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Reducing Soil Compaction of Tennessee Valley Soils in Conservation Tillage Systems

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INTERPRETIVE SUMMARY

Reduced cotton yields have been shown to occur on many farms in the Tennessee Valley region of northern Alabama when farmers attempted to adopt no-till farming. Soil compaction limited yields and prevented proper root elongation. Measurements of soil strength were obtained after a 4-yr period in a systems experiment that included use of cover crops, different depths and times of tillage. Results showed that the simple addition of cover crops reduced soil compaction and raised crop yields to a level similar to that achieved with conventional tillage systems. Fall in-row tillage in conjunction with a cover crop tended to produce the greatest yields. Farmers wishing to adopt conservation tillage systems can use a cover crop and shallow in-row tillage to maintain surface residue without sacrificing crop yield.

ABSTRACT

Inadequate rooting systems due to excessive soil compaction have prevented farmers in the Tennessee Valley region of northern Alabama from adopting conservation tillage systems. Cotton (*Gossypium hirsutum* L.) yields declined on many farms when conventional tillage systems were replaced with strict no-till systems. Experiments were initiated in 1994 to develop conservation tillage systems that incorporated in-row tillage and rye (*Secale cereale* L.) cover crops as methods of maintaining surface cover and alleviating extreme soil compaction conditions. Depth of in-row tillage [18 cm (7 in.) or 33 cm (13 in.)] and timing of tillage (fall or spring) were also investigated in this experiment. Cone index measurements taken in the spring and fall of 1997 prior to tillage and bulk density measurements taken in fall 1998 immediately after harvest were used to examine changes in soil condition resulting from several years of experimentation. The results showed reduced cone index and bulk density from either shallow or deep in-row tillage performed in the spring or fall of the year. Although fall measurements in no-till plots showed no effect of cover crops, the spring measurements of cone index were reduced substantially by the use of cover crops, most likely due to increased soil moisture. Therefore, reduced soil compaction beneath the row to depths adequate to sustain proper root growth was achieved by either shallow in-row tillage and/or cover crops.

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Switching from conventional tillage systems to conservation tillage systems is not always easy or profitable in the short-term. This transition can be especially difficult when the soils are extremely degraded from more than 100 yr of annual moldboard plowing and excessive soil erosion. Cotton producers in the Tennessee Valley region of northern Alabama reported reduced yields when they adopted conservation tillage systems, which prompted USDA-NRCS to request that USDA-ARS perform research to assist farmers with this transition. Traditional methods of tillage that covered cotton residue included fall moldboard plowing, chisel plowing, and disking. Development of conservation systems that reduced soil disturbance and maintained adequate amounts of surface residue became an important component of reducing soil erosion in this region.

During preliminary investigations it was found that the soil that had been converted recently to strict no-till systems exhibited considerable soil strength at relatively shallow depths. Many cotton taproots in the shape of a “J” were found at depths of less than 15 cm (6 in.) in no-till fields (Fig. 1). We hypothesized that extreme soil compaction was

Fig. 1. Deformed cotton taproot showing depths of extreme impedance.

responsible for this rooting problem, and that this compaction was due to long-term moldboard plowing and that erosion had severely degraded the soil.

Soil compaction has long been noted to cause root restrictions and yield reductions in many crops in the U.S. Southeast (Kashirad et al., 1967; Cooper et al., 1969). This root-limiting condition can be alleviated by subsoiling (Campbell et al., 1974; Box and Langdale, 1984). Subsoiling densely compacted soil allows deeper rooting for withstanding short-term droughts prevalent during the growing season in the Southeast. Typically, soils in this region are subsoiled every year to depths of 0.3 to 0.5 m. Annual subsoiling is recommended because soils recompact quickly due to natural consolidation processes and random wheel traffic (Tupper et al., 1989; Busscher et al., 1986; Busscher and Sojka, 1987).

Deep tillage, particularly subsoiling, often results in yield increases for crops grown in this region (Box and Langdale, 1984; Hammond and Tyson, 1985; Reeves et al., 1992). However, one experiment conducted in the Tennessee Valley region of northern Alabama found a negative cotton yield response for in-row subsoiling in one of two years for silt loam soils (Touchton et al., 1986). These authors also found a positive cotton yield response for in-row subsoiling in two years for a sandy loam soil from southern Alabama. These results indicate that subsoiling response for cotton is highly dependent upon soil type.

Increasing the organic matter content in the soil also has been used to alleviate compacted soil conditions. Thomas et al. (1995) reported that with approximately 2.5% organic matter content, concerns of soil compaction were groundless. They stated that one of the prime benefits of increased organic matter content was reduced soil compaction. One method of increasing soil organic matter content for cotton production is to include a cover crop in the management system. Benefits of cover crops include increased surface residue and increased soil moisture (Reeves, 1994). Higher values of soil moisture found during the cotton growing season would reduce soil strength and, therefore, decrease the negative effects of soil compaction.

We determined that a systems approach that included tillage timing, tillage depth, and cover crops would be the most logical research approach to solve the soil compaction problem. The objectives of the research reported in this paper were to assess the level of reductions in soil strength, as measured by cone index and bulk density that occurred due to the use of cover crops, different times of tillage, and different depths of tillage in conservation tillage systems.

MATERIALS AND METHODS

The experiment was begun in fall 1994 with fall tillage being applied at the Alabama Agricultural Experiment Station's Tennessee Valley Substation in Belle Mina. The soil type in this region is predominantly a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudults). Prior to this tillage, the field had been tilled conventionally for cotton production for many years.

The plots were four 102-cm (40 in.) rows wide by 920 cm (30 ft) long. The experimental design was a randomized complete block with a 2-by-2-by-2 factorial arrangement of treatments augmented with three additional control treatments of (i) no-tillage with no cover crop, (ii) no-tillage with a cover crop, and (iii) conventional tillage with no cover crop. The three items studied were: (i) cover crop (none or rye), (ii) tillage timing (fall or spring), and (iii) tillage depth (shallow or deep). To determine the depth of tillage, multiple cone-index profiles were obtained in plots that had been used to grow conventionally tilled

Fig. 2. Multiple-probe soil measurement system that obtains cone index values in five positions across a row.

cotton and that were going to be used for our experiment. These measurements showed that the depth of the compacted soil layer began at approximately 15 cm (6 in.). The shallow depth of tillage was chosen as 18 cm (7 in.) and the deep depth of tillage was set to be at 33 cm (13 in.), approximately twice the shallow depth.

An experimental Yetter[1] implement (Yetter Mfg. Co., Colchester, IL) with in-row subsoilers that could be adjusted to operate at both shallow and deep depths was used for all tillage treatments. Fingered wheels and fluted coulters were used to move residue away from the shanks. A small bedded region approximately 30 cm (12 in.) wide and 10 cm (4 in.) tall was created by closing disks mounted on the rear of the shank. The conventional tillage treatment consisted of fall disking and chiseling followed by disking and field cultivating in the spring prior to planting.

Table 1. Significance levels of treatments for bulk density measurements (C, cover crop effect; T, tillage timing effect; D, tillage depth effect).

Depth (cm)	C	T	D	C × T	C × D	D × T	C × T × D
0-5	0.58	0.08†	0.54	0.31	0.88	0.60	0.22
5-10	0.37	0.31	0.99	0.09†	0.75	0.16	0.80
10-15	0.36	0.00†	0.10†	0.32	0.03†	0.01†	0.68
15-20	0.46	0.43	0.00†	0.58	0.63	0.25	0.76
20-25	0.56	0.03†	0.00†	0.86	0.78	0.12	0.96
25-30	0.09†	0.65	0.26	0.88	0.15	0.08†	0.45
30-36	0.87	0.59	0.87	0.99	0.61	0.73	0.60

† Statistically significant at the *P* = 0.10.

Cotton was planted in early May, with Deltapine ‘DP15' used in 1995, Deltapine ‘NuCOTN 33^{B}’ in 1996, Deltapine ‘DP20B’ in 1997, and PM1220 BG/RR in 1998.

Starting with fall 1994, soil strength and soil moisture measurements were taken both spring and fall immediately before and after tillage treatments. These measurements continued until fall 1998. Soil strength was determined by using a tractor-mounted multiple-cone penetrometer (Raper et al., 1999; Fig. 2) and then calculating the cone index (ASAE, 1999a, b).

Five penetrometer probes were inserted (i) in the row, (ii) midway between the row and the untrafficked row middle [25 cm (10 in.) from the row], (iii) in the untrafficked row middle [50 cm (20 in.) from the row], (iv) midway between the row and the trafficked row middle [25 cm (10 in.) from the row], and (v) in the trafficked row middle [50 cm (20 in.) from the row]. Even though statistical comparisons are not possible from contour graphs, they were created from the cone index measurements because these graphs allow the reader to visually examine depth and width of disturbance of tillage shank. Soil moisture was determined gravimetrically at shallow [0 -15 cm (6 in.)] and deep [15 cm (6 in.) -30 cm (12 in.)] depths. The same soil sampling unit was used to obtain measurements of bulk density at 5.1-cm (2-in.) depth increments in the row following harvest of the 1998 crop.

The factorial arrangement of eight treatments within the randomized complete block was analyzed with an appropriate ANOVA model (SAS Institute Inc., Cary, NC). A predetermined significance level of $P \leq 0.10$ was chosen to separate treatment effects.

[1] The use of trade names or company names does not imply endorsement by USDA-ARS or Auburn University.

RESULTS AND DISCUSSION

A factorial analysis of bulk density measurements showed some significant main effects within the tillage depth range (Table 1). Timing of tillage treatments was found to be significant at the 0 to 5, 10 to 15 cm, and 20 to 25 cm ranges, with spring tillage having reduced values of bulk density (Fig. 3). This result was reasonable, because the most recent tillage event would have been spring tillage and the soil could have consolidated from the previous fall's tillage. Significant depth of tillage effects were also found in the 10 to 15 cm, 15 to 20 cm, and 20 to 25 cm depth ranges due to the different depths of tillage applied.

Also, cover crops only caused a statistical difference in bulk density at one depth (25 -30 cm). Bulk density did not show a significant effect of a cover crop (Fig. 3). The highest values of bulk density near the surface were found in the no-till plots, with the effect of the cover crop increasing bulk density in these plots (Fig. 3). As mentioned previously from the statistical comparison, clear benefits of spring tillage were seen in this figure, with significant consolidation resulting from the previous fall's tillage practice. Differences also were seen in the depth range of 15 to 30 cm between shallow and deep tillage conducted either in spring or fall.

Cover crops were found to be important in assisting conservation tillage systems, producing similar yields compared to conventional tillage (Fig. 4). Only those plots that had the benefits of a cover crop produced average yields greater than those of conventionally tilled plots during a 4-yr period. Those tillage systems that produced yields statistically similar to, but numerically in excess of, the conventional tillage system (2780 kg ha $^{-1}$) were the fall shallow tillage treatment with a cover crop (2890 kg ha $^{-1}$), the spring shallow tillage treatment with a cover crop (2830 kg ha $^{-1}$), and the no-till with a cover crop (2820 kg ha $^{-1}$). It is particularly interesting that deep tillage either in fall with a cover crop (2790 kg ha $^{-1}$) or in spring with a cover crop (2710 kg ha $^{-1}$) produced yields slightly less than (i) conventional tillage, (ii) fall shallow tillage with a cover crop, or (iii) spring shallow tillage with a cover crop treatments. This trend seems to indicate that tillage deeper than necessary not only wastes energy, but also may reduce yields. A thorough analysis of seed cotton yield on an annual basis can be found in Raper et al. (2000).

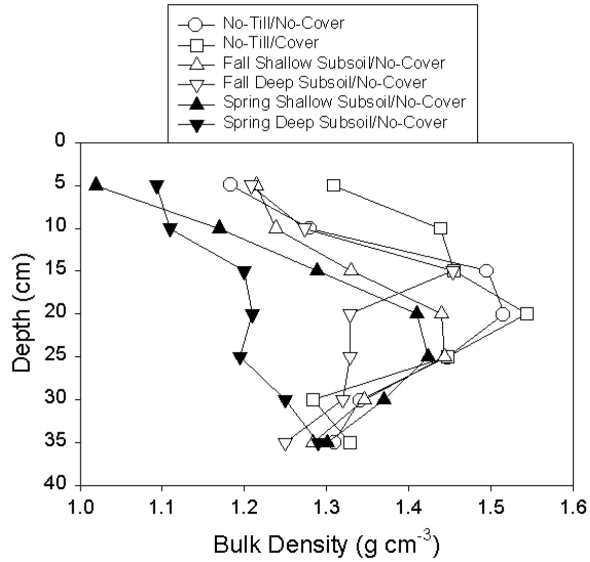

Fig. 3. Bulk density values obtained in fall 1998 beneath the row.

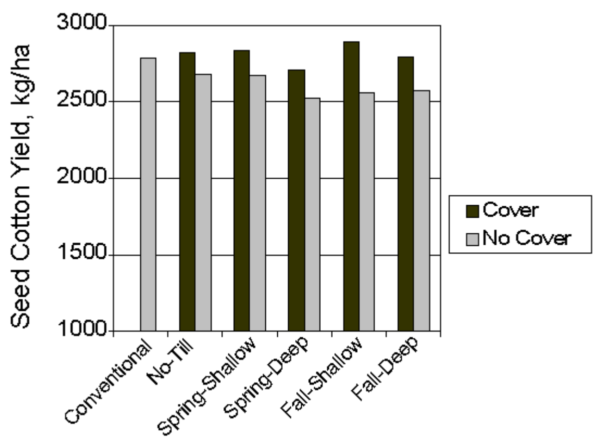

Fig. 4. Averaged seed cotton yield data for the entire 4-yr experiment. LSD (0.10) = 198 kg ha^{-1}.

Contour plots (Fig. 5, 6, 7, 8, and 9) were constructed from the cone index profiles obtained with the multiple-probe soil cone penetrometer in 1997. These data should show the benefits of 3 yr of conservation tillage as compared with those data collected closer to the beginning of the experiment. Profiles measured in spring 1997 in the no-till plots without cover crops (Fig. 5A) showed somewhat increased values of cone index as compared with the profiles measured in fall 1997 (Fig. 5B). This was most likely due to differences in soil moisture with values of 17.0 and 20.4 kg kg $^{-1}$ (17.0 and 20.4%) being measured in spring 1997 at 0 to 15 cm and 15

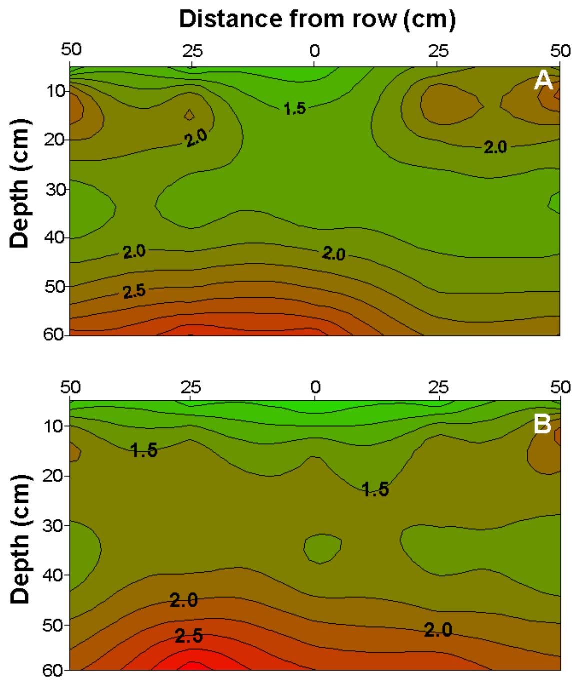

Fig. 5. No-till with no cover. Cone index iso-lines (MPa) with the top (A) obtained in spring 1997 and the bottom (B) obtained in fall 1997.

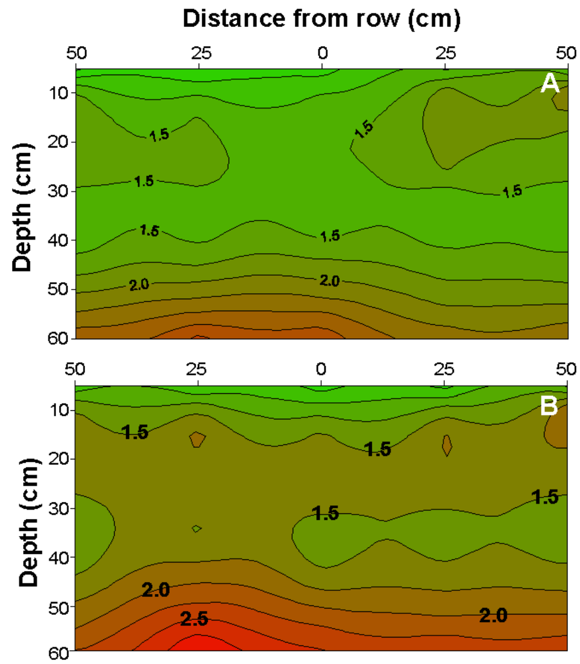

Fig. 6. No-till with cover. Cone index iso-lines (MPa) with the top (A) obtained in spring 1997 and the bottom (B) obtained in fall 1997.

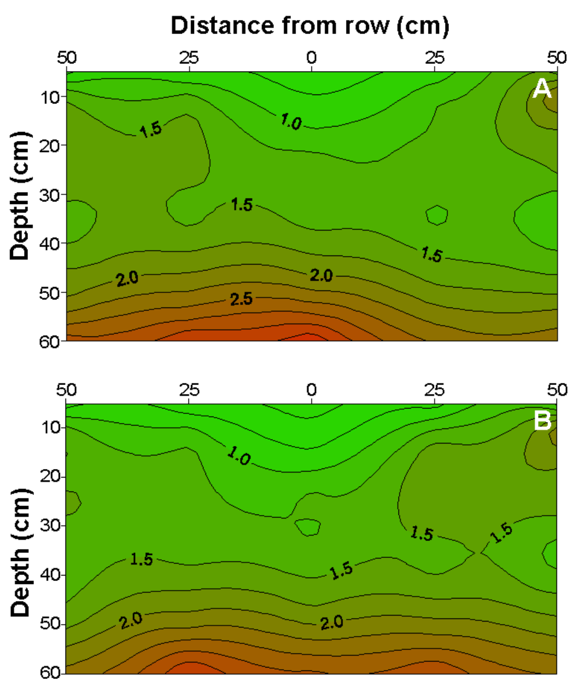

Fig. 7. Fall 1996 shallow tillage with cover. Cone index iso-lines (MPa) with the top (A) obtained in spring 1997 and the bottom (B) obtained in fall 1997.

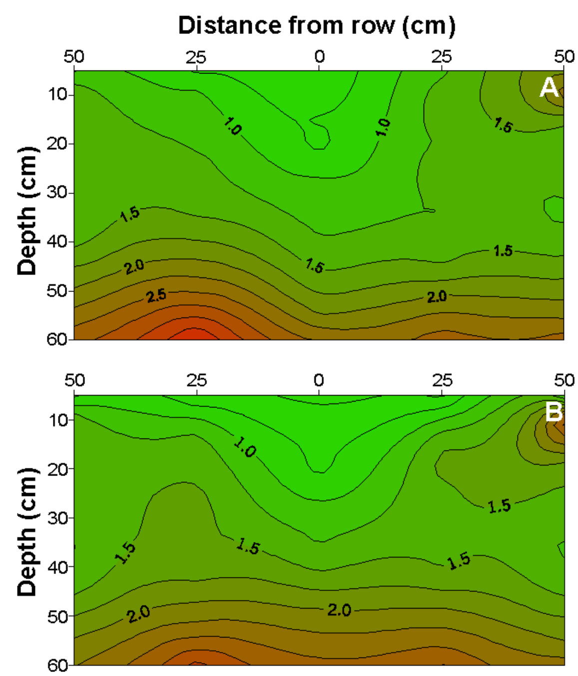

Fig. 8. Fall 1996 deep tillage with cover. Cone index iso-lines (MPa) with the top (A) obtained in spring 1997 and the bottom (B) obtained in fall 1997.

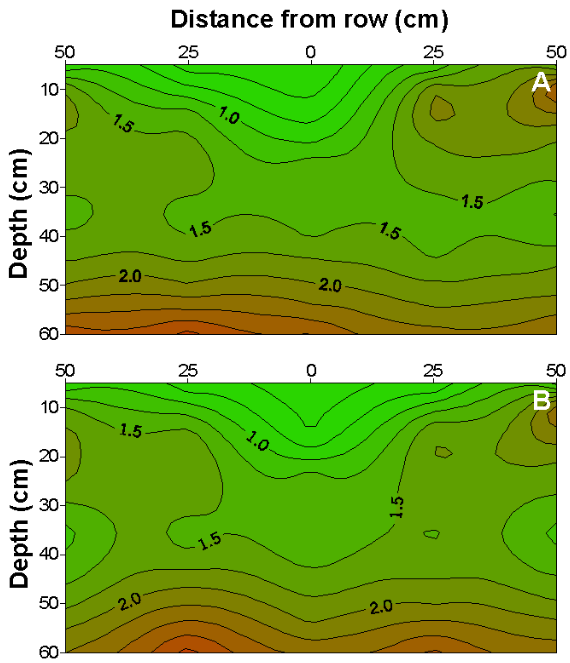

Fig. 9. Spring 1997 shallow tillage with cover. Cone index iso-lines (MPa) with the top (A) obtained in spring 1997 and the bottom (B) obtained in fall 1997.

cm to 30 cm, respectively, and 20.3 and 19.7 kg kg^{-1} at 0 to 15 cm and 15 to 30 cm being measured in fall 1997.

Similar values of moisture content were measured in the no-till plots with a cover crop with values of 19.4 and 20.5 kg kg^{-1} being measured at 0 to 15 cm and 15 cm to 30 cm , respectively, in spring 1997, and 20.5 and 20.0 kg kg^{-1} being measured in fall 1997. Comparisons in the cone index graphs from the no-till with a cover crop (Fig. 6) showed a lack of a compacted zone extending across the row in the spring of the year. Also, comparing Fig. 5A with 6A, and Fig. 5B with 6B, showed that a cover crop tended to reduce cone index values in the spring, but had little positive effect by fall. This effect is probably due to greater infiltration during the winter months when rainfall is plentiful in the U.S. Southeast - as evidenced by the spring measurements of increased moisture contents of the no-till with a cover crop at the 0-15 cm depth (19.4 kg kg^{-1}) as compared with the no-till without a cover crop at this same depth (17.0 kg kg^{-1}).

The benefits of shallow tillage conducted in fall 1996 is illustrated in cone index profiles measured in spring 1997 (Fig. 7A) and fall 1997 (Fig. 7B). Note that the compacted zone directly beneath the row has been reduced by the in-row tillage. Any increased consolidation that may have taken place over the summer months is probably not visible due to the increased soil moisture contents in these plots in fall 1997 (17.0 and 19.5 kg kg^{-1} for 0 -15 cm and 15 -30 cm depths in spring 1997 vs. 21.2 and 21.2 kg kg^{-1} for 0 -15 cm and 15 -30 cm depths in fall 1997).

Deep tillage conducted in fall 1996 showed similar trends as the shallow tillage in cone index profiles measured in spring 1997 (Fig. 8A) and fall 1997 (Fig. 8B). The only substantial difference between Fig. 7 and Fig. 8 is the increased depth of soil disturbance by the deeper tillage treatment. The moisture contents for these plots also were reduced in the spring of the year with 17.2 and 19.2 kg kg^{-1} at 0 -15 cm and 15 -30 cm depths being measured as compared with 21.7 and 21.3 kg kg^{-1} being measured in fall 1997.

When shallow tillage was conducted in spring 1997, cone index profiles taken immediately after (Fig. 9A) and those taken in fall 1997 (Fig. 9B) showed similar profiles. Some consolidation must have taken place over the summer because soil moisture measurements increased from spring to fall; 16.8 and 19.2 kg kg^{-1} at 0 -15 cm and 15 -30 cm depths in spring 1997, and 21.3 and 20.4 kg kg^{-1} at 0 -15 cm and 15 -30 cm depths in fall 1997. Also, some improvements in cone index values were visible with spring 1997 shallow tillage (Fig. 9B) having reduced values as compared to fall 1996 shallow tillage (Fig. 8B). These results are reasonable with the most recent tillage event having the least opportunity to consolidate.

These results illustrate the shortcomings of using bulk density as the sole method of determining optimum growing conditions for plants. Obvious differences due to tillage timing or tillage depths were found, but no significant benefits of cover crops were found using bulk density measurements. Measurements of cone index also did not show improved soil condition for cover crops in fall 1997, however improvements were seen in spring 1997. One explanation may be that cover crops increase infiltration and reduce evaporation during winter months.

The resulting soil condition has increased soil moisture and decreased soil strength, which may benefit crop yield. This effect would dissipate by fall because all residue has decomposed. Also cotton crops in soil of greater initial moisture and decreased compaction would likely have increased root growth and water extraction, thereby reducing fall soil moisture and increasing cone index.

CONCLUSIONS

In-row tillage performed either in fall or spring, at either shallow (18 cm) or deep (33 cm) depths, reduced cone index and bulk density measurements to their depth of operation, compared with no-till plots.

Spring tillage reduced cone index and bulk density values in the fall of the year, compared with fall tillage performed almost 12 mo prior.

A winter cover crop reduced cone index measurements in the spring of the year, most likely due to increased soil moisture. However, this benefit dissipated by fall, after harvest.

Yields similar to conventional tillage could be obtained by simply using a cover crop. In addition, slightly increased yields might be obtained by including a fall shallow in-row tillage treatment with the cover crop.

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