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COTTON YIELD RESPONSE AND ENERGY REQUIREMENTS OF MATCHING TILLAGE DEPTHS TO ROOT-IMPEDING LAYERS

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Summary:

Declining cotton yields have plagued farmers trying to eliminate tillage from their farms in the Tennessee Valley Region of North Alabama. Many farmers have tried to reduce tillage to meet conservation compliance programs, but have found inadequate rooting systems due to excessive soil compaction severely reduced yields. Measurements of soil strength, energy requirements, and crop yield all point to the need for cover crops and possibly shallow fall in-row tillage as management alternatives to help farmers achieve optimum yields while enhancing their soil erosion protection over traditional conventional tillage systems.

Keywords:

Subsoil, soil compaction, implement, cotton, cone index, draft, energy

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COTTON YIELD RESPONSE AND ENERGY REQUIREMENTS OF MATCHING TILLAGE DEPTHS TO ROOT-IMPEDING LAYERS

R.L. Raper[1], D.W. Reeves[2], and C.H. Burmester[3]

ABSTRACT

Declining cotton *(Gossypium hirsutum* L.) yields have plagued farmers in the Tennessee Valley Region of North Alabama who have tried to eliminate conventional farming systems including moldboard and/or chisel plowing. Many farmers have tried to replace conventional tillage systems to meet conservation compliance programs, but found severely reduced yields, possibly due to inadequate rooting systems from excessive soil compaction. A study was conducted from 1995-1997 to develop conservation tillage systems that incorporated a rye *(Secale cereale* L.) cover crop and in-row tillage as a means of maintaining surface cover and disrupting root-impeding soil layers. Energy requirements of shallow tillage (18 cm) and deep tillage (33 cm) performed in the fall and spring were also investigated. Seed cotton yields similar to conventional cropping systems were found using the rye cover crop with no-tillage. Decreased yields were observed when any form of spring tillage was used. Slightly improved yields occurred when shallow fall tillage was used with a winter cover crop. This conservation tillage practice 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.

INTRODUCTION

Cotton farmers in the Tennessee Valley Region of North Alabama have experienced problems maintaining yields when highly erodible soils were placed in conservation tillage systems. These soils have been conventionally farmed for more than 100 years. 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, with soil containing platy structure and exhibiting considerable strength at relatively shallow depths, particularly

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in no-till fields. Cotton tap roots have been observed to be bent at 90-degree angles at depths of less than 15 cm when cotton was directly planted into the previous year's cotton stubble. Cotton is particularly susceptible to soil compaction problems (Cooper et al., 1969; McConnell et al., 1989; Mullins et al., 1992; Reeves and Mullins, 1995). One method of alleviating soil compaction and recovering soil productivity is subsoiling 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 treatments in previous experiments (Touchton et al., 1986). Complete management systems are 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 offered the most potential for developing a successful tillage system that could generate comparable yields relative to conventional tilled systems. Our approach was targeted toward developing tillage systems that would minimally disturb the soil while maintaining adequate surface residue coverage. Factors involved 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 fall (when producers have time readily available) would benefit cotton as much as in-row spring tillage performed immediately before planting. A cover crop was used to generate additional surface residue and to retain soil moisture (Reeves, 1994).

Determining the appropriate depth of tillage involved recognizing that cotton roots were constrained differently in various locations in the field. When the fields in question were examined, rooting depth in some locations was minimal while in other locations no problems were noticed. Many factors can restrict root growth including soil physical impedance caused by excessive soil compaction. Soil cone index has been identified as a measurement that can simulate the process of root elongation and determine zones of extreme root impedance (ASAE, 1997). Fulton et al. (1996) found in Kentucky that significant variations in bulk density and cone index exist within the same field.

Variations in soil density or cone index can indicate a potential need for variable-depth 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 shallowly to do significant good. However, before judgments 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:

(1) to determine the effect of tillage performed at various depths on draft requirements, soil strength, and cotton yield response,

(2) to determine the effect of tillage timing performed either in the fall or spring of the year on draft requirements, soil strength and cotton yield response,

(3) to determine the effect of a winter cover crop on draft requirements of tillage, resulting soil strength, and cotton yield response,

(4) to identify the best overall system for cotton production in the Tennessee Valley region while using conservation tillage approaches.

MATERIALS AND METHODS

Fall tillage treatments were first applied in the fall of 1994 at the AAES Tennessee Valley Substation in Belle Mina, AL. The soil type in this region and on the experimental site is predominantly a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult). The field had been used for conventional cropped cotton for several years prior to this experiment. The plots were four l-m (40-inch) rows wide by 9.1-m (30-ft) long. The experimental design was a randomized complete blockwith a 2x2x2 factorial arrangement of treatments augmented with three additional control treatments of 1) no-tillage with no cover crop, 2) no-tillage with a cover crop, and 3) conventional tillage with no cover crop. The three factors were: 1) cover crop (none or rye), 2) tillage timing (fall or spring), and 3) tillage depth (shallow, or deep). The depth of tillage was established by taking multiple cone-index profiles of the field and determining the average depth and thickness of the root-impeding soil layer. This layer was located at an approximate depth of 10-15 cm (fig. 1). Therefore, the shallow depth of tillage was chosen as 18 cm and the depth of deep tillage was set at 33 cm to completely disrupt this profile. An experimental Yetter™ [4] implement with in-row subsoilers that could be adjusted to operate at both depths was used for all tillage treatments. Residue managers that consisted of fingered wheels and fluted coulters were used to move residue away from the shanks. Closing disks were also mounted on the rear of the shank to create a small seedbed region approximately 30 cm wide and 10 cm high. The conventional tillage treatment consisted of fall disking and chiseling followed by disking and field cultivating in the spring prior to planting.

Plots that received a cover crop were seeded in rye with a grain drill immediately after fall tillage. The cover crop was terminated in the spring of the year prior to planting with glyphosate [N-(phosphonomethyl) glycine]. Cotton was planted in early May of each year with Deltapine 'DP 15' being used in 1995, Deltapine 'NuCOTN 33[B]' being used in 1996, and Deltapine 'DP 20B' being used in 1997. A four-row John Deere Maxi-Emerge® (Deere & Company, Moline, IL) 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 using Auburn University Extension recommendations along with all applications of insecticides and defoliants.

Soil strength measurements were taken both spring and fall of each year immediately before and after tillage treatments were applied. Soil strength was determined by using a tractor-mounted multiple-cone penetrometer and then calculating the cone index (ASAE, 1997). Values of cone index were measured at

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[4]The use of companies, tradenames, or company names does not imply endorsement by USDA-ARS or Auburn University.

approximately every 4-6 mm and then summed and averaged over 5 cm depth increments to simplify data comparison. Five penetrometer probes were inserted 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). Soil samples for gravimetric water content were taken in each plot at two locations at the conclusion of the tillage events at shallow (0-15 cm) and deep (15-30 cm) depths (Table 1).

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

The factorial arrangement of eight treatments within the randomized complete block were analyzed using the appropriate model. All eleven treatments were also analyzed using a randomized complete block model to compare effects of the three augmented control treatments. Data were analyzed with year in the model and where significant year by treatment interactions occurred, data were analyzed by year and treatment effects are presented and discussed by year. Depth, position, and interaction effects of these variables with response variables were analyzed using a 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

Cone index profiles taken immediately after tillage in the spring of 1997 were plotted as contour graphs across the entire row area from untrafficked middle to trafficked middle to illustrate the effects of in-row tillage (figs. 2-5). Soil strength profile across the row in the conventional tillage control is illustrated in fig. 2. Note the relatively shallow depth of 0.25 m of the 1.5 MPa iso-line beneath the row (center of the graph). When a cover crop was used without tillage, the depth of this iso-line increased beneath the row down to 0.4 m (fig. 3). Using shallow tillage with a cover crop reduced cone index measurements to at least the 0.25 m depth (fig. 4). When deep tillage was used, the entire profile beneath the row was dramatically changed to a depth of 0.35 m (fig. 5).

Cone index measurements taken in the row prior to tillage in the fall of 1996 showed the benefits afforded to those plots that were tilled the previous fall (fig. 6). The filled symbols illustrate that deep tillage loosened soil down to approximately 33 cm while the shallow tillage loosened a zone down to about 18 cm. These profiles contrast greatly with soil conditions in plots that received no tillage. The effect of the cover crop slightly decreased cone index at most depths for all tillage treatments. In fall of 1996, moisture content at the time of the cone index measurements was not statistically significant with depth.

In the spring of 1997, cone index measurements for the row position prior to tillage demonstrated tillage effects from the previous spring; deep tillage loosening soil to greater depths than shallow tillage, and clearly more than no-tillage (fig. 7). Cover crop effects were not easily seen in these graphs.

In 1997, moisture content data was found to be statistically different at the two depths of sampling, with greater values occurring deeper ($P \leq 0.001$; Table 1). Cover crops (19.9%) were also found to increase the average moisture content ($P \leq 0.01$) compared to no-cover crops (18.2 %). A depth by cover crop interaction was also found ($P \leq 0.006$). The moisture content from the shallow (0-15 cm) no-cover crop treatment (18.1 %) was found to be statistically less than the moisture content from the deep (15-30 cm) 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 in the no-cover crop treatment.

When the cone index data was statistically compared at multiple depths, trends emerged which helped to determine the relative depths and positions that tillage treatments affected. In the fall of 1996, prior to applying tillage treatments, there was a strong residual tillage and depth of tillage affect directly beneath the row (Table 2); differences occurred to a depth of 25 cm as a result of tillage performed the previous fall. Cover crop effects occurred down to a depth of 20 cm across all sample positions; it is important to note that these measures were taken in the fall of the year and a cover crop had not been grown on this soil for almost 6 months. Also, conspicuously absent was the seasonal effect of tillage; tillage performed the previous spring did not decrease cone index compared to plots where tillage was performed several months earlier in the fall.

Statistically significant differences were found for cone index data from the spring of 1997 (Table 3). Tillage effects were seen, primarily in the row, but also in other locations across the plots. A strong depth of tillage effect was found from a depth of 15-30 cm directly under the row. Cover crop effects were stronger and extended down to depths of 30 cm. The cone index values for plots with cover crops were decreased down to 30 cm in all locations except directly under the row.

Seed cotton yield in 1995 was decreased due to a severe tobacco budworm [Heliothis virescens (F.)] infestation, particularly in plots with large and healthy plants (fig. 8). In general, in this year conventional tillage had the highest yields (1752 kg/ha), significantly greater than either no-till without a cover crop (1501 kg/ha), or no-till with a cover crop (1326 kg/ha). Conservation tillage showed a strong tillage timing treatment effect ($P \leq 0.007$) and a strong cover crop effect ($P \leq 0.001$). Fall tillage (1363 kg/ha) reduced yields below spring tillage (1521 kg/ha) and cover crops (1354 kg/ha) decreased yields over those plots with no-cover crops (1511 kg/ha). In all subsequent years, these effects were reversed with fall tillage and cover crops having yield advantages. These results suggest that plants having the greatest yield potential in 1995 were attacked more vigorously by the insects, thereby decreasing yields.

Statistical analysis of the 1996 yield data (which was aided by ample rainfall; fig. 8) only showed a cover crop effect ($P \leq 0.004$) with cover crops increasing seed cotton yield. Depth of tillage and timing of tillage had no effect on yield. No-till with a cover crop (3960 kg/ha) was found to have slightly, though statistically insignificant, greater yields than conventional tillage (3741 kg/ha) or no-till without a cover crop (3735 kg/ha).

Statistical analysis of the 1997 yield data (which was drought stressed during mid-season; fig. 8) showed effects of tillage timing ($P \leq 0.010$) with fall tillage and cover crop ($P \leq 0.001$) increasing yields. There was no significant advantage of shallow tillage compared to deep tillage although a trend may have existed ($P \leq 0.110$). Seed cotton yields from the no-till with a cover crop treatment (3181 kg/ha) were found to be statistically greater than the no-till without a cover crop treatment (2879 kg/ha) but were found to be similar to the conventional tillage treatment (3164 kg/ha).

The previous fall and spring's tillage draft and energy data were included together for statistical analysis because of their combined respective influence on the crop. Draft and energy requirements were found to have significant interactions with year for each of the three sets of yearly energy and force data (figs. 9 and 10). In the first two years' analysis, the effect of timing of tillage (either spring or fall) was significant. Fall 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 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 18 cm) usually required 50% of the draft and energy requirements of deep tillage (approximately 33 cm). In the second and third year's analysis, a trend existed that indicated that a cover crop caused an increase in tillage forces. The large amounts of residue that had to be sheared or moved by the residue managers may have contributed to these increased energy requirements and draft forces.

Caution should be exercised before considering each of the three year's data as 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 actually yielded the worst. In 1996, the growing season was one of the best in the history of the state of Alabama, and yields were high regardless of any management practice. Only in 1997 did we experience a somewhat typical growing season. This year's results should be considered more representative of a typical growing season, with some periods of drought stress and water abundance.

Overall, seed cotton yield data indicated that the presence of a cover crop provided the greatest potential for improving yields with conservation tillage systems. Comparable yields with conventional farming systems were achieved through the simple addition of a cover crop to a no-till farming system. In a year typical of slight water stress, fall tillage offered slight benefits over spring tillage systems. Tilling deeper than necessary to disrupt the hardpan did not increase yields and in some cases actually led to reductions in seed cotton yield. The 15-20 kW energy requirement of shallow tillage treatment over 4 rows makes it possible for farmers to till 8 rows at a time with their large tractors to ameliorate the effects of severe surface soil compaction. Most farmers are reluctant to till less than 8 rows because of the time and energy costs involved. Farmers looking to adopt a conservation tillage system that includes cover crops may want to consider adding a shallow fall in-row tillage treatment. The combination of fall 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 (4129 kg/ha in 1996 and 3358 kg/ha in 1997). Producers should then receive excellent soil protection from erosion, reduced soil compaction effects, and superior crop yields.

Many farmers will want to incorporate some form of tillage with their use of a cover crop. Those wishing to do this may slightly increase yields, but should be careful to not till too deeply as this seems to negatively affect yields. Matching the depth of the root-impeding layer with the tillage depth 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 treatments. Soil strength was decreased below hardpan depths using shallow tillage, which would allow cotton roots to reach moisture during periods of temporary water stress. Seed cotton yields with shallow tillage were slightly greater than with conventional tillage and also slightly greater than with deep tillage.

(2) Except in the first year of the study, fall tillage tended to take slightly less energy and draft than spring tillage. The soil condition resulting from either spring or fall tillage was beneficial and residual effects of the tillage was seen 12 months later. In a typical growing season, seed cotton yield response seemed to favor fall tillage. These results are particularly useful because fall 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 measurements. Seed cotton yields benefitted greatly from the use of a cover crop.

(4) Seed cotton yields competitive with conventional tillage systems were obtained by conservation tillage systems that incorporated cover crops. A slight, but not statistically significant, increased seed cotton yield was obtained by using shallow fall tillage that only went deep enough to disrupt the root-impeding layer in combination with a cover crop. Energy measurements indicate that farmers wishing to utilize this conservation tillage practice can till 8-rows at a time with their large tractors and minimize the negative effects of soil compaction and root-impeding layers. This may be beneficial when moving highly degraded soils with compaction problems into conservation tillage systems.

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Table 1. Average soil moisture contents for first two years of experiment.

	Shallow (O-l 5cm) Moisture Content (%)	Deep (15-30 cm) Moisture Content (%)
Fall 1994	14.7 (0.1)[5]	15.5 (0.5)
Spring 1995	15.6 (0.7)	15.9 (1.0)
Fall 1995	14.7 (0.6)	16.3 (0.9)
Spring 1996	16.0 (1.2)	16.1 (1.7)
Fall 1996	18.5 (9.0)	21.0 (6.0)
Spring 1997	18.1 (1.2)	20.0 (1.0)

[5] indicates standard deviation of mean

Table 2. Statistical significance levels of treatment effects from fall 1996 cone index measurements taken before tillage

Depth (cm)	Untrafficked Middle (-50 cm)	Midway Between (-25 cm)	Row (0 cm)	Midway Between (+25 cm)	Trafficked Middle (+50 cm)
0-5	C-[6]		T-	S+	
5-10	C-	T-,D-	T-,D-	C-	
10-15	C-,D-	T-,D-	T-,D-	C-,T-	C-
15-20	C-,T+	T-,D-	C-,T-,D-	C-	C-
20-25			D-	C-	
25-30					D+
30-35			C-		D+,T-
35-40			C-		
40-45					
45-50					D+
50-55					D+
55-60					T+,D+

[6] letter indicates treatment effect at the 0.05 level

C = cover crop effect
T = tillage effect
D = depth of tillage effect
S = season of tillage effect

sign indicates direction of effect

C- = negative indicates cover crop decreases cone index as compared to no-cover crop
T- = negative indicates tillage decreases cone index as compared to no-tillage
D- = negative indicates deep tillage decreases cone index as compared to shallow tillage
S- = negative indicates spring tillage decreases cone index as compared to fall tillage

Table 3. Statistical significance levels of treatment effects from spring 1997 cone index measurements taken before tillage

Depth (cm)	Untrafficked Middle (-50 cm)	Midway Between (-25 cm)	Row (0 cm)	Midway Between (+25 cm)	Trafficked Middle (+50 cm)
0-5	C-[6]	C-,T-,D-	T-	S+	C-,T+
5-10	C-,T-,D-	C-,T-	T-	C-,T-,S+	C-,S-
10-15	C-,T-,D-,S+	C-,T-	T-	C-,T-,S-	C-,S+
15-20	C-,T-,D-	C-,S-	T-,D-,S+	C-,T-	C-
20-25	C-	C-	T-,D-	C-	C-,T-
25-30	C-	C-	T-,D-	C-	C-,T-
30-35		C-,D+	T-	C-	D+
35-40					D+
40-45		C-			D+
45-50		C-	T-		D+
50-55	C-	C-,T+	T-		
55-60	C-	C-, T+	T-,D-	T+	D+

[6] <u>letter indicates treatment effect at the 0.05 level</u>

C = cover crop effect
T = tillage effect
D = depth of tillage effect
S = season of tillage effect

<u>sign indicates direction of effect</u>

C- = negative indicates cover crop decreases cone index as compared to no-cover crop
T- = negative indicates tillage decreases cone index as compared to no-tillage
D- = negative indicates deep tillage decreases cone index as compared to shallow tillage
S- = negative indicates spring tillage decreases cone index as compared to fall tillage

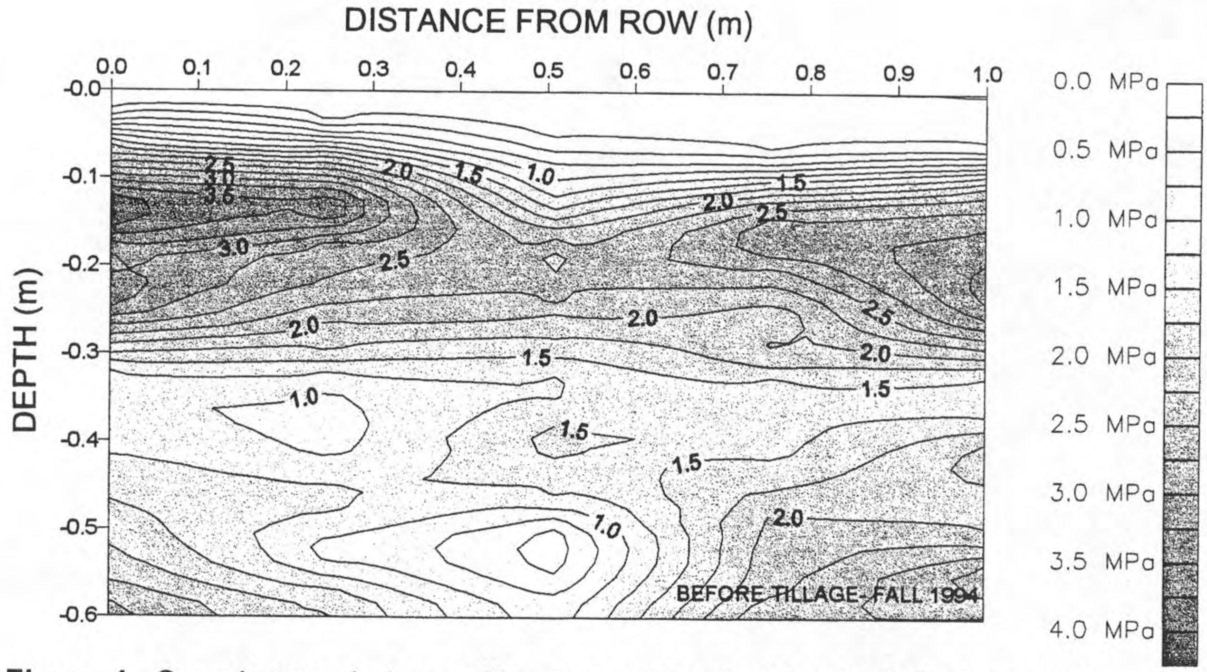

Figure 1. Sample cone index profiles across the row from trafficked middle to untrafficked middle in fall of 1994 showing depth of root-impeding layer.

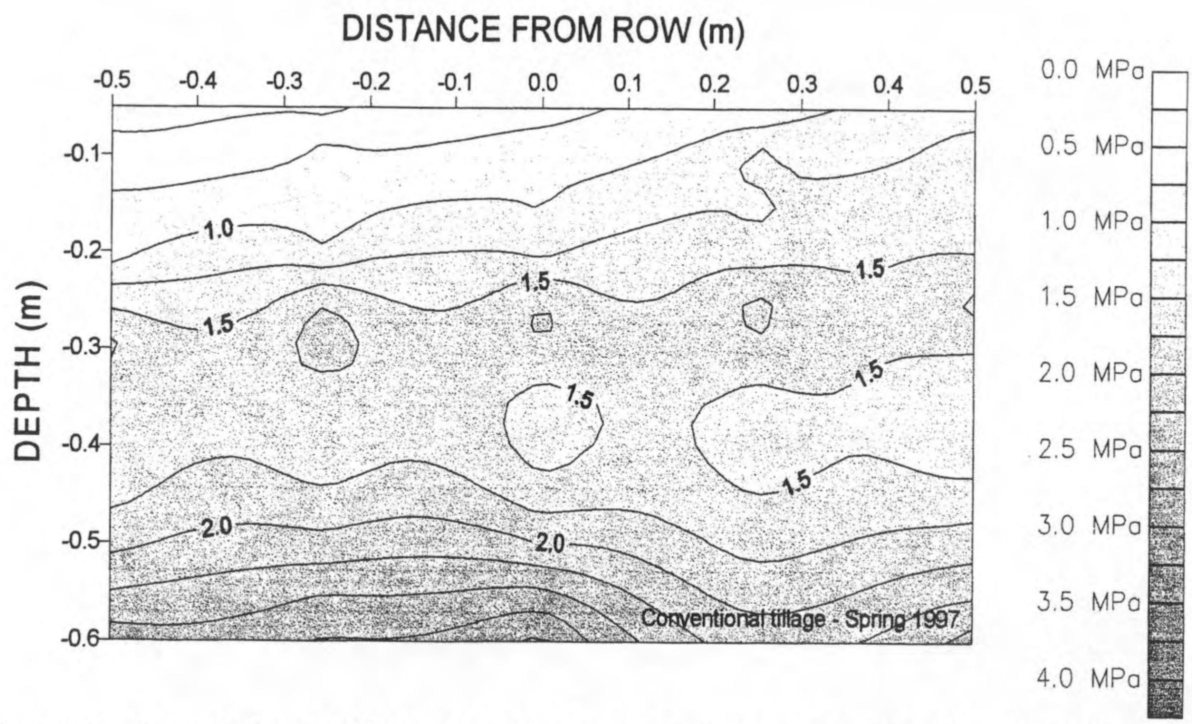

Figure 2. Cone index profiles across the row from trafficked middle to untrafficked middle in spring of 1997 showing effects of conventional tillage with no cover crops.

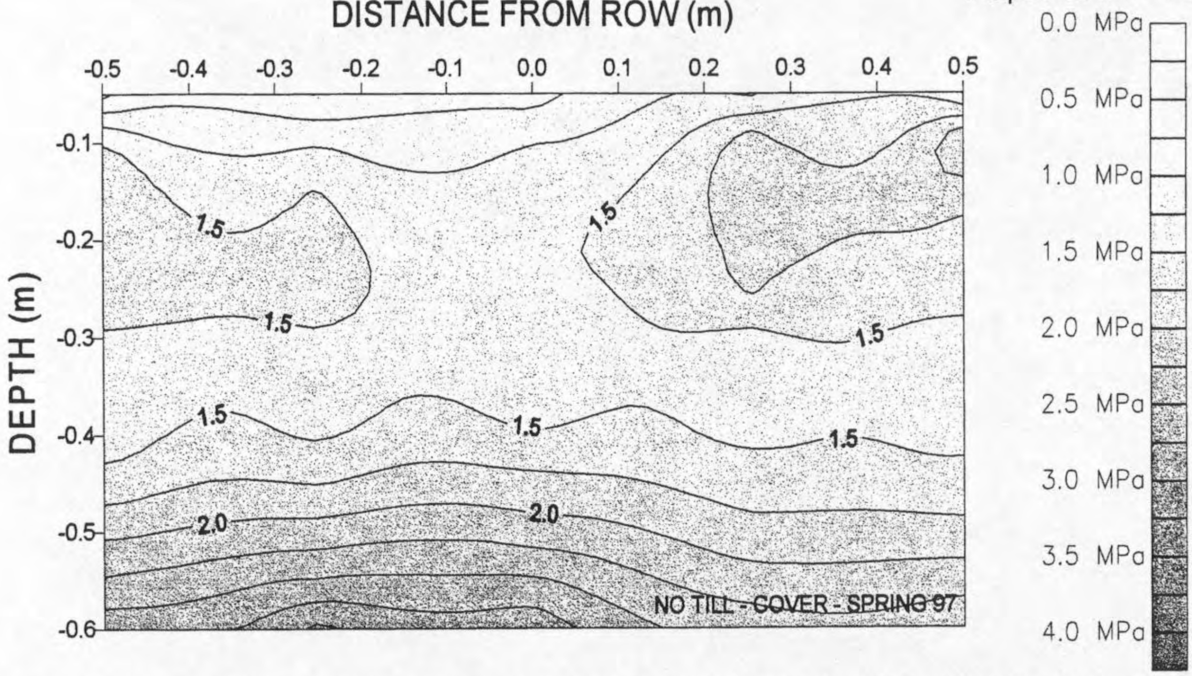

Figure 3. Cone index profiles across the row from trafficked middle to untrafficked middle in spring of 1997 showing effects of cover crops with no tillage.

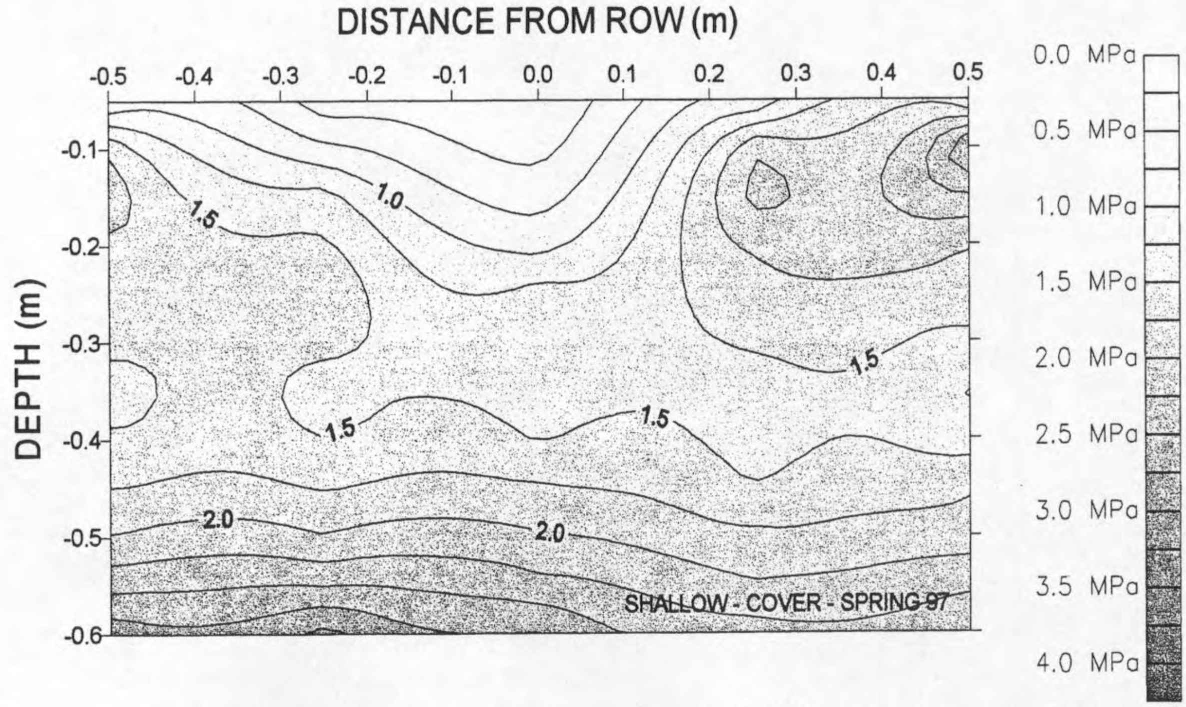

Figure 4. Cone index profiles across the row from trafficked middle to untrafficked middle in spring of 1997 immediately after tillage showing effects of shallow tillage with a cover crop.

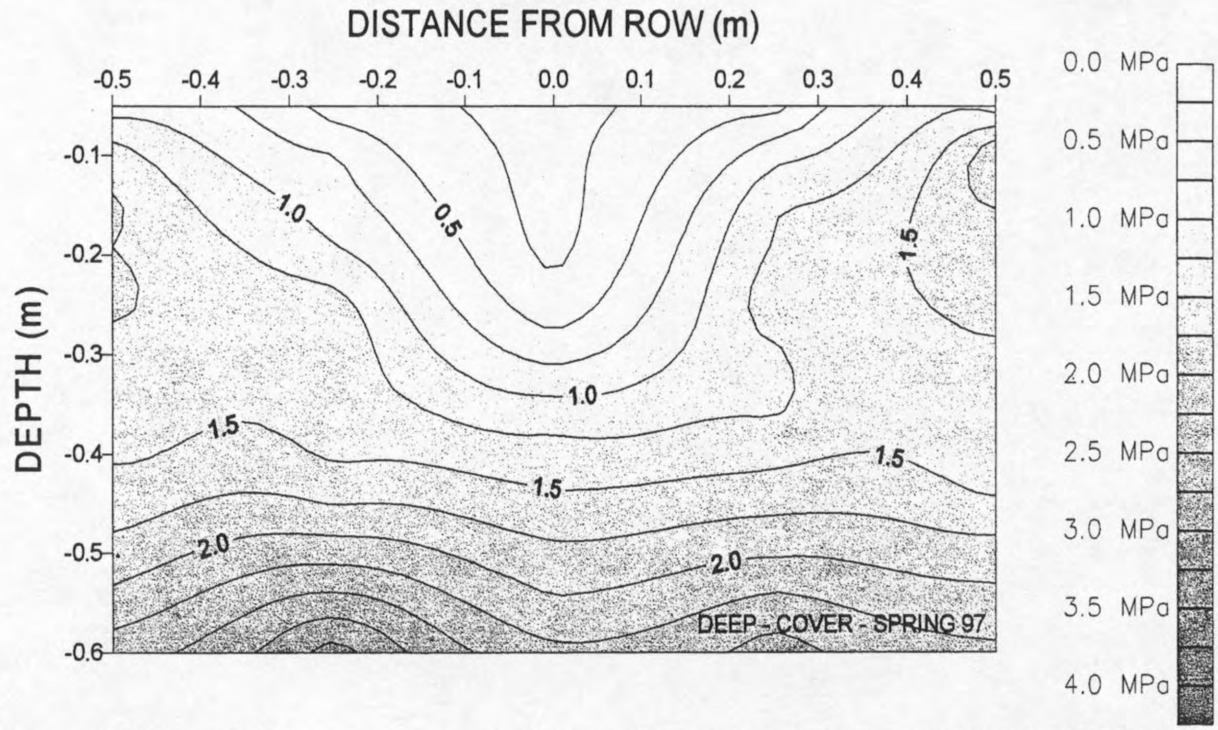

Figure 5. Cone index profiles across the row from trafficked middle to untrafficked middle in spring of 1997 immediately after tillage showing effects of deep tillage with a cover crop.

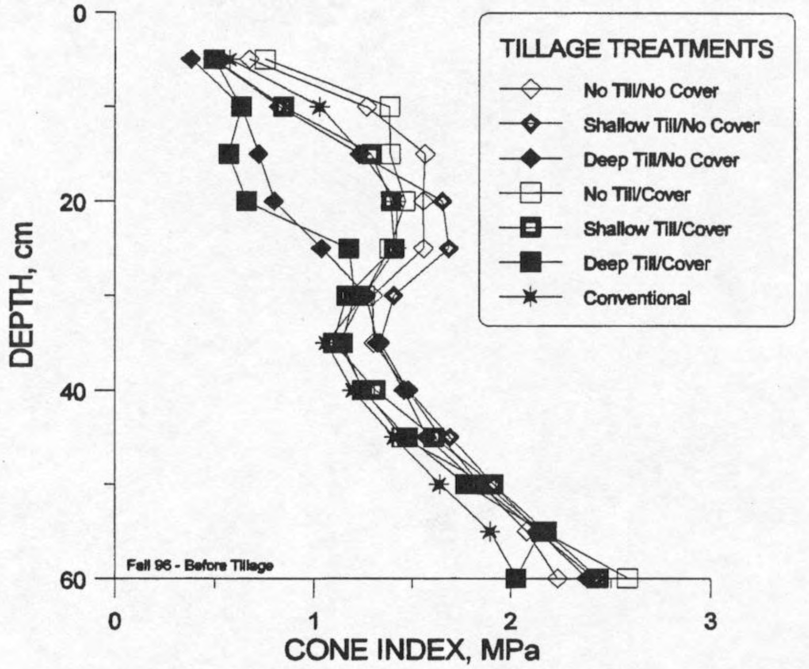

Figure 6. Cone index profiles beneath the row in fall of 1996 showing results of tillage treatments performed in Fall of 1995.

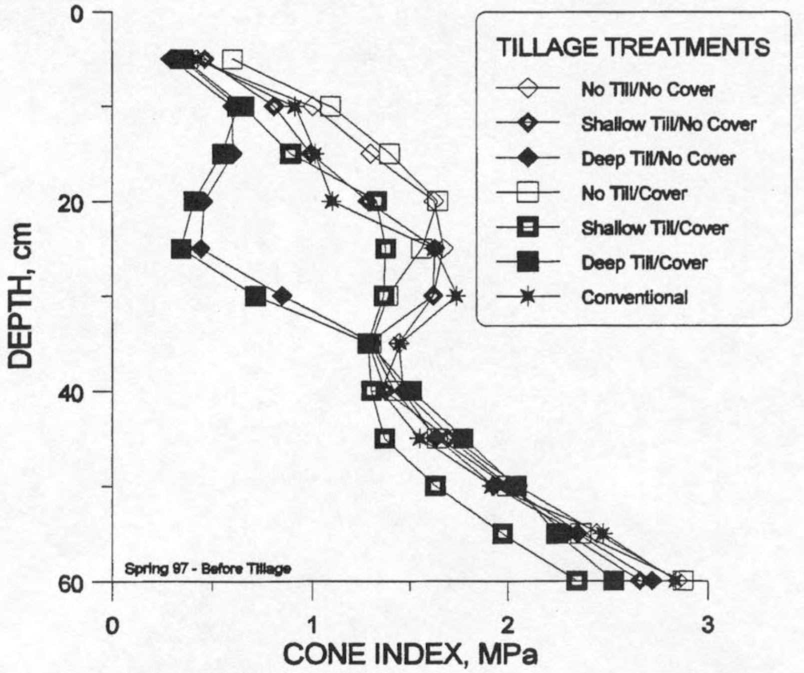

Figure 7. Cone index profiles beneath the row in spring of 1997 showing results of tillage treatments performed in spring of 1996.

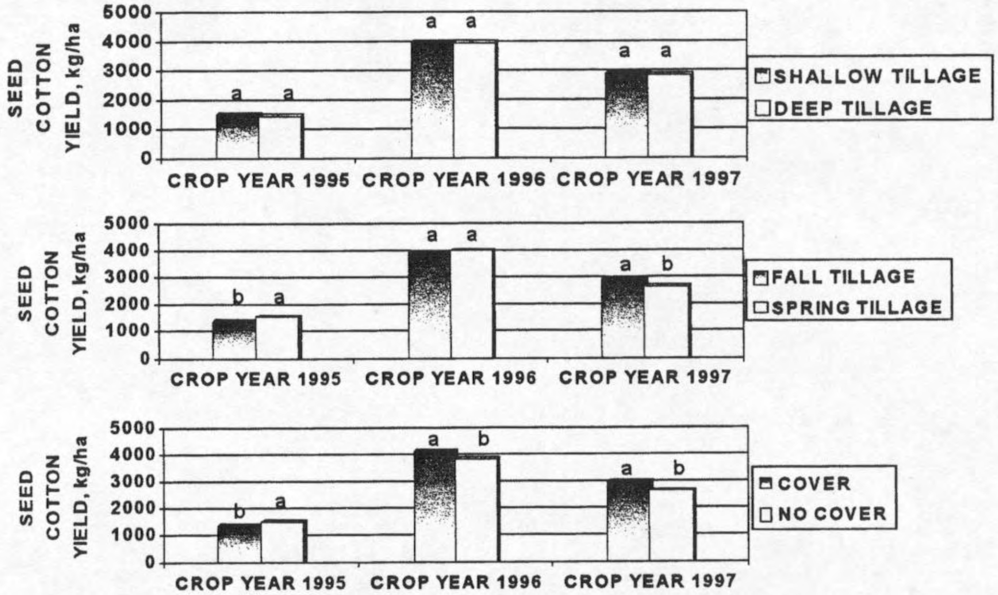

Figure 8. Seed cotton yield, (kg/ha) showing effects of cover crop, season of tillage, and depth of tillage. Means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

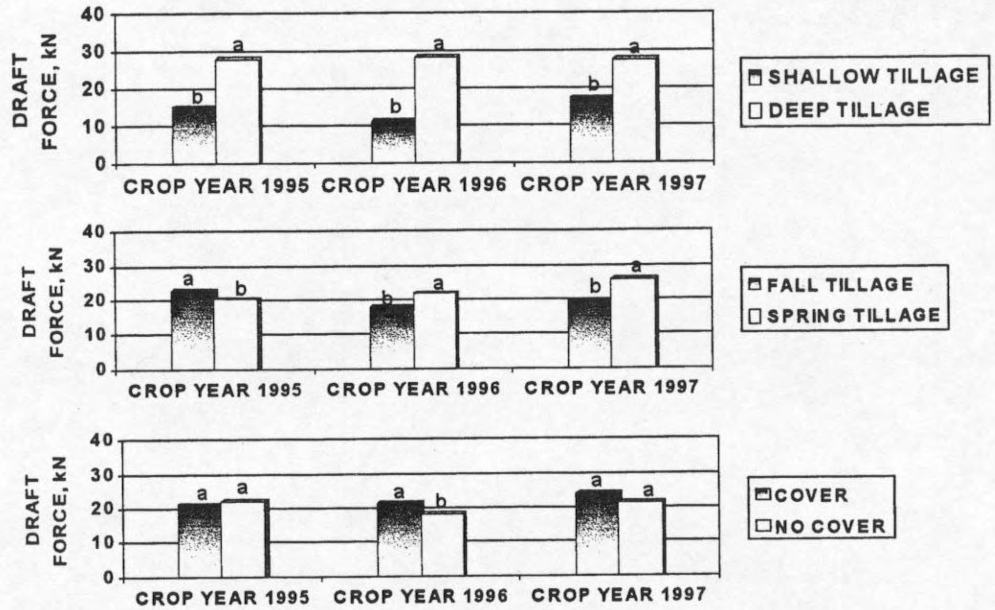

Figure 9. Tillage draft force (kN) showing effects of cover crop, season of tillage, and depth of tillage. Means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

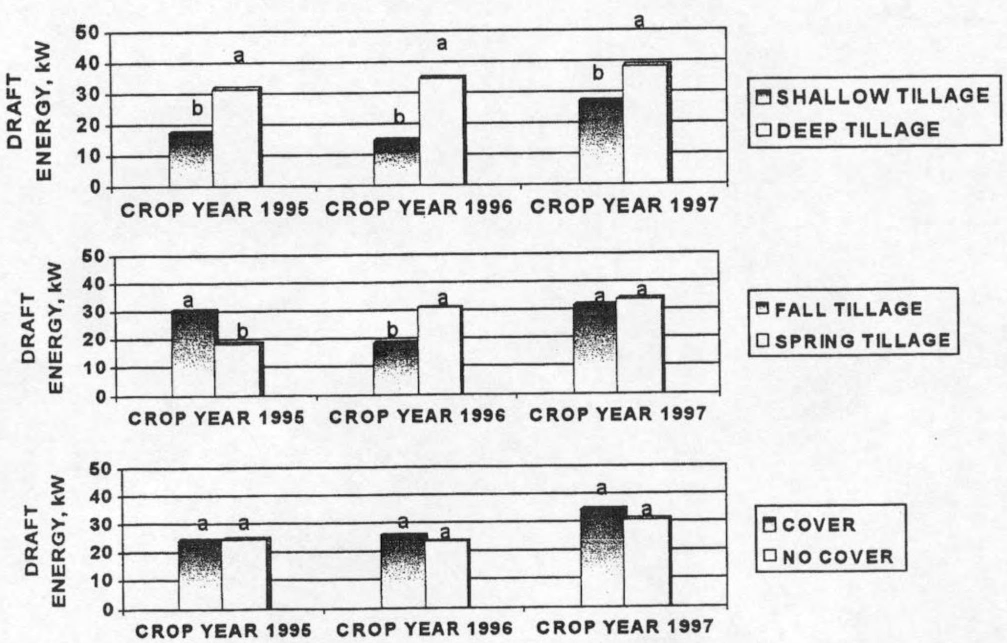

Figure 10. Tillage energy (kW) showing effects of cover crop, season of tillage, and depth of tillage. Means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).