Comparison of Tillage Type and Frequency for Cotton on Piedmont Soil

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ABSTRACT

In-row chisel (IC) and paratill (PT) tillages disrupt root restricting consolidated soil zones and improve rooting capacity. Compaction-disrupting tillages increase costs of farm operations because of the need for more powerful tractors and greater fuel use. We evaluated the need for continuous or less frequent disrupting tillages for cotton (*Gossypium hirsutum* L.) production in a typic Kanhapludult soil. Lint yields of IC treatments were 15 to 20% greater than conventional disk tillage (DT) each year. In 1994, yields ranged from 480 to 750 lbs acre^{-1} (0.53 to 0.84 Mg ha^{-1}) with continuous IC having better yields than continuous secondary tillage (ST) or PT. In 1995, cotton yields ranged from 830 to 1150 lbs acre^{-1} (0.92 to 1.29 Mg ha^{-1}) with the top yield associated with current year IC application. In 1996, the fifth year of the study, no significant differences in yields were observed among tillages; however, two of the top five yields were IC treatments. For the three cotton years, continuous IC plots out yielded DT and had numerically greater yields than continuous PT and (ST). Yields for PT and ST were no better than those of DT. Average annual net returns from continuous IC were 179, 154, and 113 \$ acre^{-1} greater than those from continuous DT, PT, and ST, respectively. In-row chisel appears to be a more economically viable production practice for heavy Piedmont soils with consolidated zones because of its lower energy requirement and greater cotton yield response compared to PT.

KEYWORDS

Conservation tillage, paratill, in-row chisel, economic return, Cecil soil

INTRODUCTION

Nearly two thirds of the Southern Piedmont region is covered by Cecil series and related soils (clayey, kaolinitic, thermic typic Kanhapludults) (Hendrickson *et al.*, 1963). These soils have a zone of high strength at 6 to 10 in (0.15 to 0.25 m) below the surface usually near the top of the Bt horizon (NeSmith *et al.*, 1987; Radcliffe *et al.*, 1988; Tollner *et al.*, 1984). Hardpan development in these soils has been associated with fall disk tillage (NeSmith *et al.*, 1987) wheel traffic (Radcliffe *et al.*, 1989) and disturbance of the low organic matter-weakly structured horizons by deep tillage (Radcliffe *et al.*, 1989). Annual use of an in-row chisel can disrupt the hardpan in these soils (Radcliffe, *et al.*, 1989) and improve infiltration (Mills *et al.*, 1988).

Several studies have compared deep tillage implements, and deep tillage with conventional and no-tillage (Busscher *et al.*, 1988; Reeder *et al.*, 1993; Kanwar *et al.*, 1997; Raper *et al.*, 2000a & b). Few studies have compared tillage type and frequency especially for soils of the Southern Piedmont and cotton production systems. Raper *et al.* (2000a) showed that shallow in-row chisel in the fall was as effective or more effective than deeper tillage to disrupt an impeding clay layer and increase cotton yield on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult) in Alabama. Subsoiling in the autumn was equally effective as spring subsoiling and was more beneficial to time management.

Limited data are available on response of cotton to annual or less frequently applied shallow or deep tillage (in-row chisel or paratill) in Southern Piedmont soils. We evaluated combining no-tillage with shallow or deep tillage to improve water penetration or with secondary tillage (to control weeds) and residual effects of these tillages on cotton yield. Economic evaluations were conducted to determine net return and profitability of the various tillage-management systems.

MATERIALS AND METHODS

Tillage and residual tillage effects were evaluated on a slightly eroded Cecil sandy loam soil (clayey, kaolinitic, thermic Typic Kanhapludult) near Watkinsville, GA begin-

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Table 1. Mean depth of the soil profile horizons, bulk density and soil texture (Radcliffe *et al.*, 1989)

Horizon	Depth		Bulk Density		Sand	Silt	Clay
	in	m	lbs in^{-3}	g cm^{-3}	---------------- % ----------------		
Ap1	1 to 5	0.03 to 0.13	0.046	1.28	73	20	7
Ap2	5 to 10	0.13 to 0.24	0.055	1.53	67	23	10
Bt1	10 to 14	0.24 to 0.36	0.055	1.53	43	20	37
Bt2	14 +	0.36 +	0.051	1.41	30	20	50

ning in the fall of 1991. The study was located on a site between terraces in a summit position on uniform slopes of 3%. Soil characteristics are given in Table 1.

The experimental design was a randomized complete block with three replications and 16 treatments (tillage-by-year of tillage combinations). Four tillage systems were evaluated: (IC) coulter planting with in-row chisel to a depth of 9 in (230 mm) with 1.5 in (38 mm)-wide points; (PT) paratill with a Tye Paratill plow (Bigham Brothers, Lubbock, TX) equipped with six legs (three right and three left) spaced 24 in (0.61 m) apart and angled at 45^{o} to the side and outfitted with a 0.25 in (6.4 mm) serrated coulter ahead of each leg; (ST) coulter planting with trash wipers followed by secondary tillage using 24 in (0.6 m) sweeps to control weeds during the summer crop season, and (DT) conventional tillage using a 12 ft (3.05 m)-wide offset disk harrow to a depth of 4 to 5 in (0.1 to 0.13 m) followed by coulter planting. Years of tillage application and treatment designations are given in Table 2.

Each plot consisted of eight rows on 30 in (0.76 m) spacing (20 ft wide by 75 ft long, 6.10 m by 22.86 m) with wheel traffic confined to areas between alternating rows. Rows were re-established so that tillage, planting, and traffic occurred in the same location each year. The study began with disking the entire area to a depth of 4 to 5 in (0.1 to 0.13 m) with a 160 hp (120 kW) Hesston 180-90 tractor and offset disk harrow. The same tractor was used each fall to paratill PT plots approximately 12 to 14 in (30 to 36 cm) deep following summer crop harvest (except in the fall of 1992 when soils were too wet and PT was delayed until May 1993). The tillage depth was approximately the top of the Bt horizon. The 160 hp tractor was used in the spring to disk harrow DT plots and plant designated IC plots. A 75 hp (56 kW) John Deere 3020 tractor was used in the spring to plant remaining plots with a four-row no-till planter and in the fall on all plots to plant cover crops with a conservation tillage grain drill. Field operation dates are presented in Table 3. Management followed standard recommended practices from the University of Georgia Extension Service.

Hybrid pearl millet (*Pennisetum glaucum*) (4 lbs $acre^{-1}$, 4.5 kg ha^{-1}) was planted following crimson clover *(Trifolium incarnatum*) (15 lbs $acre^{-1}$, 17 kg ha^{-1}) in 1992 and 1993. Poor yields and bird damage caused the cropping system to be switched to cotton (15 lbs $acre^{-1}$, 17 kg ha^{-1}) following winter rye (*Secale cereale*) (70 lbs $acre^{-1}$, 78 kg ha^{-1}) for 1994, 1995 and 1996. Cover crops were planted on all plots in the fall and were killed with a burn-down herbicide (paraquat or glyphosate) following emergence on DT1 plots and in the spring 2 to 3 weeks prior to planting summer crops on remaining plots (Table 3). In 1994, 1995,

Table 2. Primary tillage treatments and years of application.

	Year of tillage application				
Treatments†	1992	1993	1994	1995	1996
IC1, PT1, ST1, DT1	X	X	X	X	X
IC2, PT2, ST2	X		X		
IC3, PT3, ST3	X			X	
IC4, PT4, ST4	X				X
IC5, PT5, ST5	X				

† IC in-row chisel, PT paratill, ST secondary tillage, DT disk tillage

Table 3. Field operation dates (dd/mm/yy).

Field	Summer Crop Year				
Operation	1992	1993	1994	1995	1996
Plant Cover Crop	25/09/91	23/11/92	07/10/93	09/11/94	20/10/95
Fertilize	20/09/91	02/12/92	07/10/93	09/11/94	18/10/95
Paratill	28/09/91	17/05/93†	07/10/93	09/11/94	18/10/95
Kill Cover Crop	22/05/92	06/05/92	01/04/94	04/04/95	13/04/96
Plant Summer Crop	01/06/92	21/05/93	09/05/94	04/05/95	10/05/96
Harvest	17/11/92	27/09/93	07/11/94	12/10/95	22/10/96

† Due to a wet fall the paratill operation was delayed until the spring.

and 1996 cotton was harvested with a two-row cotton picker (John Deere, Model 299, John Deere and Company, Moline, IN) and yield was determined on 60 ft (18.3 m) of the middle two plot rows.

Crop enterprise budgets were developed that focused on the three years of cotton production using the Farm Suite whole farm planning system (Lamb *et al.*, 1992). Application rates for variable inputs were those used in the study. Operating costs, overhead, and returns on investments were computed for 1994, 1995, and 1996 using data from various published sources (Givan, 1994, 1995, and 1996; Ga. Ag. Stat. Service, 2001) and records collected for actual costs. Gross returns were calculated annually as the product of treatment yields and Georgia market-year average prices. Variable costs were actual prices paid by farmers each year and include costs of herbicides, seed, labor, fuel, repair and maintenance of equipment, and interest on operating capital. Fixed costs include costs of tractors, self-propelled equipment, and implements. Total specified costs included both variable and fixed costs. Appropriate tillage expenses were charged annually for DT1, IC1, PT1, and ST1. For other tillage treatments, costs were prorated on an annual basis to allocate a cost incurred during one year over all years that received benefit from tillage. No charges were included for land, management, or general farm overhead. Net returns were calculated as the difference between gross income and total specified costs. Average net returns were calculated from the annual net returns over the study period.

Statistical analysis of year and treatment effects on cotton yields and net returns were evaluated using the MIXED model procedure in the Statistical Analysis System (SAS Inst, 1990; Littell *et al.*, 1996). Year, replication, year-by-replication, and year-by-treatment were considered random effects. Covariance structures were modeled with the repeated option. Degrees of freedom were determined using Satterthwaite's procedure. Specific single degree of freedom contrasts were used to compare treatments across and within years. All means were estimated as Best Linear Unbiased Predictors (Littell *et al.*, 1996). Differences were considered significant at alpha = 0.10 unless otherwise stated. Treatment effects on plant populations for each year were determined using the GLM procedure of SAS (SAS Inst, 1990).

RESULTS

Climate

The three growing seasons were different in terms of heat unit (growing degree days base 60 F, 15.6 C, GDD) accumulation, rainfall amount, and rainfall distribution (data not shown). In 1994, rainfall from planting to 01 September was 23.8 in (695 mm) and only five rainfall events exceeded 3 in (75 mm) per 24 hours. A period of water stress occurred from mid-August to mid-September. Above average fall rainfall combined with early cool temperatures delayed and impeded boll development in1994. Heat unit accumulation was insufficient (1596 by 01 September) to complete crop maturation (2100 to 2200 GDD needed for crop maturation). Significant numbers of unopened bolls were present at the time of harvest.

Temperatures were more favorable for boll development in 1995 and 1996; however, rainfall from planting to 01 September was limited in 1995 (16.7 in, 426 mm) and 1996 (12 in, 303 mm) with very poor distribution particularly in 1995. During 1995, there was a long dry period from mid-June to mid-August that made it necessary to irrigate to avoid crop loss. Water (approximately 1 in, 0.025

m) was applied using a traveling gun over a three-day period (one day per replication) during July 18 to 20 and again July 26 to 28. In 1996, the limited growing season rainfall was more evenly distributed and along with early spring rain that resulted in significant stored water, helped eliminate the need for irrigation. A period of water stress was experienced during late July that almost certainly depressed cotton yields.

Plant Stands

Stand establishment was influenced by tillage treatments all three years ($p < 0.02$). Cotton populations (plants acre^{-1}, plants m^{-2}) ranged from 17,800 to 64,300 (4.4 to 15.9) in 1994, 16,500 to 52,000 (4.1 to 12.9) in 1995, and 28,000 to 54,600 (7.0 to 13.5) in 1996. Populations below 28,300 to 36,400 (7 to 9) can result in decreasing yields with decreasing populations but above these values are considered adequate for cotton production with little change in yield as populations increase (Bednarz *et al.*, 2001). Populations tended to be greatest for IC treatments during the year of application. Although planting equipment was nearly identical, the chisel may have created better seedbed conditions compared to that of other treatments.

Cotton Yields

Significant year ($P = 0.012$), treatment ($P = 0.134$), and year-by-treatment ($P = 0.093$) effects were present in the yield analysis. The significant year-by-treatment interaction resulted from greater yields in 1995 than in 1994 and 1996, and a greater yield response to in-row chisel in 1994 and 1995 than for the other tillages (Table 4). Comparison of yields among reduced tillage treatments each year indicated that continuous IC had the greatest positive effect on cotton yield while continuous PT and ST did not respond as favorably (Tables 4 and 5). Averaged across years, yields of IC1 were 274, 239, and 197 lbs acre^{-1} (306, 268 and 221 kg ha^{-1}) greater than DT1, PT1, and ST1, respectively. Response to in-row chisel tended to be greatest during the year of application as indicated by the absence of a significant difference between IC1 and IC2 in 1994 or IC1 and IC 3 in

Table 4. Cotton lint yield, annualized net return, and tillage cost for tillage treatments.

Tillage [‡]	Lint cotton [†]				Annual	
	1994	1995	1996	Avg	Net return	Tillage cost
	lbs acre^{-1}				$ acre^{-1}	
DT1	486	838	666	663	122	20.12
IC1	754	1150	909	937	302	20.62
IC2	715	996	808	840	249	14.88
IC3	636	1077	822	845	243	14.88
IC4	532	845	644	674	140	14.88
IC5	592	997	764	784	207	12.97
PT 1	538	865	694	699	147	20.51
PT 2	523	881	763	723	162	14.84
PT 3	547	964	719	743	178	14.84
PT 4	630	920	766	772	202	14.84
PT 5	628	978	805	803	220	12.95
ST1	586	909	727	741	188	18.38
ST2	593	881	721	732	178	13.57
ST3	570	845	653	689	155	13.57
ST4	615	928	802	782	211	13.57
ST5	483	847	677	669	132	12.10

[†] Yields are best linear unbiased predictor means.

[‡] Tillage treatments are listed in Table 2.

1995 but IC1 was better than IC4 in 1996 due to poor stand establishment in IC4. Yield of IC1 was greater than that of plots that had not received a second IC by 29% in 1994 (IC3, IC4, and IC5), 27% in 1995 (IC4 and IC5) and 17% in 1996 (IC5). Yield of IC1 was greater than that of plots in-row chiseled the previous year in 1995(IC2) but not greater than that of plots in-row chiseled the previous year in 1996 (IC3). The in-row chisel treatment appeared to provide an improved soil condition that enhanced cotton stand establishment, growth and yield predominantly in the year of application.

Yields of cotton were not differentially influenced by continuous or alternative year paratill treatments (Table 4). In each year, yields for PT1 were similar to plots paratilled for that season and to plots paratilled in previous seasons. Response to paratilling may have been reduced due to insufficient fracturing of the soil profile in the fall (moist soils) and subsequent re-consolidation of the soil profile between paratilling and cotton establishment. Three tractor operations (planting the rye cover crop, herbicide application to kill the cover crop, and cotton planting) occurred following paratilling, which probably enhanced re-consolidation of the disturbed subsoil (Reeder *et al.*, 1993). Although tractor traffic was confined to the same area in the plots each year some drift across plots during field operations was possible.

Similar to the yields with PT, few differences in yields were apparent among ST plots that received continuous ST and those that received less frequent ST (Table 4). The ST treatment caused some disturbance of the soil surface but minimal burial of crop residues. Keeping residues on the soil surface is important in these soils to reduce soil crusting, runoff, and decreased infiltration associated with depletion of organic matter in the top 1 inch (0.025 m) (Bruce *et al.*, 1995). One advantage of the ST treatment is that it could be used for weed control in a sustainable

Table 5. Average annual lint yield and net return comparisons between treatments.

Contrast†	Lint Cotton	P > |t|	Net return	P > |t|
	lbs acre^{-1}		\$ acre^{-1}	
DT1‡ - IC1	-274	0.0023	-179	0.0010
DT1 - PT1	-35	0.6879	-25	0.6339
DT1 - ST1	-77	0.3814	-66	0.2127
IC1 - PT1	239	0.0078	154	0.0044
IC1 - ST1	197	0.0275	113	0.0339
PT1 - ST1	-42	0.6349	-41	0.4384
IC1 - IC2	97	0.2706	53	0.3165
IC1 - IC3	92	0.2981	58	0.2689
IC1 - IC4	263	0.0034	161	0.0030
IC1 - IC5	153	0.0854	95	0.0754
PT1 - PT2	-24	0.7866	-15	0.7827
PT1 - PT3	-44	0.6144	-31	0.5599
PT1 - PT4	-73	0.4061	-54	0.3054
PT1 - PT5	-105	0.2369	-72	0.1737
ST1 - ST2	9	0.9217	10	0.8437
ST1 - ST3	51	0.5624	33	0.5298
ST1 - ST4	-41	0.6395	-22	0.6705
ST1 - ST5	72	0.4174	56	0.2895

† Contrasts are between best linear unbiased predictor means for each treatment.

‡ Tillage treatments are listed in Table 2.

agriculture or organic system where reductions in yield would be offset by greater premiums paid for organic cotton (usually 3 to 1).

Plant populations were significantly correlated to yields all three years. The correlation (r value) was 32 % in 1994, 54% in 1995, and 29% in 1996. Although significant correlation between yield and population existed each year, reduced yields due to stand density were probably present only for treatments with very low populations. Bednarz *et al.* (2001) found that plant populations had little effect on final cotton yields because of changes in boll retention and position as populations changed. Although low populations may have influenced yield for some treatments, the greater yield response to in-row chisel is attributed to additional effects like water availability or hardpan disruption because populations of several other treatments were similar to those of IC1 but yields were consistently lower for these treatments.

Economic analysis

Net returns were significantly influenced by year (P = 0.047) and treatment (P = 0.078) but there was no significant year-by-treatment interaction. Net returns averaged across the three years of cotton ranged from \$122 to \$300 acre^{-1} (\$300 to \$745 ha^{-1}) annually depending primarily on cotton yield (Table 4). Costs for tillage, planting, and weed control ranged from \$13 to \$21 acre^{-1} (\$30 to \$51 ha^{-1}). Operational costs of IC1 were greatest but net returns were also greatest (Table 4). Surprisingly, operational costs of DT1 were nearly the same as for IC1 (Table 5). The yield advantage with reduced tillage treatments increased profits over DT1. Net return for paratill plots increased from PT1 to PT5, which was unexpected. The PT1 plots were paratilled each year while those of PT2, PT3, and PT4 were paratilled 2 times with the second paratill operation occurring in succeeding years. Net returns indicate that a paratill operation once every five years is the most economical approach to deep tillage on these soils. This is in contrast to the results of Clark *et al.* (1993) and Radcliffe *et al.* (1989) who concluded that annual paratilling was needed in these soils due to reconsolidation and increases in soil strength following paratillage. Our results may have been affected by poor stands in the PT plots and because including the winter rye cover crop on infrequently paratilled plots may have helped establish more permanent root networks and channels of less resistance due to the absence of disturbance in these plots.

DISCUSSION

Variable growing conditions experienced during the three years of this study illustrate why many producers have adopted cotton as a crop of choice in the Southeast. Even with poor growing conditions yields were generally better than 500 lbs acre^{-1} (0.56 Mg ha^{-1}) for most treatments (Table 4). In two out of the three years, the reduced tillage plots that received annual tillage treatments significantly out yielded the conventional tillage plots. Previous work on soils at the same location has demonstrated the beneficial effects of conservation tillage on soil physical, biological and chemical properties (Bruce *et al.*, 1995; Langdale *et al.*, 1990; Franzluebbers *et al.*, 1999). Bruce *et al.* (1995) showed that for Cecil soils in the Southern Piedmont, reduced tillage and increased crop residue inputs increase soil organic matter and water stable aggregates at the soil surface. Infiltration rates were 51 % greater in no-till plots compared to conventional tillage plots, and that removal of residues from the soil surface during the infiltration measurements was detrimental to conventional tillage plots but had little effect on NT plots. Franzluebbers *et al.* (1999) found that at a depth of 0 to 150 mm, mean-weight diameter averaged 0.041 in (1.03 mm) with conventional tillage, 0.044 in (1.12 mm) with paratill, 0.046 (1.17 mm) with secondary tillage, and 0.048 in (1.23 mm) with in-row chisel for plots in the current study. Biophysical improvement of surface soil structure would lead to greater water infiltration and presumably improved water use efficiency.

The benefit of current year IC was apparent in all three. In each year, the annual IC (IC1) and current year IC, had similar yields. It was somewhat surprising that IC was superior to PT since PT results in a deeper disturbance of the soil profile, which should allow greater soil exploration by the cotton roots. Two possible effects may have negated the impact of the PT treatment. First, PT was executed during the fall and therefore some reconsolidation of the profile may have occurred before the following cotton growing season. Reeder *et al.* (1993) found that soil strength following paraplowing returned to pre-subsoiling strength during the first growing season and reconsolidation occurred more rapidly than with other subsoiling equipment. Clark *et al.* (1993) and Radcliffe *et al.* (1989) indicate that in Cecil soil, wheel traffic contributes to hardpan formation at 6 to 10 in (0.15 to 0.25 m) below the surface. One to two tractor operations following PT may be enough to re-compact the soil profile to the same state as prior to the PT operation (Reeder *et al.*, 1993). Radcliffe *et al.* (1989) concluded that compaction is a problem without deep tillage in this region and that the depth of compaction caused by traffic exceeds the depth of secondary tillage. Since IC was performed at planting any negative effects of wheel traffic would be minimized compared to fall PT, which was followed by killing of the cover crop and planting the summer crop. This subsequent wheel traffic may be one reason that IC effects were consistently present in the year IC was performed. A second reason for the less significant response to PT may have been due to poor germination and stand establishment. Plant stands were reduced in some PT plots but cotton can compensate for lower stand density and this was not considered to be the major cause of yield reduction. In situations where PT is not performed at the proper depth, the soil surface can remain rough, which may adversely affect seed to soil contact and reduce stand density.

Our results indicate that paratilling Cecil and similar soils may not provide a positive economic return to producers. Costs associated with PT were similar to IC but required an additional tractor operation (time and labor) and a large tractor. Additional savings for IC could be accrued with use of a smaller tractor and its associated reduced maintenance costs. Therefore, IC appears to be a superior choice on these Southern Piedmont soils. West *et al.* (1996) concluded that PT in no-till systems was beneficial only on dark, poorly drained soils and provided little benefit on other silty loam soils in Indiana. Wesley *et al.* (2000) found that fall deep tillage had 9% greater net returns for nonirrigated soybean than fall paratillage on Tunica clay (clayey over loamy, smectitic, nonacid, thermic Vertic Haplaquept) in Mississippi. When deep tillage was performed every second or third year, yields and returns were within 5% of continuous deep tillage. They concluded fall deep tillage should be performed at least once every 3 yr to maximize and sustain higher yields and net returns. Clark *et al.* (1993) concluded from cone index and water infiltration data that moderately and severely eroded soils of the Southern Piedmont require annual chiseling to ensure minimizing the effect of soil compaction on crop growth. Our results along with other studies demonstrating variable response to PT indicate that in-row chisel is probably a better option. Development of tools to measure soil strength on the go to help determine the need for in-row chisel or paratilling would be beneficial to producers.

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