# Cotton Responses to Tillage and Rotation during the Turn of the Century Drought

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## ABSTRACT

**Longer rain-free periods are predicted to occur more often in the southeastern United States as a result of global climate change. This nonirrigated field study was conducted from 1997 through 2002, which coincided with the 1998–2002 drought that affected most of the United States. The objective was to determine the effect of rotation and tillage on cotton (*Gossypium hirsutum* L.) productivity. Treatments in the study were rotation [cotton rotated with corn (*Zea mays* L.), cotton planted after a rye (*Secale cereale* L.) winter cover crop, and continuous cotton with no cover crop] and tillage system (conventional tillage and conservation tillage). Two levels of aldicarb [2-methyl-2-(methylthio)propanal *O*-{(methylamino)carbonyl}oxime] (0 and 1.18 kg a.i. ha$^{-1}$) were also included because of known soil management effects on thrips (*Frankliniella* sp.) and root-knot nematodes (*Meloidigyne incognita*). The predominant soil types were Bonneau loamy sand (loamy, siliceous, subactive, thermic Arenic Paleudult) and Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult). Rotation did not affect cotton yield in any year. Tillage did not affect cotton yield in 1997. Conservation tillage resulted in an average 25% yield increase in cotton lint yield over conventional tillage during the 5-yr drought. Tillage and aldicarb affected both thrips and root-knot nematodes, but lack of interaction among these factors for lint yield suggested that management of these pests was not the predominant cause for the cotton yield increase with conservation tillage. Conservation tillage for cotton production could be an important method to help mitigate the effects of climate change in the region if change occurs as predicted.**


Periods of drought are predicted to occur more often in the southeastern United States as a result of global climate change as greenhouse gasses continue to accumulate in the atmosphere (Karl et al., 2009). If this occurs, growers will need farming practices that increase the crop water availability from precipitation for nonirrigated production. One widely-used practice in the region that may mitigate the effects of prolonged rain-free periods is conservation tillage. Conservation tillage can increase soil water, especially before the soil is covered with the crop canopy, and can increase crop yields compared to conventional tillage (Phillips et al., 1980). Higher yields with conservation tillage have been attributed to reduced evaporation from the soil surface (Lascano et al., 1994) and reduced runoff (Truman et al., 2003).

Crop residues have been suggested to be an important component of conservation tillage production systems in the region (Langdale et al., 1990). The amount of residue needed for improving soil productivity in the Southeast has been estimated to be more than 12 Mg ha$^{-1}$ (Bruce et al., 1995). In conservation tillage systems for cotton, crop residues left on the soil surface following cotton harvest are typically minimal. Previous research indicates that cover crops (Bauer and Busscher, 1996; Raper et al., 2000) or rotations with high residue crops (Bordovsky et al., 1994; Reddy et al., 2006) have the potential to increase the productivity of cotton in conservation production systems.

Tillage management and crop rotations also can affect two major pests of cotton, thrips and root-knot nematodes. All et al. (1992) found fewer tobacco thrips in conservation tillage systems than in conventional tillage systems. Less is known about how rotation may affect thrips, though Bauer and Roof (2004) did not find substantial differences in thrips populations or thrips damage in cotton following cover crops of rye, crimson clover (*Trifolium incarnatum* L.), or a mixture of the two. Olson et al. (2006) reported an inverse relationship between rye cover crop residue density and thrips populations and damage in cotton. With regards to root-knot nematodes, more eggs and second stage juveniles were reported in cotton grown following a terminated rye winter cover crop than in cotton following winter fallow (Wheeler et al., 2008). On the other hand, McSorley and Dickson (1995) found that rye was effective at limiting root-knot damage when soil incorporated as a green manure. Subsequently, McBride et al. (1999) reported that the protection from damage with soil-incorporated rye was effective for up to 21 d after incorporating the rye. Preventative in-furrow applications of aldicarb are commonly used to control both root-knot nematodes and thrips.

Following the 1997–1998 El Nino, a prolonged drought affected much of the United States and parts of Mexico and Canada (Seager, 2007). The southeastern United States was impacted between 1998 and 2002 (Seager, 2007). In 1997, we began this 6-yr experiment to investigate the effect of crop rotation and tillage on cotton production on a coastal plain soil. Soil specific yield and fiber quality responses to tillage and winter cover crop use during the first 3 yr of this study have

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Cotton

been published (Bauer and Frederick, 2005). In this report, cotton yield responses to tillage and rotation are presented for the entire 6 yr of the study across the different soil map units. Our hypothesis was that rotation with corn or a winter cover crop of rye would enhance productivity, particularly for conservation tillage production through increased soil residue cover.

## MATERIALS AND METHODS

This field study was conducted from 1997 through 2002 at Clemson University's Pee Dee Research and Education Center near Florence, SC. In the early 1990s, soil scientists with the USDA-NRCS conducted a soil survey of the fields on the property, using a 30.5-m grid sampling pattern. For this experiment, a 3.6-ha field was selected that contained Bonneau sand and Norfolk loamy sand as the predominant soil map units. Corn was grown on the site using conventional tillage in 1996. Precipitation and temperature were measured with a weather station located within 10 km of the field.

Treatments in the experiment consisted of crop rotation and tillage. Two levels of aldicarb were also included as treatments because of known soil management effects on thrips and root-knot nematodes. The crop rotation treatments were cotton rotated with corn, cotton grown following a winter cover crop of rye, and continuous cotton with no cover crop. Tillage treatments were conventional and conservation. Aldicarb levels were 0 and 1.18 kg a.i. $ha^{-1}$. There were three replicates of each treatment combination. A split-plot experimental design was used with the rotation and tillage combinations as the main plots and aldicarb levels as the subplots. Each subplot consisted of six 1-m wide cotton rows that ranged from 122 to 213 m in length. Subplot lengths varied because they all ended at the field edge which was irregular and the variation in length allowed for the two soil types to be included in each plot.

Corn was grown in the corn rotation treatment plots in 1997, 1999, and 2001 using the conservation or conventional tillage practices described below. Hybrid 'DK 687' was planted in 38-cm wide rows (58,000 seeds $ha^{-1}$) on 27 Mar. 1997, 25 Mar. 1999, and 5 Apr. 2001 with a 12-row planter equipped with wavy coulters. Fertilizer N (134 kg N $ha^{-1}$) was broadcast applied shortly after planting. Corn was harvested in September with a combine equipped with a yield monitor. Tillage did not have a significant effect on corn yield in any of the 3 yr. Corn yields averaged 5021 kg $ha^{-1}$ in 1997, 5648 kg $ha^{-1}$ in 1999, and 3848 kg $ha^{-1}$ in 2001.

In the rye winter cover plots, 134 kg $ha^{-1}$ of 'Gurley Grazer' rye seed was planted directly into the previous crop residue with a no-tillage grain drill in mid-November of each year. In the spring of each year, P, K, and Mn were broadcast applied to the entire experimental area at rates based on soil test analysis. The fertilizer application also included 22.4 kg S $ha^{-1}$ and 2.24 kg B $ha^{-1}$. Lime (1120 kg $ha^{-1}$) was applied once on 16 Mar. 1999. Rye and the winter weeds in all conservation tillage plots were sprayed with either paraquat dichloride (1-1′dimethyl-4-4′-bipyridinium dichloride) (0.17 kg a.i. $ha^{-1}$) or glyphosate [*N*-(phosphonomethyl)glycine)] (1.12 kg a.i. $ha^{-1}$) in April of each year. At this time, the conventional tillage plots were disked twice (to a depth of 15 cm) and then smoothed with an S-tined harrow. A six-legged paratill was used (to a depth of 40 cm) to alleviate subsoil compaction in all plots.

Cotton was planted in 1-m wide rows with a four-row planter equipped with wavy coulters on 7 May 1997, 18 May 1998, 12 May 1999, 2 May 2000, 23 May 2001, and 6 May 2002. For subplots that did not receive aldicarb, the drive chains for the insecticide hoppers on the planter were disengaged before planting. 'DPL Acala 90' was planted in 1997 and 1998, 'DPL 675RR' was planted in 1999 and 2000, and 'DPL 451BtRR' was planted in 2001 and 2002. Seeding rate each year was approximately 10 seeds $m^{-1}$ of row. Weeds were controlled using appropriate herbicides and hand-weeding. At least once per year a cultivator was used in the conventional tillage plots. Insect pests were regularly scouted and controlled with insecticides (except thrips in the subplots that did not receive aldicarb) as needed. Fertilizer N was applied to the cotton in a split-application of $NH_4NO_3$ each year. Within 1 wk of planting, 45 kg N $ha^{-1}$ was applied each year using a four-row applicator equipped with fertilizer coulters and rear knives. A subsequent application of 45 kg N $ha^{-1}$ was made with the same applicator in early to mid-June of each year.

Root samples were collected approximately 60 d after planting in 1997, 1998, 2000, and 2002 and immediately after harvest in 1999 and 2001 for determination of root-knot nematode numbers. Roots were collected from each soil type in each subplot. A 15-g composite sample of cotton roots was collected from 10 plants. The root samples were incubated in a $ZnSO_4$ solution (10 mg $L^{-1}$) for 4 d. Then, nematodes were collected on a 25-μm pore sieve (Bird, 1971) and counted.

In 1998, 2000, and 2002 (the years when cotton was grown on all plots), plant height and total number of mainstem nodes was determined in early July on all plants in a meter of row in 1998 and on five consecutive plants in 2000 and 2002. Measurements were collected from an interior row at three places within each plot.

In the fall of each year, cotton was chemically defoliated with thidiazuron (*N*-phenyl-*N*′-1,2,3-thiadazol-5-ylurea), S,S,S-tributyl phosphorotithioate, and bolls were opened with ethephon [(2-chloroethyl) phosphonic acid] at the recommended rates. Cotton was harvested with a spindle picker on 30 Oct. 1997, 26 Oct. 1998, 12 Nov. 1999, 30 Oct. 2000, 7 Nov. 2001, and 2 Oct. 2002. Two rows from each 13.7-m subsection of each subplot were individually harvested into bags. After weighing the bags of seedcotton, samples were taken from the harvest bags for determination of lint percentage. Seedcotton was ginned with a 10-saw laboratory gin.

Data were analyzed by year because every other year included corn instead of cotton and because different cotton cultivars were used in each 2-yr period. Soil and root nematode data were transformed before analysis by adding 1 to the counts and then calculating the $\log_{10}$ of the number. All data were analyzed as a split-plot design using the GLIMMIX procedure of SAS v9.2. Rotation and tillage combinations were the main plots, and aldicarb levels were the subplots. Rotation, tillage, and aldicarb were considered fixed effects. Replicates were considered random.

## RESULTS AND DISCUSSION

Precipitation varied considerably among years, but prolonged rain-free periods occurred during each growing season from 1998 through 2002 (Fig. 1). Averaged over all treatment combinations, lint yield in the year before the drought began (1997) was 847.5 kg $ha^{-1}$. Average yield in 1998, 2000, and 2001were only marginally lower (between 100 and 140 kg $ha^{-1}$) than the yield in 1997. The effect of the drought was most severe in 1999 and 2002. Average yield in 1999 was only 44% of the yield in

1997 while average yield in 2002 was only 18% of the yield in 1997. In these two low yielding years, rainfall deficit during midsummer was the greatest of the 6 yr (Fig. 1).

There was no significant difference ($P \leq 0.05$) in cotton yield between conventional tillage and conservation tillage in 1997, the year before the drought (Tables 1 and 2). In each of the 5 yr during the drought period, conservation tillage averaged 25% greater cotton yields than conventional tillage. In each of those years, greater yield with conservation tillage was essentially the same for all three crop rotations. No rotation × tillage interactions occurred for yield in any year of the study. Although rotation with corn (Reddy et al., 2006) or after a rye cover crop (Raper et al., 2000) increased yield over continuous cotton in previous research, neither of these rotations had a significant effect on cotton yield in any year of this study (Tables 1 and 2).

Tillage management influenced root-knot nematode numbers and damage by thrips in this study. Root-knot nematode numbers on plant roots were lower in cotton grown under conservation tillage than in cotton grown under conventional tillage in two of the five drought years (Table 3). As we reported for the first 3 yr of the study (Manley et al., 2003), fewer thrips were found on the cotton plants grown under conservation tillage than on the cotton grown with conventional tillage. Thrips populations were not monitored during the last 3 yr of the study, but plant damage by thrips was rated in 2000 and 2002. In those 2 yr, plants grown under conservation tillage had less damage from thrips than plants grown under conventional tillage (data not presented).

Reduction in pest infestations under conservation tillage does not explain all of the yield increase over conventional tillage management. If it did, differences in yield for the two tillage treatments would have been greater for the cotton grown without aldicarb than the cotton grown with aldicarb. There were no significant interactions involving aldicarb and tillage in any year (Table 1). In addition, aldicarb was most effective in 1997 where yield of cotton was 189 kg lint $ha^{-1}$ greater for cotton grown with aldicarb than for cotton grown without aldicarb. Of the years during the drought, aldicarb application resulted in greater yield in 1998 (76 kg lint $ha^{-1}$ increase) and 2002 (49 kg lint $ha^{-1}$). In the other 3 yr, there was no difference between cotton that had aldicarb applied at planting and cotton that did not.

Phillips et al. (1980) suggested the benefit of conservation tillage on soil water is primarily before canopy closure. Perhaps the main reason for the greater yields for the cotton managed under conservation tillage during the drought years was more available soil water early in reproductive growth. At this growth stage in 1998, 2000, and 2002 (the 3 yr height and node measurements were collected), plants grown under conservation tillage were taller and had greater height to node ratios (Table 4) than plants grown under conventional tillage. Water deficit stress causes young bolls to abscise and bolls become less susceptible to water deficit stress with age (Guinn, 1982). Extending soil water reserves a few days during precipitation-free periods could reduce young boll losses. With plant populations of about nine plants per meter and assuming cotton bolls contain approximately 2.0 g of fiber per boll, the yield increases during the drought years correspond to an average of 1.1 bolls per plant in 1998, 0.6 bolls per plant in 1999 and 2000, 1.0 bolls per plant in 2001, and 0.16 bolls per plant in 2002.

Any soil water content advantage with conservation tillage in this study was likely primarily due to reduced evaporation

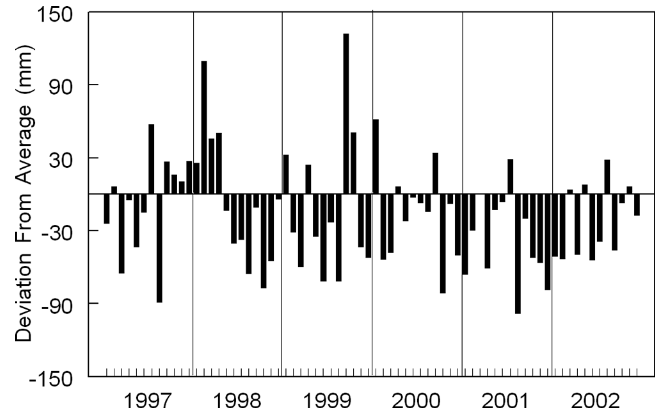


**Fig. 1. Monthly deviation from average rainfall at Florence, SC between 1997 and 2002.**

**Table 1. Probability of significance for sources of variation for lint yield.**

| Source | Year 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|
| | $P > F$ value | | | | | |
| Rotation | 0.056 | 0.698 | 0.618 | 0.315 | 0.231 | 0.325 |
| Tillage | 0.727 | 0.002 | 0.005 | 0.018 | 0.009 | 0.042 |
| Rotation × tillage | 0.286 | 0.988 | 0.185 | 0.396 | 0.153 | 0.256 |
| Aldicarb | <0.001 | 0.002 | 0.095 | 0.900 | 0.852 | <0.001 |
| Rotation × aldicarb | 0.604 | 0.998 | 0.146 | 0.216 | 0.359 | 0.024 |
| Tillage × aldicarb | 0.092 | 0.155 | 0.382 | 0.907 | 0.882 | 0.173 |
| Rotation × tillage × aldicarb | 0.301 | 0.845 | 0.643 | 0.197 | 0.857 | 0.188 |

**Table 2. Tillage and rotation effect on cotton lint yield. Data are averaged over aldicarb levels.**

| Year | Tillage | Rotation: Corn–cotton | Rye–cotton | Continuous cotton | Mean |
|---|---|---|---|---|---|
| | | | –kg $ha^{-1}$– | | |
| 1997 | conventional | – | 767 | 914 | 840 |
| | conservation | – | 831 | 880 | 855 |
| | mean | – | 799 | 897 | |
| 1998 | conventional | 674 | 640 | 633 | 649 |
| | conservation | 857 | 830 | 805 | 831** |
| | mean | 766 | 735 | 719 | |
| 1999 | conventional | – | 310 | 334 | 322 |
| | conservation | – | 456 | 405 | 431** |
| | mean | – | 383 | 370 | |
| 2000 | conventional | 645 | 724 | 658 | 675 |
| | conservation | 823 | 796 | 719 | 779* |
| | mean | 734 | 760 | 688 | |
| 2001 | conventional | – | 553 | 688 | 621 |
| | conservation | – | 798 | 784 | 791** |
| | mean | – | 676 | 736 | |
| 2002 | conventional | 128 | 158 | 147 | 145 |
| | conservation | 179 | 180 | 151 | 170* |
| | mean | 154 | 169 | 149 | |

* Indicates tillage means differed at $P \leq 0.05$.

** Indicates tillage means differed at $P \leq 0.01$.

**Table 3. Effect of aldicarb on root-knot nematodes in cotton roots at approximately 60 d after planting in 1997, 1998, 2000, and 2002 and immediately after harvest in 1999 and 2001. Data are averaged over rotations.**

| | Conventional | | | Conservation | | |
|---|---|---|---|---|---|---|
| Year | Without aldicarb | With aldicarb | Mean | Without aldicarb | With aldicarb | Mean |
| | no. per 15 g of root | | | | | |
| 1997 | 31.6 | 6.9 | 19.2 | 21.1 | 5.4 | 13.3 |
| 1998 | 8.3 | 6.7 | 7.5 | 10.3 | 1.8 | 6.0 |
| 1999 | 16.7 | 0.0 | 8.3 | 37.5 | 12.5 | 25.0 |
| 2000 | 105.6 | 88.2 | 96.9* | 88.9 | 46.5 | 67.7 |
| 2001 | 22.9 | 0.0 | 11.5 | 12.5 | 2.1 | 7.3 |
| 2002 | 101.4 | 78.1 | 89.7* | 68.1 | 33.3 | 50.7 |

* Indicates mean of conventional tillage was significantly ($P \leq 0.05$) than conservation tillage in that year. Statistical analysis was conducted on data that were transformed by the equation $\log_{10}$ (nematode count + 1).

from the soil surface. Lascano et al. (1994) reported evaporation accounted for most of the difference in soil water between cotton grown with conventional tillage and cotton grown in wheat stubble. Although some difference in rainfall infiltration may have occurred, both tillage treatments in our study employed paratill subsoiling which has a large effect on increasing rainfall infiltration (Truman et al., 2003).

In summary, production practices that increase the amount of surface residues, that is, an annual rotation with corn or the use of a rye winter cover crop, did not increase cotton productivity in this study. Conservation tillage use during the drought years resulted in a significant yield increase. Climate prediction models indicate that the southeast United States will have higher average annual temperature with little change in annual total precipitation (Karl et al., 2009) as greenhouse gasses continue to accumulate in the atmosphere. Even though total precipitation will change little, these models predict precipitation will occur in more intense events. Thus, there will be longer periods within growing seasons without precipitation (Karl et al., 2009). These results suggest that conservation tillage for cotton production could be an important method to help maintain productivity if climate change in the region occurs as predicted.

**Table 4. Effect of tillage on plant height and height to node ratio on 2 July 1998, 6 July 2000, and 1 July 2002. Data are averaged over rotations and aldicarb levels.**

| | Height | | Height/node ratio | |
|---|---|---|---|---|
| Year | Conventional | Conservation | Conventional | Conservation |
| | cm | | ratio | |
| 1998 | 48.3 | 52.5† | 4.6 | 4.9* |
| 2000 | 71.1 | 77.8* | 5.8 | 6.1† |
| 2002 | 37.3 | 42.5* | 4.7 | 5.0† |

* Indicate tillage means differed at $P \leq 0.05$.

† Indicate tillage means differed at $P \leq 0.1$.

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