Effects of Conventional Tillage and No-Tillage on Cotton Gas Exchange in Standard and Ultra-Narrow Row Systems

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ABSTRACT

The availability of soil water to crops is a major limitation to crop production. Use of conservation tillage systems enhances soil residue cover, water infiltration and reduces evaporative soil water loss. Our objective was to measure cotton (*Gossypium hirsutum* L.) leaf level photosynthesis, stomatal conductance, and transpiration during reproductive growth under different row spacing and tillage conditions on a Norfolk loamy sand (Typic Kandiudults; FAO classification Luxic Ferralsols) in east-central AL. Gas exchange measurements occurred in the summer of 1999, 2000, and 2001. The study used a split-plot design replicated four times with row spacing (standard 40 inch row and ultra-narrow row) as main plots and tillage systems (conventional and no-tillage) as subplots. In 1999, standard row cotton under conventional tillage maintained higher photosynthetic rates during early reproductive growth when soil water was not limiting; the opposite pattern occurred latter during drought cycles. During drought periods, photosynthetic rates were higher in no-tillage systems especially under standard row conditions. In 2000 and 2001, the benefits of no-tillage were sporadic due to frequent rainfall events occurring throughout reproductive growth. In 2000, ultra-narrow row cotton consistently had lower photosynthesis rates compared to standard row cotton; lesser degrees of this occurred in 1999 and 2001. In all years, stomatal conductance and transpiration measurements generally mirrored those of photosynthesis. These results suggest that during periods of infrequent rainfall, high rates of photosynthesis can be maintained in no-tillage systems that conserved soil water needed during critical reproductive stages such as boll filling.

KEYWORDS

Residue management, soil water loss, photosynthesis, transpiration, stomatal conductance

INTRODUCTION

Plant growth is often reduced under soil water deficits owing to decreases in photosynthesis, stomatal aperture, and water potential (Boyer, 1982). In particular, cotton grown on loamy sand soils is highly susceptible to periods of soil water deficits due to low soil water holding capacity. Furthermore, periods of soil water deficits often occur during critical reproductive stages when demand for water is high. Adoption of conservation tillage systems that maintain high levels of residue cover can help mitigate such problems by enhancing soil C storage and soil water holding capacity, reducing evaporative soil water loss, and improving soil water infiltration (thereby reducing water and nutrient runoff). Recent work at the National Soil Dynamics Laboratory has shown that planting cotton with a grain drill in ultra-narrow rows (UNRC) to be a very promising cotton production system (Reeves *et al*., 2000); however, little information exists on the physiological response of cotton in this production system. The objective of this study was to quantify the impact of row spacing (standard *vs*. ultra-narrow row) and tillage systems (conventional *vs*. conservation tillage) on gas exchange of cotton during reproductive growth.

MATERIALS AND METHODS

This study is a component of a larger farming systems experiment (Reeves *et al.*, 2000), which was established on a site that had been in conventional and conservation tillage for over 10 years (Reeves *et al*., 1992; Torbert *et al*., 1996). The cotton systems evaluated (summer of 1999, 2000, and 2001) were standard row (40 inch) and ultra-narrow row (8 inch) under conventional and no-tillage using a black oat (*Avena strigosa* Schreb.) - rye (*Secale cereale* L.) cover crop mix on a Norfolk loamy sand at the E.V. Smith

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Research Center of the Alabama Agricultural Experiment Station in east central Alabama, U.S.A. (N 32˚ 25.467', W 85˚ 53.403'). The cover crop was killed 2-3 weeks prior to planting using a mechanical roller and glyphosate; weeds were also controlled with glyphosate. Cotton seeds (PayMaster 1220) were sown in early May of each year. The study used a split-plot design replicated four times with row spacing as main plots and tillage systems as subplots. Extension recommendations were used in managing both the soil and crop. Fertilizer application rates were based on standard soil test.

During reproductive growth, leaf level measurements (i.e., photosynthesis, stomatal conductance, and transpiration) were made twice a week using a LI-6400 Portable Photosynthesis System (LI-COR, Inc., Lincoln, NE). Measurements were taken at midday on six different randomly chosen leaves (fully expanded, sun exposed leaves at the canopy top) per plot and were initiated near first flower (mid July, ~DOY 197) and terminated towards the end of August (~DOY 232), approximately ten days before defoliant application. Also during this period, soil water status was monitored at two depths (20 and 40 cm) using time domain reflectometry (data not shown). The study site had a total of 1.96, 0.05, and 1.74 inches of rainfall during the two weeks prior to study initiation in each respective year. During the 1999 study period, one irrigation and six rainfall events occurred (total of 2.5 inches). During the 2000 study period, one irrigation and ten rainfall events occurred (total of 4.07 inches). During the 2001 study period, fourteen rainfall events occurred (total of 4.77 inches).

Statistical analyses of data were performed using the Mixed procedure of the Statistical Analysis System (Littell *et al*., 1996). A significance level of $P < 0.10$ was established *a priori*.

RESULTS AND DISCUSSION

Summer of 1999

At the beginning of the study (DOY 197, 201, 222) the main effects of row spacing and tillage were often significant. Gas exchange measurements were generally high since soil moisture conditions were optimum due to rainfall events two weeks prior to (total of 1.96 inches) and during this period (Fig. 1A). Photosynthesis, stomatal conductance, and transpiration were higher for cotton grown in standard rows and were lower under no-tillage conditions (Figs. 1B - D). The lower values noted in the ultra-narrow systems was not surprising since higher plant density (due to closer row spacing) promotes more plant to plant competition for belowground resources (i.e., water and nutrients) which results in a smaller or shorter crop when compared to standard row cotton. These results also suggest no advantage of no-tillage for standard row cotton under conditions of adequate soil moisture. However, it is important to note that although standard row cotton under conventional tillage initially exhibited higher rates of photosynthesis, this competitive advantage rapidly diminished during a water stress period due to larger plants being more susceptible to lack of available soil water.

Following DOY 203, soil water depletion was rapid due to extensive boll development and lack of rainfall (Fig. 1A).

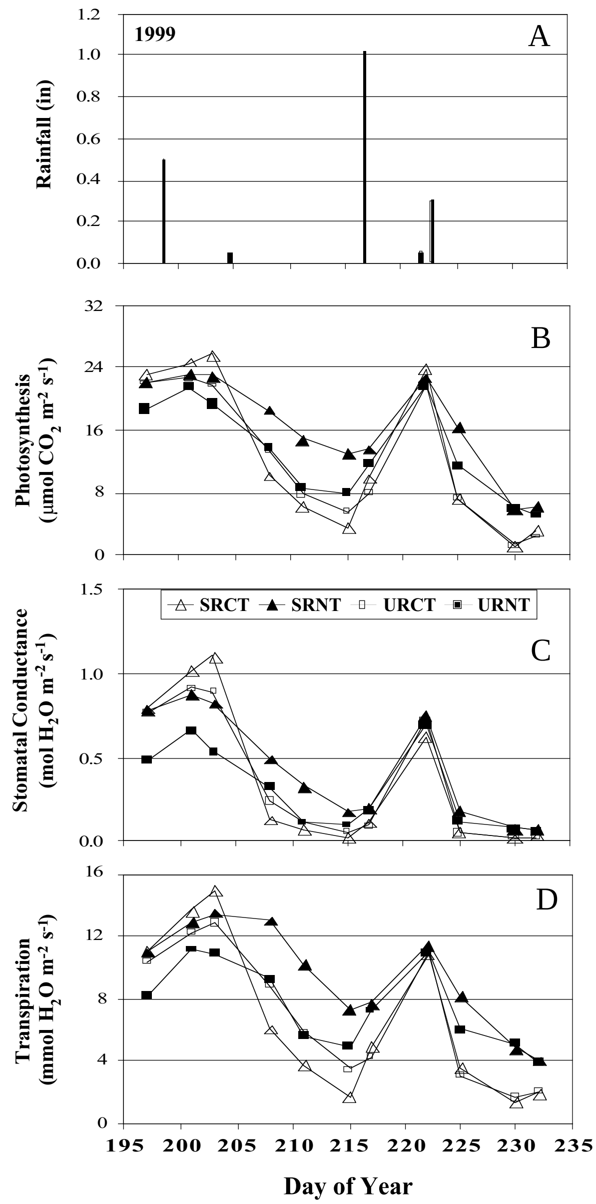

Fig. 1. Rainfall (A) and leaf level photosynthesis (B), stomatal conductance (C), and transpiration (D) for cotton during repro-ductive growth in 1999 as affected by row spacing (SR = standard row; UR = ultra-narrow row) and tillage (CT = conventional tillage; NT = no-tillage).

During this time (DOY 208, 211, 215), the main effects of tillage and row spacing by tillage interactions were significant for photosynthesis, stomatal conductance, and transpiration. In general, these measures were highest in the standard row system under no-tillage, lowest in the standard row system under conventional tillage, and somewhat intermediate for the ultra-narrow system regardless of tillage system. Dry, hot conditions during this period contributed to the shedding of late-developing bolls, especially under conventional tillage in the standard row system.

Measurements taken on DOY 217 and 222 followed irrigation/rainfall events. On DOY 217, the main effects of tillage were significant for all variables. Under no-tillage conditions, photosynthesis, stomatal conductance, and transpiration were increased; no differences were noted on DOY 222. Measurements taken on DOY 225, 230, and 232 show similar patterns as observed on DOY 217. At all dates, photosynthesis, stomatal conductance, and transpiration were increased due to optimum soil moisture conditions found under no-tillage conditions.

Summer of 2000

Gas exchange measurements were initially very low (Figs. 2B - D) due to inadequate soil moisture conditions caused by lack of rainfall (Fig. 2A). The total amount of rainfall in the two weeks preceding the start of gas exchange measurements was 0.05 inches. On DOY 200 and 202, a significant interaction indicated that photosynthesis, stomatal conductance, and transpiration were highest in no-tillage cotton grown in standard rows and were lower in the ultra-narrow system especially under no-tillage conditions.

On DOY 206, gas exchange measurements increased to a high level due to irrigation and rainfall events (total of 1.8 inches) and remained high for an extended period (i.e., DOY 206 to 224) due to eight rainfall events (total of 2.12 inches; Fig. 2A). During this period, the main effects of row spacing were often significant for photosynthesis (DOY 206, 208, 213, 221, and 224), stomatal conductance (DOY 206, 208, 213, and 221), and transpiration (DOY 206, 208, and 221). In general, these measures were typically higher for the standard row system compared to the ultra-row system.

After DOY 224, gas exchange measurements dropped rapidly due to minimal rainfall (Fig. 2A) and remained low until study termination (DOY 235). As seen previously, the main effects of row spacing were significant; the standard row system exhibited higher values of photosynthesis (DOY 224, 228, and 231), stomatal conductance (DOY 228 and 231), and transpiration (DOY 228 and 231) compared to the ultra-row system. Under no-tillage conditions, photosynthesis and stomatal conductance were increased on DOY 224; similar trends were noted on DOY 228. No treatment effects were observed on the final study day.

Summer of 2001

Initial gas exchange measurements in 2001 were generally high (Fig. 3B - D) since soil moisture conditions were optimum due to rainfall/irrigation events (total of 1.74 inches) two weeks prior to this period. In comparison, the amount of rainfall two weeks before measurement initiation was 0.05 and 1.96 inches for years 1999 and 2000, respectively. Due to adequate soil moisture conditions,

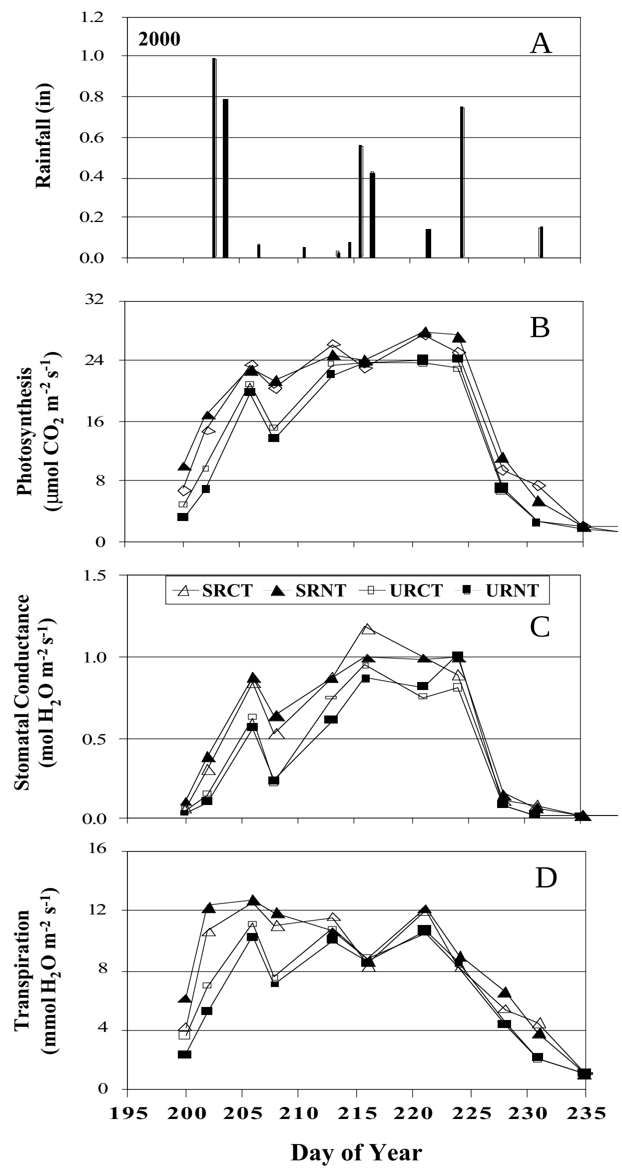

Fig. 2. Rainfall (A) and leaf level photosynthesis (B), stomatal conductance (C), and transpiration (D) for cotton during repro-ductive growth in 2000 as affected by row spacing (SR = standard row; UR = ultra-narrow row) and tillage (CT = conventional tillage; NT = no-tillage).

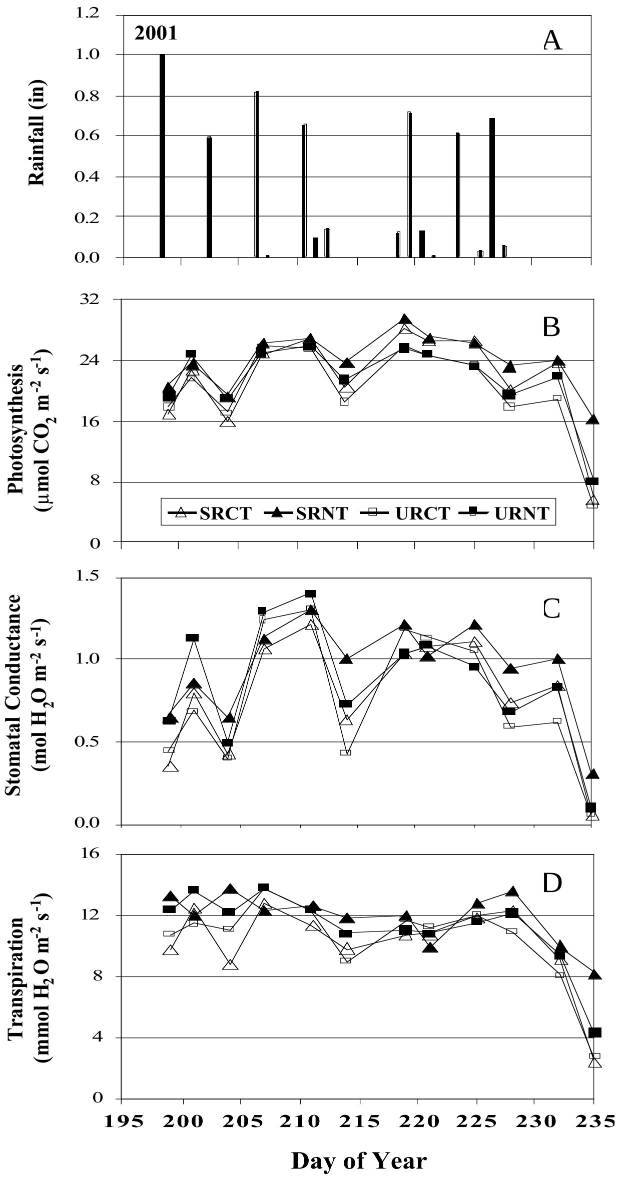

Fig. 3. Rainfall (A) and leaf level photosynthesis (B), stomatal conductance (C), and transpiration (D) for cotton during repro-ductive growth in 2001 as affected by row spacing (SR = standard row; UR = ultra-narrow row) and tillage (CT = conventional tillage; NT = no-tillage).

initial gas exchange measurement for years 1999 (Figs. 1B - D) and 2001 (Figs. 3B - D) were similar to each other, but much higher than year 2000 (Figs. 2B - D). However, it is important to note that most of the measurements in year 2000 and 2001 were consistently high, and similar to each other, due to the frequent rainfall events that occurred over most of the sampling period in both years (i.e., between DOY 204 to 225; Figs. 2A and 3A); this was in stark contrast to the sporadic rainfall patterns observed in 1999 (Fig. 1A).

During the first week of sampling in 2000 (DOY 199 to 204), photosynthesis tended to be slightly higher under no-tillage conditions. Stomatal conductance and transpiration exhibited similar patterns, but were more variable. For example, on DOY 201 a significant interaction was noted indicating that these measurements were higher for cotton grown in ultra-narrow rows under no-tillage conditions.

On DOY 207 and 211, treatment effects were negligible, except for stomatal conductance on DOY 207, which was higher in the ultra-narrow row treatments. On DOY 214, photosynthesis, stomatal conductance, and transpiration tended to be higher under no-tillage conditions. On this same day, the main effects of row spacing were significant for stomatal conductance, which was lower in the ultra-narrow row systems.

During the period covering DOY 219 to 232, photosynthesis exhibited the most consistent treatment effects relative to the other measures, which were more variable. During this period, the main effect of row spacing was often significant; photosynthesis was lower in the ultra-row system compared to standard row cotton. On DOY 228, the main effect of tillage was significant for photosynthesis and stomatal conductance; these measures were higher under no-tillage. On the final sample date (DOY 235), gas exchange measures dropped due to declining soil moisture. A significant row spacing by tillage interaction was noted for all variables. Photosynthesis, stomatal conductance, and transpiration were highest in the standard row system under no-tillage, while the other treatment combinations were similar to each other.

CONCLUSIONS

Our findings suggest that management schemes favoring surface residue accumulation could help conserve soil water. The benefits of no-tillage are most probable in years experiencing sporadic precipitation patterns throughout reproductive growth as seen in the first year of study (1999). Reflective of optimum soil water status, no-tillage cotton exhibits high stomatal conductance that contributes to a higher transpirational loss of water while allowing for good CO_2 uptake required to maintain high rates of photosynthesis. In years exhibiting frequent rainfall during reproductive growth (e.g., years 2000 and 2001), the benefits of no-tillage can occur, but are less frequent. Compared to standard row cotton, ultra-narrow cotton tends to exhibit lower rates of photosynthesis and the benefits of no-tillage are less pronounced in this system. Faster canopy closure and greater plant-to-plant competition for soil resources are contributing factors that may explain these differential responses. Adoption of no-tillage practices can help minimize detrimental impacts of water stress on cotton grown in coarse textured soils.

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LITERATURE CITED

Boyer, J.S. 1982. Plant productivity and environment. Sci. 218:443-448.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS System for Mixed Models, SAS Institute, Inc., Cary, NC. 633 p.

Reeves, D.W., H.H. Rogers, J.A. Droppers, S.A. Prior, and J.B. Powell. 1992. Wheel traffic effects on corn as influenced by tillage systems. Soil Tillage Res. 23:177-192.

Reeves, D. W., D. P. Delaney, and R. M. Durbin. 2000. Farming systems for ultra-narrow row cotton. Beltwide Cotton Conf., January 4-8, 2000. San Antonio, TX, Vol. 2, pp. 1415-1416. National Cotton Council.

Torbert, H.A., D.W. Reeves, and R.L. Mulvaney. 1996. Winter legume cover crop benefits to corn: Rotation versus fixed nitrogen effects. Agron. J. 88:527-535.