COTTON GROWTH AND YIELD RESPONSES TO NITROGEN RATE IN THE SOD-BASED PEANUT-COTTON ROTATIONS

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Abstract

Diversity and integration of perennial grasses into crop rotations have many advantages. Nitrogen management is important in high-yielding cotton production. A long-term sod based peanut-cotton rotation study has been conducted at University of Florida's North Florida Research and Education Center, Quincy, FL. Objectives of this study were to determine cotton plant growth and N status in conventional (peanut-cotton-cotton) and sod based (bahiagrass-bahiagrass-peanut-cotton) rotations and to investigate physiological mechanisms of N effect on cotton growth and yield. Two N rates in each rotation were 0 and 95 kg N ha^{-1}. Lint yield of sod based cotton was 12 to 22% greater than that of the conventional cotton in 2007. Averaged across rotation treatments, cotton that received the 95 N had an 18% higher lint yield than the 0 N treated cotton. Crop rotation and N rate also affected most growth and physiological variables measured. Based on leaf N and chlorophyll concentrations and monitoring of plant nodes above white flower (NAWF) and cutout (NAWF = 5) date, the 0 N treated plants faced N deficiency with low lint yield, but the 95 N treated plants seemed to be overuse of N. Ongoing study emphasizes to optimize N application in cotton in the sod based rotation.

Introduction

Cotton (*Gossypium hirsutum* L.) is responsive to changes in growth environments due to its indeterminate growth habit (Reddy et al., 1997). Nitrogen (N) management is one of the important practices in high-yielding cotton production systems (Gerik et al., 1998). Both N deficiency and excess N negatively affect plant growth, boll retention, lint yield, and fiber quality (Gerik et al., 1998). Insufficient N supply often reduces leaf area, leaf photosynthetic rate, and biomass production in cotton (Zhao and Oosterhuis, 2000), resulting in low lint yield and poor fiber quality (Heagle et al., 1999; Reddy et al., 2004). However, lint yield of irrigated cotton does not always continue to increase as amount of N fertilizer is increased (Wood et al., 1992; Boquet et al., 1994; Zhao et al., 2005). When N rate reaches a certain amount, a further increase in N fertilizer may limit lint yield if fruit abscission is increased due to poor light environment in the canopy. Excess use of N fertilizer increases not only production cost but also the potential for environmental problems, such as groundwater contamination by NO_3^- leaching.

Compared to conventional monoculture of cotton crop, diversity and integration of cotton production are important for conserving environment and improving agricultural sustainability and profitability. Integration of perennial grasses such as bahiagrass and bermudagrass into the current rotation system of peanut and cotton has been proposed by several states, such as Florida, Alabama, Georgia, and Virginia, in the southeast USA. Studies have shown numerous advantages of diverse cropping systems across the nation (Allen et al., 2005; Katsvairo et al., 2006; Allen et al., 2007; Franzluebbers, 2007; Russelle et al., 2007; Sulc and Tracy, 2007). Two of the most important advantages of the sod-based rotation are increase in soil organic matter (OM) and improvement of soil quality (Katsvairo et al., 2006). In sod based peanut-cotton rotation, peanut yield is significantly increased, but cotton lint yield has little or no improvement as compared with the conventional cotton (Katsvairo et al., 2007). Katsvairo et al. (2007) documented that although cotton plants grown in the sod based rotation had greater and deeper roots, lint yield did not differ statistically from a conventional rotation.

We speculated that cotton plants in sod based rotations may require less N fertilizer and irrigation water supply than the conventional cotton because of high soil quality in the sod based crop rotations, including soil nutrients and soil water holding capacity. Therefore, refining sod based cotton management practices, especially N and irrigation management should improve cotton yield and profitability. From 2006 we modified our cotton management strategies in the sod based rotations to improve cotton yield. The specific objectives of this study were to: (1) determine cotton plant growth and N status in the conventional and sod based cropping rotations and (2) investigate physiological mechanisms of N rate effect on cotton growth and yield. The sod based peanut-cotton rotation study has been established since 2000 for investigating long-term sustainability and profitability of two cropping systems. In this report, we only presented some data collected from the 2007 growing season.

Materials and Methods

Experimental Background and Treatments

The sod based peanut-cotton rotation study was initiated in 2000 at the University of Florida's North Florida Research and Education Center in Quincy, FL (84°33' W, 30°36' N). The soil type at the experimental location is Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudult). Treatments included two cropping systems (sod-based and conventional peanut/cotton rotations) and two N rates. The sod based system was a 4-yr rotation with bahiagrass-bahiagrass-peanut-cotton (BBPC) and the conventional system was a 3-yr rotation with peanut-cotton-cotton (PCC). Both systems were used conservation tillage (strip-till for summer crops) with winter oat cover crop following the summer crops. Based on the Florida cotton N fertilizer recommendation, all plots received a total of 95 kg N ha^{-1} (28 kg at planting and 67 kg at the first square) in 2000 to 2004. Nitrogen treatments were started from 2005 and two N rates were 61 and 95 kg N ha^{-1}. Because there was no yield difference between the two N rates in 2005, in 2006 and 2007 two N rates were reset 0 and 95 kg ha^{-1}, respectively.

Bahiagrass was cut one (first year) or three (second year) times during the growing season and hay yield of forage was estimated for system economic analysis purpose. The second year bahiagrass of the sod based rotation was killed in late October of each year with 3 qts of Rundup Weather Max per acre for the coming year peanut. In late March of each year, about 3 weeks prior to cotton planting, oat cover crop was killed with Rundup and plot rows were strip-tilled using a Brown Ro-till implement (Brown Manufacturing Co., Ozark, AL) and oat residues were remained in field. Cotton cultivar Deltapine DP 458 BG (2002-2004) or DP 555 BG/RR (2005-2007) was used for this long-term cropping system study. Cotton was planted between late April and early May depending on weather conditions in a specific year with a Monosem pneumatic planter (ATI Inc., Lenexa, KS). Rows were orientated west to east with a row spacing of 0.91 m and about 18 seeds per meter row. Starting from 2006, two levels of 0 and 95 N (i.e., 0 and 95 kg N ha^{-1}) were composed in each rotation. For the 95 N treatment, N (28 kg N ha^{-1}), P (56 kg P ha^{-1}), and K (84 kg K ha^{-1}) from a combination fertilizer (5-10-15) were band applied adjacent to each row at planting and an addition of 68 kg N ha^{-1} was sidedressed with ammonia nitrite at first square stage. For the 0 N treatment, the equal amount of P and K was band adjacent to each row at planting time by using commercial AIP (0-46-0) and Muriate of potash (0-0-60), but no any N was used during growing season. Irrigation was applied using a lateral move irrigation system if needed based on Florida cotton production guidelines (Rhoads, 2000) in 2000-2006. In 2007, water saving irrigation was implemented when the lowest leaf water potential of uppermost fully expanded mainstem leaves, measured with a plant water status console (Soil Moisture Inc., CA) between 1300 and 1400 h EDT, was about -1.5 MPa during squaring and fruiting (Zhao et al., 1991). A total of 1.17 (for the 0 N plots) or 2.34 (for the 95 N plots) L PIX was split applied at first square (FS) and first flower (FF) stages. Details of bahiagrass and peanut management and other cotton crop management practices, including disease and insect control, herbicide application, and chemical defoliation, were employed according to standard University of Florida crop production recommendations (Ferrell et al., 2006).

Measurements

In the 2007 growing season, plant height, the number of main-stem node, and height:node ratio were determined biweekly from the pre-marked 10 plants in each plot. Leaf area index (LAI) was also measured throughout the growing season by destructively harvesting plants of 1-m row in each plot. Leaf photosynthetic rates were measured from five uppermost fully expanded main-stem leaves in each plot at squaring (June 13) and fruiting (July 12) stages using a potable photosynthesis system (LI-COR 6400, LICOR Inc., Lincoln, NE). Petioles and leaf blade samples of 10 upper most-fully expanded main-stem leaves were collected biweekly from each plot. Chlorophyll content of the leaves was estimated using a SPAD-502 chlorophyll meter (Minolta Co., LTD., Japan). Petiole sap NO_3-N concentration was measured using a C-141 CARDY meter (Horiba, LTD., Kyoto, Japan). After measurement of chlorophyll, leaf samples were dried in a forced draft oven at 60°C for 48 hours. Dried samples were ground to determine total N concentration in a commercially analytical laboratory (Waters Agricultural Laboratories, Inc., Camilla, GA).

Starting from the first flower stage, the number of nodes above white flower (NAWF) was recorded using a CONTMAN model developed by University of Arkansas (Bourland et al., 1997). To avoid effect of plot edges (usually with bigger plants) and to reflect the real production conditions, plants in 2 m long area in each end of all plots were mowed down prior to mechanical harvest time. Thereafter, four middle rows (no any destructive sampling in these rows) in each plot were harvested with a spindle picker (International Harvester model 1822; Case Corp., Racine, WI) 2 weeks after defoliation on 24 September 2007. Seedcotton yield was determined based on seedcotton harvested from the four middle rows. Two seedcotton subsamples (1000 g each) in each plot were ginned to determine lint %. Lint yield was calculated based on seedcotton yield and lint %.

Experimental Design and Data Analysis

The experiment was arranged in split-block design with 3 replicates. Crop rotation was main plot and N rate was sub-plot. The sub-plot size was 21 m long and 9.1 m wide with 10 rows of cotton in each sub-plot. All data were analyzed for variances and Fisher LSD test using the GLM procedures of SAS statistics package (SAS Inc., 2002).

Results and Discussion

Leaf Photosynthesis

At squaring stage (June 13), cotton leaf photosynthetic rate ranged from 22.4 to 23.8 μmol CO_2 m^{-2} s^{-1} and did not differ between the 0 N and 95 N treatments in any cropping systems (Table 1). At fruiting stage (July 12), there was no difference between the two N rates in leaf photosynthesis. Averaged across cropping systems, leaf photosynthetic rates of the 0 N and 95 N treated plants were 24.6 and 25.0 μmol CO_2 m^{-2} s^{-1}, respectively. The sod based cotton and the first-year conventional cotton had comparable leaf photosynthetic rates (25.6 to 27.4 μmol CO_2 m^{-2} s^{-1}) at fruiting, but the second-year conventional cotton had 6 μmol CO_2 m^{-2} s^{-1} less leaf photosynthetic rate ($P < 0.05$) than the sod based cotton and the first-year conventional cotton (Table 1).

Table 1. Photosynthetic rate of uppermost fully expanded leaves measured at squaring (June 13) and fruiting (July 12) stages in 2007.

Growth Stage	Sod-based Cotton		Conventional Cotton 1		Conventional Cotton 2		$LSD_{0.05}$
	0 N	95 N	0 N	95 N	0 N	95 N	
	------------ (μmol CO_2 m^{-2} s^{-1}) ------------						
Squaring	23.0	23.8	24.4	23.7	22.4	22.7	NS
Fruiting	25.6	27.4	26.8	26.9	21.4	20.7	2.8

Plant Height, Main-stem Nodes, and Height:Node Ratio, and LAI

Both plant height and number of mainstem nodes increased rapidly between 35 and 80 days after planting (DAP) and reached maximum value around 90 DAP (Fig. 1A and B). The height:node (H:N) ratio increased linearly from 35 to 60 DAP. Thereafter, there was no change in H:N ratio for all the treatments (Fig. 1C). The crop rotation and N rate influenced plant height. Starting from 65 DAP, cotton plants grown in the BBPC rotation with 95 kg N ha^{-1} were significantly taller and the second year cotton in the PCC rotation with the 0 N was much shorter ($P < 0.05$) than other treatments (Fig. 1A). Between 80 and 110 DAP, cotton grown in the BBPC and in the first year cotton of PCC with high N rate had the greatest number of nodes, while the second year cotton in the PCC rotation with the 0 N had 3 to 6 less nodes than other treatments (Fig. 1B). The H:N ratio is an indicator reflecting cotton plant vigor. The H:N ratio of cotton plants grown in the BBPC rotation with the 95 kg N ha^{-1} was greater than that of other treatments during fruiting (Fig. 1C). In addition, greater H:N ratio for the sod based cotton received 95 kg N ha^{-1} was mainly associated with longer inter nodes rather than the number of nodes because plant height increased more than the increase in nodes as compared with other treatments (Fig. 1A and B).

In general, LAI increased slowly in early growing season (from emergence to 45 DAP) and fast after the first square stage, reached maximum 80 to 90 DAP, and then declined during boll filling (Fig. 1D). Similar to plant height and the number of nodes, LAI had great variation among treatments during flowering and boll development (Fig. 1D). Overall, LAI of the 95 N treatments was greater than that of the 0 N treatments within a crop rotation. At the same N rate level, the sod based cotton had greater LAI than the conventional cotton.

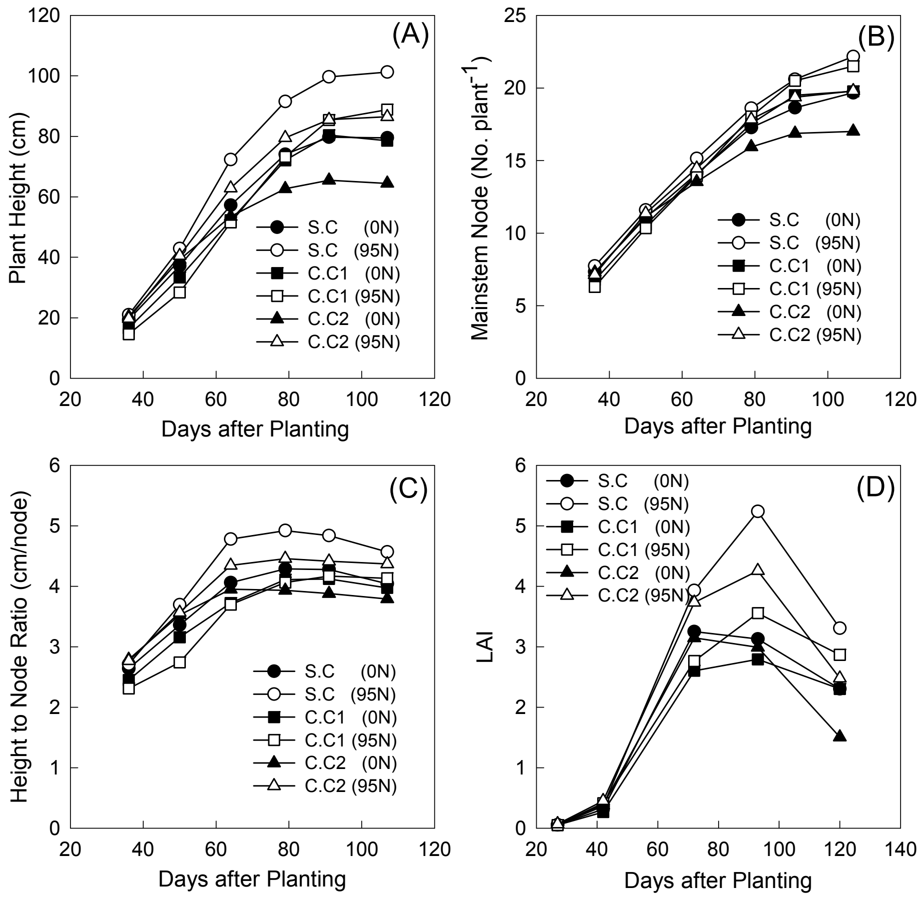

Fig. 1. Changes in (A) plant height, (B) the number of main-stem nodes, (C) height to node ratio, and (D) leaf area index (LAI) during the 2007 growing season for different crop rotations and N rates. Note: the 'S.C', 'C.C1', and 'C.C2' are the sod based cotton, the first-year conventional cotton, and the second-year conventional cotton, respectively.

Concentrations of Leaf Total N, Leaf Chlorophyll and Petiole NO_3-N

Leaf total N concentration slowly declined, chlorophyll (SPAD readings) was almost unchanged, and petiole NO_3-N level decreased sharply as plants aged (Fig. 2). The crop rotations had little effect on any of leaf N concentration, leaf chlorophyll or petiole NO_3-N level. In contrast to the rotations, N rate significantly affected all the three tested variables of plant N status. The high N rate (95 N) treatment had greater concentrations of leaf N, chlorophyll and petiole NO_3-N than the low N (0 N) treatment at most sampling dates throughout the growing season (Fig. 2). Among the three measured variables of reflecting plant N status, petiole NO_3-N had the greatest, while leaf chlorophyll had the smallest changes over the growing season and among the treatments. Averaged across the crop rotations, leaf N concentrations of the 0 and 95 N treatments were 5.2 and 5.2%, respectively at FS stage; 4.2 and 5.1%, respectively at FF stage; and 3.9 and 4.7%, respectively at 3 weeks after FF stage. Bell et al. (2003) reported that cotton leaf N concentration associated with seed cotton yield loss was 5.4% at FS stage, 4.3% at early-flower stage, and 4.1% at mid-flower stage. According to Bell et al. (2003), leaf N concentrations of the 0 N treatment in our study were around these critical level, but leaf N of the 95 N treatment were greater than the critical levels reported by Bell et al. (2003) at all growth stages. In a recent report (Zhao et al., 2005), leaf chlorophyll (SPAD readings) of cotton received 168 kg N $ha^{-1}$and 1.17 to 2.34 L PIX ha^{-1} was 43 to 46 averaged across the growing season. The mean chlorophyll reading (50.4) across the season in the present study for the 95 N treated cotton was much greater than that reported by Zhao et al. (2005). These results suggest that no N application has risk to negatively affect cotton growth and yield, but a total amount of 95 kg N ha^{-1} seems to be too high for cotton in the sod based rotations in the southeast.

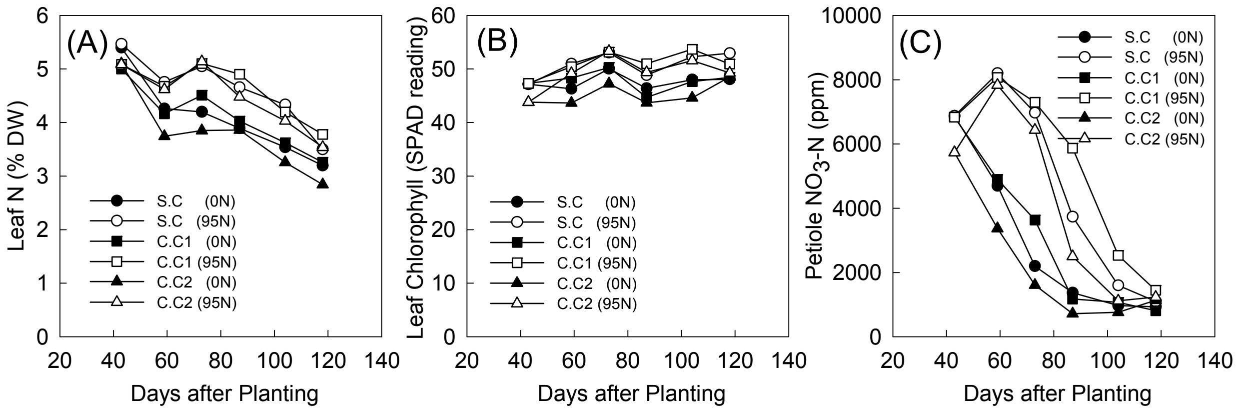

Fig. 2. Changes in (A) leaf N concentration, (B) leaf chlorophyll level, and (C) petiole NO_3-N concentration during the 2007 growing season for different crop rotations and N rates. Note: the 'S.C', 'C.C1', and 'C.C2' are the sod based cotton, the first-year conventional cotton, and the second-year conventional cotton, respectively.

Nodes Above White Flower (NAWF)

In the COTMAN target curve developed by Bourland et al. (1997), target days of the FS, FF and cutout (NAWF = 5) are about 35, 60, and 80 DAP, respectively (Fig. 3). Dates of FS (41 DAP) and FF (66 DAP) in the present study were about 6 days later than the target days for all treatments (Fig. 3). Based on the target curve, the ideal field cotton plants should reach cutout date around 86 DAP in our study. Averaged across crop rotations, however, the real cutout date of the 0 N treated plants was about 5 days earlier and the cutout date of the 95 N treated plants was 6 days later than the predicted cutout date (86 DAP) (Fig. 3). Results of cutout dates further suggested that excess N application for the 95 N treatment and N deficiency for the 0 N treatment are evident.

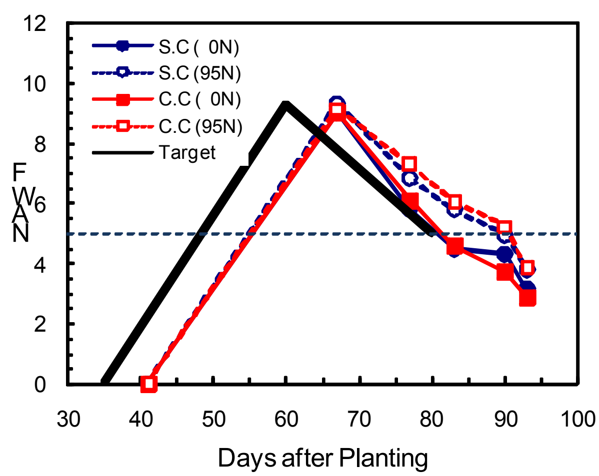

Fig. 3. Nodes above white flower (NAWF) of the sod based cotton (S.C) and conventional cotton (C.C) as affected by N rate at Quincy, FL in 2007.

Lint Yield

Among the treatments, the 95 N treatment of the sod based cotton had the greatest and the 0 N treatment of the second-year conventional cotton had the lowest lint yield ($P < 0.05$, Fig. 4). Compared to the conventional rotation, the sod based rotation improved cotton yield. Averaged across the N treatments, the sod based cotton had a 12% greater lint yield than the first-year conventional cotton and 22% greater yield than the second-year conventional cotton. Lint yields of the 0 and 95 N treated cotton were 1306 and 1538 kg ha^{-1}, respectively averaged across the rotations. As we mentioned earlier about leaf N and chlorophyll concentrations and cutout date, the 0 N plots (especially for the second-year conventional cotton) may face N deficiency during fruiting, but the 95 N plots (especially for the sod based cotton) may face an overuse of N fertilizer in this study. It seems to be that cotton optimum N rate is lower than 95 kg N ha^{-1} in the sod based rotations. More studies are needed to quantify cotton optimum N application for current sod based rotations in the Southeast.

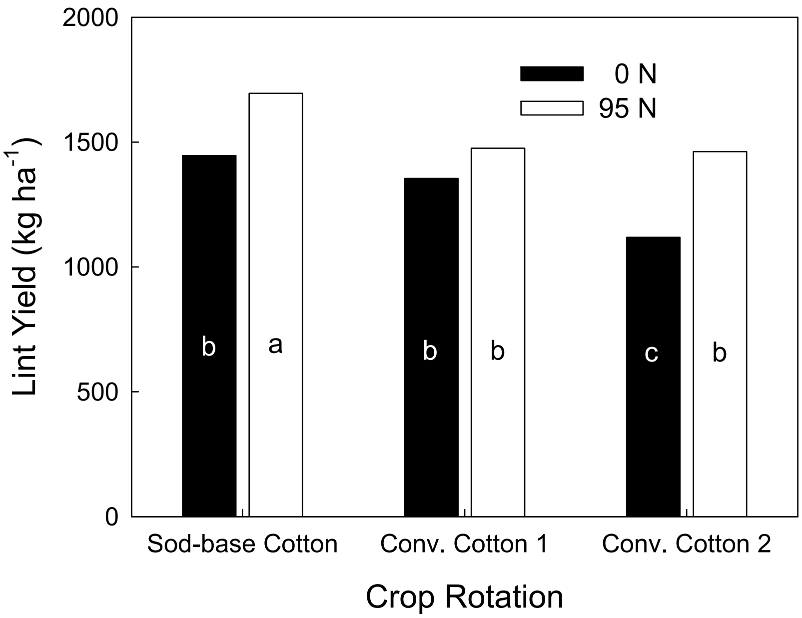

Fig. 3. Lint yield of the sod-based cotton, conventional first-year cotton (Conv. Cotton 1), conventional second-year cotton (Conv. Cotton 2) as affected by N rate At Quincy, FL in 2007. Means followed the same letter are not significantly different ($P > 0.05$) across the six treatments.

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References

Allen, V.G., M.T. Baker, E. Segarra, and C.P. Brown. 2007. Integrated irrigated crop–livestock systems in dry climates. Agron. J. 99:346–360.

Allen, V.G., C.P. Brown, R. Kellison, E. Segarra, T. Wheeler, P.A. Dotray, J.C. Conkwright, C.J. Green, and V. Acosta-Martinez. 2005. Integrating cotton and beef production to reduce water withdrawal from the Ogallala aquifer in the southern high plans. Agron. J. 97:556–567.

Bell, P.F., D.J. Boquet, E. Millhollon, S. Moore, W. Ehelhar, C.C. Mitchell, J. Varco, E.R. Funderburg, C. Kennedy, G.A. Breiten-beck, C. Craig, M. Holman, W. Baker, and J.F. McConnell. 2003. Relationships between leaf-blade nitrogen and relative seedcotton yields. Crop Sci. 43:1367–1374.

Boquet, D.J., E.B. Moser, and G.A. Breitenbeck. 1994. Boll weight and within-plant yield distribution in field-grown cotton given different levels of nitrogen. Agron. J. 86:20–26.

Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell, M.J. Cochran, and D.M. Danforth. 1997. Interpretation of Crop Growth Patterns Generated by COTMAN. Ark. Agric. Exp. Station. Division of Agriculture, Univ. of Ark. Special Report 181. pp.10 (available online: http://arkansasagnews.uark.edu/Special_Report_181.pdf.).

Ferrell, J.A., G.E. MacDonald, and B. J. Brecke. 2006. Weed management in cotton. [Online] Available at http://edis.ifas.ufl.edu/WG003. (accessed 14 Oct. 2006; verified 20 Dec. 2007).University of Florida IFAS. Gainesville, FL.

Franzluebbers, A.J. 2007. Integrated crop–livestock systems in the southeastern USA. Agron. J. 99:361–372.

Gerik, T.J., D.M. Oosterhuis, and H.A. Torbert. 1998. Managing cotton nitrogen supply. Advn. Agron. 64:15–147.

Heagle, A.S., J.E. Miller, F.L. Booker, and W.A. Pursley. 1999. Ozone stress, carbon dioxide enrichment, and nitrogen fertility interactions in cotton. Crop Sci. 39:731–741.

Katsvairo, T.W., D.L. Wright, J.J. Marois, D.L. Hartzog. J.R. Rich, and P. Wiatrak. 2006. Sod/Livestock integration in the peanut/cotton rotation: A systems farming approach. Agro. J. 98:1156–1171.

Katsvairo, T.W., D.L. Wright, J.J. Marois, D.L. Hartzog, J.R. Rich, and P. Wiatrak. 2007. Cotton roots, earthworms and infiltration characteristics in sod/livestock peanut/cotton cropping systems. Agron. J. 99:390–398.

Reddy, K.R., H.F. Hodges, and J.M. McKinion. 1997. Crop modeling and applications: A cotton example. Advn. Agron. 59:225–290.

Reddy, K.R., S. Koti, G.H. Davidonis, and V.R. Reddy. 2004. Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth, development, yield, and fiber quality. Agron. J. 96:1148–1157.

Russelle, M.P., M.H. Entz, and A.J. Franzluebbers. 2007. Reconsidering integrated crop–livestock systems in North America. Agron. J. 99:325–334.

SAS Institute. 2002. The SAS system for Windows. Version 9.00. SAS Inst., Cary, NC.

Sulc, R.M., and B.F. Tracy. 2007. Integrated crop–livestock systems in the U.S. Corn Belt Agron. J. 99: 335–345.

Wood, C.W., P.W. Tracy, D.W. Reeves, and K.L. Edmisten. 1992. Determination of cotton nitrogen status with a hand-held chlorophyll meter. J. Plant Nutr. 15:1435–1448.

Zhao, D., and D.M. Oosterhuis. 2000. Nitrogen application effect on leaf photosynthesis, nonstructural carbohydrate concentrations and yield of field-grown cotton. pp. 69–71. *In* D.M. Oosterhuis (ed.) Proc. 2000 Arkansas Cotton Res., AAES Special Report 198.

Zhao, D., K.R. Reddy, V.G. Kakani, J.J. Read, and S. Koti. 2005. Selection of optimum reflectance ratios for estimating leaf nitrogen and chlorophyll concentrations of field-grown cotton. Agron. J. 97:89–98.