Impact of Starter Fertilizer on Cotton Growth, Development, Lint Yield, and Fiber Quality Production for an Early Planted No-Till System

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Abstract
Improved yield potentials occur when planting cotton (*Gossypium hirsutum* L.) early, but cool conditions associated with early planting can hamper seedling growth. Starter fertilizers could be a source of P for seedling growth under cool conditions due to reduced soil P mineralization. The objective was to document how cotton cultivars responded to starter fertilizer application when planted early in a no-till production system. Seven cultivars were grown no-till during 2008 through 2010. Plots received an in-furrow starter fertilizer application or were untreated. Dry matter partitioning, light interception, lint yield, and fiber quality data were collected. Stands were reduced 20% by the starter fertilizer. Few growth differences were detected by treated and untreated plots although the starter fertilizer did elicit a single 17% increase in the blooming rate at 90 days after planting in 2009. Despite the lack of growth differences and the reduced stands, starter fertilizer increased yields 4% in 2 of the 3 yr. Few consistent fiber quality differences were detected between the fertility treatments. Starter fertilizer application can produce a modest yield improvement when used in an early planting no-till cotton production system. Producers must decide whether this modest yield boost is economically sufficient to justify the additional input costs.

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Abbreviations: AFIS, Advanced Fiber Information System; DAP, days after planting; HVI, high volume instrument; LAI, leaf area index; NAWB, nodes above white bloom; PPFD, photosynthetic photon flux density.

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INTRODUCTION

PROFIT MARGINS for cotton producers have continued to be squeezed by ever increasing input costs and the lack of consistent price appreciation for lint. As a result, acreage devoted to cotton production in Mississippi has declined from over 648,000 ha in 2001 to just over 149,000 ha in 2011 (16). Helping to fuel this acreage shift has been the considerable appreciation in prices offered for maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.], such that producers are now growing maize and soybean on what has historically been land devoted to continuous cotton production in the Mississippi Delta.

Addressing this profit squeeze is a matter of survival for most of the remaining cotton producers. Some producers are now considering adoption of conservation tillage both as a means of reducing inputs (i.e., fewer trips across the field) and in response to a diminishing labor supply. However, there can be challenges after initially converting from a conventional tillage to a conservation tillage production system (11). An alternative strategy some producers have adopted instead of reducing input costs is to increase the yield production side of the profit equation by planting earlier than has traditionally occurred to minimize exposure to late-season stresses. Cotton yields have previously been documented to benefit from early planting in the Mississippi Delta (9). Pairing early planting with conservation tillage would seem to be a reasonable approach for maximizing profit potential. However, even though no planting date × tillage system interactions were detected, minimum tillage reduced lint yield during 2 yr of a 4-yr study (12).

Although input reductions still make conservation tillage a viable production consideration, the yield penalty sometimes associated with conservation tillage in the Mississippi Delta is an important problem. This issue could be further exacerbated when the crop is planted early. The challenge with early planting is consistently achieving an adequate stand because of the cool and possibly wet conditions that can often be encountered when planting during this time frame (2). The reduced soil preparation that comes with conservation tillage can also delay soil warming and further complicate seed germination and stand establishment.

Starter fertilizer use in cotton has also been investigated across the southeastern United States with yield increases usually occurring when cool conditions persist after planting (1,6). These starter fertilizers are usually an ammonium polyphosphate solution providing supplemental N and P to the seedlings. Phosphorus-containing starter fertilizer solutions are good P sources for cool conditions during seedling growth because of the reduced soil P mineralization under cool conditions (1). Even though cool soil conditions are often associated with no-till conditions, Hutchinson and Howard (4) found no differences between no-till and conventional tillage systems in response to starter fertilizer. The yield response to starter fertilizer was inconsistent regardless of the tillage treatment. In addition, Guthrie (5) reported no interaction between planting dates and fertilizer treatments in North Carolina; the side-banded starter fertilizer treatment increased yields regardless of planting date. Nonetheless, because cool and damp soil conditions can occur under both conservation tillage and early planted conditions, it would appear to be a logical assumption that a starter fertilizer application could provide a yield boost when paired with conservation tillage and early planting.

At this point, it is not well understood how cotton would respond to starter fertilization when it is planted early and into a conservation tillage system. In addition, few of these prior cotton starter fertilizer studies looked at multiple cultivars. Therefore, the objectives of this research were to investigate how starter fertilization impacted cotton growth and development, lint yield, yield components, and fiber quality when planted early into conservation tillage systems.

Evaluations in Early Planted Cotton

Field Experiments

A 3-yr field study was conducted at Stoneville, MS, during the 2008 through 2010 growing seasons on a Dubbs silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs) soil. No-till cotton was grown on the experimental area during the growing season immediately before the initiation of the study. After that crop was harvested, wheat (*Triticum* spp.) was seeded into the experimental area as a cover crop during the autumn before the initiation of the study and each subsequent autumn thereafter following cotton harvest. The wheat was terminated with glyphosate (2.45 kg a.i. ha^{-1}) in late February or early March each season to allow for sufficient dry down of the plant material before cotton planting. Also before planting each spring, 100 kg N ha^{-1} were applied to the experimental area as a urea–ammonium nitrate solution by injecting into the soil on both sides of each old row. Preplant soil samples were collected each season and analyzed for soil concentrations of various important plant nutrients. None of the nutrients assayed were at levels considered to be deficient or limiting for cotton production for any year of the study.

Each season seven cotton cultivars were planted into the wheat stubble using a no-tillage planting planter. The cotton cultivars planted were 'DPL 445BR', 'DPL 555BR', 'FM 840B2RF', 'FM 960BR', 'PHY 485WRF', 'ST 4554B2RF', and 'ST 5599BR'. Plots were planted on 28 Mar. 2008, 7 Apr. 2009, and 5 Apr. 2010 using a seeding rate of approximately 100,000 seeds ha^{-1}. During planting, half the plots received an in-furrow liquid application of 11–37–0 ammonium polyphosphate solution at the rate of 28 L ha^{-1} in a 93 L ha^{-1} volume (plus starter) while the remaining plots did not receive the fertilizer (no starter). This fertility treatment delivered 4.4 kg N ha^{-1} and 6.5 kg P ha^{-1} in furrow as a starter fertilizer treatment. Also applied in furrow during planting were 0.84 kg aldicarb ha^{-1}, 0.056 kg mefenoxam ha^{-1}, and 1.12 kg pentachloronitrobenzene ha^{-1} to suppress seedling disease infections and early season insect infestations. Weeds were controlled each season with two postemergence applications of glyphosate (2.12 kg a.i. ha^{-1} total). The first application was broadcast applied before the development of the fourth true leaf and the second was applied between the rows using a hooded sprayer. Furrow irrigations were applied as needed each growing season to minimize moisture deficit stress. Recommended insect control measures were used throughout each growing season as needed.

Plots consisted of four rows 18.3 m long with a 1-m row spacing. The experimental design used was randomized complete block design with the cultivars and starter fertility treatments arranged factorially. Six replications were used each year.

Data Collection

Dry matter harvests were performed during the transition between early squaring to early bloom each year. Dry matter harvests were conducted at 67 to 69 days after planting (DAP) in 2008, 62 to 64 DAP in 2009, and 63 to 65 DAP in 2010. The aboveground portions of plants from 0.3 m of row from one of the outer plot rows were harvested. Plant heights and the number of main stem nodes were recorded before separating the plants into the component parts of leaves, stems and petioles, squares, and blooms and bolls. The leaves were passed through a LI-3100 leaf area meter (LI-COR, Lincoln, NE) to determine leaf area index (LAI). All plant part samples were dried for at least 48 h at 60°C and the dry weights recorded. Dry weights and leaf areas of the leaf samples were used to calculate specific leaf weights. Harvest index was calculated as the ratio of reproductive dry weight:total dry weight.

Leaf area index was also determined nondestructively by use of the LAI-2000 plant canopy analyzer (LI-COR). Detailed methodologies used in quantifying LAI with the LAI-2000 have been previously discussed (10). All readings were taken between 0800 to 1000 h. A total of 16 readings were collected throughout the entire plot area of each plot. In 2008, readings were collected between 80 through 84 DAP. In 2009, readings were collected from 97 through 101 DAP and also from 111 through 115 DAP. Finally, readings were collected from 98 through 102 DAP and again from 112 through 116 DAP in 2010.

Canopy interception of the incoming photosynthetic photon flux density (PPFD) was quantified with a LI 190SB point quantum sensor (LI-COR) positioned above the canopy and a 1-m-long LI 191SB line quantum sensor placed on the ground perpendicular to and centered on one of the inner plot rows. All measurements were collected between 1230 and 1300 h with all the above-canopy PPFD readings ≥1700 $\mu mol\ m^{-2}\ s^{-1}$. Two measurements were collected per plot with the average of the two measurements used for statistical proposes. Readings were collected on 76 and 95 DAP in 2008, 63 and 107 DAP in 2009, and 63, 94, and 107 DAP in 2010.

The number of white blooms (blooms at anthesis) produced per plot was counted on a weekly basis beginning with the onset of early blooming. These counts were continued until the rate of blooming had essentially ceased. Counts were taken on a 6.1-m section of row from one of the inner plot rows, avoiding the ends. The number of main stem nodes above a sympodial branch with a white bloom occupying the first branch fruiting position (nodes above white bloom [NAWB]) were also determined weekly on three randomly selected plants per plot.

A mixture of tribufos and ethephon was used to defoliate the crop and open the remaining unopened bolls. Defoliation was initiated when approximately 65% of the bolls had opened, usually early September. Approximately 2 wk after defoliation, a 50-boll sample was hand harvested from one of the inner plot rows. The boll sample was initiated on a randomly selected plant, harvesting all the bolls on that plant before moving to the next adjacent plant until 50 bolls had been collected. Following the boll sample harvest, seed cotton from the two inner plots row of each plot was mechanically harvested using a spindle picker equipped with an automatic weighing system. Boll mass was determined by dividing the seed cotton weight of the 50 boll sample by the number of bolls harvested in the sample. The 50 boll sample was ginned on a 10-saw laboratory gin to determine the lint percentage of each plot, which was used to calculate lint yield from the mechanically harvested seed cotton. The number of bolls produced per unit ground area was calculated using the boll mass and total seed cotton weights from each plot. Seed mass was determined from 100 nonacid delinted seeds per sample and reported as weight per individual seed.

A sample of the lint from each plot was sent to Starlab Inc. (Knoxville, TN) for fiber quality analysis. Fiber quality on that sample was quantified by high volume instrument (HVI). An additional sample of lint was subjected to fiber quality analyses by the Advanced Fiber Information System (AFIS) (Zellweger Uster Inc., Knoxville, TN).

Statistical Analyses

Data were analyzed statistically by using analysis of variance (PROC MIXED; SAS; SAS Institute Inc., Cary, NC) (13). When statistically significant interactions were not detected, fertility treatment means were averaged across cultivars and cultivars were averaged across fertility treatments. Means were separated by a protected LSD at the $P \leq 0.05$ level.

Growth Response to Starter Fertilizer

The 3 yr during which this study was conducted presented three distinct growing environments with which to test the hypothesis that starter fertilizer would provide a benefit when cotton was planted early under no-till conditions (Table 1). The 2008 growing season was characterized by a dry June and July but was unusually wet during August and September. May and July were excessively wet during 2009 while June was dry. In contrast, 2010 was hot and dry throughout almost the entire growing season.

Stand counts of surviving plants were collected each year approximately 30 DAP. Application of the starter fertilizer in the furrow reduced the stand counts of viable plants per unit area by an average of 21% (Table 2). However, this reduced population density associated with the starter fertilizer use still fell within an optimal population density for cotton (3,10). This reduction in stand establishment has previously been reported (14) and is most likely due to the toxic effects the free ammonia released from the fertilizer has on the seedlings.

Statistical analyses indicate that there were no significant interactions between fertility treatments and cultivars. Therefore, the fertility treatment main effects for most traits were averaged across cultivars and presented by years. Cultivar main effects were presented

Table 1. Monthly weather summary for 2008 through 2010 at Stoneville, MS.[y]

Month	2008	2009	2010
Precipitation, cm			
April	20.3	7.54	6.0
May	17.5	34.3	13.4
June	1.1	0.7	3.1
July	4.2	22.2	4.8
August	15.3	3.6	0.6
September	30.9	12.9	5.4
October	4.8	39.4	4.5
Thermal units[z]			
April	89	92	124
May	211	203	273
June	348	363	401
July	400	342	412
August	338	340	458
September	245	265	315
October	103	64	129
Solar radiation, MJ m^{-2}			
April	550	602	–
May	668	547	681
June	731	759	743
July	781	663	710
August	550	656	667
September	485	442	609
October	478	317	566

[y]All observations made by National Oceanic and Atmospheric Administration, Mid-South Agricultural Weather Service, and Delta Research and Extension Center Weather, Stoneville, MS (8).

[z][(maximum temperature + minimum temperature)/2] – 15.

Table 2. Cotton stand counts collected approximately 1 month after planting each year as affected by the use (Plus Starter) or nonuse (No Starter) of starter fertilizer for the years 2008 through 2010. Fertility treatment means were averaged across seven cotton cultivars.

Fertility treatment	2008	2009	2010
	plants m^{-2}		
No Starter	8.5	9.3	7.9
Plus Starter	6.7	6.5	7.0
LSD 0.05	0.5	0.5	0.3

averaged across fertility treatments and years due to the lack of significant interactions with either fertility treatments or years.

For insight into how a starter fertilizer application might impact early season growth, dry matter partitioning data was collected during the transition period between early squaring and early bloom. These data revealed few growth differences between the two fertility treatments (Table 3). Neither plant height, the number of main stem nodes, LAI, or total aboveground dry weight were impacted any year when starter fertilizer was applied compared to plots that did not receive starter fertilizer. Specific leaf weight was increased 3% when starter fertilizer was applied in 2009 but not in 2008 or 2010. Similarly, only a few differences were detected between the fertility treatments for nondestructive LAI and canopy solar radiation interception (data not shown). One of those differences was a 9% early season LAI reduction when starter fertilizer was applied in 2008, possibly due to the stand reduction associated with starter fertilizer. The other difference found the starter fertilizer canopies intercepting slightly more mid-season sunlight than the untreated in 2009.

Few differences between the fertility treatments were detected any year of the study in either the blooming rate or the rate of canopy maturation (NAWB) (Fig. 1 and 2). In 2008 no differences whatsoever were detected between the fertility treatments for either blooming rate or NAWB. At 90 DAP in 2009, the plots receiving starter fertilizer exhibited a 17% greater blooming rate than the nonfertilized, but that difference was not observed on any of the other measurement dates (Fig. 1). Similarly, the starter fertilizer plots had a 4% lower NAWB count at 99 DAP in 2009, but no fertilizer treatment differences were observed on any of the other dates that year (Fig. 2). It is easy to envision how the slight increase in the blooming rate at 90 DAP in 2009 noted when starter fertilizer was applied could have also advanced the white bloom progression up the main stem enough to generate the slight decrease in NAWB observed at 99 DAP with the starter fertilizer plots.

Table 3. Cotton dry matter partitioning data as affected by the use (Plus Starter) or nonuse (No Starter) of starter fertilizer for the years 2008 through 2010. Fertility treatment means were averaged across seven cotton cultivars.

Year	Fertility treatment	Height	Main stem nodes	Leaf area index	Specific leaf weight	Total dry weight
		inches	nodes $plant^{-1}$		g m^{-2}	g m^{-2}
2008	No Starter	6.8	7.8	0.25	59.1	20.5
	Plus Starter	7.0	8.0	0.25	61.8	22.3
	LSD 0.05	0.4 (ns)[z]	0.2 (ns)	0.04 (ns)	4.0 (ns)	2.8 (ns)
2009	No Starter	5.7	7.6	0.18	63.1	15.2
	Plus Starter	5.5	7.9	0.16	65.3	14.3
	LSD 0.05	0.4 (ns)	0.4 (ns)	0.03 (ns)	1.6	2.5 (ns)
2010	No Starter	18.7	13.8	1.40	52.4	140.1
	Plus Starter	19.0	13.8	1.52	51.5	150.4
	LSD 0.05	0.8 (ns)	0.5 (ns)	0.16 (ns)	1.3 (ns)	17.2 (ns)

[z]ns, not significantly different at the 0.05 level of significance.

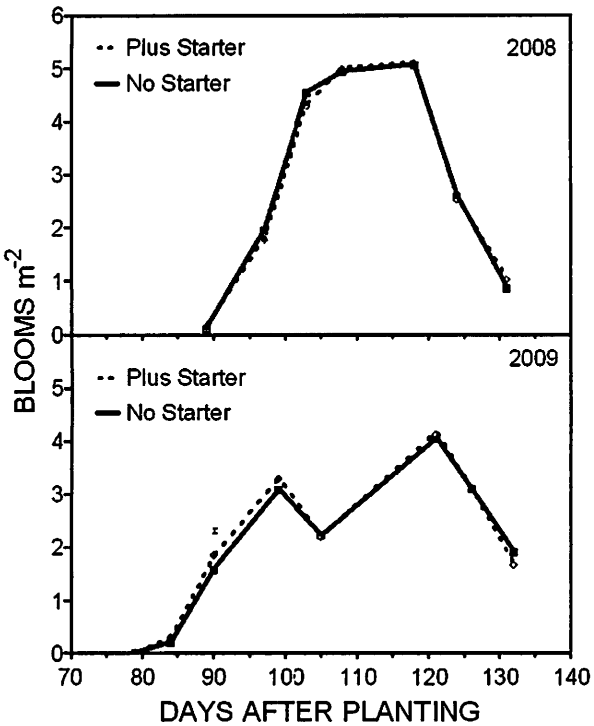

Figure 1. White blooms (blooms at anthesis) m^{-2} of ground area at various times throughout the 2008 and 2009 growing seasons as impacted by starter fertilizer application (Plus Starter) or the lack of starter fertilizer application (No Starter). Vertical bars denote LSD values at the 0.05 level and are present only when the fertility treatment means for that date are statistically different at the 0.05 level.

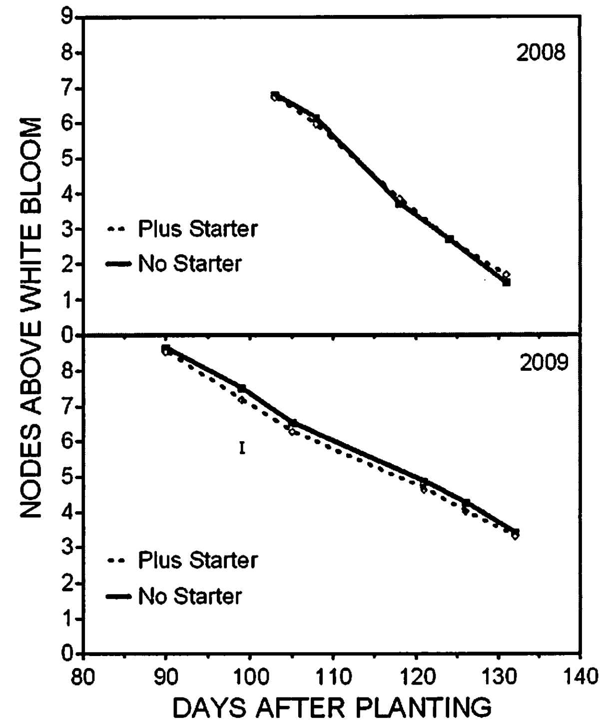

Figure 2. Number of main stem nodes of cotton above a sympodial branch with a first position white bloom (blooms at anthesis) at various times throughout the 2008 and 2009 growing seasons as impacted starter fertilizer application (Plus Starter) or the lack of starter fertilizer application (No Starter). Vertical bars denote LSD values at the 0.05 level and are present only when the fertility treatment means for that date are statistically different at the 0.05 level.

Yield Response to Starter Fertilizer

Despite the few growth and development impacts observed from starter fertilizer application, cotton responded to the starter fertilizer with significant yield increases 2 out of the 3 yr. Lint yields were increased 4% in both 2008 and 2009 by the starter fertilizer application (Table 4). Although not statistically different, yields from plots receiving starter fertilizer were also numerically higher in 2010. The 2008 yield increase was caused by the starter fertilizer producing 5% more bolls than the nonfertilized plots. On the other hand, no fertility differences were observed for boll production in 2009, but plants receiving the starter fertilizer had a 4% greater lint index. None of the other yield components differed between fertility treatments any year of the study.

Cultivar differences were detected in lint yield and each yield component (data not shown), indicating a wide range of cultivar types was used. This group of cultivars also exhibited considerable fiber quality differences, regardless of whether the quality was quantified by HVI or AFIS methodology (data not shown). Despite this diversity of cultivars, none of them responded differently to starter fertilizer application in terms of the either the quantity or quality of the fiber produced.

Fiber Quality Response to Starter Fertilizer

Similar to most of the other traits monitored, few (HVI) fiber quality traits were impacted by the starter fertilizer application (Table 5). None of the HVI traits were impacted by the varying fertility treatments in 2008, but in 2009 the starter fertilizer treatment increased fiber elongation by 2%. Application of starter fertilizer also increased fiber strength (2%) and fiber length (1%) in 2010 but decreased the color grade component +b (degree of yellowness for the fiber) by 2%. Even though these few fiber quality differences were statistically significant, they were quite small and would not elicit either a premium or discount value assigned to the fiber price received when compared to the fiber from the untreated plots.

Advanced Fiber Information System fiber quality traits were not affected by the fertility treatments during 2 of the 3 yr (2008 and 2010) (Table 6). However, in 2009, starter fertilizer decreased the production of fiber neps 9% and seed coat fragments 22%. In addition, fiber fineness and the fiber maturity ratio were both increased 2% by starter fertilizer application in 2009. These fineness and fiber maturity differences observed in response to the starter fertilizer in 2009 were not reflected in a significant fertilizer response to micronaire, however. Micronaire is composed from components of both fiber fineness and fiber maturity (7).

Table 4. Cotton lint yield and yield components as affected by the use (Plus Starter) or nonuse (No Starter) of starter fertilizer for the years 2008 through 2010. Fertility treatment means were averaged across seven cotton cultivars.

Year	Fertility treatment	Lint yield	Boll number	Boll mass	Lint percent	Seed mass	Seed number	Lint index
		pound acre^{-1}	bolls m^{-2}	g boll^{-1}	%	mg seed^{-1}	seed boll^{-1}	mg seed^{-1}
2008	No Starter	1341	81	4.23	44.6	95	25	76
	Plus Starter	1391	85	4.24	44.2	96	25	76
	LSD 0.05	39	4	0.14 (ns)[z]	0.5 (ns)	2 (ns)	1 (ns)	2 (ns)
2009	No Starter	1192	75	4.39	41.6	96	27	68
	Plus Starter	1242	74	4.51	42.0	98	27	71
	LSD 0.05	38	4 (ns)	0.13 (ns)	0.5 (ns)	2 (ns)	1 (ns)	2
2010	No Starter	1123	75	4.03	42.2	96	24	70
	Plus Starter	1135	75	4.10	41.9	98	24	70
	LSD 0.05	35 (ns)	4 (ns)	0.14 (ns)	0.4 (ns)	3 (ns)	1 (ns)	2 (ns)

[z]ns, not significantly different at the 0.05 level of significance.

Table 5. High volume instrument fiber quality as affected by the use (Plus Starter) or nonuse (No Starter) of starter fertilizer for the years 2008 through 2010. Fertility treatment means were averaged across seven cotton cultivars.

Year	Fertility treatment	Fiber strength	Fiber length	Length uniformity	Fiber elongation	Fiber micronaire	Rd[x]	+b[y]
		cN per tex[w]	inches	%	%			
2008	No Starter	30.8	1.12	83.9	6.6	4.9	69.5	7.9
	Plus Starter	30.7	1.13	84.0	6.6	4.9	69.6	7.9
	LSD 0.05	0.7 (ns)[z]	0.01 (ns)	0.4 (ns)	0.1 (ns)	0.3 (ns)	1.2 (ns)	0.2 (ns)
2009	No Starter	28.1	1.15	84.5	6.6	4.4	70.8	8.2
	Plus Starter	28.5	1.15	84.8	6.7	4.5	70.5	8.2
	LSD 0.05	0.6 (ns)	0.01 (ns)	0.3 (ns)	0.1	0.1 (ns)	0.7 (ns)	0.2 (ns)
2010	No Starter	28.8	1.14	83.8	7.1	4.5	74.9	8.2
	Plus Starter	29.5	1.15	84.0	7.1	4.6	74.4	8.0
	LSD 0.05	0.6	0.01	0.3 (ns)	0.2 (ns)	0.1 (ns)	0.8 (ns)	0.2

[w]tex, fiber linear density in grams per kilometer of fiber.

[x]Rd, degree of reflectance.

[y]+b, degree of yellowness.

[z]ns, not significantly different at the 0.05 level of significance.

Table 6. Advanced Fiber Information System fiber quality as affected by the use (Plus Starter) or nonuse (No Starter) of starter fertilizer for the years 2008 through 2010. Fertility treatment means were averaged across seven cotton cultivars.

Year	Fertility treatment	Fiber neps	Seed coat fragments	Short fiber content	Fiber fineness	Fiber maturity ratio
		number g^{-1}	number g^{-1}	% weight	millitex[y]	
2008	No Starter	96	5.0	6.2	179	0.96
	Plus Starter	99	4.1	6.5	178	0.95
	LSD 0.05	10 (ns)[z]	1.4 (ns)	0.5 (ns)	2 (ns)	0.01 (ns)
2009	No Starter	115	4.6	6.3	172	0.93
	Plus Starter	105	3.6	6.0	175	0.95
	LSD 0.05	9	0.9	0.5 (ns)	2	0.01
2010	No Starter	129	3.7	6.8	175	0.91
	Plus Starter	123	3.0	6.5	175	0.91
	LSD 0.05	13 (ns)	0.9 (ns)	0.5 (ns)	3 (ns)	0.01 (ns)

[y]millitex, fiber linear density in micrograms per meter of fiber.

[z]ns, not significantly different at the 0.05 level of significance.

CONCLUSION

The most consistent response observed from the starter fertilizer application was the reduced surviving plant population density relative to that of the untreated, but that density still fell within an acceptable range (3,10). Despite the lower population density, the starter fertilizer treated plots still produced higher yields in 2 of the 3 yr during this study compared to the untreated. However, none of the growth and development parameters that we monitored during the course of this research could consistently offer explanations for the increased yield. Although they were statistically significant, the observed lint yield increases were small and one could make an argument that that they were not economically relevant. The small but consistent stand reduction that occurred when starter fertilizer was applied in the furrow complicates this strategy and must also be considered. Producers could also use an alternative placement of the starter fertilizer to minimize seedling lose rather than placing the fertilizer in the furrow. Others have reported yield improvements when the starter fertilizer was placed 5 cm to the side and 5 cm below the seed without the stand reduction issues (14,15). However, this method of fertilizer placement is not as convenient as in-furrow placement because it can require specialized equipment or modification of the planter. In addition, the cost of this equipment or modification must be recovered before this placement method becomes economical.

Because of the added seed or equipment costs that may be associated with this production technique, it is questionable whether this approach will would consistently return profits for most Mississippi Delta cotton producers. For those producers who decide that a starter fertilizer application would be an economically justifiable input to add to their production strategies, it does not appear to matter which cotton cultivars paired with the starter fertilizer. All the cultivars we tested responded similarly to starter fertilizer.

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