Tillage Depth, Tillage Timing, and Cover Crop Effects on Cotton Yield, Soil Strength, and Tillage Energy Requirements

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Abstract. *During the early 199Os, declining cotton (Gossypium hirsutum L.) yields plagued farmers in the Tennessee Valley Region of North Alabama who tried to eliminate moldboard and/or chisel plowing from their conventional farming systems to meet conservation compliance programs. The severely reduced yields were possibly due to inadequate rooting systems caused by excessive soil compaction. A study was conducted from 1995-1998 to investigate conservation tillage systems which incorporated a rye (Secale cereale L.) cover crop to maintain surface cover and in-row tillage to disrupt root-impeding soil layers. Energy requirements for shallow tillage (0.18 m) and deep tillage (0.33 m) performed in the autumn and spring were also assessed. Factors investigated included time of tillage, depth of tillage, and use of a cover crop. A rye cover crop was found to be the largest single factor in increasing seed cotton yield, with positive results seen in three of four years. Of somewhat lesser importance, autumn tillage and shallow tillage increased seed cotton yield in those years containing more typical growing seasons. The conservation tillage practice of shallow, autumn, in-row subsoiling in conjunction with a cover crop may offer the best alternative for farmers trying to reduce the negative effects of soil compaction, maintain adequate residue cover, and improve seed cotton yield.*

Keywords. *Tillage, Conservation tillage, Tillage depth, Tillage timing, Subsoiling, Soil compaction, Cotton yield, Cover crop.*

Cotton farmers in the Tennessee Valley Region of North Alabama have experienced problems maintaining yields when highly erodible soils, which have been conventionally farmed for more than 100 years, were placed in conservation tillage systems. The USDA-NRCS (Natural Resource Conservation Service) has mandated that some of these fields be managed using conservation tillage systems for the farmers to participate in farm programs. Traditional methods of moldboard plowing, chisel plowing, and disking do not leave adequate amounts of crop residue on the surface to meet compliance standards and protect soil from erosion (USDA-SCS and EMI, 1992). Because cotton produces low amounts of residue, minimum or no-tillage is often required to maintain adequate surface coverage.

Soil compaction problems also plague this region. The platy soil structure exhibits considerable strength at relatively shallow depths, particularly in no-till fields. Cotton tap roots have been observed to be bent at 90^{o} angles at depths of less than 0.15 m when cotton was directly planted into the previous year's cotton stubble. Cotton is particularly susceptible to soil compaction (Cooper et al., 1969; McConnell et al., 1989; Mullins et al., 1992; Reeves and Mullins, 1995). One method of alleviating compaction and recovering soil productivity is to subsoil to a depth of 0.3 to 0.5 m (Garner et al., 1984; Reid, 1978; Campbell et al., 1974; Raper et al., 1994). However, soils in the Tennessee Valley Region of North Alabama have not responded positively to subsoiling in a previous experiment (Touchton et al., 1986). Complete management systems may be needed to either loosen the soil profile or increase soil moisture in order to reduce soil strength and increase rooting depth.

A systems-type approach appeared to offer the most potential for developing a successful tillage system that could generate comparable yields relative to conventional tilled systems while maintaining adequate surface residue. Our approach was targeted toward developing tillage systems that would minimally disturb the soil surface to maintain adequate surface residue coverage and at the same time shatter the compacted layer. Factors studied included timing of tillage, depth of tillage, and use of a cover crop. Timing of tillage was investigated to determine whether in-row tillage performed in the autumn (after harvest when producers have more time readily available) would benefit cotton as much as in-row spring tillage performed immediately before planting. A cover crop was incorporated to generate additional surface residue and to retain soil moisture as has been shown by Reeves (1994).

Determining the appropriate depth of tillage involved recognizing that cotton roots were constrained at different depths throughout fields in this region. When fields were examined, rooting depth in some locations was minimal (less than 0.1 m) while in other locations within the same field, no problems were found. Soil cone index has been identified as a measurement that can determine these

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depths of extreme root impedance (ASAE, 1999a,b) and could be used to determine appropriate tillage depths.

Variations in soil density or cone index with depth could be used to indicate a potential need for variable-depth tillage. Fulton et al. (1996) used two measures of soil compaction, cone index and bulk density, and found that significant variation occurred within the same Kentucky field. From their measurements, they stated that adjusting tillage depth could save as much as 50% of fuel necessary for deep tillage. Variable-depth tillage could contribute to decreasing overall input costs for southeastern soils due to potential energy savings from tilling the soil deep enough to eradicate root-impeding layers without tilling too deeply and wasting energy or tilling too shallow to do significant good. However, before judgements can be made about savings in tillage energy, increased plant response must be achieved due to the effect of tillage.

Therefore, the objectives of this experiment were to:

- Determine the effect of tillage performed at two depths on draft requirements, soil strength, and cotton yield response.
- Determine the effect of tillage performed either in the autumn or the spring on draft requirements, soil strength, and cotton yield response.
- Determine the effect of a winter cover crop on tillage draft requirements, soil strength, and cotton yield response.
- Identify the interactive effects of these variables and develop a recommended system of cotton production in the Tennessee Valley region using conservation tillage.

MATERIALS AND METHODS

The field selected for the trials had been used for conventional tilled cotton for several years prior to the experiment. Tillage treatments were applied in the autumn of 1994, in the spring and autumn of 1995, in the spring and autumn of 1996, in the spring and autumn of 1997, and in the spring of 1998 at the Alabama Agricultural Experiment Station's Tennessee Valley Substation in Belle Mina, Alabama. The predominant soil type in this region, and at the experimental site, is a Decatur silt loam (clayey, kaolinitic, thermic ***Rhodic Paleudult).*** The plots were comprised of four 1 m (40 in.) rows, 9.1 m (30 ft) long, with the two middle rows harvested for yield. The experimental design was a randomized complete block, with a 2x2x2 factorial arrangement of treatments augmented with three additional control treatments of no-tillage with no cover crop, no-tillage with a cover crop, and conventional tillage with no cover crop. The three factors were (1) cover crop (none or rye), (2) tillage timing (autumn or spring), and (3) tillage depth (shallow or deep). Depth of tillage was established in 1994 by taking multiple cone-index profiles (Raper et al., 1999) of the field and determining the average depth and thickness of the root-impeding soil layer. This layer was located at a" approximate depth of 0.10 to 0.15 m. Therefore, the shallow depth of tillage was chosen as 0.18 m and the depth of deep tillage was set at 0.33 to completely disrupt this profile. An experimental Yetter™ implement with in-row subsoilers that could be adjusted to operate at each depth was used for all tillage treatments. Residue attachments that consisted of fingered wheels and fluted coulters were used to move residue away from the shanks. Closing disks were mounted on the rear of the shank to create a small seedbed region approximately 0.3 m wide and 0.1 m high. The conventional tillage treatment consisted of autumn disking and chiseling, followed by disking and field cultivating in the spring prior to planting.

Plots that received a cover crop were seeded to rye with a grain drill immediately after autumn tillage. The cover crop was terminated in the spring prior to planting with glyphosate [N-(phosphonomethyl) glycine]. Cotton was planted in early May, with Deltapine 'DP 15' used in 1995, Deltapine 'NuCOTN 33B' in 1996, Deltapine 'DP 20B' in 1997, and PM 1220 BG/RR in 1998. A four-row John Deere Maxi-Emerge® (Deere & Company, Moline, Illinois) planter equipped with Martin® row cleaners was used to plant the cotton. Starter fertilizer and an additional application of phosphorous and potassium were applied after planting following Auburn University Extension recommendations as were all applications of insecticides and defoliants.

Soil strength measurements were taken in the spring and autumn of each year immediately before, and then after the tillage treatments were applied. Soil strength was determined using a tractor-mounted multiple-cone penetrometer to obtain cone index (ASAE, 1999a,b; Raper et al., 1999). Cone index values were measured approximately every 4 to 6 mm and then averaged over 50-mm depth increments to simplify data comparison. Five penetrometer probes were inserted simultaneously: (1) in the row; (2) midway between the row and the untrafficked row middle (0.25 m from the row); (3) in the untrafficked row middle (0.50 m from the row); (4) midway between the row and the trafficked row middle (0.25 m from the row); and (5) in the trafficked row middle (0.50 m from the row). Three insertions of the multiple-probe soil cone penetrometer were made in each plot.

Soil samples for gravimetric water content were taken in each plot at the conclusion of the tillage events at shallow (0 to 0.15 m) and deep (0.15 to 0.30 m) depths.

Tillage energy was measured with a tractor-mounted three-point hitch dynamometer capable of measuring draft, vertical, and side forces up to 90 kN. This device was attached to the four-row Yetter implement and was used to measure tillage forces for all spring and autumn in-row tillage treatments.

The factorial arrangement of eight treatments within the randomized complete block was analyzed using the appropriate ANOVA model. No interactions were found and all discussions relate to main effects. All 11 treatments also were analyzed using a randomized complete block model to include effects of the three augmented control treatments. Data were analyzed with year in the model and when significant year by treatment interactions occurred, the data were analyzed by year and treatment effects are then presented and discussed by year. Depth, position, and interaction effects of these variables with response variables were analyzed using a split-split plot model where appropriate. Means were separated using Fisher's protected LSD ($P \leq 0.05$). The augmented control treatments effects were also separated using single degree of freedom contrasts.

RESULTS AND DISCUSSION

Only main effects of seed cotton yield were found in all years with no interactions (table 1). Seed cotton yield in 1995, the first year of the trial, was decreased due to a severe tobacco budworm [*Heliothis virescens* (F.)] infestation (table 1). In general, for this year conventional tillage had the highest seed cotton yields (1750 kg/ha), significantly greater than either no-till without a cover crop (1500 kg/ha), or no-till with a cover crop (1320 kg/ha). Analyzing the factorial treatments (table 2) revealed a strong tillage timing treatment effect ($P \leq 0.010$) and a definite cover crop effect ($P \leq 0.015$). Autumn tillage (1360 kg/ha) reduced yields compared to spring tillage (1520 kg/ha) and cover crops (1350 kg/ha) decreased yields compared to no-cover crops (1510 kg/ha). In all subsequent years, these effects were reversed, with autumn tillage and cover crops having yield advantages. Visual observations during the first year of the experiment indicated that larger, more vigorous plants with the greatest yield potential were attacked more vigorously by budworms, thereby decreasing yields.

In 1996, a. season of ample rainfall, yields for no-till with a cover crop (table 1; 3960 kg/ha) were greater, though not statistically significant, than for conventional tillage (3740 kg/ha) or no-till without a cover crop (3730 kg/ha). Analyzing factorial treatments (table 2) showed only a cover crop effect ($P \leq 0.020$), with cover crops (4090 kg/ha) increasing seed cotton yield over the no cover crop treatment (3820 kg/ha). Depth of tillage and timing of tillage had no effect on yield.

Table 1. Seed cotton yield for each treatment, for each year of the experiment

	Seed Cotton Yield (kg ha^{-1})			
	1995	1996	1997	1998
Spring shallow/No CC*	1590 ab	3930	2660 de	2510 cd
Spring deep/No CC	1530 ab	3900	2420 e	2240 e
Spring shallow/Rye CC	1510 b	4150	2790 bcde	2870 a
Spring deep/Rye CC	1440 bcd	4000	2750 cde	2640 abc
Autumn shallow/No CC	1510 b	3630	2710 de	2410 cde
Autumn deep/No CC	1420 bcd	3820	2680 de	2370 de
Autumn shallow/Rye CC	1230 d	4130	3360 a	2830 ab
Autumn deep/Rye CC	1280 cd	4090	3010 abcd	2780 ab
Conventional tillage	1750 a	3740	3160 abc	2480 cd
No-till/No CC	1500 bc	3730	2880 bcd	2620 bc
No-till/Rye CC	1320 bcd	3960	3180 ab	2830 ab
$LSD_{(0.05)}$	222	ns	426	239

* CC indicates cover crop.

Table 2. ANOVA for factorial comparison of seed cotton yield for each year of the experiment*

	Probability > F			
	1995	1996	1997	1998
Main Effects				
Tillage Depth (TD)	0.460	0.934	0.110	0.001
Tillage Timing (TT)	0.010	0.481	0.010	0.300
Cover Crop (CC)	0.015	0.020	0.002	0.001
Interactions				
TD × TT	0.656	0.448	0.814	0.154
TD × CC	0.562	0.431	0.778	0.150
TT × CC	0.257	0.322	0.197	0.204
TD × TT × CC	0.492	0.781	0.202	0.461

* Shaded regions indicate statistically significant results ($P \leq 0.05$).

Mid-season drought stress in 1997 affected seed cotton yields (table 1). Yields for no-till with a cover crop (3180 kg/ha) were statistically greater than no-till without a cover crop (2880 kg/ha), but were similar to conventional tillage (3160 kg/ha). Analyzing factorial treatments (table 2) showed tillage timing effects ($P \leq 0.010$), with autumn tillage (2940 kg/ha) having greater yields than spring tillage (2660 kg/ha). Cover crop treatments ($P \leq 0.002$; 2980 kg/ha) showed increased yields over no cover crop treatments (2620 kg/ha). There was no significant advantage of shallow tillage compared to deep tillage, although a trend existed ($P \leq 0.110$).

In 1998, seed cotton yields from no-till with a cover crop (2830 kg/ha) were slightly larger, but statistically similar, to the no-till without a cover crop treatment (2620 kg/ha; table 1). Yield from conventional tillage (2480 kg/ha) was similar to no-till without a cover crop but statistically less than no-till with a cover crop. Analyzing the factorial treatments (table 2) showed no effects of tillage timing, however, cover crops (2780 kg/ha) were found to statistically increase yields cover no cover crop treatments (2380 kg/ha) ($P \leq 0.001$). Shallow tillage (2660 kg/ha) was also found to significantly increase yields compared to deep tillage (2500 kg/ha) ($P \leq 0.001$).

The cone index data obtained throughout this experiment is too voluminous to present in entirety. Cone index data taken in the row during 1997 were used to show important trends (fig. 1). Measurements taken in the spring immediately prior to planting are shown in the top half of the figure. Both top sections of figure 1 contain the same cone index data for conventional tillage, no-till with a cover crop, and no-till without a cover crop. Cone index measurements on the top left show the remaining soil strength considering over-wintering effects since the last occurrence of autumn tillage. The no-till with and without a cover crop treatments were found to have greater cone index values than all other treatments, with the exception of the conventional tillage treatment at depths of 0.05, 0.10, and 0.15 m. At depths of 0.2 to 0.3 m, deep tillage, regardless of cover crop, reduced cone index values below all others.

Cone index measurements on the top right of figure 1 shows the effect of spring tillage. A general reduction in cone index is seen between the top right and the top left portions of the figure and are a result of the more recent tillage operation. Because of the wider separation of the data, evidence of shallow tillage is noted to depths of 0.2 m while the deeper tillage treatment decreased cone index values down to 0.3 m.

The bottom portion of figure 1 shows cone index values for autumn 1997, immediately after harvest. Both figures contain the same cone index data for conventional tillage, no-till with a cover crop, and no-till without a cover crop. Cone index measurements shown on the left side were from soil tilled the previous autumn. Overall, these data show little change from the set of measurements obtained in the spring of 1997. Reductions in cone index were found as a result of shallow tillage down to 0.2 m and deep tillage down to 0.3 m.

The bottom right portion of figure 1 shows cone index values in the plots which were tilled the previous spring. Significant reductions in cone index were found at depths of 0.05, 0.10, and 0.15 m between the shallow and deep

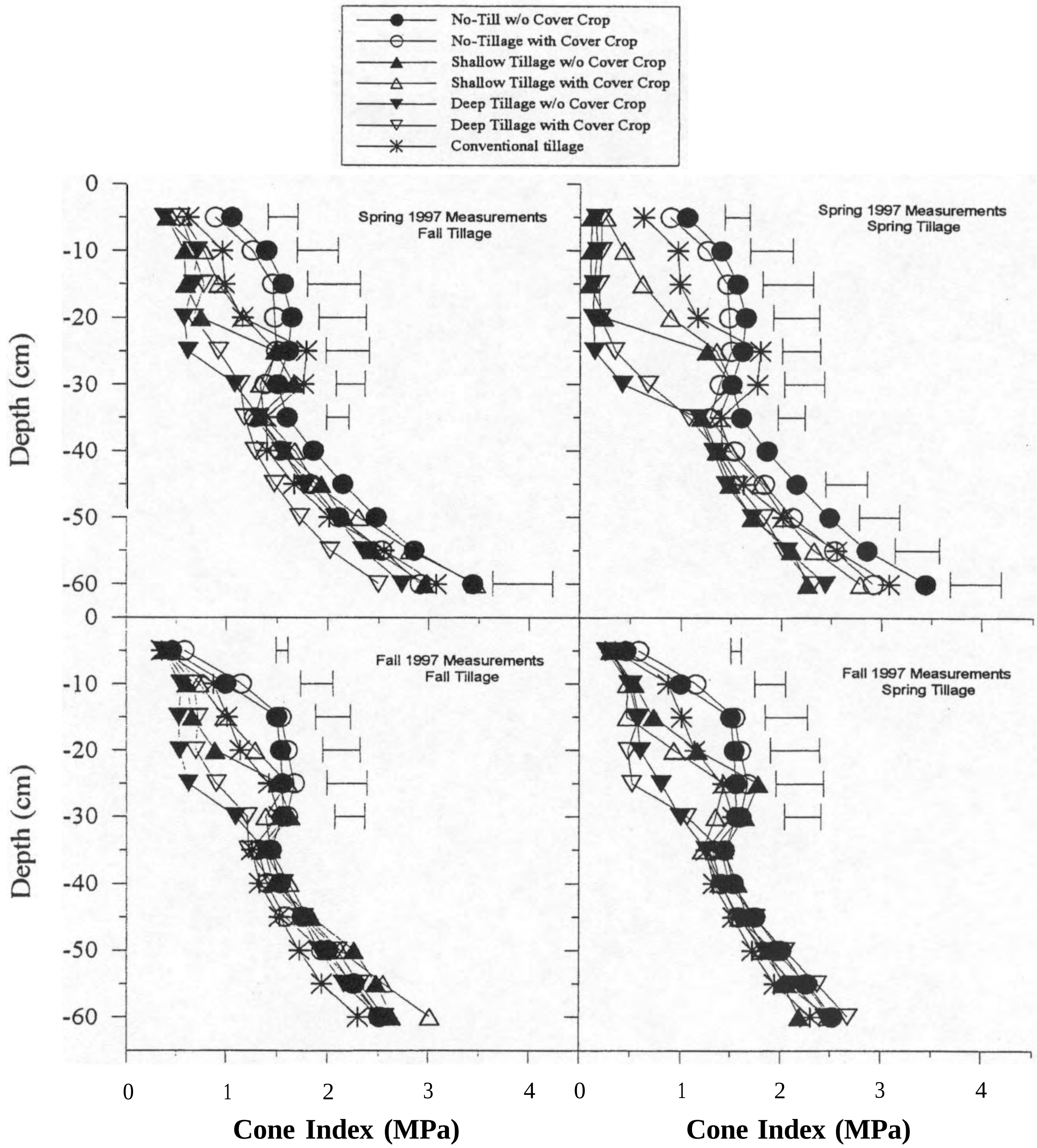

Figure l-Cone index profiles taken beneath the row in 1997. The upper portion of the graph shows measurements taken in the spring prior to planting and after spring tillage while the lower portion shows measurements taken in the autumn immediately after harvest The left portion of the graph shows soil strength resulting from tillage performed in the autumn of 1996 while the right potion of the graph shows soil strength resulting from tillage performed in the spring of 1997. The error bars shows statistically different results based on LSD (0.05).

tillage treatments and for the no-till without cover, no-till with cover, and conventional tillage treatments. At depths of 0.20, 0.25, and 0.30 m, the deep tillage treatments exhibited decreased cone index values compared to all treatments.

Considering all four sections of figure 1 simultaneously indicates that the only major transition that was detected was the increased cone index values measured in autumn 1997, compared to those measured in spring of 1997 in the spring tillage treatments. Very little change occurred in the autumn tillage treatments as most consolidation had already taken place in spring 1997 from the tillage that had been conducted the previous autumn.

In 1997, moisture content data were found to be statistically different at the two depths of sampling, with greater values occurring deeper ($P \leq 0.001$; table 3). Cover crops were also found to increase the average soil moisture content (19.9%) compared to no-cover crops (18.2%) ($P \leq$

0.01). A depth by cover crop interaction was also found ($P \leq 0.006$). Moisture content from the shallow (0 to 0.15 m) no-cover crop treatment (18.1%) was found to be statistically less than the moisture content from the deep (0.15 to 0.30 m) no-cover crop treatment (18.4%) and the shallow (19.8%) and deep (20.0%) values obtained in the cover crop treatments. This effect is probably due to increased evaporation near the surface and/or reduced infiltration in the no-cover crop treatment.

The previous autumn and spring's tillage draft and energy data were combined for statistical analysis because of their combined influence on the same cropping season. Draft and energy requirements were found to be affected by year for the three sets of annual energy and force data (figs. 2 and 3). In the first two years, the effect of time of tillage (either spring or autumn) was significant. Autumn tillage usually required lesser draft force and energy requirements, with the exception of the first year's data at the deeper tillage depth. This particular treatment was a first time occurrence for this type of tillage in these plots, and could have required greater tillage energy. Also in each of the three years, the effect of tillage depth was significant. Shallow tillage (approximately 0.18 m) usually required 50% of the draft and energy requirements of deep tillage (approximately 0.33 m). In the second and third year, there was an indication that the cover crop caused an increase in tillage forces. The large amounts of residue that had to be sheared or moved by the residue attachments in the spring may have contributed to the increased energy and draft forces.

Table 3. Soil water contents (%) measured immediately after cone index measurements were obtained

	Soil Water Content			
	Spring 1997		Autumn 1997	
	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m
Spring shallow/No CC*	16.8	19.2	21.3	20.4
Spring deep/No CC	17.2	19.8	21.6	24.0
Spring shallow/Rye CC	19.2	20.2	21.0	21.2
Spring deep/Rye CC	19.2	20.5	21.3	23.5
Autumn shallow/No CC	17.0	19.5	21.2	21.2
Autumn deep/No CC	17.2	19.2	21.7	21.3
Autumn shallow/Rye CC	18.8	20.8	21.0	20.0
Autumn deep/Rye CC	19.2	21.0	20.8	21.9
Conventional tillage	17.3	21.5	20.5	19.9
No-till/No CC	17.0	20.4	20.3	19.7
No-till/Rye CC	19.4	20.5	20.5	20.0
$LSD_{(0.05)}$	0.8	1.1	ns	1.6

* CC indicates cover crop.

Caution should be exercised before considering each of the four year's yield data as being equally valid for determining an appropriate management practice for growing cotton. In 1995, a severe insect infestation depressed yields so much that plots with the greatest yield potential (as defined by increased plant size) actually yielded the lowest. In 1996, one of the best growing seasons in the history of the state of Alabama, yields were high regardless of management practice. Only in 1997 and 1998 were somewhat typical growing seasons encountered. As a result, these years' data should be considered more representative of a typical growing season, with some periods of drought stress and water abundance occurring.

Overall, seed cotton yield data indicated that the presence of a cover crop provided the greatest potential for improving yields with conservation tillage. Comparable yields to conventional tillage were achieved through the simple addition of a cover crop to the no-till farming system. In one year typical of slight water stress, autumn tillage offered slight benefits over spring tillage. In two years of the study, tilling deeper than necessary to disrupt compacted soil did not increase yields, and actually led to reductions in seed cotton yield. The 15 to 20 kW energy requirement of shallow tillage treatment over four rows, makes it possible for farmers to till eight rows at a time with large tractors to ameliorate the effects of severe

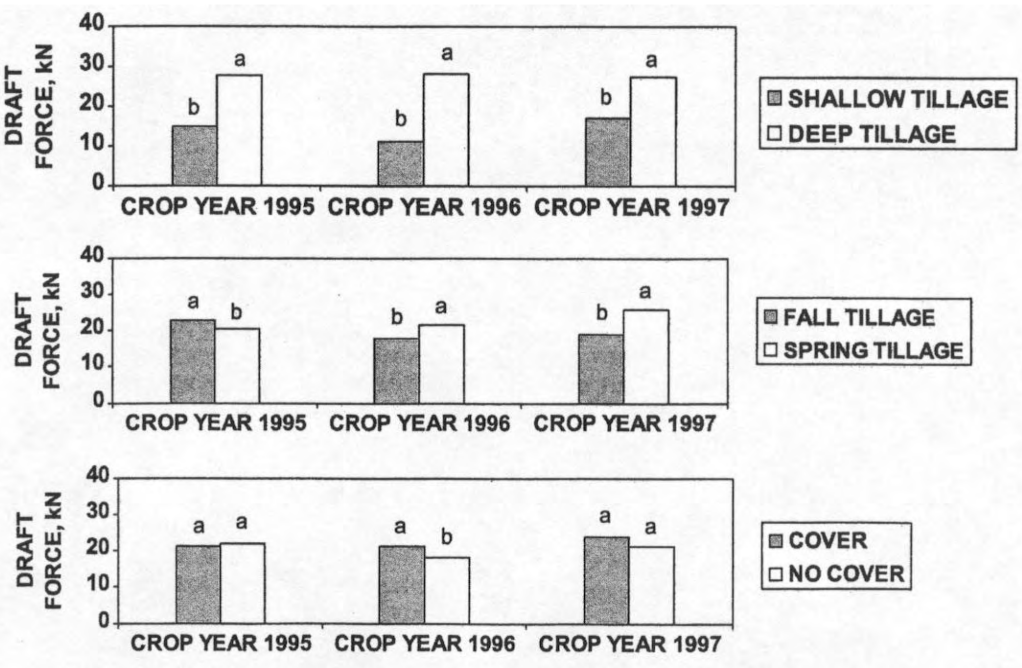

Figure 2–Tillage draft force (kN) showing effects of cover crop, tillage season, and depth of tillage. Means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

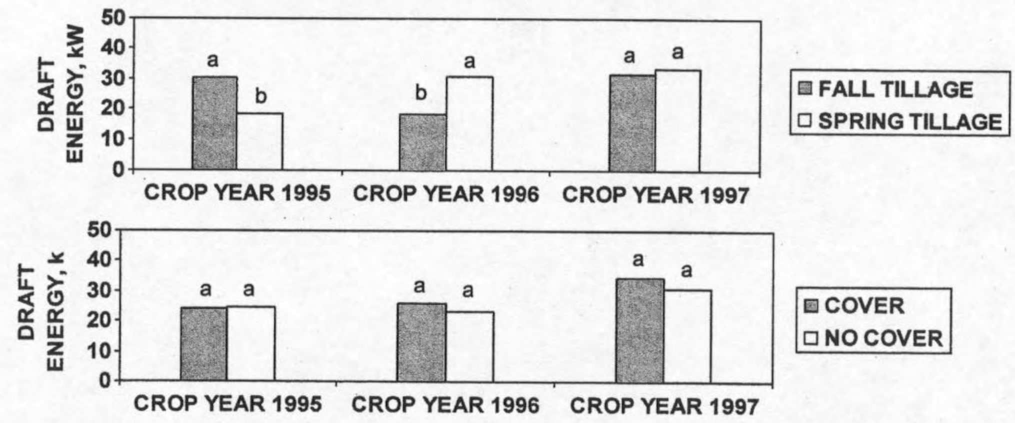

Figure 3–Tillage energy (kW) showing effects of cover crop, tillage season, and depth of tillage. Means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

surface soil compaction. Most farmers are reluctant to till less than eight rows because of the time and energy cats involved. Farmers looking to adopt a conservation tillage system that includes cover crops may want to consider adding a shallow autumn in-row tillage treatment, especially when moving a degraded soil into conservation tillage. The combination of autumn shallow in-row subsoiling (which can be performed when time is more readily available for producers) and a cover crop typically had the highest seed cotton yields (4130 kg/ha in 1996 and 3360 kg/ha in 1997). With such a system, producers should receive excellent soil protection from erosion, reduced soil compaction, and superior crop yields.

Farmers that may want to incorporate some form of tillage with a cover crop should be careful to not till too deeply as this seems to negatively effect yield. Matching tillage depth with the depth of the compacted soil saved energy, and led to slightly increased crop yields over conventional systems. These reasons would tend to indicate that variable depth tillage could be a potential tool for management of southeastern United States soils.

CONCLUSIONS

1. Shallow tillage took approximately 50% of the draft and energy requirements of deep tillage. Soil strength was decreased below depths of compacted soil using shallow tillage, which allowed cotton roots to reach moisture during periods of temporary water stress. Seed cotton yields were found to be significantly improved with shallow tillage in one year of the study as compared to deep tillage.
2. Except in the first year of the study, autumn tillage tended to take slightly less energy and draft than spring tillage. The soil condition resulting from either spring or autumn tillage was beneficial, and residual effects of the tillage were seen almost a year later. In one typical growing season, fall tillage caused an increase in seed cotton yield as compared to spring tillage. These results are particularly useful because autumn tillage can be performed when time is more readily available for producers.
3. The effect of a winter cover crop (two of three years) was to slightly increase draft and energy requirements. The cover crop also tended to slightly decrease soil strength. Cover crops were found to statistically increase yields in three of four years, with the highest seed cotton yielding treatments consistently benefitting from the use of a cover crop.
4. Seed cotton yields competitive with those of conventional tillage systems were obtained by conservation tillage systems that incorporated cover crops. In three of the four years of the study, numerically, the highest seed cotton yield was obtained by using shallow tillage that only went deep enough to disrupt compacted soil in combination with a cover crop. Energy measurements indicated that farmers wishing to use this conservation tillage practice can till eight rows at a time with their large tractors while minimizing the negative effects of soil compaction and root-impeding layers. This may be beneficial when changing highly degraded soils with compaction problems into conservation tillage systems.

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