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AGRONOMY AND SOILS

Irrigated Cotton Response to Tillage Systems in the Tennessee Valley

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) growers have adopted no-tillage systems with a cover crop in the Tennessee Valley under non-irrigated conditions, but a comparison of plant and soil parameters across irrigated tillage systems has not been investigated in this region of Alabama. This study was conducted to compare seed cotton yields, whole plant biomass, leaf nitrogen (N) concentrations at mid-bloom, soil moisture contents at two depths, and leaf stomatal conductance on a Decatur silt loam across different tillage systems and irrigation regimes during the 2001 to 2003 growing seasons. Treatments were arranged as a split-plot in a randomized complete block design with three replications. Tillage systems (conventional tillage; no cover crop and no surface tillage with a cover crop both with and without fall paratillage) were the main plots, and irrigation regimes (0, 2.7, 5.4, 8.1 mm day^{-1}) were the subplots. Tillage system and irrigation regime increased seed cotton yields two out of three years, and leaf stomatal conductance during a drought year. No surface tillage, regardless of fall paratillage, produced 15% more whole plant biomass than conventional tillage treatments one of three years, while an irrigation rate of 5.4 mm day^{-1} maximized plant biomass two of three years. Leaf N concentrations at mid-bloom were approximately 7% lower in the no surface tillage systems compared with the conventional tillage systems when averaged across all three years. Differences in soil water contents were only observed in 2001 with soil water contents 15% lower in the 0 to 20-cm depth following fall paratillage compared with no fall paratillage. Higher soil moisture contents were observed in the conventional tillage system following paratillage, while soil moisture contents following no fall paratillage were higher in the no surface tillage system in the 20- to 40-cm depth. Results of these plant and soil measurements suggest that cotton growers in the Tennessee Valley using irrigation should not change from the recommended conservation tillage system with a cover crop.

Approximately 223,000 ha of cotton are planted in Alabama each year (AASS, 2005). Approximately 33% of the cotton hectares are concentrated in four counties (Lauderdale, Lawrence, Limestone, Madison) of northern Alabama within a region known as the Tennessee Valley. This region is intensively cultivated because of the long growing season and the relatively productive limestone-derived soils. Recently, growers have shifted cotton production from conventional systems (fall disking and chiseling) to conservation systems that maintain crop residues on the soil surface and use a winter cover crop. The adoption rate of conservation tillage within this four county region is over 70% (CTIC, 2004).

The positive benefits associated with using some form of conservation tillage are well documented. Conservation systems can significantly improve soil physical, chemical, and biological properties (Langdale et al., 1990; Reeves, 1997). A low residue crop, such as cotton, does not provide adequate residue to benefit the soil (Reeves, 1994; Daniel et al., 1999). Winter cover crops, such as rye (*Secale cereale* L.), maximize residue on the soil surface and protect the soil from erosion during the winter months when precipitation exceeds evapotranspiration and intensive runoff occurs. Cover crop residues combined with cash crop residues improve water management for cotton by reducing soil water evaporation and increasing infiltration of irrigation and rainfall (Lascano et al., 1994). Roots of decomposing cover crops create channels through compacted soil layers, which enable subsequent crop roots to grow through

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the compacted zone (Williams and Weil, 2004) and improve infiltration.

Non-inversion deep tillage can also be used to alleviate compacted zones in the soil profile. One implement used for this purpose is a bent-leg subsoiler or paratill (Bigham Brothers Inc.; Lubbock, TX). The elimination of compacted layers with non-inversion tillage enables roots to explore a larger soil volume to obtain nutrients and moisture, and cover crop residue remains undisturbed on the soil surface (Busscher et al., 1988; Schwab et al., 2002). Previous research has documented the benefits of a conservation system for degraded, monocropped, fine-textured soils of the Tennessee Valley (Raper et al., 2000a; Raper et al., 2000b; Schwab et al., 2002). These researchers pointed out that the elimination of deep tillage is one benefit of a properly managed winter cover crop on these fine-textured soils (Raper et al., 2000a; Raper et al., 2000b).

In the Tennessee Valley, as in other areas of the Southeast, rainfall can be erratic depending on the year. Rainfall can range from minimal, which corresponds to drought conditions and requires irrigation to salvage yields, to adequate, which maximizes yields and minimizes the need for irrigation depending on the frequency of rainfall, to heavy, which usually associated with the remnants of tropical storms and hurricanes and generally reduces yields depending on the growth stage of the crop when they occur. Other growing seasons may experience at least two of these rainfall patterns, in no particular order, throughout the season. High residue conservation systems can conserve soil moisture, regardless of the frequency of rainfall; therefore, these systems may be able to sustain yields under lower irrigation amounts and/or less frequent irrigation applications compared with a traditional conventional tillage system.

An evaluation of the interactive effects of irrigation regimes with a conservation system (cover crop combined with or without non-inversion deep tillage) on soil and crop properties has not been conducted in the Tennessee Valley region. The objective of this study was to compare whole plant biomass, leaf N concentrations at mid-bloom, leaf stomatal conductance, and soil water contents at two depths across irrigation regimes in a conventional and conservation tillage system.

MATERIALS AND METHODS

A test with a split-plot arrangement of treatments in a randomized complete block design with three replications was established on a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudults) at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama, from 2001to 2003. Main plots were four tillage systems, and sub-plots were four irrigation regimes. Tillage systems consisted of factorial combinations of conventional tillage (CT; fall chisel/disk, spring disk/level) and no surface tillage (NST) with a rye cover crop. Each tillage system also included a fall paratill operation and no fall paratill operation. Irrigation regimes were 0, 2.7, 5.4, and 8.1 mm d^{-1}. Cotton irrigation scheduling was assisted with Moiscot, a computer based scheduling program that uses historic cotton water-use curves and soil moisture readings to predict irrigation requirements (Tyson et al., 1996). Irrigation applications were based on a depletion of 2.54 cm of available water in the upper 61 cm of the soil profile determined with soil moisture sensors (Irrometer; Riverside, CA) for 5 d each week, beginning at first bloom (mid-June) and terminating 1 mo prior to the anticipated harvest date. The 2.54-cm depletion was chosen for two reasons. First, it represents a typical or common amount of water applied by growers capable of irrigation in the Tennessee Valley. Second, run-off can be a potential problem for the heavier soils located in the Tennessee Valley, and 2.54 cm can be applied with minimum run-off. Two soil moisture sensors were installed in each subplot at depths of 22.9 and 45.7 cm. When soil water was depleted 2.54 cm below field capacity, the Moiscot irrigation scheduling program called for an irrigation event to bring the soil back to field capacity.

It was possible for Moiscot to call for an irrigation event that would not be conducted. This allowed for the simulation of different irrigation capabilities, similar to the operation of a center pivot. For example, if a center pivot system was designed to irrigate a particular field, the system cannot irrigate the field at one time. The flow rate of the system is fixed, so the pivot speed will determine the application amount. A high irrigation amount requires the pivot to travel slower compared with a low irrigation amount at the same flow rate or particular pumping capacity. Consequently, a low application rate can complete the circle of the pivot quicker compared with a high application rate. In order to simulate a center pivot system irrigating a large field with only sprinkler heads in research plots, built-in wait times were used before the irrigation could apply water again. The 2.54 cm of water was applied in a 12- to

24-h period to minimize runoff. The wait times were 9.4, 4.7, and 3.1 d based on 2.54 cm of water applied, which corresponds to the irrigation regimes of 2.7, 5.4, and 8.1 mm d^{-1}. The wait times were used even though the Moiscot program may have scheduled an irrigation event. Depending on rainfall received, the irrigation level could result in deficit irrigation; however, the system enabled us to determine if the lower irrigation capabilities could provide economical yields or increase yields within tillage systems. This is of particular interest when irrigation water supplies are limited.

Irrigation was applied with four sprinkler nozzles located in each corner of the sub-plot that were aligned to uniformly irrigate only the specific plot. Treatments remained in the same location each year. Sub-plot dimensions were 11.2 m wide (8, 40-inch rows) and 11.9 m long separated by 7.9-m alleys.

Phosphorus, K, and lime were applied prior to planting the rye cover crop based on Auburn University soil test recommendations (Adams et al., 1994). Rye was drilled at 100 kg ha^{-1} during the first 2 wk of October each year. Fall paratill treatments were administered to appropriate plots at the time of cover crop planting. The rye cover crop in the NST plots was chemically terminated with glyphosate (Roundup; Monsanto Company; St. Louis, MO) at least 2 wk before planting. Aboveground cover crop dry matter samples (0.5 m^2 per plot) were collected after chemical termination, but prior to cotton planting. The samples were oven-dried at 55 °C for 72 h and weighed.

A Tektronix 1502B cable tester (Tektronix, Inc.; Beaverton, OR) was used for soil water determination using time domain reflectometry (TDR) at two depth increments (0 to 20 cm and 20 to 40 cm) approximately once a week. Volumetric soil water content was determined from 80 to 108 days after planting (DAP) in 2001, from 76 to 104 DAP in 2002, and from 77 to 96 DAP in 2003 from the 0 and 5.4 mm d^{-1} irrigation regimes. These measurement periods encompassed the peak bloom. Measurements were performed in the non-traffic middle, 10 to 15 cm from adjacent crop rows. Stainless steel TDR rods (0.4-cm diameter) spaced 3 cm apart (Heimovaara, 1993) were placed into the soil and connected to a cable tester with coaxial cable. The Topp calibration equation was used to derive volumetric soil water contents at each sampling point (Noborio, 2001).

Leaf stomatal conductance was measured with a LI 1600M steady state porometer (LI-COR; Lincoln, NE) from the upper-most, unshaded, mature single leaves from the CT treatment without fall paratillage and the NST treatment with fall paratillage across the 0 and 5.4 mm d^{-1} irrigation regimes. Measurements were collected weekly between 1100 h and 1400 h from five leaves from separate plants per plot. The measurement period corresponded to 90 to 132 DAP (late season bloom) in 2001 and 82 to 99 DAP (peak bloom) in 2002 with leaf stomatal conductance values averaged over those time periods.

PayMaster 1218 BG/RR (Delta Pine and Land Co.; Scott, MS) was planted 20 April 2001 and Suregrow 215 B/R (Delta Pine and Land Co.) was planted on 24 April 2002 and 1 May 2003. Twenty-five upper-most fully expanded leaves were collected from each plot at mid-bloom on 1 Aug. 2001, 30 Jul. 2002, and 31 Jul. 2003. All leaves were dried at 55 °C for 72 h and ground to pass through a 2-mm screen with a Wiley mill (Thomas Scientific; Swedesboro, NJ). Leaf samples were further ground to pass through a 1-mm screen with a Cyclone grinder (Thomas Scientific). Subsamples were analyzed for total N by dry combustion on a LECO CHN-600 analyzer (Leco Corp.; St. Joseph, MI). The aboveground portion (bolls, leaves, stems) of two non-harvest cotton rows (1 m long) were collected prior to defoliation from each plot on 20 Sept. 2001, 15 Sept. 2002, and 18 Sept. 2003 by clipping stems of each plant at the soil surface. Each sample was dried at 55 °C for 72 h and weighed to determine cotton whole plant biomass production. Cotton was harvested on 1 Oct. 2001, 24 Sept. 2002, and 8 Oct. 2003 with a mechanical spindle picker equipped with a bag attachment system.

Data analysis. Treatments were arranged as a split-plot in a randomized complete block design with three replications. Main plots were the factorial combination of tillage systems and sub-plots were four irrigation regimes. All response variables were analyzed using the MIXED procedure (Littell et al., 1996) and the LSMEANS PDIFF option to distinguish between treatment means (release 9.1; SAS Institute Inc.; Cary, NC). Data were analyzed with year as a fixed effect in the model. There were significant year by treatment interactions for all response variables, so data were analyzed within each year, and data and discussion presented by year. Tillage system and irrigation regime were also considered as fixed effects, while replication and replication by tillage were considered random. Orthogonal contrast statements were used to further distinguish between tillage systems.

The variable irrigation regime was continuous and quantitative, which creates an infinite level of treatment comparisons. In order to compare across the entire range of irrigation regimes, a relationship between the response and treatment is preferred. The relationship was determined based on trend comparisons, otherwise known as method of orthogonal polynomials that determines the lowest degree polynomial that represents the relationship between the response and treatment (Gomez and Gomez, 1984). Orthogonal contrast statements were used to evaluate linear and quadratic effects of irrigation regimes on seed cotton yields, whole plant biomass, and leaf N concentrations. If the orthogonal contrasts indicated a significant linear or quadratic response, the specified regression model was fit with the PROC REG procedure (SAS Institute, 2002). Treatment differences were considered significant if $P \leq 0.10$.

RESULTS AND DISCUSSION

Rainfall, heat units, and irrigation totals for the 2001, 2002, and 2003 growing seasons are shown in Table 1. Rainfall received during the 2001 and 2003 growing seasons was similar and averaged 74% higher than rainfall received during the 2002 growing season. Accumulated heat units averaged 17% higher during the 2002 growing season compared with the 2001 and 2003 growing seasons. Rainfall totals and accumulated heat units were similar between the 2001 and 2003 growing seasons, and illustrates that the 2002 growing season was drier and warmer than in 2001 and 2003. The amount of irrigation water applied also demonstrates that the 2002 growing season was warmer and drier than the 2001 and 2003 growing seasons.

The effect of the paratill operation on rye biomass production was examined by measuring rye biomass across all corresponding NST plots. The paratill operation increased biomass production ($P < 0.0382$) compared with no paratill only in 2001, but the total biomass produced in 2001 was severely limited due to an early termination date (data not shown). In 2001, rye biomass production following paratilling was 278 kg ha^{-1} compared with 198 kg ha^{-1} following no paratilling. There were no differences in rye biomass production between paratill and no paratill operations for the other growing seasons, but biomass production averaged 4158 kg ha^{-1} and 2954 kg ha^{-1} in 2002 and 2003, respectively.

Seed cotton yield. Seed cotton yields were affected by tillage treatments in 2001 and 2003 (Table 2). In 2001, seed cotton yields were approximately 4% higher following the fall paratill operation compared with no fall paratill operation when averaged across tillage system. The response to a non-inversion deep tillage operation occurred following essentially no cover crop biomass present because of an early termination date. This corresponds to the findings of Raper et al. (2000a; 2000b) who concluded that in the presence of a high residue cover crop, deep tillage is not required on these fine-textured soils. An interaction within the tillage main effect between the amount of surface tillage and fall paratill operations was observed during the 2001 growing season. In the CT system, seed cotton yields were higher following no fall paratill operation compared with the fall paratill treatment. In the NST system, seed cotton yields increased in response to paratilling.

Cover crop residue was non-existent during the 2001 growing season. The response of seed cotton yields in the NST system to fall paratill operations

Table 1. Total rainfall received, heat units accumulated, and irrigation water applied during the 2001 to 2003 growing seasons

Year	Rainfall (mm)	Heat units^z	Total water (mm)^y		
			Low	Medium	High
2001	759	2305	100	173	166
2002	448	2704	176	237	275
2003	799	2309	109	136	136
Average	669	2439	128	182	192

^{z} **Heat units were calculated as follows: (Tmax + Tmin/2)-15.5 °C, where Tmax = daily maximum temperature and Tmin = daily minimum temperature. Heat unit calculations and rainfall collection began on the day of planting and ended on the day of harvest.**

^{y} **Irrigation regimes correspond to 2.7 mm d^{-1} (low), 5.4 mm d^{-1} (medium), and 8.1 mm d^{-1} (high).**

without significant cover crop residue present was not unexpected. Soil compaction is detrimental to cotton production (Vepraskas and Guthrie, 1992; Reeves and Mullins, 1995). Deep tillage performed with an implement, such as the paratill, can alleviate soil compaction, which allows deeper wetting of the soil profile (Pringle and Martin, 2003) and increased root volume that may also enhance nutrient uptake (Mullins et al., 1997).

The NST systems yielded 12% higher than CT systems during the 2003 growing season. This data indicates that the increase in seed cotton yield in 2003 could be attributed to the cover crop because the fall paratill operation had no effect on seed cotton yields. Interestingly, the difference between the CT and NST systems occurred during the last year of the experiment. Rhoton (2000) reported that beneficial changes in soil properties by adoption of no-tillage system may not be immediate, but can occur within 4 yr. This supports the increased seed cotton yields observed for NST systems in the final year (2003).

Seed cotton yields responded to the irrigation regimes in 2002 and 2003 (Fig. 1A and Table 2). The irrigation regime of 5.4 mm d^{-1} maximized seed cotton yields in the 2002 and 2003 growing seasons. The lower lint yields observed in 2002 across all irrigation regimes highlight the differences in rainfall and temperatures between growing seasons. Limited rainfall combined with warmer temperatures during the 2002 growing season depressed seed cotton yields across all irrigation regimes compared with the 2003 growing season and to a lesser extent with the 2001 growing season. Non-irrigated seed cotton yields measured in 2003 were greater than seed cotton yields measured in 2002 across all irrigation regimes, while the 2001 non-irrigated seed cotton yields were equivalent to seed cotton yields observed at the higher (5.4 and 8.1 mm d^{-1}) irrigation regimes in 2002 (Fig. 1A). Although irrigation had no significant effect on seed cotton yields in 2001, the highest yields were observed with the 2.7 mm d^{-1} irrigation regime.

Whole plant biomass. Whole plant biomass was affected by tillage systems only in 2003 (Table 2). The NST system produced 15% more whole plant biomass than the CT system, regardless of fall paratill operations. Fall paratilling had no effect on whole plant biomass. Although not significant, whole plant biomass was greater in the CT system than the NST system during 2001. This may be partially explained by the low cover crop biomass measured in the NST system resulting from an early termination date, which masked the benefit of the no-tillage system (Raper et al., 2000a; Raper et al., 2000b). The amount of biomass was small enough that cover crop biomass was considered non-existent during the 2001 growing season. In the absence of a cover crop, surface tillage in the CT plots trended towards greater whole plant biomass produced.

Table 2. Seed cotton yields, whole plant biomass, and leaf N concentrations measured in conventional and no surface tillage plots with and without fall paratill operation during the 2001 to 2003 growing seasons

	Seed cotton yield (kg ha^{-1})			Whole plant biomass (kg ha^{-1})			Leaf N (%)		
Treatment	2001	2002	2003	2001	2002	2003	2001	2002	2003
Conventional tillage (CT)									
No fall paratill (NFP)	3312	2724	3712	8429	6673	11,251	4.3	4.7	3.7
Fall paratill (FP)	3289	2683	3790	8483	6778	11,651	4.3	4.7	3.6
No surface tillage (NST)									
No fall paratill (NFP)	3060	2766	4224	7481	7023	13,810	3.9	4.2	3.4
Fall paratill (FP)	3329	2641	4190	7924	6847	12,563	4.1	4.5	3.6
				Analysis of variance ($P > F$)					
Tillage system	0.0423	0.7666	0.0004	0.1039	0.8115	0.0238	<0.0001	<0.0001	0.0427
CT vs. NST	0.1462		<0.0001			0.0067	<0.0001	<0.0001	0.0311
NFP vs. FP	0.0947		0.8081			0.4759	0.2223	0.0313	0.7283
Interaction	0.0503		0.5366			0.1718	0.3266	0.0154	0.0532
Irrigation	0.1116	<0.0001	0.0038	0.0620	<0.0001	0.0463	0.0042	0.0098	0.1558
Tillage x irrigation	0.5315	0.1542	0.7871	0.3503	0.3125	0.9597	0.3317	0.0172	0.4730

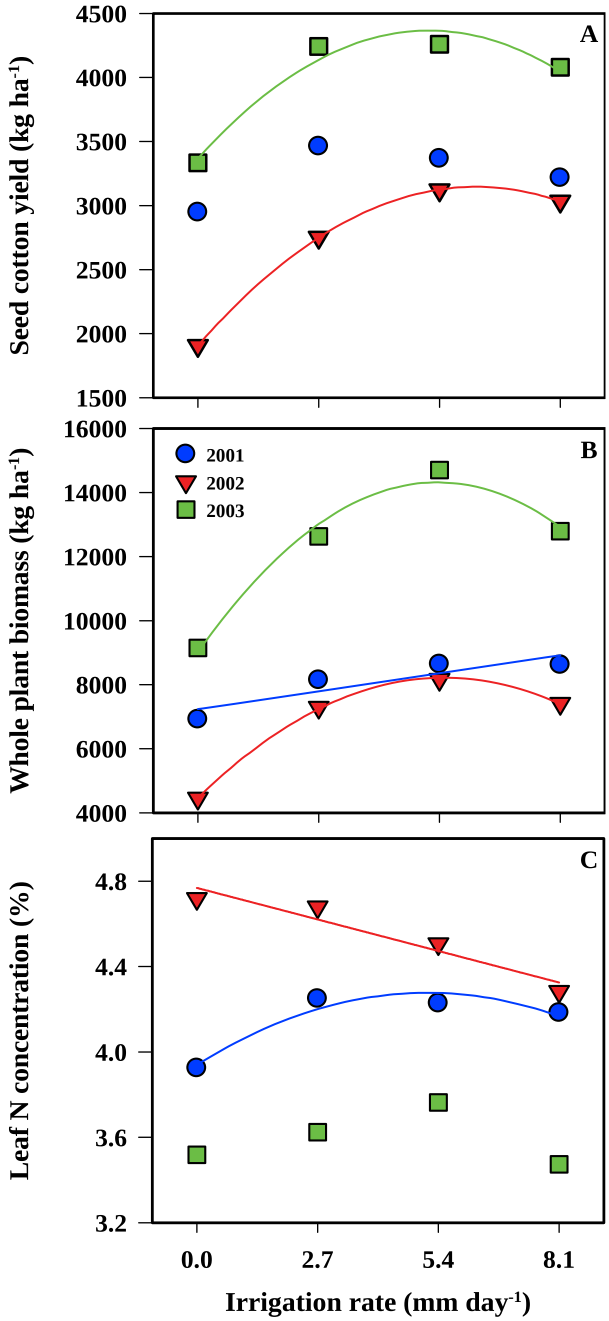

Figure 1. Seed cotton yield (A), whole plant biomass (B), and leaf N concentrations (C) measured across irrigation regimes during the 2001, 2002, and 2003 growing seasons.

Irrigation regime affected whole plant biomass production during each year of the experiment; however, the relationship between irrigation regime and whole plant biomass production varied across years (Fig. 1B). Linear and quadratic equations were used to describe the relationship between whole plant biomass and irrigation regime (Table 3). In 2001, whole plant biomass production was relatively constant across all irrigation regimes, and whole plant biomass produced in the non-irrigated plots was similar to plots receiving irrigation. The effect of irrigation regimes was more pronounced during the 2002 growing season, but whole plant biomass across all irrigation regimes was lower in 2002 compared with the 2003 growing season and to a lesser extent to the 2001 growing season (Fig. 1B). The reduction in whole plant growth could be attributed to the hot, dry conditions during the 2002 growing season (Table 1), although the cotton plants were irrigated and more water was applied during this dry growing season. Although growing conditions were much warmer and drier, biomass production appeared to maximize at 5.4 mm d^{-1} and decreased as irrigation increased. Whole plant biomass in 2003 was much greater than the previous two growing seasons. This may be attributed to higher precipitation with better distribution throughout the growing season, which created favorable growing conditions for cotton production. Non-irrigated whole plant biomass production measured in 2003 was higher than whole plant biomass production measured in the 2001 and 2002 growing seasons across all irrigation regimes. Even though growing conditions may have been more favorable, whole plant biomass production appeared to respond to increasing amounts of irrigation more in 2003 than in the 2001 and 2002 growing seasons. The 5.4 mm d^{-1} irrigation regime maximized whole plant biomass production, while 8.1 mm d^{-1} (the highest irrigation regime) decreased whole plant biomass production during the 2003 growing season.

Table 3. Regression equations for seed cotton yields, whole plant biomass, and leaf N concentrations as a function of irrigation regime for the 2001 to 2003 growing seasons

Year	Equation	R^2	Model $P > F^z$
Seed cotton yields			
2001	NS[y]		
2002	$Y = 1907 + 399x - 32.0x^2$	0.99	< 0.0001
2003	$Y = 3368 + 386x - 37.3x^2$	0.96	0.0033
Whole plant biomass			
2001	$Y = 7239 + 208x$	0.80	0.0186
2002	$Y = 4470 + 1359x - 123x^2$	0.99	< 0.0001
2003	$Y = 9019 + 1979x - 185x^2$	0.98	0.0414
Leaf N			
2001	$Y = 3.94 + 0.13x - 0.01x^2$	0.92	0.0076
2002	$Y = 4.77 - 0.05x$	0.93	0.0020
2003	NS[z]		

[z] Probability determined by trend comparisons.
[y] Irrigation regime not significant.

Leaf N concentration. Leaf N concentrations measured at mid-bloom were different across tillage systems for each year of the experiment (Table 2). Nitrogen concentrations were approximately 7% lower from the NST systems compared with the CT systems, averaged across all three years. The interaction between fall paratill operations and tillage systems was significant in the 2002 and 2003 growing seasons (Table 2). In 2002, leaf N concentrations following the fall paratill operation were equal to leaf N concentrations following no fall paratill operation in the CT system; however, fall paratillage increased leaf N concentrations ompared with no fall paratillage in the NST system. In 2003, leaf N concentrations were higher with no fall paratillage in the CT system, but leaf N concentrations were higher with the fall paratill operation in the NST system. The critical concentration of leaf N reported for the Southeast Cotton Belt is 4.1% at mid-bloom (Bell et al., 2003). In 2003, leaf N concentrations were lower than this critical value, but whole plant biomass measurements were greater during this growing season, which could have had a dilution effect on the leaf N concentrations. Another possible explanation was the plants in 2003 were more mature and may have been sampled slightly later than mid-bloom. Bell et al. (2003) reported lower leaf N concentrations as maturity increased.

Irrigation regime affected leaf N concentrations measured at mid-bloom during the 2001 and 2002 growing seasons (Fig. 1C and Table 2). In 2001, leaf N concentrations measured across all irrigation rates were higher than leaf N concentrations measured from the non-irrigated treatment. During the 2001 growing season, all irrigated leaf N concentrations were above the critical value of 4.1% at mid-bloom suggested by Bell et al. (2003). Leaf N concentrations decreased as irrigation regime increased during the 2002 growing season. All leaf N concentrations at mid-bloom were above the critical sufficiency value for cotton in the Southeast. The observed inverse relationship between leaf N concentration and irrigation regime occurred during the warmest and driest growing season encountered during the experiment. Boquet et al. (1993) showed that cotton plants were positively affected by a favorable climate, especially the amount and distribution of rainfall. Plants grew faster, were taller, produced more vegetative and reproductive growth, and increased harvestable boll development. As irrigation increases, the number of harvestable bolls potentially increases, which can cause a redistribution of N to developing bolls attributable to increases in boll sink strength (Bell et al., 2003).

An interaction ($P \leq 0.0172$) between tillage systems and irrigation regimes was observed during the 2002 growing season (drought year) for leaf N concentrations at mid-bloom (Fig. 2). The lowest leaf N concentrations were observed in the NST system without the fall paratill operation and decreased with irrigation. Although differences in whole plant biomass production were not significant, whole plant biomass was greatest for the NST system without fall paratillage (Table 2). The lowest whole plant biomass measured tended to be in the CT systems (Table 2), and the highest leaf N concentrations were observed in the CT systems.

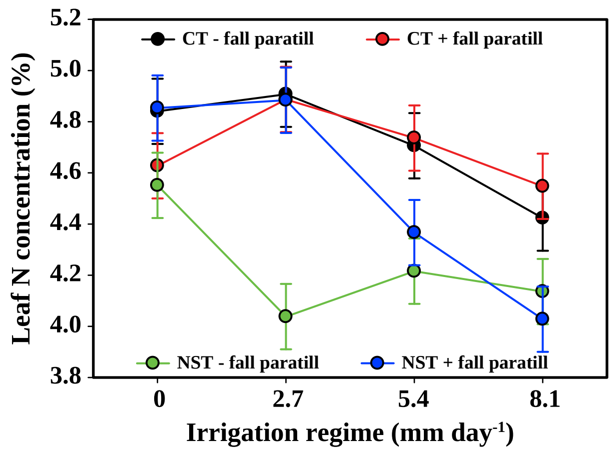

Figure 2. Leaf N concentrations at mid-bloom from four tillage systems across four irrigation regimes measured during the 2002 growing season.

Soil water content. Soil water contents measured at two different depths for the non-irrigated treatment and the 5.4 mm d^{-1} irrigation regime are shown in Table 4. Comparisons among tillage systems are shown for each irrigation regime within each depth zone. No attempt was made to compare between the non-irrigated and irrigated regime within a depth zone because of obvious differences in water application and the magnitude of the soil moisture values observed between the irrigation regimes (Table 4). In the shallow depth zone (0 to 20 cm), different soil water contents were only observed among tillage systems during the 2001 growing season in the no irrigation treatments. Soil water content measured following fall paratill operations, regardless of tillage system, were approximately 15% lower than soil water contents measured following no fall paratill. The lower soil water contents measured following fall paratill operations did not affect whole plant biomass, although biomass from NST systems was lower than CT systems (Table 2). The paratill operation was deeper than 20 cm, which likely allows water to infiltrate below the shallow soil water content measurement zone leading to lower soil water contents compared with the no fall paratill operation.

Soil water contents measured at the deeper soil depth (20 to 40 cm) exhibited differences between tillage systems in both the non-irrigated and the 5.4 mm d^{-1} irrigation regime during the 2001 growing season (Table 4). For both irrigation regimes, there was an interaction between the fall paratill operation and tillage system during the 2001 growing season. Fall paratill operations resulted in higher soil moisture contents in the CT system, while soil moisture contents following no fall paratillage were higher in the NST system. Differences in soil moisture contents in the CT system between fall paratill operations were greater than differences in soil moisture contents in the NST system between fall paratill operations.

The soil is in a very loose condition from the surface to the depth of tillage following a paratill operation when no additional surface tillage is performed. The paratill operation enables deeper rooting in a densely compacted soil (Raper et al., 2000b). Schwab et al. (2002) also observed lower soil water contents following a fall paratill operation or a subsoiled conservation system on these fine-textured soils. These researchers attributed the lower soil water contents to increased rooting, which would enable more soil water extraction. Increased rooting could occur in the shallow (0 to 20 cm) or deep (20 to 40 cm) depth, but it should be pointed out that the differences in soil water contents observed between tillage systems at both depths were only observed during one growing season. These differences coincided with the growing season that resulted in small amounts of cover crop biomass because of an early termination date. No comparisons were made between soil water contents at the shallow and deep soil depths; however, soil water contents were generally higher at the deeper soil depth.

Leaf stomatal conductance. Leaf stomatal conductance was measured during the 2001 and 2002 growing seasons. Stomatal conductance was not affected by tillage system or irrigation regime during the 2001 growing season, but both factors influenced stomatal conductance during the drought year of 2002, and the interaction between tillage and irrigation was nearly significant ($P \leq 0.1073$) (Table 5). Stomatal conductance was approximately 12% higher in the NST treatment with fall paratillage compared with CT without fall paratillage, and the 5.4 mm d^{-1} irrigation regime increased stomatal conductance approximately 15% compared with no irrigation. Although each treatment was not represented, increased stomatal conductance observed during the dry 2002 growing season did not correspond to increased seed cotton yields or whole plant biomass (Table 2). Prior et al. (2002) also found increased stomatal conductance values, as well as higher photosynthesis and transpiration rates, in NT systems compared with CT systems during drought periods.

Table 4. Mean volumetric soil water contents for two irrigation regimes measured from the shallow depth (0-20 cm) and deep depth (20-40 cm) within conventional and no surface tillage plots with and without fall paratillage during the 2001 to 2003 growing seasons

	0-20 cm depth						20-40 cm depth					
	0 mm d^{-1}			5.4 mm d^{-1}			0 mm d^{-1}			5.4 mm d^{-1}		
Treatment	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003
Conventional tillage (CT)							$m^3\ m^{-3}$					
No fall paratill (NFP)	0.195	0.088	0.147	0.211	0.120	0.184	0.326	0.251	0.318	0.322	0.272	0.311
Fall paratill (FP)	0.169	0.097	0.152	0.206	0.163	0.201	0.352	0.278	0.299	0.370	0.327	0.302
No surface tillage (NST)												
No fall paratill (NFP)	0.194	0.111	0.173	0.223	0.144	0.177	0.324	0.184	0.258	0.360	0.312	0.357
Fall paratill (FP)	0.160	0.142	0.166	0.181	0.173	0.204	0.317	0.260	0.281	0.354	0.312	0.253
							Analysis of variance ($P > F$)					
Tillage system	0.0581	0.5257	0.5890	0.3318	0.5401	0.1479	0.0385	0.3243	0.5831	0.0054	0.4566	0.1332
CT vs. NST	0.6144						0.0327			0.1053		
NFP vs. FP	0.0109						0.2356			0.0156		
Interaction	0.6241						0.0494			0.0060		

Table 5. Leaf stomatal conductance measured across two irrigation regimes (0 and 5.4 mm d^{-1}) and two tillage treatments (conventional tillage without fall paratill and no surface tillage with fall paratill) during the 2001 and 2002 growing seasons

	2001 (mmol m^{-2} s^{-1})			2002 (mmol m^{-2} s^{-1})		
Treatment	**0 mm d^{-1}**	**5.4 mm d^{-1}**	**Mean**	**0 mm d^{-1}**	**5.4 mm d^{-1}**	**Mean**
Conventional tillage No fall paratill	588.0	511.2	549.5	444.5	563.0	502.7
No surface tillage Fall paratill	418.4	442.3	430.3	542.5	608.0	574.9
Mean	501.0	476.7		493.0	585.0	
	Analysis of variance ($P > F$)					
Tillage	0.1432			0.0017		
Irrigation	0.7475			0.0004		
Tillage x Irrigation	0.5224			0.1073		

CONCLUSIONS

Tillage system and irrigation regimes influenced seed cotton yields, whole plant biomass production, leaf N concentrations measured at mid-bloom, soil water contents, and leaf stomatal conductance. An interaction was observed between tillage systems and irrigation regimes for leaf N concentrations at mid-bloom and a nearly significant interaction for leaf stomatal conductance during the warmer and drier 2002 growing season. Seed cotton yields responded to fall paratill operations in 2001 and tillage systems in 2003, while an irrigation regime of 5.4 mm d^{-1} maximized seed cotton yields in 2002 and 2003. The NST system increased whole plant biomass production 15% during the 2003 growing season. Irrigation regime affected whole plant biomass all three years with whole plant biomass production generally maximized at 5.4 mm d^{-1}. Leaf N concentrations were approximately 7% lower from the NST systems compared with the CT systems when averaged across all three years, but irrigation regime only influenced leaf N concentrations during the 2001 and 2002 growing seasons. Soil water contents were influenced by tillage systems, but only during the growing season with little cover crop biomass production. Leaf stomatal conductance was 12% higher in the NST treatment with fall paratillage compared with CT without fall paratillage, and the 5.4 mm d^{-1} irrigation regime increased stomatal conductance approximately 15% compared with no irrigation. These results demonstrate how tillage system and irrigation regime can influence plant and soil characteristics in a cotton production system on fine-textured soils of the Tennessee Valley. Growers that adopt irrigation into their existing cotton production system are advised to continue using a conservation system with a cover on fine-textured soils of the Tennessee Valley.

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DISCLAIMER

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA or Auburn University and does not imply approval of a product to the exclusion of others that may be suitable.

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