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REGULAR ARTICLE

Cotton gas exchange response to standard and ultra-narrow row systems under conventional and no-tillage

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ABSTRACT

The availability of soil water to crops is a major limitation to crop production. We measured soil moisture and cotton (*Gossypium hirsutum* L.) leaf level photosynthesis, stomatal conductance, and transpiration during reproductive growth under different row spacing [standard 102 cm row (SR) and ultra-narrow row of 20 cm (UNR)] and tillage [conventional (CT) and no tillage (NT)] conditions during the summers of 1999 to 2001. In 1999, SR cotton under CT maintained higher photosynthetic rates during early reproductive growth when soil water was not limiting. However, during dry periods photosynthetic rates were higher in NT especially under SR. The benefits of NT were sporadic in 2000 and 2001 due to frequent rainfall. Cotton in UNR typically had lower photosynthesis compared to SR. Stomatal conductance and transpiration measurements generally mirrored those of photosynthesis. The results suggest that during periods of infrequent rainfall, photosynthesis can be maintained in NT since soil water is conserved during critical reproductive stages.

Key Words: *tillage; soil water content; photosynthesis; transpiration; stomatal conductance.*

INTRODUCTION

Water availability for cotton production is critical. This is especially important in coarse soils, such as loamy sands, since they have a low water holding capacity. Cotton grown in these soils is susceptible to periods of water deficit during times of high water demand, such as reproductive growth. Plant growth is often reduced under soil water deficit due to decreases in photosynthesis, stomatal aperture, and water potential (Boyer, 1982). Further, soils in the southeastern U.S. typically have a low soil organic carbon content, which tends to reduce water infiltration and retention.

Conservation agricultural systems have been shown to improve soil organic carbon content and soil physical properties, increasing plant-available water and water use efficiency in cotton systems (Tennakoon and Hulugalle, 2006). Two key components of conservation agriculture are no-till or reduced tillage and winter cover crops. No-till and reduced tillage practices minimize soil carbon losses by reducing surface soil disturbance, while winter cover crops increase soil organic carbon content by increasing the amount of organic residue returned to the soil surface and deeper in the soil profile in the form of decomposing roots (Raper et al., 2000; Ess et al., 1998). Additionally, the winter cover crop residue left on the soil surface serves as a mulch, reducing evaporative losses (Reicosky et al., 1999). Nevertheless, improving the organic content of soil in the southeastern U.S. can take several years due to relatively high temperatures and rainfall.

Cotton grown in UNR might provide some benefits, including better water utilization and increased yield (Vories and Glover, 2006; Larson et al., 2005; Nichols et al., 2004). Cotton plants in UNR systems use less energy for vegetative growth as plants tend to be shorter and have fewer nodes (Nichols et al., 2004; Vories and Glover, 2006). Further, cotton plants concentrate their boll production in upper positions, indicating an earlier maturing crop (Vories and Glover, 2006).

Sowing cotton in UNR has the potential to enhance cotton production systems. The use of conservation agriculture systems can further improve cotton production in UNR. However, little information exists on the physiological response of cotton in this production system. Therefore, the objective of this study was to quantify the impact of row spacing (standard vs. ultra-narrow rows) and tillage system (conventional vs. conservation tillage) on the gas exchange of cotton during reproductive growth.

MATERIALS AND METHODS

The study was conducted in the Field Crops Unit of the E.V. Smith Research Center near Shorter, Alabama, U.S.A. (N 32º 25.467', W 85º 53.403') during the summers of 1999, 2000 and 2001. The site was part of a farming systems experiment (Reeves and Delaney, 2002) and the plot area used in this experiment had been in conventional and conservation tillage for at least 10 years prior to the start of this work (Reeves et al., 1992). The soil was a Norfolk loamy sand (Fine-loamy, kaolinitic, thermic Typic Kandiudults). A sandy surface layer and weak structure throughout its profile characterizes this soil.

Two cotton row spacing systems were evaluated, standard row spacing (SR) of 102 cm and ultra-narrow row (UNR) of 20 cm. Tillage treatments were conventional tillage (CT) and no-tillage (NT) that incorporated the use of a winter cover crop mix of black oat (*Avena strigosa* Schreb.) and rye (*Secale cereale* L.). The cover crop was sown in the fall and was terminated in the spring with glyphosate and flattened with a mechanical roller 2-3 weeks prior to planting cotton (Kornecki et al., 2009; Kornecki et al., 2006). Double-stacked cotton (PayMaster 1220) was sown in early May each year. Fertilizer and pesticide applications were based on recommendations of the Alabama Cooperative Extension Service.

Soil water content (θ_v) was measured weekly during the reproductive growth of the cotton with using time-domain reflectometry (TDR) using a Tektronix's 1502B cable tester (Tektronix Inc, Beaverton, OR). The soil moisture sensors had 40 cm long stainless steel rods, with a rod spacing of 3.0 cm. The sensors were installed vertically from the soil surface for a reading depth of 0 to 40 cm. Sensors were placed at 10 cm from the cotton row. Measurements were converted to volumetric water content values using Topp's equation (Topp et al., 1980).

Leaf transpiration, stomatal conductance and photosynthesis were measured twice a week during cotton reproductive growth with a LI-6400 Portable Photosynthesis System (LICOR, Inc., Lincoln, NE). Data were collected from the abaxial surface of the uppermost, fully developed leaf of six random plants from each plot. Readings were taken as close to solar noon as possible. Data collection started near first flower and ended approximately 10 d before defoliant application in late August.

The treatments were arranged in a completely randomized block design (r = 4) with a split-plot restriction, in which row spacing was the main plot and tillage the sub-plot. Plots were 6.1 by 21.3 meters in size. Data were analyzed with a mixed procedure using the Statistical Analysis System (Littell et al., 1996) with replication and row spacing x replication considered as random effects. A significance level of $p \leq 0.10$ was established *a priori*.

RESULTS

RAINFALL

Rainfall during cotton reproductive growth varied considerably among years (Fig. 1). In 1999 there were fifteen rainfall events recorded during the reproductive stage of cotton for a total of 124.1 mm. Fourteen rainfall events occurred in 2000 for a total of 97.9 mm and in 2001 there were fifteen rainfall events during reproductive growth (117.3 mm).

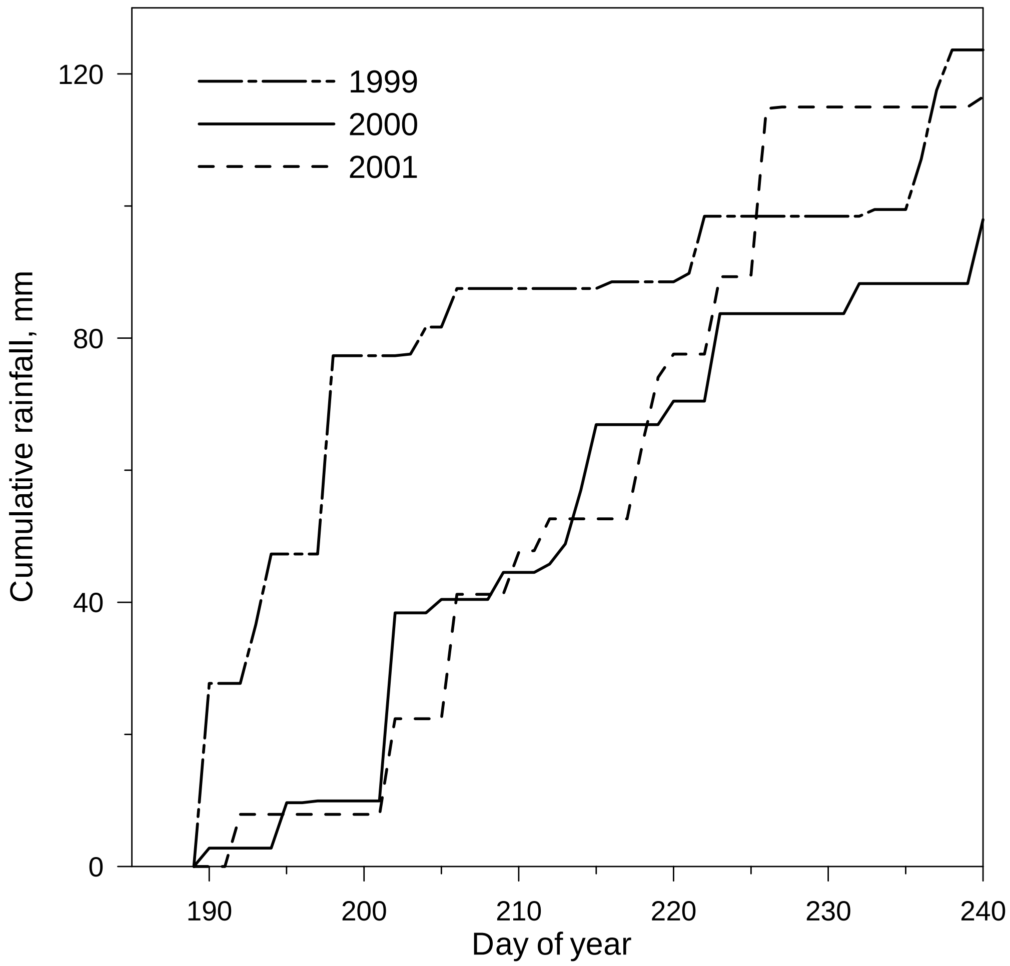

Figure 1. Cumulative rainfall during reproductive growth of cotton in the 1999-2001 growing seasons.

SOIL WATER CONTENT

Soil moisture measurements during the three years of the study typically ranged between 0.05 and 0.15 m^3 m^{-3} (Fig. 2). Although these values appear somewhat low, this is expected since the Norfolk soil series are well drained and have a moderately high saturated hydraulic conductivity (USDA-NRCS). However, in the 1999 season θ_v values were high early in the season, due to significant rainfall (Fig. 1), but θ_v values decreased quickly in all treatments (Fig. 2).

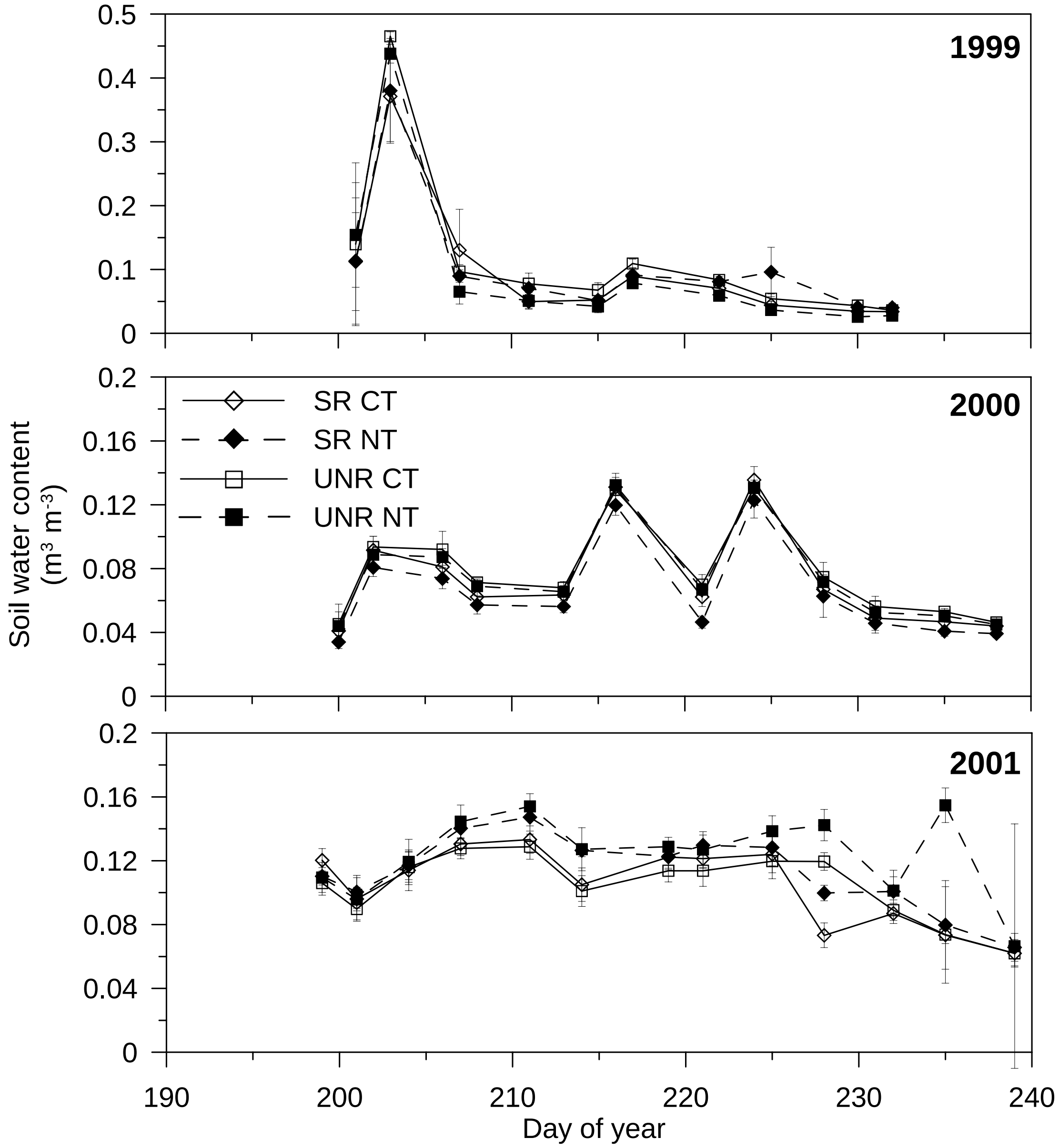

Figure 2. Volumetric soil water content for cotton grown in 102 cm standard row spacing (SR) and 20 cm ultra-narrow row spacing (UNR) under conventional (CT) and no-tillage (NT) during the reproductive growth stage in the 1999-2001 seasons. (Note that the scale on the y-axis for 1999 is larger than for the other two years). Error bars indicate the standard error.

Significant differences in θ_v among treatments were small. There was a row-spacing by tillage interaction (P = 0.04) at day 225 in 1999 (Fig. 2). This interaction can mainly be attributed to a greater θ_v for SR under NT at this sampling time. However, during most of the 1999 season there was a trend of greater θ_v observed with UNR under CT.

Row spacing significantly affected θ_v at days 206 and 235 in 2000 (Fig. 2). Soil water content was significantly greater for UNR compared to SR on day 206 (P = 0.10) and day 235 (P = 0.06). There was a trend for a greater θ_v with UNR during most of the 2000 growing season.

Tillage had a significant impact (P = 0.06) on θ_v on day 214 during the 2001 season (Fig. 2). The NT systems had significantly greater θ_v on day 214. This was also the trend during most of the reproductive growth of the cotton in 2001. However, at day 228 row spacing had a significant impact (P = 0.05) on θ_v. Similar to the previous year, θ_v was greater with UNR than SR. Nevertheless, tillage appeared to have a greater impact on θ_v in 2001 than row spacing.

STOMATAL CONDUCTANCE

Stomatal conductance was mainly affected by row spacing, although tillage had some effect and its interaction with row spacing was observed at times. Generally, stomatal conductance was greater with SR compared to UNR, and tended to be greater in NT. Early in the reproductive season stomatal conductance was higher in 1999 than in 2000 and 2001 (Fig. 3). This can be attributed to greater rainfall (Fig. 1) and θ_v (Fig. 2) early in 1999. However, θv declined rapidly due to boll development. Stomatal conductance at days 208, 211 and 215 was significantly affected by row spacing x tillage interaction (P = 0.10, 0.09 and 0.04, respectively). Generally, stomatal conductance was greatest in SR with NT, lowest with CT, and somewhere in between for UNR systems regardless of tillage. Similarly, there was a significant row spacing x tillage interaction on days 200 and 202 in 2000 (P = 0.07 and 0.10, respectively). Stomatal conductance was greater in SR with NT and lower in UNR systems. However, in 2001 a significant (P = 0.04) row spacing by tillage interaction at day 201 was observed in UNR with NT, but a different effect was noted at day 235 when conductance was significantly greater (P = 0.07) in SR with NT.

The main effects of row spacing and tillage had some significant effect on stomatal conductance. Stomatal conductance was significantly greater with SR than UNR at days 206, 208, 213, 216, 221, 228 and 231 (P = 0.01, <0.01, 0.08, 0.04, 0.03, 0.04 and 0.02, respectively) in 2000, and on day 207 (P = 0.04) in 2001. Row spacing did not have a significant impact on stomatal conductance at any other sampling date. However, there was a trend of greater stomatal conductance with SR.

Stomatal conductance was significantly greater with NT at days 208, 211, 215, 217, 225, 230 and 232 (P = 0.02, 0.09, <0.01, <0.01, <0.01, <0.01 and <0.01, respectively) in 1999, day 224 and 228 (P = 0.10 and 0.09, respectively) in 2000, and days 199, 201, 204, 214, 228 and 235 in 2001 (P = 0.01, 0.01, 0.05, 0.04, 0.06 and 0.06, respectively). However, early in the 1999 season (days 197, 201 and 203) stomatal conductance was significantly greater (P = 0.10, 0.04 and 0.01, respectively) for CT than NT. This effect can be attributed to the greater θ_v early in the 1999 season (Fig. 2). Nevertheless, there was a general trend of greater stomatal conductance with NT than CT over the three-year study.

TRANSPIRATION

As with stomatal conductance, transpiration generally was greater with SR and NT (Fig. 4). There was a significant interaction of row spacing by tillage on days 208, 211, and 215 in 1999 (P = 0.04, 0.04 and 0.02, respectively), and in 2000 during days 200 and 202 (P = 0.05 and 0.03, respectively). Transpiration was higher in cotton growing in SR with NT and lowest for SR with CT. Contrary to these findings, a significant interaction in 2001 during day 201 (P = 0.09) indicated greater transpiration with UNR and NT.

Main treatment effects had a significant impact on transpiration. Standard row spacing had significantly higher transpiration rates at day 203 (P = 0.07) in 1999, and at days 200, 206, 208, 221, 228 and 231 in 2000 (P = 0.02, 0.03, <0.01, 0.02, 0.05 and 0.04, respectively). However, tillage appeared to have more impact on transpiration. Transpiration was significantly higher with NT at days 208, 211, 215, 217, 225, 230 and 232 (P = 0.02, 0.05, <0.01, <0.01, <0.01, <0.01 and <0.01, respectively) in 1999, and days 199 and 204 in 2001 (P = 0.01 and 0.04).

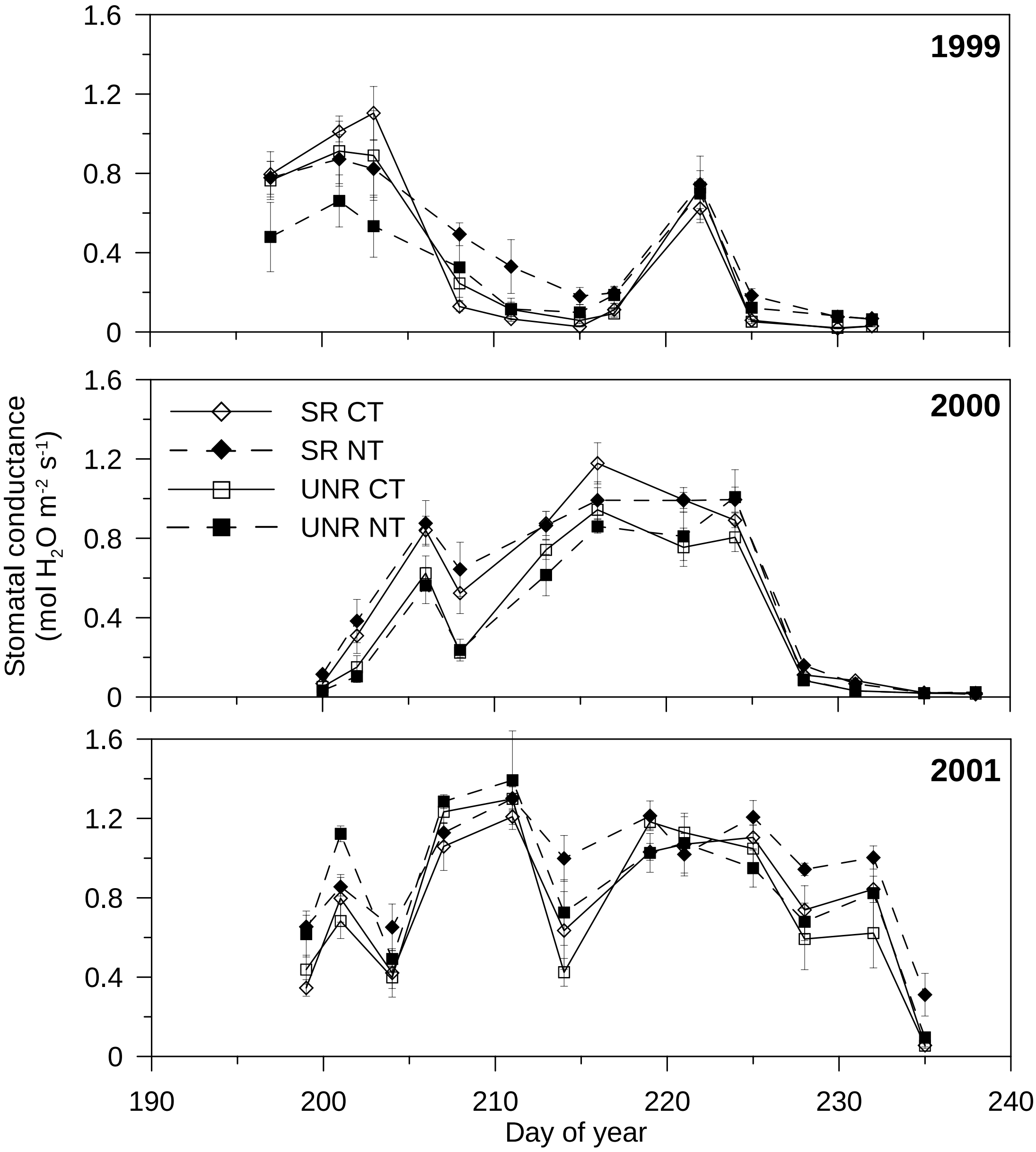

Figure 3. Stomatal conductance for cotton grown in 102 cm standard row spacing (SR) and 20 cm ultra-narrow row spacing (UNR) under conventional (CT) and no-tillage (NT) during the reproductive growth stage in the 1999-2001 seasons. Error bars indicate the standard error.

PHOTOSYNTHESIS

Since the main substrates during photosynthesis are CO_2 and water, adequate water availability is crucial for optimal plant development and reproduction. Therefore, agricultural management practices that affect plant environmental conditions will impact photosynthesis and thus, plant growth and yield. Row spacing and tillage practices significantly affected cotton photosynthesis. The row spacing by tillage interaction was significant at days 208 and 215 in 1999 (P = 0.02 and 0.10, respectively), days 200 and 202 in 2000 (P = 0.07 and <0.01, respectively), and day 235 in 2001 (P = 0.03) (Fig. 5). As with stomatal conductance and transpiration, photosynthesis was higher in SR with NT compared with the other treatments. The exception was day 201 in 2001 where photosynthesis was greatest in cotton grown in UNR and NT.

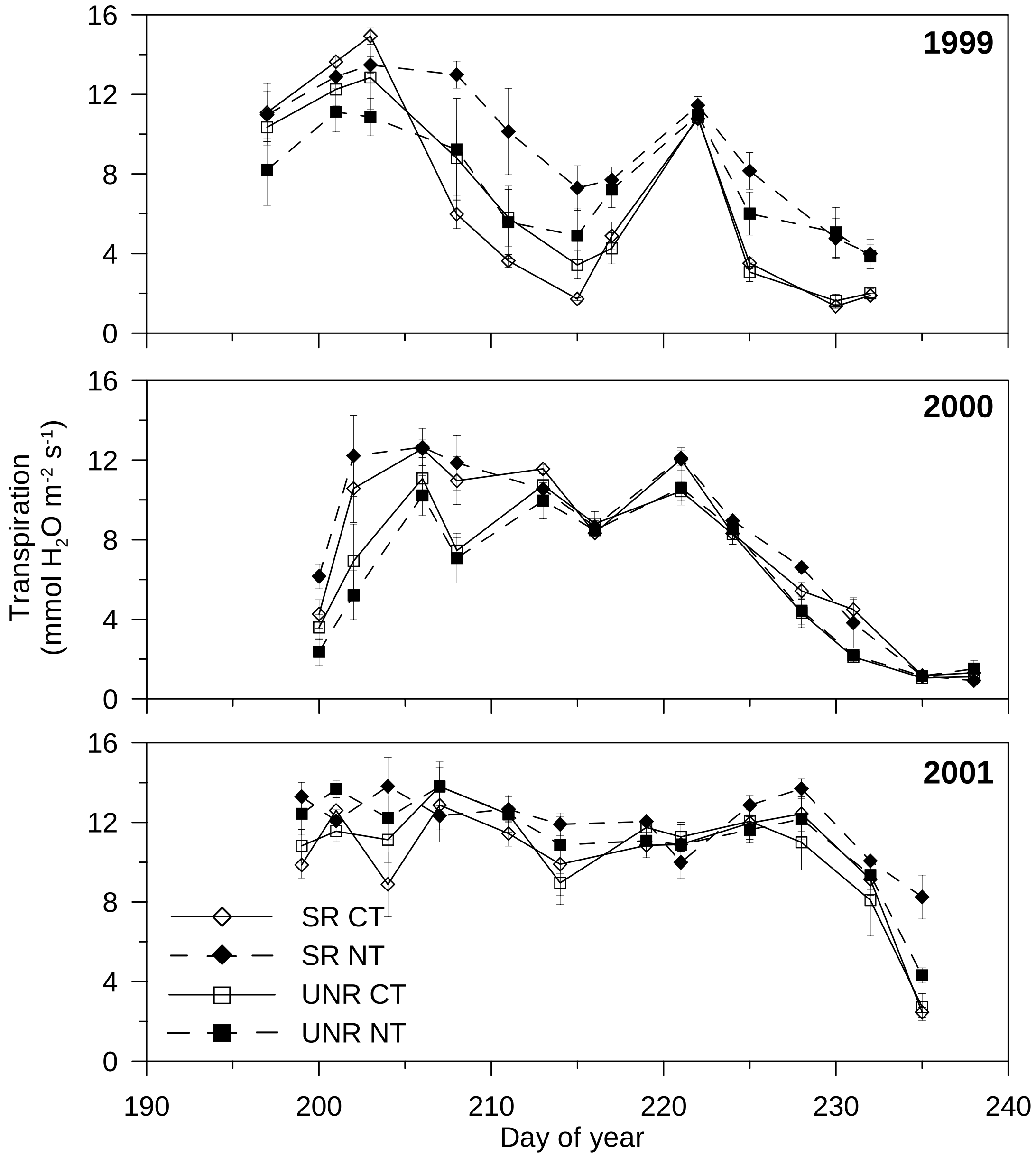

Figure 4. Transpiration of cotton grown in 102 cm standard row spacing (SR) and 20 cm ultra-narrow row spacing (UNR) under conventional (CT) and no-tillage (NT) during the reproductive growth stage in the 1999-2001 seasons. Error bars indicate the standard error.

The main effect of row spacing significantly affected photosynthesis on days 197 and 203 (P = 0.08 and 0.01, respectively) in 1999, days 206, 208, 213, 221, 224, 228 and 231 (P = 0.05, 0.01, 0.07, <0.01, 0.01, 0.04 and 0.01, respectively) during the 2000 season, and, in 2001, for most of the period between days 219 to 232. Generally, photosynthesis was higher with SR than UNR on the above days.

Photosynthesis was generally higher with NT compared to CT (Fig. 5). This difference was significant at days 211, 217, 225, 230 and 232 (P = 0.07, <0.01, <0.01, <0.01 and <0.01, respectively) in 1999, day 224 in 2000 (P = 0.08), and during the 2001 season on days 199 and 228 (P = 0.04 and 0.07). These trends are consistent with stomatal conductance and transpiration observations.

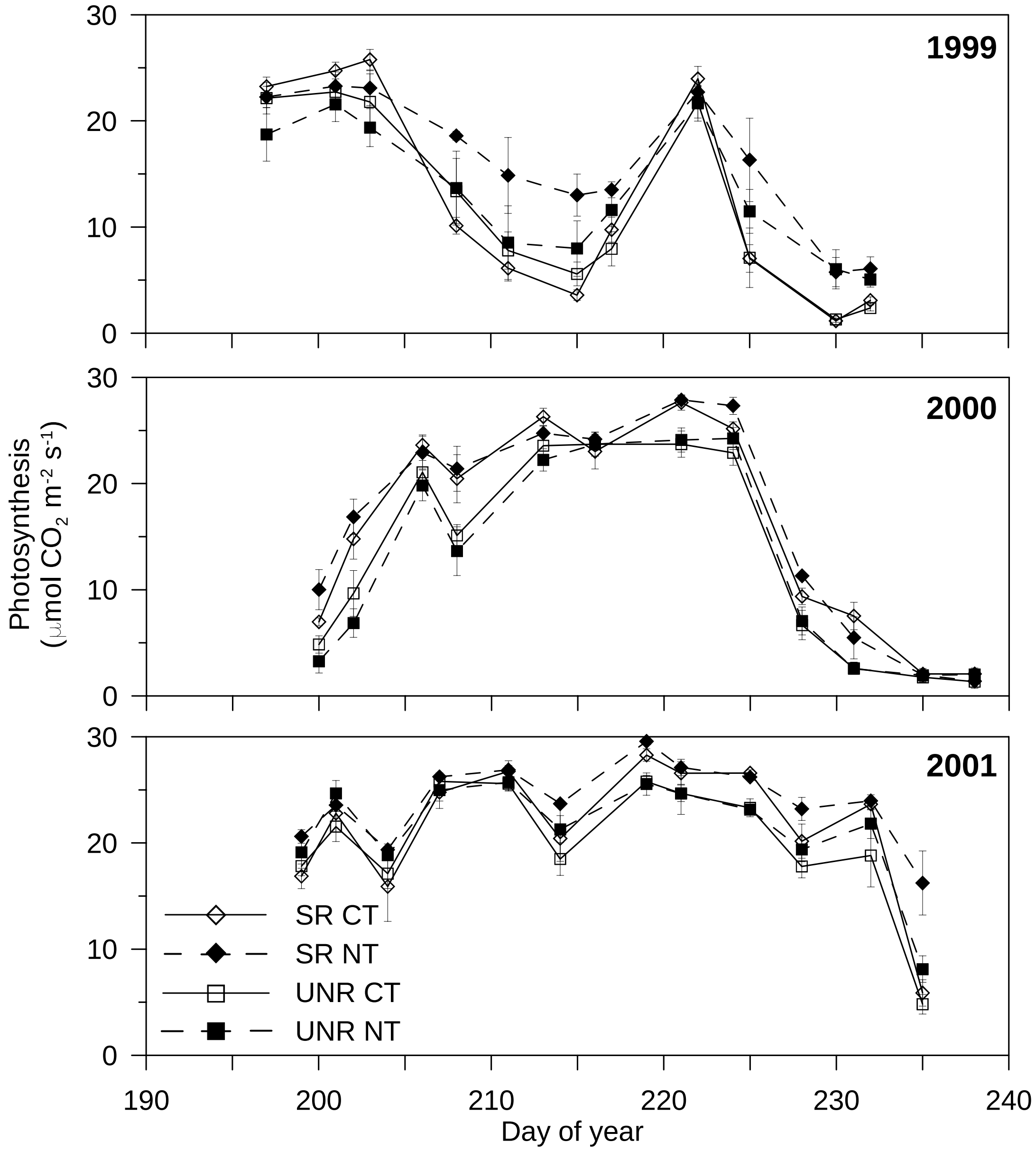

Figure 5. Photosynthesis of cotton grown in 102 cm standard row spacing (SR) and 20 cm ultra-narrow row spacing (UNR) under conventional (CT) and no-tillage (NT) during the reproductive growth stage in the 1999-2001 seasons. Error bars indicate the standard error.

CONCLUSIONS

Generally, photosynthesis, stomatal conductance, and transpiration were higher in cotton grown in SR and were lower under NT conditions. The lower values observed in the UNR treatments were not surprising since higher plant density from closer row spacing promotes greater plant to plant competition for below ground resources, resulting in a shorter crop compared to SR cotton (Vories and Glover, 2006; Nichols et al., 2004). These results also suggest no advantage of NT for SR cotton under conditions of adequate θ_v. However, it is important to note that although SR cotton under CT initially had higher rates of photosynthesis, this competitive advantage rapidly diminished during a water stress period due to larger plants being more susceptible to a lack of available soil water.

The cotton yields for this study have been published by Reeves and Delaney (2002). In general, UNR out yielded the SR system by 8.3, 19.8 and 46.1% in 1999, 2000 and 2001, respectively. Similar results were reported by Vories and Glover (2006) and Nichols et al. (2004). In this study, lower stomatal conductance appeared to be related with greater yields in the UNR. This contradicts the findings of Ulloa et al. (2000) where high stomatal conductance was associated with high cotton yields in New Mexico and Arizona. However, climatic difference between the two research sites could explain the differences. Conversely, Lu et al. (1998) concluded that higher stomatal conductances could be disadvantageous because of wasteful water use. It has been suggested that cotton, under water stress, has a high transpiration rate (Inamullah and Isoda, 2005). It appears that cotton in the UNR system used water more effectively and gave greater yields than in SR. This is partially supported by the θ_v results.

Our findings suggest that management schemes favoring surface residue accumulation could help conserve soil water. The benefits of NT are most probable in years experiencing sporadic precipitation patterns throughout reproductive growth as seen in the first year of this study (1999). Reflective of optimum soil water status, NT cotton exhibited high stomatal conductance, which contributed to higher transpirational water loss while allowing for good CO_2 uptake required to maintain high photosynthesis rates. In growing years with frequent rainfall during reproductive growth (e.g., 2000 and 2001), benefits of NT can occur, but are less frequent. Compared to SR cotton, UNR cotton tends to have lower photosynthesis rates and the benefits of NT are less pronounced in this system. Faster canopy closure and greater plant-to-plant competition for soil resources are contributing factors which may explain these differential responses. Adoption of NT and UNR can help to minimize the detrimental impacts of water stress on cotton grown in coarse textured soils.

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DISCLAIMER

The mention of company names or trade names does not imply endorsement by the USDA-Agricultural Research Service or Auburn University.

REFERENCES

Boyer, J.S. (1982). Plant productivity and environment. *Science* 218, 443–448.

Ess, D.R., Vaughan, D.H., Perumpral, J.V. (1998). Crop residue and root effects on soil compaction. Transactions of the *American Society of Agricultural Engineers* 41, 1271–1275.

Inamullah, Isoda, A. (2005). Adaptive responses of soybean and cotton to water stress, I. Transpiration changes in relation to stomatal area and stomatal conductance. *Plant Production Science* 8, 16–26.

Larson, J.A., Gwathmey, C.O., Hayes, R.M. (2005). Effects of defoliation timing and desiccation on net revenues from ultra-narrow-row cotton. *Journal of Cotton Science* 9, 204–214.

Kornecki, T. S., Raper, R.L., Arriaga, F.J., Schwab, E.B., Bergtold, J.S. (2009) Impact of rye rolling direction and different no-till row cleaners on cotton emergence and yield. *Transactions of the ASABE* 52(2), 383–391.

Kornecki, T.S., Price, A.J., Raper, R.L. (2006) Performance of different roller designs in terminating cover crops. *Applied Engineering in Agriculture* 22(5), 633–641.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D. (1996). *SAS System for Mixed Models*. SAS Institute Inc., Cary, North Carolina.

Lu, Z., Percy, R.G., Qualset, C.O., Zeiger, E. (1998). Stomatal conductance predicts yields in irrigated Pima cotton and bread wheat grown at high temperatures. *Journal of Experimental Botany* 49, 453–460.

Nichols, S.P., Snipes, C.E., Jones, M.A. (2004). Cotton growth, lint yield, and fiber quality as affected by row spacing and cultivar. *Journal of Cotton Science* 8, 1–12.

Raper, R.L., Reeves, D.W., Burmester, C.H., Schwab, E.B. (2000). Tillage depth, tillage timing and cover crop effects on cotton yield, soil strength and tillage energy requirements. *Applied Engineering in Agriculture* 14, 379–385.

Reeves, D. W., Delaney, D.P. (2002). Conservation rotations for cotton production and carbon storage. In: van Santen, E. (Ed.), *Making Conservation Tillage Conventional: Building on 25 Years of Research. Proceedings of the 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture*. Auburn, AL 24-26- June 2002. Special Report No. 1 Alabama Agric. Expt. Station and Auburn University, AL 36849. USA.

Reeves, D.W., Rogers, H.H., Droppers, J.A., Prior, S.A., Powell, J.B. (1992). Wheel traffic effects on corn as influenced by tillage systems. *Soil Tillage Research* 23, 177–192.

Reicosky, D.C., Reeves, D.W., Prior, S.A., Runion, G.B., Rogers, H.H., Raper, R.L. (1999). Effects of residue management and controlled traffic on carbon dioxide and water loss. *Soil Tillage Research* 52, 153–165.

Tennakoon, S.B., Hulugalle, N.R. (2006). Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol. *Irrigation Science* 25, 45–52.

Topp, G.C., Davis, J.L., Annan, A.P. (1980). Electromagnetic determination of soil water content: measurement in coaxial transmission lines. *Water Resources Research* 16, 574–582.

Ulloa, M., Cantrell, R.G., Percy, R.G., Zeiger, E., Lu, Z. (2000). QTL analysis of stomatal conductance and relationship to lint yield in an interspecific cotton. *Journal of Cotton Science* 4, 10–18.

USDA-National Resource Conservation Service. http://www2.ftw.nrcs.usda.gov/osd/dat/N/NORFOLK.html (verified August 29, 2008).

Vories, E.D., Glover, R.E. (2006). Comparison of growth and yield components of conventional and ultra-narrow row cotton. *Journal of Cotton Science* 10, 235243.