Lint Yield Advantages of No-till and Poultry Litter-Based Cotton/Rye Cropping System in a Southern Piedmont Soil: A Five-year Data Set

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ABSTRACT

Cotton [*Gossipium hirsutum* (L.)] is a dominant crop in the Southeast. It is largely grown using conventional tillage and fertilizers. Georgia and bordering states produce about 42% of the poultry in the United States, but only a small percentage of the litter is utilized as fertilizer. We measured and compared cotton yield from conventional tillage (CT) and no-till (NT) plots fertilized either with ammonium nitrate as conventional fertilizer (CF) or poultry litter (PL) from 1996 to 2000 near Watkinsville, GA. The soil was a Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludult), a dominant soil series in the Southern Piedmont. The four treatments CTCF, CTPL, NTCF, and NTPL were replicated three times on twelve nearly level (0-2% slope) 30 ft by 100 ft plots. Rye [*Secale cereale* (L.)] was the winter cover crop. Mean lint yields over five years in lbs acre^{-1} were: 971 for NTPL, 915 for NTCF, 753 for CTPL, 686 for CTCF, 943 for NT, 719 for CT, 862 for PL, and 800 for CF. Statistically significant (*P* = 0.05) yield differences were: NTPL > CTCF by 42%, NTCF > CTCF by 34%, NTPL > CTPL by 29%, NTCF > CTPL by 22%, and NT > CT by 31%. Drought during first bloom to peak bloom reduced yield and negated all treatment effects in the fourth year and reduced yield in the fifth year. It is possible to increase cotton productivity in the Southern Piedmont by adopting no-till and fertilizing with poultry litter instead of tilling and fertilizing conventionally.

KEYWORDS

Conservation tillage, no-till, poultry litter, Cecil sandy loam

INTRODUCTION

The Southern Piedmont lies in southeastern USA extending along the eastern face of the Appalachian Mountains from Virginia to Alabama and covering approximately 40.7 million acres. Soil erosion has been a serious problem in the region as a result of over 200 years of intense row crop agriculture (Bruce and Langdale, 1997). Much of the row crop agriculture is conventionally tilled and fertilized. The soils have relatively low fertility and organic matter, are highly erodible and easily compacted by rainfall and machine traffic (Carreker *et al*., 1977). The soils, however, are responsive to good management practices, including adequate levels of nutrients, and cropping systems that restore organic matter and soil structure increase available water and reduce machine traffic, such as those under conservation tillage. Conservation tillage has many benefits such as soil and water conservation, lower production costs, higher yields, and greater production efficiency (CTIC 1998; Domitruk and Crabtree, 1997; Langdale *et al*., 1992).

Cotton and poultry production are of great economic importance in the Southeast. In Georgia, for example, cotton acreage increased from about 0.3 million in 1987 to about 1.4 million in 1996 (Rodekohr and Rahn, 1997). Poultry production is a growing agribusiness in Georgia worth about $10 billion annually (Rodekohr and Rahn, 1997). The poultry enterprise produces large quantities of litter annually. Poultry litter is typically applied to pasture and crop land because of its nutrient value (Moore *et al*., 1995) and because it is considered to be environmentally safe to do so (Edwards and Daniel, 1992). However, only a small percentage is applied to crop land. Reasons for this include: limitations of timely availability of poultry litter for application to row crops; perceived risk due to variability in nutrient content compared to conventional fertilizers; and insufficient information on its impact when used in conservation tillage and on different crops.

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The Southern Piedmont has a favorable climate, including 200 to 250 frost-free-days and abundant and generally well-distributed annual rainfall, that supports production of a wide range of crops that include cotton. However, short-term summer droughts that can lead to yield reduction are common. Cotton under conventional tillage is more at risk of suffering moisture stress during these drought periods because of factors such as crusting, pore size distribution and connectivity, which reduce soil water reserves. Conservation tillage often creates a more favorable soil water regime by improving surface soil properties that favor more infiltration and conduction of water to lower soil profile and, consequently, a higher reserve of soil water (Fawcett *et al*., 1994). Conservation tillage systems are recommended for cotton production on highly erosive soils (Bradley, 1995).

Adoption of conservation tillage for major crops such as cotton and soybeans has risen in the Southeast in recent times. According to CTIC (2000), about 20% of the cotton and 58% of the soybeans in the Southeast are now under no-till, a form of conservation tillage. Nationally, approximately 37% of crops were planted with conservation tillage in 2000. Research evaluating the performance of cotton managed under contrasting tillage and nutrient sources is limited in the Southern Piedmont. The objective of this research was to evaluate and compare lint yield from no-till and conventionally tilled cotton fertilized either with poultry litter or ammonium nitrate on a Cecil soil, the dominant soil series in the Southern Piedmont.

MATERIALS AND METHODS

Experimental Site and Soil

The experiment was conducted from 1996 to 2000 at the USDA-ARS, J. Phil Campbell, Sr., Natural Resource Conservation Center, Watkinsville, Ga (83°24' W and 33°54' N) on 12 subsurface-drained and instrumented plots, each 30 ft by 100 ft, located on nearly level (0-2% slope) Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludults). Typic Kanhapludults cover about two-thirds of approximately 34.8 million acres available for cropping in the Southern Piedmont (Langdale *et al*., 1992). Endale *et al*. (2002) give details for climate and soil characteristics of the research site.

Tillage and Fertilizer Treatments

The experiment was laid out as a randomized complete block split-plot design with three replications. Conventional tillage (CT) and no-tillage (NT) were main plots. Fertilizer subplots consisted of ammonium nitrate as conventional fertilizer (CF) or poultry litter (PL). The CT consisted of a 12 in. deep chisel plowing to break possible hard pans, followed by a one to two diskings to a depth 8 in., and a subsequent disking to 3 in. to smooth the seed bed. The only soil disturbance in NT was a coulter disk for planting. NT treatments have continued on the same plots since the fall of 1991.

Fertilizer rates were targeted at 54 lbs available N acre^{-1}. This amounted to an application of 2 tons acre^{-1} (30% moisture) for poultry litter. Mineralization of N in poultry litter was assumed to be 50% (Vest *et al*., 1994) during the cotton season. A specially designed spreader was used to apply fresh litter that was brought to the research site and kept under cover for no more than two weeks. Soil tests were used to determine P and K needs and rates. All N, P and K fertilizers were applied one to two days before cotton planting each year.

Cropping System and Operations

Details for cropping system and operations are given in Endale *et al*. (2002). These are summarized in this section. The cropping system consisted of rye (cv. Hy-gainer) grown from November to May as a cover crop, followed by cotton grown from May to November. Light disking was carried out in CT plots in November, two to three days prior to planting rye. Ammonium nitrate (50 lbs N acre^{-1}) and potassium chloride (40 lbs K acre^{-1}) were applied on all plots and incorporated by light disking in CT but not NT plots. Glyphosate [N-(phosphonomethyl) glycine] was applied to kill the rye about two weeks prior to cotton establishment. Rye produced 2680 to 4465 lbs of dry matter residue acre^{-1}.

Cotton pesticides were: aldicarb [2-methyl-2-(methylthio) propionaldehyde o-(methylcarbamoyl) oxime], fluometuron [N,N-dimethyl-N‘-(3-trifluoromethyl-phenyl) urea], and pendimethalin [N-(1-ethylpro-pyl)-3,4-dimethyl-2,6-dinitrobenzenamine]. Except for aldicarb, which was applied at the same time as planting, fertilizers and pesticides were applied one to two days before planting and were incorporated into the soil by light disking in CT and applied only to the soil surface in NT plots.

The early-maturing ‘Stoneville 474’ cotton cultivar was planted in 34-inch rows at three to four plants per foot in 1996 and 1997. Planting dates were 30 May 1996, 14 May 1997, 14 May 1998, 16 May 1999, and 24 May 2000. Harvesting was on 1 November 1996, 4 November 1997, 12 November 1998, 10 November 1999, and 16 November 2000.

Additional chemical and mechanical means were used to control persistent sporadic weeds after cotton emergence. Vegetative growth of cotton was controlled on all plots in 1996 and 1997 with the growth regulator mepiquat chloride

[Mepiquatchloride: N,N-dimethyl-piperidinium chloride]. Due to persisting drought conditions, mepiquat chloride was not applied after 1997. Dimethipin [2,3-dihydro-5,6-dimethyl-1,4-dithiine 1,1, 4-tetraoxide)], a defoliant, and ethephon[(2-chloro ethyl)phosphonic acid], a boll opener, were also used two weeks prior to harvest. Cotton was hand harvested first for yield determination and the rest was mechanically harvested. Stalks were shredded after harvest with a rotary mower. Yield was expressed as lint as 40% of seed cotton weight and at 10% moisture.

DATA ANALYSIS

Data were analyzed using the MIXED procedure of SAS (Littell *et al*., 1996). Degrees of freedom were calculated using the SATTERTH option in the MODEL statement. In addition, yield was analyzed as repeated measures for years, with Heterogeneous Compound Symmetry (CSH) error structure providing the best fit of variance and covariance among the residuals. All significant differences are reported at $P = 0.05$.

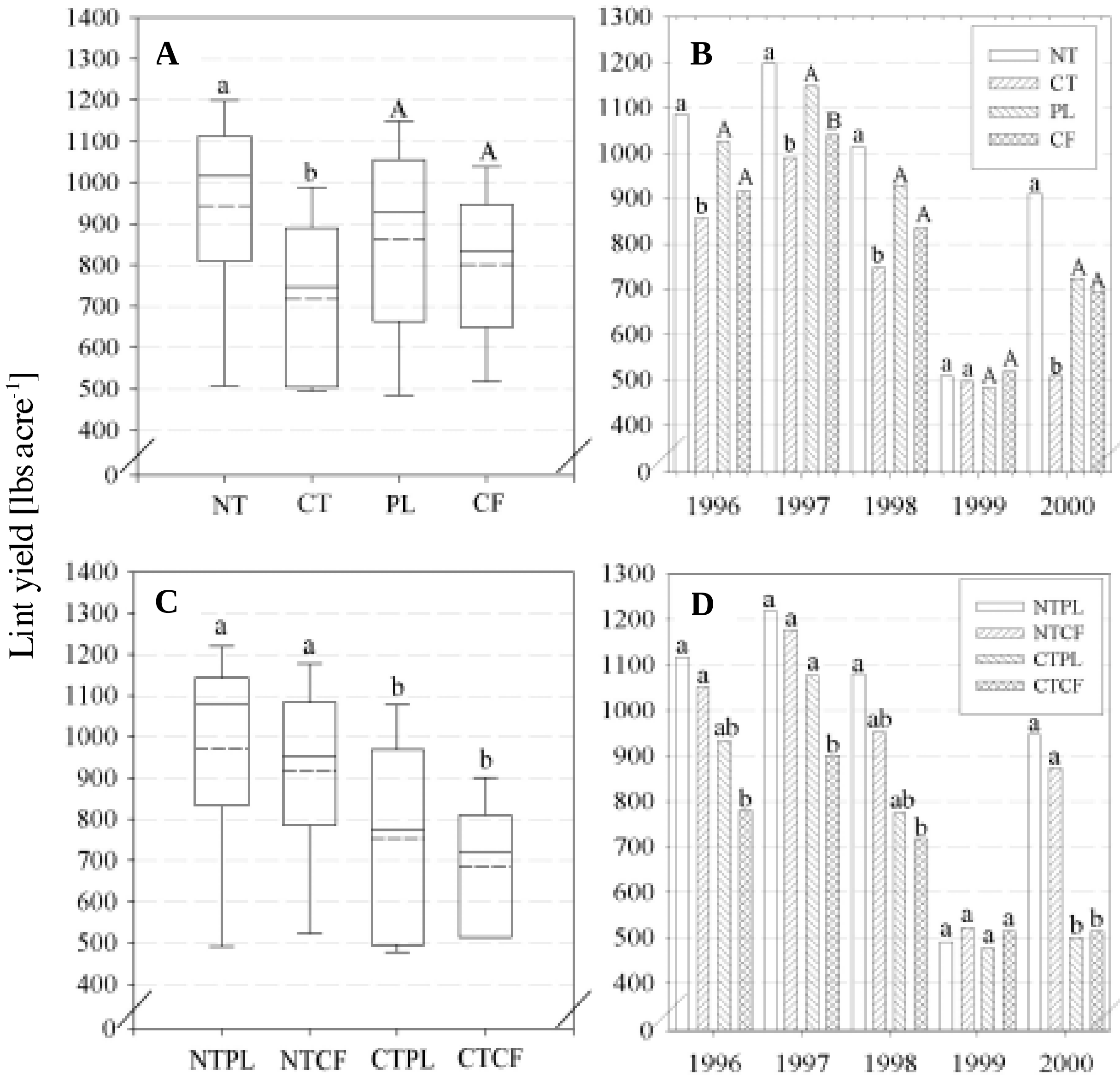

Fig. 1. Lint yield from 1996 to 1999: (A) boxplots with the five years average shown as dashed lines inside a box; (B) average yield per year. Treatments with the same letters above the boxes and bars are not significantly different at $P = 0.05$ (lower case letter show differences between NT and CT, and upper case letters between PL and CF); (C) boxplots with the five years average shown as dashed lines inside a box; (D) average yield per year. Treatments with the same letters above the boxes and bars are not significantly different at $P = 0.05$.

RESULTS

Mean Yields

Mean yields over five years from NT, CT, PL and CF are shown in Fig. 1A and for individual years in Fig. 1 B. Similarly, Figs. 1C and D show mean yield from NTPL, NTCF, CTPL and CTCF over 5 years and for individual years, respectively. Statistical differences at $P = 0.05$ are indicated by letters above the boxplots and bars in both figures. Lower case letters are used to compare NT with CT and upper case letters for PL with CF in Figs. 1A and B. Yields between two treatments with the same letter above the boxplots or bars are not significantly different. Variance was smallest in CTCF. The other 3 treatments had similar variances that were about 2 to 3 times that of CTCF.

YIELD COMPARISONS

NT vs. CT

Yield was 21 to 79 % significantly greater from NT than from CT each year, except in 1999 (Fig. 1B). The greatest difference was in 2000. Yield from NT was 31% significantly greater over five years (Fig. 1A). Drought in 1999 suppressed yield in all treatments and negated treatment differences. Endale *et al*. (2002) attribute this to 35 days of drought, which coincided approximately with first bloom to peak blooming period, when the plant was most susceptible to water stress but received only 0.78 in. of rainfall. Rainfall during the equivalent 35 days period for the other four years varied from 3.8 to 7.8 in. Endale *et al*. (2002) reported that during the first four years of research including 1999, 88 to 93% of the yearly yield variation per treatment could be explained by the rainfall amount during this 35-day critical period. This period will be referred to as "week 10 to 14" henceforth.

PL vs. CF

Yield from PL was 4 to 12% higher than CF except in 1999, when CF yielded 7% more lint (Fig. 1B). These differences were not significant except in 1997, where PL yielded 11% more than CF. This could help explain the fact that, although not significant at $P = 0.05$, the 7% difference between PL and CF over five years (Fig. 1A) is significant at $P = 0.1$.

NTPL vs. NTCF

PL did not cause a significant yield difference over CF in the NT treatments in individual years or over five years (Figs. 1C and D). Nevertheless, yield from NTPL was 4 to 13% higher than that from CTCF except in 1999, when NTCF yielded 6% more lint. Over five years NTPL yielded 6% more than NTCF (Fig. 1C).

NTPL vs. CTPL

NT had variable effects on yield in plots receiving PL (Figs. 1C and 1D). Over five years, NTPL produced 29% significantly greater lint than CTPL (Fig. 1C). In 2000, yield was 89% significantly higher from NTPL. In 1996 and 1997 NTPL had greater yield by 13 and 39%, respectively, but the differences were significant at $P = 0.1$ and not at $P = 0.05$. In 1999 NTPL produced only 3% more lint than CTPL.

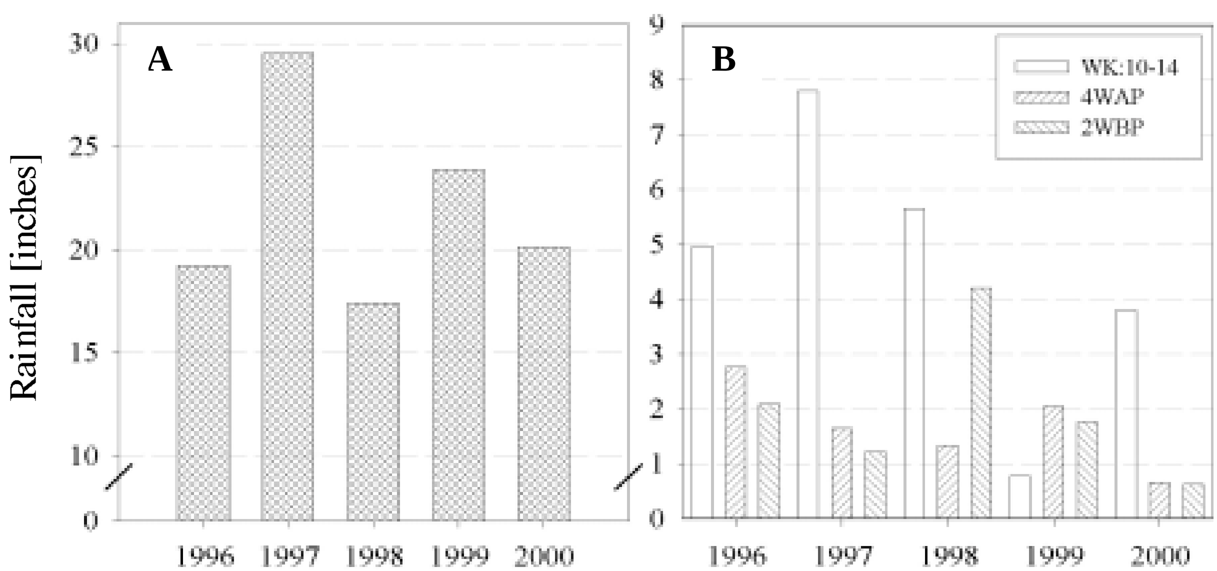

Fig.2. Rainfall during various periods of cotton growth from 1996 to 2000: (A) for weeks 1 to 20; (B) for weeks 10 to 14 [WK:10-14], for 4 weeks after planting [4WAP], and for 2 weeks before planting [2WBP].

NTPL vs. CTCF

The greatest yield differences were observed between NTPL and CTCF. Yields were significantly greater by 35 to 84% from NTPL in four of the five years and 42% greater over five years (Figs. 1C and D). The greatest difference was in 2000. The 1999 drought suppressed yield differences that year. In fact, CTCF produced 4.7% more in 1999 but the difference was not significant.

NTCF vs. CTPL

NTCF produced 9 to 22% more lint than CTPL from 1996 to 1999 but none of the differences were significant (Fig. 1D). In 2000, however, NTCF produced 74% significantly more; and, as a result, yield over five years was 22% significantly greater from NTCF than CTPL.

NTCF vs. CTCF

The second greatest yield differences were between NTCF and CTCF. In four of the five years, NTCF produced 30 to 70% significantly higher yield than CTCF, with the greatest difference occurring in 2000. In 1999, however, yield was only 1.6% higher from NTCF. Over five years, yield was 33% significantly higher from NTCF.

CTPL vs. CTCF

CTPL produced 8 to 20% more lint than CTCF during the first three years of which only the 1997 difference was significant. CTCF actually produced 7.8% more in 1999 and 2.6% more in 2000, but none of these differences were significant.

Rainfall Patterns

The timing or distribution as well as the total amount of rainfall are important in determining yield. To attempt to explain the temporal variation in yield in our research, rainfall patterns are presented in Fig. 2A and B. Rainfall for the first 20 weeks of the cotton season is presented for each year in Fig. 2A. Rainfall during the 20- week period varied between 15 and 20 in. from 1996 to 2000. The differences do not reflect the corresponding yield differences. In fact, 1999 received the second highest rainfall during the 20 weeks. Rainfall during two critical periods of growth: first bloom to peak bloom (weeks 10 to 14) and germination and early stand establishment are presented in Fig. 2B. Rainfall in the two weeks before planting, and during the first four weeks are critical for germination and stand establishment. After week 4, differences between the cumulative rainfall became smaller among the years. In 2000, rainfall was about 0.63 in. each in both the two weeks before planting and the four weeks after. Rainfall in the equivalent period of the other years varied from1.34 to 4.21 in. (2 to 6 times).

DISCUSSION

Drought

The Southeast has been dominated by a harsh drought that started in mid-1998. Cotton is generally considered as one of the most drought tolerant field cops in the Southeast. However, large yield reductions occur when there is water deficit from first bloom to peak bloom period, and loss of yield may not be recovered even if the deficit is lifted at a later date (Sweeten and Jordan, 1987). As indicated, severe water deficit occurred in 1999 from week 10 through 14 of the cotton-growing season. This coincided approximately with the period of first bloom to peak bloom. Rainfall in inches in ascending order during this critical period was: 0.78 for 1999, 3.80 for 2000, 4.97 for 1996, 5.66 for 1998, and 7.81 for 1997 (Fig. 2B). Not only was yield drastically curtailed in 1999 compared to other years, but all treatment differences were negated too (Figs. 1B and D). A linear regression of these rainfall amounts with mean yields for the equivalent years per-treatment indicated that 77 to 93 % of the year-to-year yield variation for each treatment could be explained by the rainfall received during week 10 to 14. The coefficients of determination (r^2) were: 0.91 for NTPL, 0.93 for NTCF, 0.77 for CTPL, and 0.78 for CTCF (Fig. 3A and D).

The rainfall in 2000 during week 10 to 14 was the second lowest of the five years. Although the NT treatments were able to take advantage of this 3.8 in. rainfall and improve the yield over 1999, this did not happen with CT, which had yield close to the 1999 level. This was partially due also to dry conditions during planting and the germination period, which hindered germination more in the CT than NT treatments. In fact, some replanting was necessary in some areas in five of the six CT plots even though we were forced to irrigate all plots with about 0.35 inches of water during the first 10 days after planting to avoid total loss. Replanting meant that during harvesting some of the CT cotton might not have been quite ready. It also confounds the issue of critical period when planting date is staggered. As shown in Fig. 2B, rainfall in 2000 during a six-week period beginning two weeks before planting was only 1.3 inches.

In order to relate the combined effect of dry period early in the season and during blooming to yield, we did a non-linear regression of yield as a response variable to water supply during weeks 10 to 14 and weeks 1 to 4. The data fitted well an equation of the form

$$Z = a + bx + cy$$

where Z is the mean yield, x is the rain for weeks 10 to 14, and y is the rain for weeks 1 to 4. The R^2 values were: 0.96 for CTCF, 0.98 for CTPL, 0.95 for NTCF, and 0.89 for NTPL. We were thus able to explain 96 to 98% of the yield variation for the CT treatments with this model. Recall that we could only explain 77 to 78% of the variation with a model utilizing the rain of weeks 10 to 14 only. We see also that this model fits the data a little better for NTCF. The model did worse for NTPL.

Soil Water Use and Yield Response

No-till systems can be used to reduce the negative impact of dry periods on cotton production. NT-based systems develop surface and subsurface soil physical conditions that lead to favorable soil water regimes. Endale *et al*. (2002) showed that change in soil water content during the 1998 cotton crop season of this research, an indicator of cotton water uptake, was highest in NTPL followed by NTCF, CTPL, and CTCF in that order.

Managing cotton in NT and fertilizing with either PL or ammonium nitrate has distinct yield advantages over conventionally tilled and fertilized cotton except in the years of severest water deficit. In this research, average yields during the first three years of adequate rainfall were above 1050 lbs acre^{-1} in NTPL and NTCF compared to 800 lbs acre^{-1} for CTCF. The yield advantage was greatest in NTPL. Although yield was reduced in all treatments in 1999 and 2000 due to water limiting conditions, yield differences between treatments considering all years were greatest in 2000 (70 to 89%). It appears that in 2000, the NT more than the CT-based systems were able to take advantage of the little irrigation during the first week for better and sustained germination, and the limited water supply during the

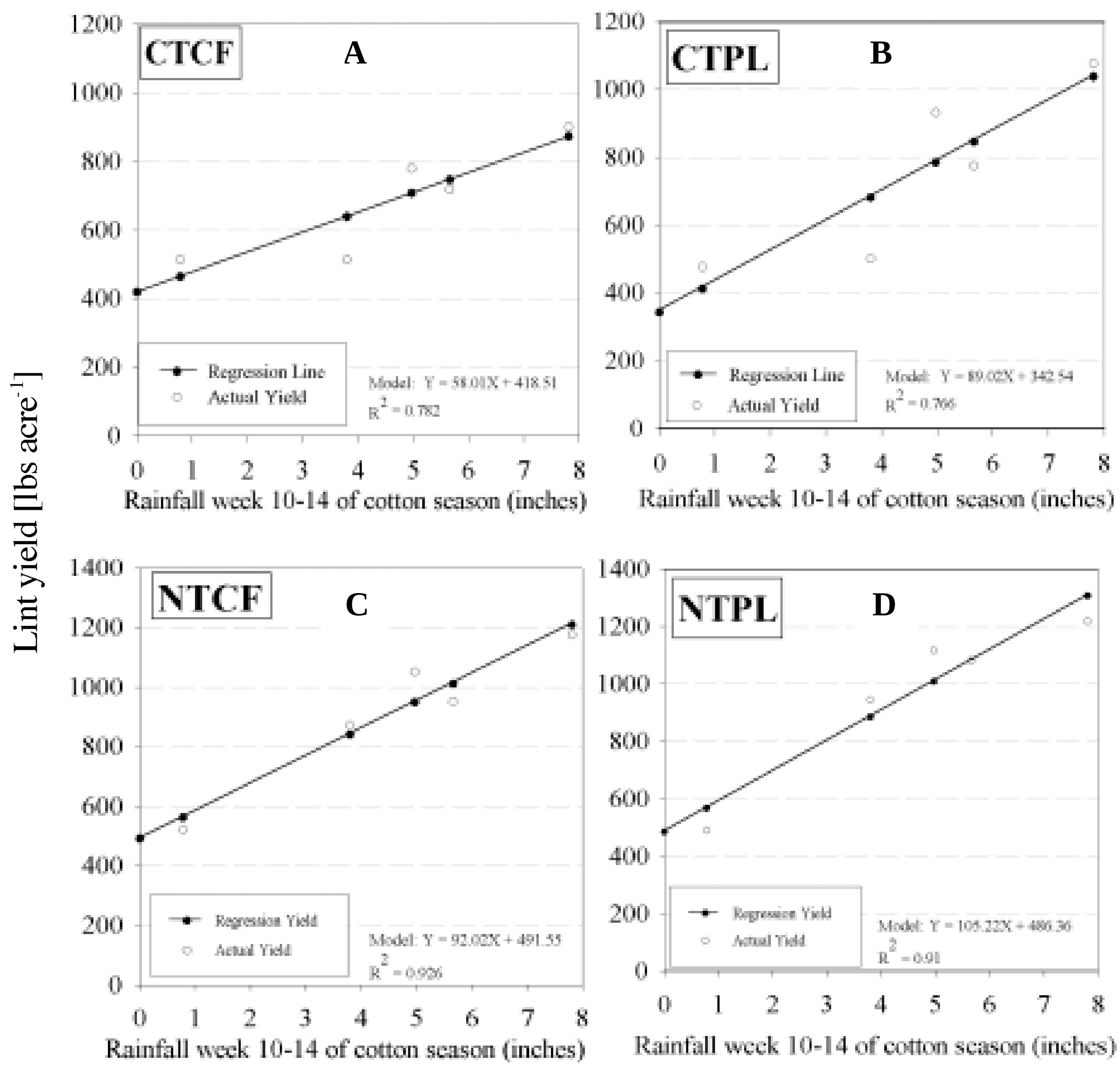

Fig 3. Linear regression of rainfall amount during weeks 10 to 14 of the cotton season versus yield from 1996 to 2000: (A) for CTCF; (B) for CTPL.; (C) for NTCF; and (D) for NTPL

blooming period. The CT-based systems were severely affected on both counts and did not perform as well. Although we used $P = 0.05$ to indicate statistical significance, actual P-values were < 0.001 for all differences in 2000, and as a result P-values were < 0.01 over the five year period. The yield advantage of poultry litter alone over ammonium nitrate is limited.

NT not only provides additional insurance during all but the severest droughts against crop failure, the yield advantage in normal years more than compensates for yield suppression in dry years so that the long-term yield advantage is maintained. This research showed that even where, in two of five years, water was moderately to severely limiting, average yields over the whole period were statistically greater in the NT-based systems. Although yield differences have been presented primarily from the statistical point of view, higher yields of the NT-based systems that were not statistically significant may, nevertheless, have positive economic implications if yield variances and/or cost of production for NT is lower. Yield variance over five years was higher in NT in this research.

CONCLUSIONS

Our five years of research showed that cotton managed under no-till and fertilized with poultry litter or ammonium nitrate has a superior yield return than that of conventionally tilled and fertilized cotton in the Southern Piedmont. A no-till and poultry litter based cotton can produce up to 50% more lint compared to conventionally tilled and fertilized cotton. Similarly, no-till cotton can produce up to 34% more lint than conventional tillage cotton when both are fertilized with ammonium nitrate. These advantages can be even higher during periods of water deficit, except in years of severest deficit. The yield advantages in years of favorable water regime more than makes up for the lack of or reduced differences in water stressed years.

The use of poultry litter as a fertilizer source in cotton production would, in addition to enhancing yield in no-till systems, also create a useful outlet for the large amount of litter produced from the poultry industry in the southeastern United States. Adoption of no-till and poultry litter use in cotton production should, however, also take into account potential build up of nutrients over time and possible environmental degradation. A good nutrient management plan should always be included in the farming system.

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LITERATURE CITED

Bradley, J.F. 1995. Success with no-till cotton. pp. 31-38. *IN* M.R. McClelland, T.D. Valco, and F.E. Frans (eds.) Conservation-tillage systems for cotton: A review of research and demonstration results from across the Cotton Belt. Ark. Agric. Exp. Stn., Fayetteville, AR.

Bruce, R.R., and G.W. Langdale. 1997. Soil carbon level dependence upon crop cultural variables in a Themic-Udic region. pp. 247-261. *IN* E.A. Paul, K. Paustian, E.T. Elliott, and C.V. Cole (eds.) Soil Organic Matter in Temperate Agroecosystems. Long Term Experiments in North America. Lewis Publishers, Ann Arbor, MI.

Carreker, J.R., S.R. Wilkinson, A.P. Barnett, and J.E. Box Jr. 1977. Soil and water management systems for sloping land. ARS-S-160. US Department of Agriculture, Washington, DC.

CTIC, 2000. National crop residue management survey. Conservation Technology Information Center, West Lafayette, IN.

CTIC, 1998. National crop residue management survey. Conservation Technology Information Center, West Lafayette, IN.

Domitruk, D., and B. Crabtree (ed.) 1997. Zero tillage: Advancing the art. Manitoba-North Dakota Zero Tillage Farmers Association, Minot, ND.

Edwards, D.R., and T.C. Daniel. 1992. Environmental impacts of on-farm poultry waste disposal-a review. Bioresour. Technol. 33: 9-33.

Endale, D.M., M.L. Cabrera, J.L. Steiner, D.E. Radcliffe, W.K. Vencill, H.H. Schomberg, and L. Lohr. 2002. Impact of conservation tillage and nutrient management on soil water and yield of cotton fertilized with poultry litter or ammonium nitrate in the Georgia Piedmont. Soil & Tillage Research 96 (In press)

Fawcett, R.S., B.R. Christensen, and D.P. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: A review and analysis. J. Soil and Water Cons. 49: 126-135.

Langdale, G.W., L.T. West, R.R. Bruce, W.P. Miller, and A.W. Thomas. 1992. Restoration of eroded soil with conservation tillage. Soil Technology 5: 81-90.

Littell, R. C., G.A. Milliken, W.W. Stroup, and W.R. Wolfinger. 1996. SAS systems for mixed models. SAS Inst., Inc., Cary, NC.

Moore, P.A., Jr., T.C. Daniel, A.N. Sharpley, and C.W. Wood. 1995. Poultry manure management: Environmentally sound options. J. Soil Water Conserv. 50:321-327.

Rodekohr, J., and D. Rahn, D (ed.) 1997. Georgia agriculture 1996. Educational Support Services. University of Georgia Extension Service, Athens, GA.

Sweeten, J.M., and W.R. Jordan. 1987. Irrigation management for the Texas High Plains: A research summary. Texas Water Resources Institute, Texas A&M University, College Station, TX.

Vest, L., B. Merka, and W.I. Segars. 1994. Poultry waste: Georgia's 50 million dollar forgotten crop. Leaflet 206/July, 1994. Georgia Cooperative Extension Service, College of Agriculture & Environmental Sciences, University of Georgia, Athens, GA (Available at http://www.ces.uga.edu/pubcd/L206-w.html; verified 11 Jan. 2002).