9 (ns)	0.43 (ns)	6 (ns)	2.0 (ns)	6 (ns)
2013	CCCC	1789	114	42.3	4.37	91	27.8	66
	SCSC	2191	145	41.5	4.28	94	26.5	67
	SCCS	2068	143	41.1	4.12	91	26.6	64
	LSD 0.05	243	17	0.7	0.28 (ns)	4 (ns)	1.8 (ns)	3 (ns)
2015	CCCC	1213	80	42.9	4.14	102	23.2	76
	SCSC	1341	86	42.2	4.34	104	24.1	76
	CSSC	1361	89	42.3	4.26	103	24.0	75
	LSD 0.05	164 (ns)	12 (ns)	0.7 (ns)	0.32 (ns)	4 (ns)	1.6 (ns)	2 (ns)

[z] Bold letters indicate the crop of a particular rotation sequence for any given year.

[y] Not different at the 0.05 level of significance.

Table 6. Cotton lint yield and yield components as affected by production systems utilizing transgenic or conventional cultivars, with or without glyphosate in the herbicide regime, when grown at Stoneville, MS during the 2012, 2013, and 2015 growing seasons.

Year	Production System	Lint Yield	Boll Number	Lint Percentage	Boll Mass	Seed Mass	Seed number	Lint Index
		kg ha^{-1}	bolls m^{-2}	%	g boll^{-1}	mg seed^{-1}	seed boll^{-1}	mg seed^{-1}
2012	Conventional	1549	103.1	39.8	4.49	98	27.3	65
	Transgenic	743	56.9	44.8	3.41	83	22.8	67
	LSD 0.05	310	25.2	1.5	0.35	7	1.6	5 (ns)
2013	Conventional	2146	133.6	39.0	4.80	103	28.6	66
	Transgenic	1886	134.4	44.3	3.71	82	25.3	65
	LSD 0.05	492 (ns) [z]	30.7 (ns)	1.3	0.37	4	1.5	5 (ns)
2015	Conventional	1539	98.8	39.0	4.67	110	25.8	71
	Transgenic	1072	71.2	45.9	3.82	95	21.8	81
	LSD 0.05	303	18.2	0.6	0.26	5	1.3	3

[z] Not different at the 0.05 level of significance.

Few differences were detected among the rotational schemes for any of the fiber quality traits (Table 7). The exception to this generalization occurred in 2013 when one of the rotational sequences that had cotton following soybean that year (SCCS) had an 8% lower fiber micronaire and 1% lower fiber maturity. The other rotational sequence that had cotton grown after soybean that year (SCSC) did not show that effect. These rotational differences in micronaire and fiber maturity seen in 2013 were not seen any other year of the study.

Consistent fiber quality differences were observed between production systems every year of the study (Table 8). Fiber from the conventional production system was 5% longer, with 2% greater uniformity in its length, and a 14% lower short fiber content than fiber from the transgenic system. The fiber strength for the conventional system was 11% greater, but its fiber elongation was 24% lower than that of the transgenic system. Although fiber micronaire was 3% lower for the conventional system in one of the three years compared to the transgenic system, fiber maturity (one of the components of micronaire) was on average 2% greater for the conventional system. These production system differences most likely represent genetic differences in the different cultivars utilized in the different production systems.

Table 7. Cotton fiber quality traits as affected by various crop rotational sequences involving cotton (C) and soybean (S) when grown at Stoneville, MS during the 2012, 2013, and 2015 growing seasons.

Year	Rotation Scheme [z]	Fiber Length	Length Uniformity	Fiber Strength	Fiber Micronaire	Fiber Elongation	Fiber Maturity	Short Fiber Index	Rd	+b
		cm	%	cN tex^{-1}		%	%		%	
2012	CCCC	2.98	84.8	32.6	4.44	6.6	-	-	75.9	7.7
	CSCS	3.01	85.0	33.9	4.13	6.8	-	-	75.5	7.2
	CSSC	3.02	84.9	33.5	4.36	6.7	-	-	75.7	7.7
	LSD 0.05	0.05 (ns) [y]	0.7 (ns)	1.2 (ns)	0.37 (ns)	0.2 (ns)	-	-	1.3 (ns)	0.5 (ns)
2013	CCCC	3.07	84.2	32.5	4.08	7.3	79.8	6.9	-	-
	SCSC	3.05	84.6	32.3	3.98	7.5	79.3	6.8	-	-
	SCCS	3.06	84.4	32.7	3.70	7.2	78.9	7.1	-	-
	LSD 0.05	0.06 (ns)	0.8 (ns)	0.7 (ns)	0.24	0.5 (ns)	0.6	0.5 (ns)	-	-
2015	CCCC	3.09	85.7	32.3	4.69	6.7	81.7	6.2	-	-
	SCSC	3.08	85.7	33.0	4.65	6.5	81.8	6.3	-	-
	CSSC	3.09	86.3	33.3	4.69	6.6	81.7	6.0	-	-
	LSD 0.05	0.06 (ns)	1.1 (ns)	1.2 (ns)	0.19 (ns)	0.5 (ns)	0.5 (ns)	0.4 (ns)	-	-

[z] Bold letters indicate the crop of a particular rotation sequence for any given year.

[y] Not different at the 0.05 level of significance.

Table 8. Cotton fiber quality traits as affected by production systems utilizing transgenic or conventional cultivars, with or without glyphosate in the herbicide regime, when grown at Stoneville, MS during the 2012, 2013, and 2015 growing seasons.

Year	Production System	Fiber Length	Length Uniformity	Fiber Strength	Fiber Micronaire	Fiber Elongation	Fiber Maturity	Short Fiber Index	Rd	+b
		cm	%	cN tex^{-1}		%	%		%	
2012	Conventional	3.06	85.5	36.1	4.38	6.2	-	-	74.5	7.3
	Transgenic	2.95	84.3	30.5	4.23	7.2	-	-	76.9	7.7
	LSD 0.05	0.05	0.6	1.5	0.30 (ns) [z]	0.3	-	-	1.1	0.6 (ns)
2013	Conventional	3.07	85.5	33.5	3.95	6.2	80.2	6.2	-	-
	Transgenic	2.84	83.3	31.5	3.89	8.5	78.5	7.6	-	-
	LSD 0.05	0.08	0.7	0.8	0.20 (ns)	0.5	0.5	0.6	-	-
2015	Conventional	3.14	86.7	34.2	4.60	5.4	82.4	5.9	-	-
	Transgenic	3.03	85.1	31.5	4.76	7.7	80.9	6.4	-	-
	LSD 0.05	0.05	0.9	1.0	0.15	0.4	0.8	0.4	-	-

[z] Not different at the 0.05 level of significance.

Cotton growth, development, and lint yield production clearly benefited when soybean was grown during the season prior to the cotton crop, with the exception of 2015. Statistically significant lint yield increases were observed in one of the two growing seasons when cotton was grown following soybean, and lint yield was numerically greater that second season. Apparently, the cotton grown following soybean benefited from the increased soil N produced via the N-fixation from the leguminous soybean crop grown the previous season. The increased leaf Chl. concentration in 2015 following two years of soybean production also suggests that increased soil N may be playing a role. However, with the exception of 2014, 112 kg N ha^{-1} was applied to the cotton plots each year, which is a recommended rate for cotton production in the Mississippi Delta (McCarty and Funderburg, 1990; McConnell et al., 1993). Multiple researchers across multiple states and locations in the Mid-South have not found a consistent yield increase when cotton was fertilized with N fertilization rates greater than 112 kg N ha^{-1} (Boquet et al., 2004; Main et al., 2013; McConnell et al. 1993; Pettigrew and Adamczk, Jr., 2006). Therefore, in theory, there should have been plenty of N available for optimal yield production for the cotton plots that were grown following cotton, with the exception of 2014. This aspect raises the possibility that something else is going on in cotton grown following soybeans that could also be impacting growth and yield production. Although, we didn't collect any data to quantify it, we speculate that growing a soybean crop for at least one season prior to growing a cotton crop could have affected the soil microbial population such that it produced a more favorable growing environment for that subsequent cotton crop. It is also possible, that the soybean variety utilized in this study could have been a reniform nematode resistant variety. Prior research has documented that growing a resistant soybean variety would reduce the reniform nematode populations and sometimes increase yield in the subsequent cotton crop (Davis et al., 2003; Westphal and Scott, 2005). This hypothetical improved soil microbial and/or soil microfauna population (reduced reniform nematode populations or otherwise) could at least partially help explain better growth and yield response when cotton is grown following soybean.

The data from this research shows that a conventional production system utilizing non-transgenic cotton varieties can be competitive with a transgenic production system utilizing transgenic cotton varieties. Although the conventional system consistently produced greater yields with superior fiber quality than the transgenic system, this aspect was most probably due to the inherent genetic differences between the two varieties rather than the different herbicide regimes utilized for the two production systems. In fairness, the transgenic variety, DP 1252B2RF, did not appear very well adapted to production at the Stoneville, MS location. It was extremely late in maturity, tended to be quite vegetative in nature, and did not set much of a bottom crop. In contrast, the conventional variety, MD 25ne, was very well adapted to the area, which is to be expected since it was bred at the Stoneville experiment station (Meredith and Nokes, 2011). Despite this unequitable pairing of well adapted conventional variety with a less than well adapted transgenic variety within the two production systems, the data from this study indicate that a conventional production system can still be a viable option for cotton producers to consider as a component of their overall production strategies.

In conclusion, when conditions (economic or production) favor the shifting of acreage among crops for a farming operation, this research demonstrates that producers should expect a favorable response when cotton is grown following a prior soybean crop in a field. This improved response could be attributable to increased available soil N or improved soil biota populations because of the prior soybean crop. This research also demonstrates that a conventional production system should remain a viable option for consideration by producers when they formulate their production strategies.

DISCLAIMER

Trade names are necessary to report factually on available data, however, the USDA neither guarantees nor warrants the standard of the product or service, and the use of the name by USDA implies no approval of the product or service to the exclusion of others that may also be suitable.

REFERENCES

Boquet, D.J., R.L. Hutchinson, and G.A. Breitenbeck. 2004. Long-term tillage, cover crop, and nitrogen rate effects on cotton: Yield and fiber properties. Agron. J. 96:1436-1442.

Bruns, H.A., W.T. Pettigrew, W.R. Meredith, Jr., and S.R. Stetina. 2007. Corn yields benefit in rotations with cotton. Crop Management doi:10.1094/CM-2007-0424-01-RS.

Bryson, C.T., K.N. Reddy, and W.T. Molin. 2003. Purple nutsedge (*Cyperus rotundus*) population dynamics in narrow row transgenic cotton (*Gossypium hirsutum*) and soybean (*Glycine max*) rotation. 2003. Weed Tech. 17:805-810.

Davis, R.F., S.R. Koenning, R.G. Kemerait, T.D. Cummings, and W.D. Shurley. 2003. *Rotylenchulus reniformis* management in cotton with crop rotation. J. Nematology 35:58-64.

Golden, B.R., W.E. Clark, N.W. Buehring, S.W. Martin, M.W Shankle, and T.P. Wallace. 2012. Mississippi cotton variety trials, 2011. Information Bulletin 468. Mississippi State Univ., Starkville, MS

Holden, M. 1976. Chlorophylls. p. 1-37. *In* T.W. Goodwin (ed.) Chemistry and biochemistry of plant pigments. Academic Press, New York.

Johnson III, W.C., T.B. Brenneman, S.H. Baker, A.W. Johnson, D.R. Sumner, and B.G. Jullinix, Jr. 2001. Tillage and pest management considerations in a peanut-cotton rotation in the southeastern coastal plain. Agron. J. 93:570-576.

Main, C.L., L.T. Barber, R.K. Boman, K. Chapman, D.M Dodds, S. Duncan, K.L. Edmisten, P. Horn, M.A. Jones, G.D. Morgan, E.R. Norton, S. Osborne, J.R. Whitaker, R.L. Nichols, and K.F. Bronson. 2013. Effects of nitrogen and planting seed size on cotton growth, development, and yield. Agron. J. 105:1853-1859.

McCarty, W.H., and E.R. Funderburg. 1990. Nitrogen recommendations for cotton and how they were developed in Mississippi. p. 43-45. *In* W.N. Miley and D.M. Oosterhuis (ed.) Nitrogen nutrition of cotton: Practical issues. ASA Madison, WI.

McConnell, J.S., W.H. Baker, D.M. Miller, B.S. Frizzell, and J.J Varvil. 1993. Nitrogen fertilization of cotton cultivars of differing maturity. Agron J. 85:1151-1156.

Meredith, W.R., Jr., and W.S. Nokes. 2011. Registration of MD 9ne and MD 25 high-fiber-quality germplasm lines of cotton. J. Plant Registrations 5:202-203.

Mitchell, C.C., D.P. Delaney, and K.S. Balkcom. 2008. A historical summary of Alabama's Old Rotation (circa 1896): The world's oldest continuous cotton experiment. Agron. J. 100:1493-1498.

Pettigrew, W.T., and J.J. Adamczyk, Jr. 2006. Nitrogen fertility and planting date effects on lint yield and Cry1Ac (Bi) endotoxin production. Agron. J. 98:691-697.

Pettigrew, W.T., W.R. Meredith, Jr., H.A. Bruns, and S.R. Stetina. 2006. Effects of a short-term corn rotation on cotton dry matter partitioning, lint yield, and fiber quality production. J. of Cotton Sci. 10:244-251.

Reddy, K.N., M.L. Locke, C.H. Koger, R.M. Zablotowicz, and L.J. Krutz. 2006. Cotton and corn rotation under reduced tillage management: impacts on soil properties, weed control, yield, and net return. Weed Sci. 54:768-774

Rochester, I.J., M.B. Peoples, N.R. Hulugalle, R.R. Gault, and G.A. Constable. 2001. Using legumes to enhance nitrogen fertility and improve soil condition in cotton cropping systems. Field Crops Res. 70:27-41.

Stetina, S.R., L.D. Young, W.T. Pettigrew, and H.A. Bruns. 2007. Effect of corn-cotton rotations on reniform nematode populations and crop yield. Nematropica 37:237-248.

Wesley, R.A., C.D. Elmore, and S.R. Spurlack. Deep tillage and crop rotation effects on cotton, soybean, and grain sorghum on clayey soils. Agron. J. 93:170-178.

Westphal, A., and A.W. Scott, Jr. 2005. Implementation of soybean in cotton cropping systems for management of reniform nematode in south Texas. Crop Sci. 45:233-239

USDA-NASS. 2015. http://www.nass.usda.gov/Statistics_by_State/Mississippi/

USDA-ARS. 2009 and 2012. National Cotton Variety Test. https://www.ars.usda.gov/southeast-area/stoneville-ms/crop-genetics-research/docs/national-cotton-variety-test/ (verified Sept. 30, 2016)