REDUCING SOIL COMPACTION AND IMPROVING COTTON YIELD WITH CONSERVATION TILLAGE IN THE TENNESSEE VALLEY

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ABSTRACT

Yield reductions with strict no-tillage in the Tennessee Valley of north Alabama jeopardized adoption of conservation systems in this region. Consequently, we implemented a four year study on a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudults) in 1994 to develop a practical conservation tillage system that results in competitive cotton yields. Treatments included a factorial combination of fall ridging (ridged and non-ridged) and fall deep tillage (none, in-row subsoiling, paratilling); along with spring strip tillage and conventional tillage. With the exception of the conventional tillage, all treatments were established with a rye (*Secale cereale* L.) cover crop. Tillage systems were evaluated for plant population, soil compaction, soil water content, and seed cotton yield. Cotton populations with conservation tillage were similar to the conventional tillage system and adequate stands were obtained in all treatments far all years. Soil compaction index (function of compaction intensity and volume of affected soil) was reduced by fall paratilling (29%-31%) and in-row subsoiling (12-15%), compared to conventional tillage and strict no-tillage, respectively. Both fall subsoiling and paratilling reduced soil water content (increased soil water removal by cotton roots) under the row compared to strict no-tillage. Fall deep tillage, either paratilling or in-row subsoiling, resulted in the highest seed cotton yields (2,760 lb ac^{-1}); 16% greater than conventional tillage, and 10% greater than strict no-tillage over a 4 y duration. Deep tillage (subsoiling or paratilling) and the use of cover crops is the most competitive system for farmers trying to convert to conservation tillage in this region.

INTRODUCTION

Long-term continuous cotton production on soils in the Tennessee River Valley of northern Alabama has resulted in soil degradation due to soil erosion, loss of organic matter, and soil compaction. Degradation of soil quality and increasing governmental regulations on the 60 to 70% of cropland classified as highly erodible land (HEL) in the region resulted in some farmers turning to conservation tillage systems in the early 1990's. The common method of conservation tillage, i.e., no-tillage cotton planted into existing cotton stubble, increases soil surface compaction; restricting root growth and reduces yields in the region (Burmester et al., 1993). Management decisions for conservation tillage systems are further complicated by slow accumulation of growing degree days (DD60s) in the spring and early fall freezes, resulting in a short growing season (Norfleet et al., 1997). Thus, many farmers were reluctant to adopt conservation tillage on a large scale, despite the possible long-term benefits of improved soil quality. To facilitate widespread adoption of conservation tillage in the region, a study was implemented in the fall of 1994 to develop a conservation tillage system for cotton that would reduce soil compaction and maintain competitive yields.

MATERIALS AND METHODS

The study was initiated in November of 1994 on the Tennessee Valley Research and Extension Center of the Alabama Agriculture Experiment Station, Belle Mina, AL. The soil type is a Decatur silt loam, the major soil type in the region. The experimental area had been cropped continuously to no-till cotton without a cover crop for four years prior to study.

The experimental design was a randomized complete block design with four replications, with a two by three augmented factorial treatment arrangement. Plots consisted of eight, 40-in wide rows which were 50 feet long. Treatments were a factorial combination of fall ridging (ridging and non-ridged) in combination with fall deep tillage (none, in-row subsoiling and paratilling). The augmented treatments were spring strip tillage and conventional tillage. Non-ridging without deep tillage is considered a strict no-tillage control. All treatments were accomplished with four-row equipment. Subsoiling was implemented under the row with a KMC® (Kelley Manufacturing Co., Tifton, GA 31793)[1] ripper bedder to a depth of 17 in. Paratilling was done with a Paratill® (Bigham Brothers, Inc., Lubbock, TX 79452)[1] to a depth of 18 in. In the fall of 1994, all ridging operations were accomplished using a KMC® ripper bedder equipped with disk bedders. The ripper subsoiler shanks were removed for implementation of fall ridging without deep tillage and ridging with paratilling. Data from the fall ridging with subsoiling treatment is not available for 1995 because of difficulties implementing this treatment in the fall of 1994, however, in fall of 1995 and consecutive years, all ridged plots were successfully created with ridging listers rather than disk bedders. Spring strip tillage in 1995 was implemented with an experimental Yetter® (Yetter Farm Equipment, Colchester, IL 62326)[1] implement. This implement has an in-row subsoiler that ran 8 to 10 in deep, with a series of in-row disks, coulters and spider tines to create a disturbed zone 12 to 14 in wide. In all other years (1996 to 1999) a specially designed KMC® implement was used for the spring strip tillage treatment. This implement has a shorter subsoil shank that ran 6 to 7 in deep in the row, and a series of in-row disks and coulters that disturbed a zone 12 in wide. Conventional tillage consisted of fall disking and chiseling (8 to 10 in deep) followed by disking and field cultivating in the spring.

All plots, except the conventional tilled plots, were seeded in rye (*Secale cereale* L.) with a grain drill immediately after fall tillage. The cover crop was terminated prior to spring planting with an application of glyphosate [N-(phosphonomethyl) glycine].

A four-row John Deere Maxi-Emerge® (Deere & Company, Moline, IL 61265)[1] planter equipped with Martin® (Martin & Company, Elkton, KY 42220)[1] row cleaners was used to plant 'DP 51' cotton on 12 May 1995, 'NuCOTN 33[B]' on 1 May 1996, 'DP

20B' on 7 May 1997 and 'PM 1220 BG/RR' on May 6 and May 5 in 1998 and 1999, respectively. Following planting, 15 lb N and 6 lb P ac^{-1} was applied in a band over the row. Nitrogen was also sidedressed at a rate of 90 lb ac^{-1} in all years. An additional 30 lb N ac^{-1} was applied in 1996 because of visual N deficiency at first bloom. Auburn University Extension recommendations were used to apply all herbicides, insecticides, and defoliants.

Average volumetric water content was determined in the top 15-in of soil under the row approximately twice a week from squaring to maturity in 1995 and 1996, and from early bloom to maturity in 1997 using time-domain reflectometry (TDR) (Topp, 1980).

A tractor-mounted, hydraulically driven, soil cone penetrometer was used for determination of soil strength after planting in 1995, 1996, and 1997 (Raper et al., 1999). The tractor-mounted penetrometer determined soil strength in five positions simultaneously: in-row, and 10 and 20 in from the row in both the trafficked and non-trafficked middles. Readings were taken continuously throughout the soil profile to a depth of 16 in and were averaged every two in. A soil compaction index was also determined for the evaluation of soil strength. Data were plotted to give scaled contour graphs using Surfer® for Windows (Golden Software Inc., Golden, CO 80401)[3]. Using this software, the area of the graph (cm^2) occupied by each incremental 0.5 MPa of soil strength was multiplied by the soil strength at the upper end of each increment and summed for all increments using the following formula:

$$SCI = \frac{1}{100}\sum_{I=1}^{N}\left[A_{I/2} - A_{(I/2 - 1/2)}\right]\frac{I}{2}$$

Where: SCI = soil compaction index (MPa-100 cm^2)

A = respective scaled area (cm^2) of contour graph between the isoline of cone index equal to (I/2) - (½) MPa and isoline of cone index equal to (I/2) MPa.

I = cone index of the isoline multiplied by 2 (MPa)

N = maximum cone index isoline multiplied by 2 (MPa)

Cotton populations were determined in 1995, 1996, 1997, and 1998 by counting the number of plants in two 5-ft sections of row from each plot. In all years, the middle 4 rows of cotton were harvested with a spindle cotton picker for the determination of seed cotton yield.

Data were subjected to analysis of variance using the Statistical Analysis System (SAS Institute, 1988). Preplanned single degree of freedom contrasts and Fisher's protected least significant difference (LSD) were used for mean comparisons. A significance level of $P \leq 0.10$ was established *a priori*.

[3] Reference to a trade or company name is for specific information only and does not imply approval or recommendation of the company by the USDA or Auburn University to the exclusion of others that may be suitable.

RESULTS AND DISCUSSION

Cotton Population

Contrary to previously reported research from the region (Touchton et al., 1984 and Brown et al., 1985), all conservation tillage treatments resulted in similar cotton populations compared to the conventional tillage treatment in all years with the exception of 1997 (Table 1). Delaying planting until 1 May or later and removing residue in the seeding zone with planter-equipped row cleaners likely minimized the soil temperature effects on cotton stands. Despite minor differences in plant populations, adequate stands were obtained in all treatments for all years.

Soil Compaction

Soil compaction as indicated by the soil compaction index was affected by tillage treatments in all measured years. The three year mean shows that conventional tillage, strict no-tillage, non-ridging without deep tillage, and spring strip tillage had greater soil compaction than all treatments with fall subsoiling or paratilling (Table 2). Fall paratilling also significantly reduced soil compaction compared to the fall subsoiled treatments. Fall subsoiling was effective in reducing soil compaction directly under the row, however, it had little effect in row middles. The bent shank of the paratill lifts the soil, causing a wide zone of disruption, unlike the subsoiler shank, which disrupts a narrow zone.

Soil Water

Tillage treatment had a significant effect on in-row soil water content in two of the three years measured (Table 3). In 1995, fall paratilling, with or without ridging, had significantly lower in-row soil water content compared to conventional tillage and strict no-tillage. This pattern of lower soil water contents in treatments with reduced compaction and higher soil water contents in treatments with greater compaction is consistent with expected differences in cotton rooting, i.e., greater root growth and soil water extraction in systems with lower soil compaction. However, average in-row soil water content for the non-ridged subsoiled treatment was not significantly lower than conventional tillage and strict no-tillage in 1995, despite reduced soil compaction. In 1996, fall ridging with paratilling had significantly lower in-row soil water content compared to all other treatments. Similar trends were seen in 1997, with fall ridging with paratilling having lower average soil water content compared to all other treatments, however this was not significantly different.

Yield

Seed cotton yields from all conservation tillage treatments were greater than or equal to conventional tillage in all five years of the study (Table 4). Despite extreme drought and severe outbreaks of tobacco budworm (*Heliothis virescens* F.), which visually appeared to have the greatest feeding pressure on the larger, less drought-stressed treatments, seed cotton yield averaged 1,480 lb ac^{-1} in 1995. Fall ridging produced greater yield compared to non-ridged treatments, as indicated by single degree of freedom contrast in 1995 (1770 vs. 1570 kg ha^{-1}, $P \leq 0.08$).

In 1996, an improved year for cotton production in the region due to adequate rainfall during the critical bloom period and the use of Bt varieties to control tobacco budworm, seed cotton yield averaged 3540 lb ac^{-1}. In 1996, non-ridging resulted in greater seed cotton yields compared to fall ridging (4210 vs. 3870 kg ha^{-1}, $P \leq 0.06$). Paratilling without ridging had greater yield than fall ridging with paratilling or subsoiling, spring strip tillage, conventional tillage and the strict no-till treatment (non-ridging without deep tillage) (Table 4). Low rainfall early in the season of 1996 resulted in dry soil conditions, which may have impacted treatments with fall ridging more then non-ridged treatments. Raised beds in the fall ridged treatments may have increased drainage from the small volume of soil occupied by the young cotton roots, consequently increasing drought stress and reducing yield potential relative to non-ridged treatments.

In 1997, rainfall was near or above normal for the early part of the season, however, rainfall was severely below normal in the critical blooming period (July through early August). Fall subsoiling (2,670 lb ac^{-1}) resulted in greater yield than treatments without deep tillage (2,420 lb ac^{-1}, $P \leq 0.08$). Compared to treatments without deep tillage, fall subsoiling reduced the soil compaction index, likely increasing rooting and allowing cotton to better cope with drier weather during the critical fruiting period. Although treatments with paratilling also reduced soil compaction, yields were not significantly greater than treatments without deep tillage (2,580 vs. 2,420 lb ac^{-1}, $P \leq 0.27$) in 1997. A delay in cotton maturity is believed to be responsible for reduced yields in treatments with paratilling.

Three of the first four weeks of the 1998 season had lower than normal rainfall and this early season drought continued midway into the critical blooming period. In this year, fall ridging (2,000 lb ac^{-1}) significantly reduced yields compared to non-ridged treatments (2,480 lb ac^{-1}, $P \leq 0.061$). As in 1996, we believe that early season drought stress resulted in lower yields with fall ridged treatments. However, despite this drought, all conservation tillage treatments had greater yields then conventional tillage, with the exception of fall ridging without deep tillage (Table 4).

In 1999, there was an extended drought from July through August, the critical fruiting period. Subsoiling without ridging had significantly greater yield than fall ridging with subsoiling, non-ridging with paratilling, strict no-tillage, and the conventionally tilled treatment (Table 4). Unlike 1996 and 1998, with drought stress in early June, fall ridged treatments were not significantly disadvantaged compared to treatments without fall ridging in 1999.

Average seed cotton yields during the study (1996-1999) were greater for all conservation tillage systems compared to conventional tillage, excluding 1995, a year with unusually heavy insect pressure. Highest yields were obtained with subsoiling or paratilling without ridging. Spring strip tillage yield was similar to paratilling or subsoiling without ridging but was not statistically greater than strict no-tillage. However, spring strip tillage did not reduce soil compaction compared to strict no-tillage and timing of this tillage system is often difficult because of wet soils in the spring, making this system impractical on a large scale.

CONCLUSION

Highly competitive yields were obtained with conservation tillage systems using a rye cover crop on fine-textured soils in the Tennessee Valley region of northern Alabama. Stand establishment problems from residue-induced cold/wet soil previously reported were overcome by delaying planting until the first of May and the use of row cleaners. Fall deep tillage (subsoiling or paratilling) reduced soil compaction and increased soil water removal by cotton roots in a conservation tillage system. Over a 4 year duration, seed cotton yields were greatest in fall subsoiled or paratilled treatments without ridging; 16% greater than conventional tillage and 10% greater than strict no-tillage. Spring strip tillage yield was reduced but statistically similar to fall deep tillage without ridging, and was not significantly different from strict no-tillage. Problems with wet soils in the spring further complicate implementation of spring strip tillage, making this system impractical. Consequently, farmers turning to conservation tillage in this region would benefit from a system that integrated fall non-inversion deep tillage and cover crops.

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Table 1. Effect of tillage system on cotton plant populations (1995 - 1998).

Treatment	1995	1996	1997	1998
	plants ac^{-1}			
Conventional Tillage	39,600	32,800	47,000	34,900
Non-ridged without Deep Tillage †	31,700	29,900	33,900	32,700
Non-ridged with Subsoiling	38,200	30,700	29,600	24,500
Non-ridged with Paratilling	31,300	35,100	37,800	32,000
Fall Ridging without Deep Tillage	38,900	22,600	49,000	40,800
Fall Ridging with Subsoiling	‡	35,300	47,600	29,400
Fall Ridging with Paratilling	40,500	36,200	47,000	32,000
Spring Strip Tillage	37,900	33,800	39,400	33,500
$LSD_{(0.10)}$	*ns*	*ns*	*6,330*	*ns*

† Non-ridged without deep tillage is considered strict no-tillage.
‡ Fall ridging with subsoiling was not implemented in 1995.

Table 2. Effect of tillage on soil compaction index (1995 - 1997).

Treatment	
	MPa-100
Conventional Tillage	6.563
Non-ridged without Deep	6.775
Non-ridged with Subsoiling	5.774
Non-ridged with Paratilling	4.683
Fall Ridging without Deep	6.619
Fall Ridging with Subsoiling	5.702
Fall Ridging with Paratilling	4.734
Spring Strip Tillage	6.872
$LSD_{(0.10)}$	*0.402*

† Non-ridged without deep tillage is considered strict no-tillage.

Table 3. Average in-row soil volumetric water content as affected by tillage treatment.

Treatment	1995	1996	1997
	Soil water (ft^3 ft^{-3})		
Conventional Tillage	0.238	0.311	0.286
Non-ridged without Deep Tillage	0.237	0.312	0.296
Non-ridged with Subsoiling	0.195	0.295	0.282
Non-ridged with Paratilling	0.187	0.294	0.286
Fall Ridging without Deep	0.225	0.318	0.288
Fall Ridging with Subsoiling	‡	0.292	0.246
Fall Ridging with Paratilling	0.144	0.243	0.239
Spring Strip Tillage	0.208	0.294	0.271
$LSD_{(0.10)}$	*0.045*	*0.039*	*ns*

† Non-ridged without deep tillage is considered strict no-tillage.
‡ Fall ridging with subsoiling was not implemented in 1995.

Table 4. Effect of tillage system on seed cotton yield (1995-1999) and percent open bolls prior to defoliation (1995-1998).

	Seed cotton Yield					
Treatment	1995	1996	1997	1998	1999	96-
		lb ac^{-1}				
Conventional Tillage	1,510	3,130	2,560	1,770	2,030	2,380
Non-ridged without Deep	1,490	3,500	2,300	2,180	2,060	2,510
Non-ridged with Subsoiling	1,560	3,780	2,740	2,250	2,420	2,790
Non-ridged with Paratilling	1,320	4,010	2,620	2,120	2,180	2,730
Fall ridging without Deep	1,620	3,730	2,530	2,850	2,300	2,600
Fall ridging with Subsoiling	‡	3,390	2,600	2,070	2,160	2,550
Fall ridging with Paratilling	1,530	3,230	2,540	2,120	2,370	2,550
Spring Strip Tillage	1,540	3,540	2,620	2,170	2,250	2,640
LSD(0.10)	*ns*	*462*	*ns*	*231*	*192*	*178*

† Non-ridged without deep tillage is strict no-tillage.
‡ Fall ridging with subsoiling was not implemented in 1995.
§ Mean excludes 1995 data because of unusually heavy insect pressure which disproportionately affected treatments with greatest yield potential.