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SOILS

Fertilizer Additive Rate and Plant Growth Regulator Effects on Cotton

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INTERPRETIVE SUMMARY

Cotton producers use products intended to enhance plant growth and yields. However, research data concerning the effect of fertilizer additives or plant growth regulators on cotton is limited and, in many instances, conflicting. Previous research indicates inconsistent plant response to some plant growth regulators applied either in-furrow at planting or foliar-applied at pinhead or bloom. Although plant response also is inconsistent with in-furrow fertilizer applications, research data indicate in-furrow fertilizer applications appear to be more effective than plant growth regulators. The present research evaluated selected rates of Asset™ RTU[1] applied in-furrow and compared them to PGR-IV, a low rate of ammonium polyphosphate (11-37-0), and Asset® for cotton produced in disk-tillage and no-tillage production systems.

Conservation tillage production systems are recommended for cotton production on highly erosive soils. The residues and/or winter covers normally used for erosion control affect the soil environment by restricting water evaporation and reducing soil temperatures - conditions that tend to reduce seed germination, plant vigor, and root growth and possibly increase pathogen activity. Two commercial products reported to improve root growth-PGR-IV and Asset RTU-were evaluated for cotton produced in disk- and no-tillage systems.

Field research was conducted from 1995 through 1997 on a Loring silt loam (Typic Fragiudalf) at the Milan Experiment Station, TN. In-furrow treatments at planting consisted of (i) 11-37-0 applied at 32 oz acre^{-1}; (ii) Asset plus 11-37-0 applied at 2 and 32 oz acre^{-1}, respectively; (iii) Asset RTU (6-20-5) applied at 16, (iv) 24, and (v) 32 oz acre^{-1}, respectively; (vi) PGR-IV applied at 1 oz acre^{-1} followed by foliar application of 4 oz acre^{-1} at pinhead square and repeated in 7 d; (vii) a nontreated check. Plots were fertilized with 80, 40, and 60 lb acre^{-1} of N, P_2O_5, and K_2O, respectively, using ammonium nitrate, concentrated superphosphate, and potassium chloride. These seven treatments were applied to cotton produced from disk-till and no-till production systems. Soil samples were collected from three sampling positions relative to the row (0, 10, and 20 cm) and three soil depths (0 to 10, 10 to 20, and 20 to 30 cm) to evaluate the effect of three treatments (Asset RTU applied at 16 and 24 oz acre^{-1} PGR-IV) and check on root growth. Soil samples were collected at pinhead square and again 21 d later.

Measurements used to evaluate treatment effects included plant height, leaf surface area, plant populations, early root development, and yield. Root length and yield were the only responses affected by in-furrow treatments applied to cotton produced in either tillage system. Compared with the disk-till check yield, in-furrow application of Asset RTU at 24 and 32 oz acre^{-1} increased first-harvest yields. Total yields were increased by Asset RTU applied at 24 and 32 oz acre^{-1} and PGR-IV. Relative to the check, first-harvest yields were increased 93 and 111 lb acre^{-1}, while total yields were 92, 125, and 60 lb acre^{-1} for the three treatments, respectively. First-harvest, no-till yields were increased 109, 110, and 157 lb acre^{-1} higher than the check, while total lint yields were increased 87, 111, and 154 lb acre^{-1} from application of 11-37-0 and Asset RTU at 24 and 32 oz acre^{-1}, respectively.

Although the treatment effects on disk- and no-till cotton differed slightly, in-furrow

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[1] The use of trade names in this publication is for clarity and does not imply approval of the product to the exclusion of others which may be of similar suitable composition, nor does it guarantee or warrant the standard of the product.

applications of Asset RTU at 24 and 32 oz acre^{-1} were consistent for increasing yields produced in both tillage systems. Treatment effect on root growth was inconsistent, but one or more of the three in-furrow treatments increased root lengths at both growth stages. These results varied with sampling position, soil depth, and year. For roots collected at pinhead square plus 21 d, Asset RTU applied at 24 oz acre^{-1} was the most consistent treatment for increasing root length.

ABSTRACT

In-furrow applications of plant growth regulators (PGRs) and starter fertilizers have been used to improve cotton *(Gossypium hirsutum* L.) yields. Information about the effects of plant growth regulators and fertilizer additives on cotton production is limited. Field research was conducted from 1995 through 1997 on a Loring silt loam (fine-silty, mixed, thermic, Typic Fragiudalf) to evaluate two commercial products, Asset RTU and PGR-IV, for cotton growth. The experimental design was a randomized complete block (RCB) with treatments replicated five times. In-furrow treatments at planting included ammonium polyphosphate (11-16-0) applied at 2.33 L ha^{-1}; Asset plus 11-16-0 applied at 0.15 and 2.33 L ha^{-1}, respectively; Asset RTU applied at 1.17, 1.75, and 2.33 L ha^{-1}; PGR-IV applied at 0.07 L ha^{-1} followed by two foliar applications of 0.28 L ha^{-1}; and a check. Treatments were applied to disk- and no-till-produced cotton. Soil samples were collected from three positions (0, 10, and 20 cm) from the row and three soil depths (0-10, 10-20, and 20-30 cm) of selected treatments to evaluate early root development. Soil samples were collected at pinhead square and again 21 d later to evaluate root lengths. Relative to the check yield, first-harvest disk-till yields were increased 104 and 124 kg ha^{-1}, while total yields were increased 103 and 140 kg ha^{-1} from in-furrow applications of 1.75 and 2.33 L ha^{-1} Asset RTU, respectively. Total disk-till yields were increased 67 kg ha^{-1} by PGR-IV. First-harvest no-till lint yields were 122, 123, and 176 kg ha^{-1} higher than the check while total lint yields were increased 97, 124, and 172 kg ha^{-1} from in-furrow applications of 11-16-0 and 1.75 and 2.33 L ha^{-1} Asset RTU, respectively. Although the treatment effects on disk- and no-till cotton differed slightly, in-furrow applications of 1.75 and 2.33 L ha^{-1} Asset RTU consistently increased yields produced by both tillage systems. Early root growth response to treatments (pinhead stage) was inconsistent and varied with sample position and soil depth. Roots evaluated at pinhead square plus 21 d showed Asset RTU applied at 1.75 L ha^{-1} was the most consistent treatment for increasing root lengths.

In-furrow applications of plant growth regulators (PGRs) and starter fertilizers are being evaluated by producers and researchers to determine if they improve early-season growth of cotton (*Gossypium hirsutum* L.). Relatively little multiyear research evaluating in-furrow application of plant growth regulators is available. Published data indicate considerable variation in the effect of plant growth regulators on the plant. Oosterhuis and Guo (1994) pointed out the need for additional knowledge about the mode of action and optimum application conditions that are required for the proper utilization of commercial plant growth regulator materials.

Conservation tillage systems are recommended for cotton production on highly erosive soils (Bradley, 1995). Crop residues and winter covers used to control erosion impact the soil environment by restricting water evaporation and reducing soil temperatures (Bradley, 1995). These conditions affect seed germination, stand establishment, and plant vigor and provide environmental conditions for increased pathogen activity (Chambers, 1995). The growing conditions associated with conservation production systems have reduced yields in certain years, possibly from restricted root growth (Bradley, 1995). Although the use of plant growth regulators may offer an opportunity for enhancing early-season plant development, research evaluating in-furrow applications of plant growth regulators and starter fertilizers for cotton has produced conflicting results. Two products reported to improve root growth are PGR-IV (Oosterhuis and Zhao, 1993) and Asset RTU (J. M. Thomas, Helena Chemical Co., personal communication).

Using growth chamber studies, Oosterhuis and Zhao (1993) reported that PGR-IV increased root length and root dry weight of cotton one week after planting. They also reported that treatment differences were diminished at pinhead square. Millhollon and Waters (1997) evaluated application rates of four plant growth regulators on seedling growth, fruiting, and yield of cotton planted in Louisiana on 22 May 1996. Results showed that these plant growth regulators did not affect seedling height, seedling weight, or seed cotton yield and had limited positive effect on boll retention. Becker et al. (1998) evaluated three rates of nine plant growth regulators for two years on West Texas cotton planted in mid to late May. They concluded that stand establishment and root growth were not affected by the plant growth regulators. Although cotton plant height was improved by one plant growth regulator one year, yields for the 2 y study were not improved.

Steger and Oosterhuis (1997) evaluated the effect of six plant growth regulators applied either as a seed treatment or in-furrow at planting on several plant measurements and reported differences within the plant growth regulators for each plant measurement. For example, germination and emergence 6 d after planting was greater for seed treated with plant growth regulators than for in-furrow applications of plant growth regulators. Egilla and Oosterhuis (1996) reported that in-furrow PGR-IV applications increased plant height and leaf area measurements. Robertson et al. (1999) evaluated three commercially available materials on farmer fields over a 2 y period and concluded that neither emergence nor lint yields were enhanced by the treatments when compared with the check. After a 3 y study on five plant growth regulators, Oosterhuis and Zhao (1999) concluded that the effect on yields of the tested plant growth regulators did not warrant their use because yields ranged from −1.2% to +1.5% of the check. Bassett (1999) reported that in-furrow application of 2.33 L ha^{-1} of Asset RTU improved germination and emergence one of two years. He indicated that root counts were increased 12% and 13% from in-furrow treatment applications in 1997 and 1998, respectively. Yields, however, were not enhanced by the treatments. Bassett also noted a higher percentage of cotton bolls set in the first position for the Asset RTU treatment. Oosterhuis (1996) evaluated several plant growth regulators and reported that in-furrow application of Asset at 0.364 L ha^{-1} had the greatest effect on seedling emergence.

Asset RTU is a 6-20-5 plant nutrient solution that also contains 0.02% B, 0.05% Cu, 0.1% chelated Fe, 0.05% chelated Mn, 0.0005% Mo, and 0.05% chelated Zn (Helena Chemical Co., 1997b). Asset is a proprietary fertilizer additive that contains 2% water-soluble Mg derived from magnesium ammonium carboxylate (Helena Chemical Co., 1997a). PGR-IV is a solution containing 0.0028% indolebutyric acid and 0.003% gibberellic acid (Micro Flo Co., 1997).

Starter fertilizers have increased cotton yields. Howard et al. (1999) reported that in-furrow $Ca(NO_3)_2$ applications increased cotton yields on two loess-derived soils. They also indicated that a wide application range (17 to 68 L ha^{-1}) of $Ca(NO_3)_2$ can be used in-furrow without affecting the plant population. Surface banding 11-16-0 at 70 L ha^{-1} resulted in higher yields than the in-furrow application on one soil. Howard and Hoskinson (1990) showed that increased lint yields from starters were more likely to occur in years of cool, wet springs. They also reported that yields were not increased every year and that side-banding 17 kg N and 7 kg P ha^{-1} produced higher no-till cotton yields than starters containing higher P rates. Research in Alabama demonstrated that side banding starters was more effective for no-till cotton production than for conventional-till production (Touchton et al., 1986). Hutchinson and Howard (1997) evaluated three methods for applying 11-16-0 to conventional and no-till cotton on two loess-derived soils. They found that in-furrow applications of either 28 or 42 L of 11-16-0 ha^{-1} reduced seed germination in both tillage systems on both soils. The yield response from surface and side-banded 11-16-0 was greater than yields from in-furrow applications.

Additional information is needed to evaluate fertilizer additives and/or in-furrow plant growth regulators on cotton. This research was established to evaluate rates of in-furrow-applied Asset RTU and compare them with PGR-IV for cotton produced in disk-till and no-till systems.

MATERIALS AND METHODS

Research was initiated in 1995 and continued through 1997 on a Loring silt loam at the Milan Experiment Station, Milan, TN. The Mehlich-I extractable P and K were 70 and 230 kg ha^{-1}, respectively, which are categorized as high (Extension Plant and Soil Science, 2000). Native winter vegetation was the cover for the no-till area. This plot area previously had been planted in no-till cotton.

The experimental design was a randomized complete block with five replications. The in-furrow treatments were (i) ammonium polyphosphate (11-16-0) applied at 2.33 L ha^{-1}; (ii) co-application of 11-16-0 (2.33 L) and Asset (Helena Chemical Company, Memphis, TN) at 0.15 L ha^{-1}; Asset RTU (Helena Chemical Company, Memphis, TN) applied at (iii) 1.17, (iv) 1.75, and (v) 2.33 L ha^{-1}; (vi) PGR-IV (Micro Flo Co., Lakeland, FL) applied at 0.07 L ha^{-1} at planting followed with a foliar application of 0.28 L ha^{-1} at pinhead square and repeated in 7 d; (vii) an untreated check. The Asset RTU applied at 2.33 L ha^{-1} was evaluated in 1996 and 1997 only. Rates of 11-16-0 and Asset applied in (i) and (ii) were selected to approximate the application rates of Asset RTU. These treatments were applied to cotton planted in two separate tillage systems, disk-till and no-till, with each tillage system being a separate experiment. The tilled system was disked twice to a depth of 10 cm immediately before planting. Plots were uniformly fertilized annually with 80, 20, and 56 kg ha^{-1} of N, P, and K, respectively. Ammonium nitrate, concentrated superphosphate, and potassium chloride were the broadcast fertilizer materials. Fertilizers were applied to both tillage systems immediately before disking the tilled plots.

Treatments were applied using the solid-stream Delavan No. 22 metering orifice (Delavan Spray Technologies, Monroe, NC) attached to the insecticide/fungicide bracket at the rear of each planter unit. Certain treatments were diluted with water to allow application at constant planter speed and 1.73×10^5 Pa CO_2 pressure. Application lines were cleared in the alleys between plots using CO_2, and filled with the next treatment. Individual plots were 9.1 m long with four rows spaced 1.02 m apart.

The cotton cultivars "Hyperformer 39," "Deltapine 50," and "Deltapine 5409" were planted in 1995, 1996, and 1997, respectively. All were planted the last week of April except in 1997, when the plots were replanted 13 May and treatments reapplied since the planted row was moved approximately 5 cm to the side of the previous row. Prior to planting, winter vegetation was killed with a tank mix of glyphosate {N-(phosphonomethyl)glycine} at 454 g a.i. ha^{-1} and prometryn {N,N'-bis(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine} at 227 g a.i. ha^{-1}. Immediately after planting, a tank mix of paraquat {1,1'-dimethyl-4,4'-bipyridinium ion} applied at 160 g a.i. ha^{-1}, pendimethalin {N-(1-ethyl propyl)-3,4-dimethyl-2,6-dinitrobenzenamine} at 419 g a.i. ha^{-1}, and fluometuron {N,N-dimethyl-N'-[trifluoromethyl-phenyl]urea} at 763 g a.i. ha^{-1} containing 0.5% (v/v) nonionic surfactant, was used. Plots were post-directed three times using three materials. The first post-directed material was clethodim {(E,E)-(+)-2-[1-[[(3-chloro-2-propenyl)oxyl]imino]propyl]-5- [e-(thylthio)propyl]-3-hydroxy-2-cyclohenen-1-one} at 57 g a.i. ha^{-1}. The second post-directed material was pyrithiobac sodium {sodium 2-chloro-6-[(4,6-dimethoxy pyrimidin-2-yl)thio]benzoate} at 147 g a.i. ha^{-1}. The third post-directed material was a tank mix of {2-[[4-chloro-6-(ethylamino)-1,3,5-trazin-2-yl]amino]-2-methylpro panenitrile} at 454 g a.i. ha^{-1} plus MSMA {monosodium salt of methylarsonic acid} at 1.39 L ha^{-1}. Additional recommended production practices (insecticides, defoliants, etc.) were used for production of the crop each year (Shelby, 1996).

Treatment effect on root development was evaluated for three selected in-furrow treatments: 1.17 and 1.75 L ha^{-1} of Asset RTU, PGR-IV, and the check. Soil cores were collected by hand at pinhead square and again 21 d later using a sampling tube having a 38-cm long barrel with a diameter of 1.9 cm. Individual samples were separated into three soil depths (0 to 10, 10 to 20, and 20 to 30 cm). Samples were collected from three row positions (in-row, 10, and 20 cm from the row). The in-row sample was collected midway between two plants spaced approximately 5 cm apart, while other samples were collected on a line perpendicular to the row. Five subsamples were collected and placed in ice chests and later refrigerated until root-soil separation. Root and soil separation was accomplished using a semiautomatic elutriator (Byrd et al., 1976). The roots were stored in 70% (v/v) ethanol and refrigerated. Root lengths were determined by the line-grid intercept method (1-cm grids) as described by Tennant (1975). The root samples were not evaluated in 1997 because plots were replanted and sampling conflicted with other operations. Also, the 20 to 30 cm depth samples were not collected at pinhead square plus 21 d (second sampling) for the 4 and 8 cm locations from the row in 1996 because of dry soil conditions.

Root length density was calculated and reported as cm cm^{-3}.

Plant growth measurements included plant population, leaves per plant within a given row length, leaf surface area within the row length, leaf surface area per plant, and plant height. Leaf surface area was evaluated using a Delta-T Area Meter (Decagon Device, Inc., Pullman, WA). These measurements were evaluated for each treatment and tillage system but were unaffected by treatment and are not reported.

A recommended defoliant was applied when 60% of the bolls were open. Lint yields were determined by mechanically picking the two center rows. Cotton was first picked approximately 2 wk after leaf drop with a second picking approximately 3 wk following the first picking. Percent lint was determined by combining seedcotton subsamples from individual treatments across replications (less than 4.5 kg) and ginning on a 20-saw gin with dual lint cleaners. Lint yield was calculated by multiplying lint fraction by seedcotton weight. Total lint yield was calculated by adding the first- and second-harvest lint yields.

The statistical analyses of lint yields, root length, and other plant measurements were performed using mixed model procedures of the Statistical Analysis System (SAS Institute, 1997). Yield means and root data were contrasted (single degree of freedom) using the estimate statement in mixed model procedures to compare the treatment effects. Mean differences with probabilities greater than $\alpha = 0.05$ were categorized as nonsignificant. To evaluate the yield response produced by Asset RTU, yield response functions were developed through regression analyses for the two tillage systems and tested for significant differences using F-tests (Chow tests) (Kennedy, 1992). The Chow test is an F-test with $T_1 + T_2 - 2K$ degrees of freedom and takes the form: $F = \{[SSE\ (constrained) - SSE\ (unconstrained)]\ /K\}/[SSE\ (unconstrained)/(T_1 + T_2 - 2K)]$ where T_1 and T_2 are the number of observations in each of the regressions being compared. K is the number of variables in each regression including the intercept. SSE (unconstrained) is the sum of the SSEs when the two regressions are performed separately and SSE (constrained) is the SSE from performing one regression using all the data from both regressions. The Asset RTU rate effect on yields was regressed utilizing relative yields produced for each year. The relative yield was utilized in an attempt to reduce variability between years.

RESULTS AND DISCUSSION

Plant height, leaf number, leaf surface area, and plant population were unaffected by the treatments even though they differed according to year (data not reported).

First-harvest and total yields in each tillage system (disk- and no-till) were affected by the in-furrow treatments (Table 1). Treatment effects on lint yields were consistent across the three years because the year-treatment interaction was not significant for either tillage system. Therefore, yields will be discussed as three-year averages for each tillage system.

First-harvest disk-till lint yields were increased by two of the six treatments, while total disk-till

Table 1. Mixed model 'F' statistical values for evaluating in-furrow applications of selected plant growth regulators for disk- and no-till-produced cotton by harvest.

		Yield by harvest					
		1st		2nd		Total	
Source	df	'F'	Pr > F	'F'	Pr > F	'F'	Pr > F
			Disk-till				
Year (Y)	2	171.7	0.0001	6.2	0.024	278.1	0.0001
Error a	8						
Treatment (T)	6	2.2	0.049	0.6	0.710	3.6	0.0039
Y*T	11	1.0	0.172	0.3	0.985	1.1	0.382
Error b	68						
			No-till				
Year (Y)	2	38.1	0.0001	6.0	0.026	111.3	0.0001
Error a	8						
Treatment (T)	6	2.3	0.047	0.4	0.871	3.8	0.003
Y*T	11	0.3	0.986	0.2	0.995	0.2	0.993
Error b	62						

yields were increased by three treatments (Table 2). First-harvest disk-till yields ranged from 909 kg lint ha^{-1} to 1033 kg lint ha^{-1}, while total yields were between 1146 and 1286 kg ha^{-1}. In-furrow application of Asset RTU applied at 1.75 and 2.33 L ha^{-1} increased first-harvest yields 104 and 124 kg ha^{-1} above the check, respectively. Total yields were increased by two Asset RTU treatments (1.75 and 2.33 L ha^{-1}) and PGR-IV. Yields were 103, 140, and 67 kg ha^{-1} higher than the check for the three treatments, respectively.

First-harvest and total no-till yields were improved by the in-furrow application of three of the six treatments compared with the check (Table 2). First-harvest yields ranged from 715 to 892 kg lint ha^{-1} while total yields ranged from 1020 to 1193 kg ha^{-1}. Relative to the check, in-furrow applications of Asset RTU at 1.75 and 2.33 L ha^{-1} and 11-16-0 increased first-harvest yields 123, 177, and 122 kg ha^{-1}, respectively. Total yields were increased 123, 173, and 97 kg ha^{-1} from the same three treatments, respectively.

In-furrow applications of Asset RTU (1.75 and 2.33 L ha^{-1}) were the only treatments that increased cotton yields in both disk-till and no-till systems. In-furrow application of a low rate (2.33 L ha^{-1}) of 11-16-0 also increased no-till yields. These results suggest that increased yields in no-till were related to in-furrow fertilizer (11-16-0) application. This fertilizer rate approximates that applied in Asset RTU. The lack of yield response from Asset relative to the check also supports this concept. No-till yields also linearly increased with higher Asset RTU rates as expressed by $Y_{NT} = 990.9925 + 106.7893*$ Asset RTU. However, increased yields with 11-16-0 were not observed in the disk-till system, although the two high Asset RTU rates did increase yields. Also, the Asset plus 11-16-0 treatment did not increase no-till yields even though the same rate of 11-16-0 was applied in both treatments. Asset RTU applied in-furrow at the two higher rates (1.75 and 2.33 L ha^{-1}) increased yields regardless of tillage system, whereas the fertilizer only increased no-till yields. Previous research evaluating in-furrow applications of 11-16-0 indicated a limited enhancement of cotton yield in conventional- and no-till production systems (Hutchinson and Howard, 1997). Yield increases were observed for only 1 of the 12 site-years (two tillage systems, two locations, and three years) from in-furrow applications of 11-16-0. For this one responsive site-year, in-furrow applications of 11-16-0 at 14.0 L ha^{-1} increased conventional-tilled cotton yields.

The in-furrow treatments primarily affected first-harvest yields (Table 1). Since plant growth measurements were unaffected by the treatments, it can be speculated that the treatments were affecting boll weight (not evaluated), boll number, or gin turnout, factors associated with improved yield. Bassett (1999) reported that in-furrow application of 2.33 L ha^{-1} of Asset RTU increased the number of bolls set on the first position. Gin turnouts for the Asset RTU treatments ranged from 0.5% to 1.6% higher than the check. These observations are an average of samples collected across the five replicated treatments and cannot be statistically evaluated.

To evaluate the yield response due to tillage from increased Asset RTU rates (1.17, 1.75, and 2.33 L ha^{-1}), regression equations were developed utilizing yields produced on both tillage systems and compared using the Chow test (Kennedy, 1992). The regressed equation for disk-till first-harvest relative yields was $RY_{DT} = 0.8632 + 0.0693*$Asset RTU rate ($R^2 = 0.51$); the equation

Table 2. Three-year-average cotton yields in disk-till and no-till production systems as affected by in-furrow applications of a fertilizer, rates of a fertilizer additive, and a plant growth regulator.

		Disk-till yields		No-till yields	
		1st	Total	1st	Total
Treatments	Rate L ha^{-1}	Lint yield kg ha^{-1}			
11-16-0	2.33	969abc†	1188bcd	837ab	1117ab
11-16-0 + Asset	2.33 + 0.15	943bc	1170cd	804abc	1079bc
Asset RTU	1.17	971abc	1198bcd	768bc	1083bc
Asset RTU	1.75	1013ab	1249ab	838ab	1143ab
Asset RTU	2.33	1033a	1286a	892a	1193a
PGR-IV	0.28 + 2.33 + 2.33	947abc	1213abc	732c	1021c
Check		909c	1146d	715c	1020c

† Within a yield column, means followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 3. Analysis of variance of cotton roots collected at pinhead and pinhead plus 21 d from disk-till and no-till cotton as affected by in-furrow-applied treatments, sampling position, and soil depth in 1995 and 1996.

		Pinhead					Pinhead plus 21 d			
		Disk-till		No-till			Disk-till		No-till	
Source	df	F	P > F	F	P > f	df	F	P > F	F	P > f
Year (Y)	1	190.7	0.0002	32.3	0.0047	1	9.0	0.039	99.1	0.0006
Error a	4					4				
Treatment (T)	3	5.4	0.006	3.5	0.030	3	25.8	0.0001	1.6	0.219
Y*T	3	4.6	0.011	1.8	0.183	3	7.5	0.001	1.9	0.163
Error b	24					24				
Position (P)	2	92.9	0.0001	2.0	0.139	2	34.6	0.0001	5.4	0.007
P*Y	2	4.1	0.022	2.7	0.076	2	6.9	0.002	9.5	0.0002
P*T	6	7.4	0.0001	2.0	0.077	6	2.6	0.025	0.9	0.517
P*T*Y	6	3.2	0.008	6.4	0.0001	6	4.2	0.0013	3.4	0.006
Error c	64					64				
Depth (D)	2	122.6	0.0001	183.1	0.0001	2	44.0	0.0001	132.9	0.0001
D*Y	2	12.9	0.0001	5.0	0.008	2	147.7	0.0001	235.8	0.0001
T*D	6	1.3	0.281	2.8	0.012	6	4.2	0.0006	2.3	0.039
D*T*Y	6	1.5	0.172	0.8	0.588	6	5.8	0.0001	2.0	0.063
D*P	4	25.0	0.0001	7.0	0.0001	4	1.3	0.256	3.3	0.0125
D*P*Y	4	2.0	0.094	6.9	0.0001	2	1.4	0.242	0.5	0.619
D*P*T	12	1.8	0.057	3.0	0.0007	12	4.0	0.0001	2.1	0.019
D*R*T*Y	12	4.4	0.0001	3.9	0.0001	6	2.0	0.069	1.1	0.356
Error d	192					160				

for no-till first-harvest relative yields was RY_{NT} = 0.8093 + 0.081*Asset RTU rate (R^2 = 0.75). The Chow test indicated that the equations developed for each tillage system were different (F = 10.46, P ≤ 0.0001). The regressed equation for disk-till total relative yields was RY_{DT} = 0.8859 + 0.0511*Asset RTU rate (R^2 = 0.66); the equation for no-till total relative yields was RY_{NT} = 0.8698 + 0.05904*Asset RTU rate (R^2 = 0.89). The Chow test indicated that these equations were also different (F = 3.97, P ≤ 0.022). An additional evaluation indicated that the intercepts of both first-harvest and total yield expressions were different, but that the slopes of the equations were not different. The rate of total yield increase was approximately 103 kg lint ha^{-1} for each L of Asset RTU applied.

Root lengths within each tillage system varied with in-furrow treatment (Asset RTU applied at 1.17 and 1.75 L ha^{-1} and PGR-IV), sampling position, and sampling depth (Table 3). Treatment effects on root lengths at pinhead square were inconsistent across the two years, as indicated by a

Table 4. Root length of disk-till cotton sampled at pinhead in 1995 and 1996 as affected by treatment, sampling position, and soil depth.

		1995				1996			
		Soil sampling depth (cm)							
	Rate	0–10	10–20	20–30	Total	0–10	10–20	20–30	Total
Treatment	L ha^{-1}	Root length (cm cm^{-3})							
		0 cm from row							
Asset RTU	1.17	0.067b[†]	0.044b	0.016b	0.127b	0.112ab	0.096a	0.051a	0.259ab
Asset RTU	1.75	0.107a	0.071a	0.026ab	0.204a	0.100b	0.074b	0.048a	0.222bc
PGR-IV		0.100a	0.042b	0.039a	0.181a	0.140a	0.094a	0.040a	0.075a
Check		0.072b	0.035b	0.024b	0.131b	0.119ab	0.054c	0.042a	0.214c
		10 cm from row							
Asset RTU	1.17	0.037b	0.027a	0.011b	0.075b	0.072ab	0.037c	0.042a	0.151b
Asset RTU	1.75	0.042b	0.018a	0.033a	0.093b	0.083a	0.075ab	0.035ab	0.192a
PGR-IV		0.074a	0.021a	0.039a	0.134a	0.086a	0.088a	0.021b	0.195a
Check		0.059ab	0.029a	0.023ab	0.111ab	0.047b	0.060bc	0.034ab	0.140b
		20 cm from row							
Asset RTU	1.17	0.031a	0.020ab	0.023a	0.073a	0.075a	0.105a	0.057a	0.237a
Asset RTU	1.75	0.011b	0.017b	0.018a	0.046bc	0.056a	0.043b	0.033ab	0.132b
PGR-IV		0.015b	0.025a	0.018a	0.059b	0.048a	0.049b	0.040ab	0.138b
Check		0.010b	0.015b	0.018a	0.043c	0.072a	0.045b	0.023b	0.139b

[†] Root lengths for each sampling position of each year followed by the same letter are not significantly different at $\alpha = 0.05$.

year-treatment-sampling position-sampling depth interaction for the two tillage systems. Treatment effects on root lengths at pinhead plus 21 d were consistent across the two years, but were affected by a treatment-sampling position-sampling depth interaction. It must be remembered that sample numbers were less in 1996 than in 1995 when collected at pinhead square plus 21 d.

The 1995 and 1996 root lengths of the disk-till cotton varied with treatments, sampling position, and depth (Table 4). In 1995, in-furrow application of Asset RTU at 1.75 L ha^{-1} and PGR-IV increased in-row (0 cm) root lengths within the 0 to 10 cm depth. Sampling the in-row position to a depth of 10 to 20 cm showed that Asset RTU (1.75 L ha^{-1}) increased root lengths, while PGR-IV increased root lengths in the 20 to 30 cm depth. For samples collected 10 cm from the row, root lengths within the three depths were not improved by the treatments. In-furrow application of Asset RTU (1.17 L ha^{-1}) increased root lengths within the 0 to 10 cm depth 20 cm from the row, while PGR-IV increased root lengths within the 10 to 20 cm depth. Root lengths totaled across the three sampling depths (0 to 10, 10 to 20, and 20 to 30 cm) showed increased root lengths for application of PGR-IV and Asset RTU at 1.75 L ha^{-1} within the in-row position and no treatment effect 10 cm from the row. Asset RTU applied at 1.17 L ha^{-1} and PGR-IV increased root lengths 20 cm from the row. In 1995, the in-furrow treatments increased root lengths in five of the nine combinations (sample position and depth) when compared with the check. Total root length for the three sampling depths shows that the treatments increased roots lengths in two of the three sampled positions.

In 1996, the in-furrow treatments did not increase disk-till root lengths of the in-row position within the 0 to 10 cm depth. In-furrow applications of PGR-IV and Asset RTU at 1.17 L ha^{-1} increased in-row root lengths within the 10 to 20 cm depth but root lengths in the 20 to 30 cm depth were unaffected by treatment. The three treatments increased root lengths in the 0 to 10 cm depth sampled 10 cm from the row. However, PGR-IV was the only treatment that increased root lengths in the 10 to 20 cm depth. The Asset RTU 1.17 L ha^{-1} increased root lengths 20 cm from the row within the 10 to 20 and 20 to 30 cm depths. Root lengths totaled across the three soil depths were increased by PGR-IV and Asset RTU at 1.17 L ha^{-1}, while PGR-IV and Asset RTU at 1.75 increased root lengths 10 cm from the row. When sampled 20 cm from the row, Asset RTU (1.17 L ha^{-1}) increased root lengths. In 1996, the in-furrow treatments increased root lengths in five of the nine position-depth combinations when compared with the check. Totaled over the three sampling depths, the in-furrow treatments increased roots lengths within each sampled position.

The 1995 in-row sampling of the no-till cotton indicated root lengths within the 0 to 10 cm depth

Table 5. Root length of 1995 and 1996 no-till cotton sampled at pinhead as affected by treatment, sampling position, and soil depth.

Treatment	Rate L ha^{-1}	1995 0–10	1995 10–20	1995 20–30	1995 Total.	1996 0–10	1996 10–20	1996 20–30	1996 Total
		Root length (cm/cm^3)							
0 cm from row									
Asset RTU	1.17	0.210a†	0.037a	0.027a	0.274a	0.074a	0.067b	0.023c	0.164b
Asset RTU	1.75	0.094b	0.032a	0.030a	0.156b	0.074a	0.123a	0.054a	0.251a
PGR-IV		0.056b	0.036a	0.019a	0.111b	0.125a	0.113a	0.037bc	0.233a
Check		0.094b	0.038a	0.029a	0.162b	0.106a	0.087ab	0.041ab	0.233a
10 cm from row									
Asset RTU	1.17	0.010c	0.024bc	0.007b	0.135c	0.165a	0.049b	0.027a	0.241a
Asset RTU	1.75	0.211a	0.036b	0.020c	0.267a	0.167a	0.088a	0.027a	0.282a
PGR-IV		0.163b	0.052a	0.010b	0.224b	0.181a	0.061ab	0.031a	0.274a
Check		0.047d	0.019c	0.018a	0.083b	0.131a	0.088a	0.018a	0.237a
20 cm from row									
Asset RTU	1.17	0.051b	0.030ab	0.018a	0.098a	0.126ab	0.044b	0.034ab	0.203b
Asset RTU	1.75	0.052b	0.021bc	0.023a	0.096a	0.257a	0.089a	0.034ab	0.380a
PGR-IV		0.119a	0.016c	0.017a	0.151a	0.154ab	0.044b	0.039a	0.237ab
Check		0.086ab	0.040a	0.022a	0.148a	0.089b	0.068ab	0.022b	0.178b

Soil sampling depth (cm) applies to all depth columns.

† Root lengths for each sampling position of each year followed by the same letter are not significantly different at $\alpha = 0.05$.

were greater for applying Asset RTU (1.17 L ha^{-1}) with no treatment differences in the 10 to 20 and 20 to 30 cm depths (Table 5). Samples collected 10 cm from the row showed that root lengths within the 0 to 10 cm depth were increased by applying the three treatments. Within the 10 to 20 cm depth, root lengths were increased by Asset RTU 1.75 L ha^{-1} and PGR-IV treatments. Root length totaled over the three sampling depths was greater for applying Asset RTU at 1.17 L ha^{-1}, while applying 1.75 L ha^{-1} increased root lengths 10 cm from the row. The 1995 in-furrow treatments increased root lengths four of the nine position-depth evaluations compared with the check. When totaled over the three sampling depths, root lengths were increased by treatment for two of the three sampling positions. In 1996, no-till root lengths were not affected by the treatments except within the 0 to 10 cm depth 20 cm from the row. Asset RTU applied at 1.75 L ha^{-1} increased root lengths of this sampling position and depth. Within the 20 to 30 cm depth, PGR-IV increased root lengths. In 1996, the in-furrow treatments increased root lengths only two of the nine position-depth evaluations when compared with the check. Totaled over the three sampling depths, in-furrow treatment effects on root lengths were observed within the 20-cm samples.

Sampling at pinhead square plus 21 d showed that in-furrow treatments were more consistent for increasing root lengths within either tillage system across the two years (no interactions by year). The disk-tilled root lengths sampled within the row were greater for applying Asset RTU at 1.75 L ha^{-1} relative to the check in both the 0 to 10 and 10 to 20 cm depths (Table 6). Root lengths of the check were greater in the 20 to 30 cm depth compared with the other treatments. When sampling 10 cm from the row, Asset RTU (1.75 L ha^{-1}) increased root length within the 0 to 10 and 10 to 20 cm depths. The Asset RTU (1.75 L ha^{-1}) and PGR-IV treatments increased root length of the 20 to 30 cm soil depth. Both Asset RTU treatments increased root systems of the 10 to 20 cm soil depth 20 cm from the row while the higher Asset RTU rate increased root lengths in the 20 to 30 cm depth. Some of the root data reported in Table 6 represents only one year (1995) because samples for certain depths were not collected in 1996. Root lengths, totaled across the three depths, were increased by the Asset RTU (1.75 L ha^{-1}) within each sample position. The in-furrow treatments increased root lengths in seven of the nine position-soil depth combinations when compared with the check root length. Totaled over the three sampling depths, treatments increased roots lengths in all of the three positions.

Roots collected at pinhead plus 21 d from the no-till system were virtually unaffected by any treatments (Table 6). The low Asset RTU rate and PGR-IV treatments increased root length of the 10 to 20 cm depth of the in-row position. Root lengths of the no-till system were improved within one of the nine observations. When totaled over the three

Table 6. Root length of disk-till and no-till cotton sampled at pinhead plus 21 d as affected by treatment,sampling position, and soil depth (averaged across 1995 and 1996).

		Disk-till				No-till			
		Soil sampling depth (cm)							
Treatment	Rate L ha^{-1}	0–10	10–20	20–30	Total	0–10	10–20	20–30	Total
		Root length (cm/cm^3)							
		0 cm from row							
Asset RTU	1.17	0.122b†	0.092ab	0.103b	0.317b	0.170a	0.093a	0.079a	0.342a
Asset RTU	1.75	0.163a	0.111a	0.105b	0.379a	0.150a	0.064b	0.099a	0.313a
PGR-IV		0.098b	0.065b	0.117b	0.279b	0.181a	0.089a	0.092a	0.365a
Check		0.104b	0.062b	0.139a	0.304b	0.156a	0.060b	0.105a	0.321a
		10 cm from row							
Asset RTU	1.17	0.103b	0.065d	0.034bc‡	0.197b	0.142ab	0.039a	0.045a‡	0.216b
Asset RTU	1.75	0.128a	0.129a	0.058a‡	0.314a	0.101b	0.057a	0.055a‡	0.208b
PGR-IV		0.074c	0.041e	0.044ab‡	0.154c	0.120ab	0.060a	0.054a‡	0.221ab
Check		0.095bc	0.052de	0.027c‡	0.174bc	0.203a	0.059a	0.048a‡	0.304a
		20 cm from row							
Asset RTU	1.17	0.075a	0.074a	0.027b‡	0.170b	0.132a	0.055a	0.051a‡	0.212a
Asset RTU	1.75	0.083a	0.078a	0.080a‡	0.201a	0.106a	0.043a	0.031b‡	0.164b
PGR-IV		0.089a	0.052b	0.030b‡	0.156bc	0.133a	0.059a	0.027b‡	0.205ab
Check		0.089a	0.037b	0.023b‡	0.138c	0.137a	0.043a	0.058a‡	0.208a

† Root lengths within each column for sampling depth and sampling position for the two tillage systems followed by the same letter are not significantly different at $\alpha = 0.05$. ‡ Underlined means are 1995 root data.

sampling depths, treatments did not increase root lengths.

The variation within root measurements was sufficient to make treatment interpretations problematic. The coefficient of variation for pinhead samples ranged from 35% to 39% for disk-till samples but ranged from 35% to 51% for no-till samples. The coefficient of variation for pinhead plus 21 d samples was 31% for disk-till and 46% for no-till samples. However, even with the high coefficient of variation, the in-furrow treatments increased root lengths in both the disk-till and no-till production systems although the increases were inconsistent with year, treatment, sample position, and soil depth.

Regression analyses of root lengths (totaled across soil depths and sampling positions) collected at pinhead square with yields indicated a positive relationship for both tillage systems. The regression analyses indicated that total disk-till yields were expressed as Y_{DK} = 618.5633 + 1032.9574root, a linear increase. This evaluation had an R^2 value of 0.62 and a coefficient of variation of 11.5%. No-till lint yields were expressed by Y_{NT} = 642.8768 + 677.5809root, a linear increase with root length. The evaluation had an R^2 value of 0.38 and a coefficient of variation of 17.4%.

CONCLUSIONS

Lint yields were increased by in-furrow applications of 1.75 and 2.33 L ha^{-1} of Asset RTU for disk- and no-till cotton production systems. Disk-till yields also were increased by PGR-IV. Applying 11-16-0 increased no-till yields. Yields within each tillage system were increased linearly with increased Asset RTU rates. Root lengths were improved by the in-furrow treatments in both tillage systems but treatment effects on root lengths were inconsistent across sampling position and soil depth.

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