Enhancement of Subsoiling Effect on Soil Strength by Conservation Tillage

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ABSTRACT

THE effects of deep tillage are believed to differ for conventional vs. conservation tillage in the sandy Ultisols of the southeastern Coastal Plains of the United States. To test this, cone indices were measured for a conventional tillage and a conservation tillage treatment before and after in-row subsoil-planting. In the first year of the study, the conservation tillage treatment had a significantly higher moisture content (15.1 vs 12.1% on a dry weight basis) and a mean soil strength that was 0.70 MPa less than the conventional treatment. In the second year, the conservation tillage treatment had a lower moisture content (13.2 vs. 14.9%) and a mean soil strength that was 0.29 MPa greater than the conventional treatment. However, after conventional treatment strengths were corrected for soil moisture content differences, the mean strengths were about the same. The differences in the distribution of the strengths favored the conservation tillage treatment which was evenly distributed while the conventional tillage treatment had areas of higher strength that could more easily inhibit root growth.

INTRODUCTION

As more equipment becomes available which is specialized for use in the southeastern Coastal Plains, crop management systems with conservation tillage can be used to encourage erosion resistant residue management (Campbell et al., 1983). However, since the Ap and E horizons of many Coastal Plains soils are single-grained or massive, low in organic matter, and sandy textured, they often produce strengths that physically impede root growth (Campbell et al., 1974; Reicosky et al., 1977; Trouse and Reaves, 1980; Box and Langdale, 1984).

Any management system, even conservation tillage, will have to include some sort of soil profile modification. Subsoiling is one of the common practices used to disrupt the E horizon and provide a pathway for roots to the less dense B horizon that has a higher clay content. Increased yields have been attributed to those cultural practices that decrease soil strength and increase the limits of root exploration (Gerard et al., 1982; Ide et al., 1984; Peterson et al., 1984).

It is the purpose of this paper to examine the differences in soil strength (cone index) between a conventionally tilled treatment that is cleared of stubble by fall disking and a conservation tillage treatment that is spring planted in the stubble. There was less traffic and no disking on the conservation treatment. Therefore, its soil strength was expected to be lower at depths below the disking after subsoiling than the conventional tillage treatment in the sandy Ultisols of the southeastern Coastal Plains.

MATERIALS AND METHODS

This study was conducted in the springs of 1984 and 1985 on a Norfolk loamy sand soil (fine, loamy, siliceous, thermic, Typic Paleudult) located at the Coastal Plains Research Center in Florence, SC. Even in the conservation tillage treatments, remnants of an Ap horizon can be seen to a depth of approximately 0.2 m. The E horizon is loamy sand. The B_t horizon has a sandy clay texture and starts at an average depth of 0.38 m.

The experimental field design was randomized complete block with four replicates and the two tillage treatments. The field had been subsoil-planted to corn in 1983, to soybeans in 1984, and back to corn in 1985. Wheel traffic patterns were not strictly maintained from year to year. Plots were approximately 14 m by 40 m. Row widths were 0.76 m. The same tillage treatments (conservation and conventional) had been maintained in the plots for 2 years before the study. Both treatments were in-row subsoiled to a depth of about 0.5-0.6 m at the time of planting using the Brown-Harden Superseeder* which has 50 mm wide, forward-angled, non-parabolic shanks with 125 mm wide shoes and strip tillers at the side of each shank in the form of fluted coulters. Treatment 1, the conventional tillage treatment, was tilled in the fall with a tandum disk harrow to a depth of 0.15 m after harvest to bury the stubble and periodically disked to keep the surface clear of weeds. Treatment 2, the conservation tillage treatment, remained in a surface cover of stover throughout the winter, and weed growth was controlled with glyphosate or paraquat as needed and at the time of planting.

Soil strength readings were taken on 26 and 27 June 1984 before and after planting. In 1985 the readings were taken on 25 March and 10 April to get strength readings just before and about two weeks after planting. Measurements were taken with a hand-operated, analogue, recording penetrometer using a 13-mm diameter, 30 deg cone tip (Carter, 1967). Mechanical impedance was recorded for the top 0.6 m of soil across

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two rows at about 0.1-m intervals. Three probings were taken at each interval across the rows and entered into the computer using the method of Busscher et al. (1985). The data consisted of cone indices for each of 13 depths at 17 positions across two rows for both treatments and all four replicates on both days of both years. Cone index was log transformed (Cassel and Nelson, 1979) before analysis. Strength was modeled using the regression procedure of SAS for depth and position across a row (using the two rows as duplicate readings). The regression involved the first through fourth order depth and position variables and the first and second order interaction terms. Significance was determined by calculating an F statistic from pooled individual treatment effects and combined treatment effects as shown on p. 72 of Draper and Smith (1966).

A simple analysis of variance was used to analyze the yield of soybeans in 1984 and corn in 1985 for the two treatments and the four replicates.

WATER CONTENT CORRECTION

Water content on a weight basis was taken for each plot at in-row positions. Analysis of these data used a split-split plot design at two dates. The same analytical design as the strength data was not used since water contents were taken at one position and six depths for each of the treatments and replicates.

For the 1984 data, there were no significant differences among water contents for different dates or for any of the interactions of date, treatment, position, and depth. However, there were significant differences (at the 1% level) for water contents over depths and treatments. The conservation tillage treatment had significantly more water in each of the first five 0.1-m depth intervals, averaging 15.1 and 12.1% for the conservation and conventional tillage treatments, respectively. Since there was no significant difference between 26 and 27 June and since the readings were taken on consecutive days, differences of moisture between them were ignored.

For the 1985 data, the only significant difference among the moisture contents was with depth. (There was a difference with date at the 6% level). In this year, the conventional tillage treatment had more water 14.9 vs. 13.1% for the conservation tillage treatment (Table 1). The spring moisture contents for the different tillage treatments in the Coastal Plains depends on rainfall patterns and winter ground cover. It is not unusual for either treatment to have more moisture than the other (Campbell et al., 1984). Because small differences in moisture content can cause large changes in soil strength (Spivey et al., 1986), cone indices were analyzed for two cases both with and without the correction for moisture content differences. There is no widely accepted method for correcting for moisture at the present time. However, there have been empirical relationships that have been used. Mirreh and Kutcheson (1972) used linear and quadratic terms for bulk density and matric potential and one interaction term to predict strength. Logarithmic or multiplicative empirical relationships have also been used by Collins (1971), Ayres and Perumpral (1982), and Bennie (1986). This latter method can give an equation such as:

$$\text{Log(CI)} = a\,\text{Log(BD)} + b\,\text{Log(M)} + \text{Log}(c) \quad [1]$$

CI is the cone index in MPa; BD is the bulk density in kgm/m^3; M is the moisture content in kgm of water per kgm of dry soil, and a, b, and c are empirical constants dependent on soil and horizon. The advantage of this method is that when the empirical equation at one moisture content is divided by it at another moisture the bulk density which remains constant for a given sample will cancel. This gives the equation:

$$CI_1/CI_2 = (M_1/M_2)^b \quad [2]$$

Indices 1 and 2 are corrected and uncorrected conditions. The A and B horizons were corrected separately. The term "b" was determined by regression of the moisture and strength field data to give values of −1.39 and −1.43 for the A and B horizons, respectively, which had an R^2 of 0.88 for the A horizons and 0.99 for the B. Corrections were made on only the conventional treatments for the 1984 data and on all the 1985 data to bring the moisture content to a level equal to the conservation tillage treatments of 1984.

TABLE 1. MOISTURE CONTENTS ON A DRY WEIGHT BASIS FOR THE CONSERVATION AND CONVENTIONAL TILLAGE TREATMENTS ON 26 AND 27 JUNE 1984 AND ON 25 MARCH AND 10 APRIL 1985. WATER CONTENTS ARE MEANS OF FOUR REPLICATES

Tillage treatment	Water content, kg/kg					
	1984		1985 Pre-till		1985 Post-till	
	Conv.	Cons.	Conv.	Cons.	Conv.	Cons.
Depth						
5	0.088	0.101	0.135	0.112	0.094	0.078
15	0.086	0.098	0.116	0.105	0.095	0.079
25	0.085	0.148	0.113	0.106	0.098	0.094
35	0.114	0.175	0.153	0.137	0.165	0.139
45	0.166	0.191	0.196	0.165	0.185	0.190
55	0.185	0.195	0.208	0.177	0.233	0.201
mean	0.121	0.151	0.153	0.134	0.145	0.130

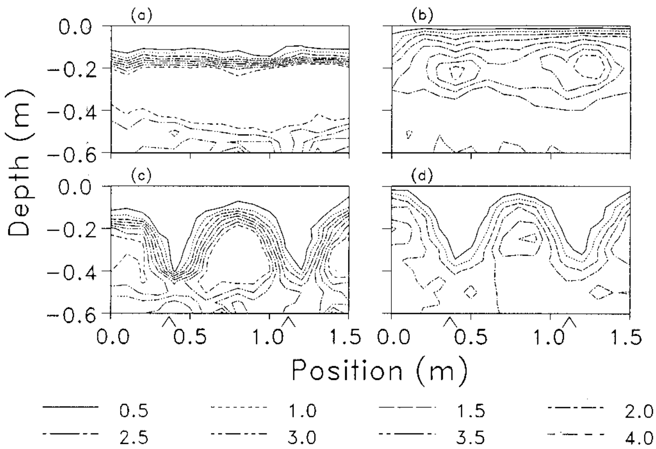

Fig. 1—Iso-strength contours at 0.5 MPa intervals for the 1984 data. (a) is the conventional tillage treatment before subsoil-planting, (b) is the conservation tillage treatment before subsoil-planting, and (c) and (d) are the same two treatments, respectively, after subsoil-planting. "Λ" marks the locations of the rows.

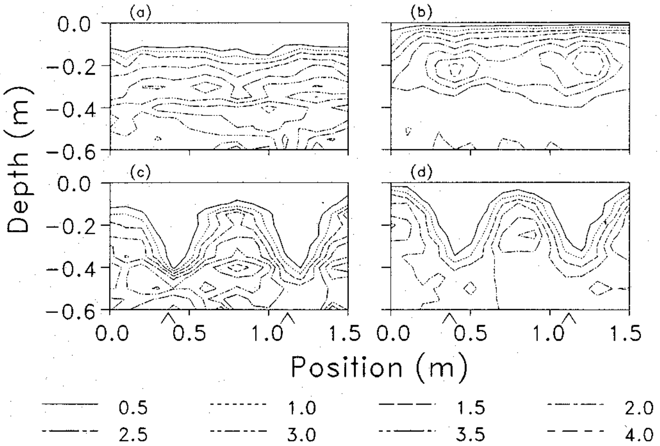

Fig. 2—Iso-strength contours at 0.5 MPa intervals drawn from data that was corrected for moisture content using equation [2] for the 1984 data. (a) is the conventional tillage treatment before subsoil-planting, (b) is the conservation tillage treatment before subsoil-planting, and (c) and (d) are the same two treatments, respectively, after subsoil-planting. "Λ" marks the locations of the rows.

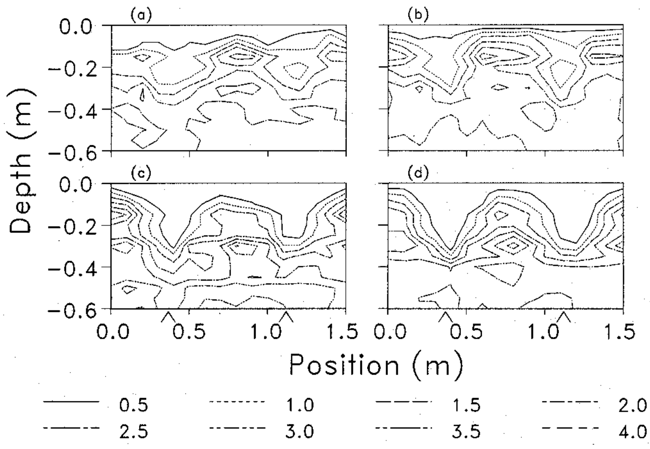

Fig. 4—Iso-strength contours at 0.5 MPa intervals drawn from data that was corrected for moisture content using equation [2] for the 1985 data. (a) is the conventional tillage treatment before subsoil-planting, (b) is the conservation tillage treatment before subsoil-planting, and (c) and (d) are the same two treatments, respectively, after subsoil-planting. "Λ" marks the locations of the rows.

RESULTS AND DISCUSSION

Figs. 1 through 4 show soil strength contours (cone index) for the conventional and conservation tillage treatments before and after subsoil-planting and before and after correction for moisture content differences between the tillage treatments. Zones of low soil strength in the plots indicate areas where the subsoil shank has disrupted the soil. In the case of the contours before the tillage operation, they indicate remnants of last year's subsoiling. Zones of high strength are the inter-row positions. For example, Threadgill (1982) and Busscher et al. (1986) showed that residual soil strength patterns could be seen up to a year after tillage. Remnants of the previous year's subsoiling were easily seen in the conservation tillage treatment (Fig. 1b) in the 1984 data but were absent in the uncorrected data for the conventionally tilled plots (Fig. 1a). It was not until after correction for the moisture differences (Fig. 2a) that an apparent tillage pan from disking breaks up and little, if any, remnants of deep tillage can be seen in the conventionally tilled plots.

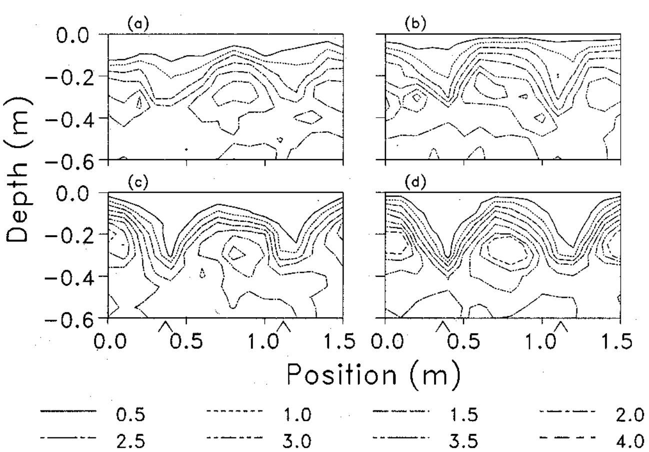

Fig. 3—Iso-strength contours at 0.5 MPa intervals for the 1985 data. (a) is the conventional tillage treatment before subsoil-planting, (b) is the conservation tillage treatment before subsoil-planting, and (c) and (d) are the same two treatments, respectively, after subsoil-planting. "Λ" marks the locations of the rows.

Significant differences between the treatments indicate a difference of strength or pattern of strengths. The differences of pattern are best illustrated by the conservation tillage treatment before and after tillage in 1985 for uncorrected strengths (Figs. 3b,d). Here the average strengths are almost identical, differing in the third place of accuracy (Table 2). However, the two sets of strength readings are statistically significantly different (at the 0.001 level). The difference is in the patterns of the strengths. After in-row subsoiling, the strengths are lower at the shallower in-row positions and higher between the rows.

For both years soil strength measured after subsoil-planting was significantly different from that measured before subsoil-planting for both tillage treatments and both before and after correction for moisture conditions. Surprisingly, the 1985 readings show an overall increase in strength after tillage for both of the tillage treatments. For the uncorrected readings, this might be explained by the decrease in water content between the dates of measurement. However, this decrease was small, averaging 0.008 and 0.004 kgm/kgm for the conventional and conservation tillage treatments, respectively (Table 1). Furthermore, this trend does not change after the strengths are corrected for moisture content (Table 2). There was an increase (or at best no significant decrease) in the mean soil strength for both treatments as a result of the tillage operations. This can be at least partially explained for the moisture

TABLE 2. MEAN STRENGTHS FOR THE DIFFERENT TILLAGE PROFILES BEFORE AND AFTER CORRECTION FOR MOISTURE CONTENT

		Soil strength, MPa			
		Uncorrected		Corrected	
Year		Conv.	Cons.	Conv.	Cons.
1984	Pre-till	3.01	2.31	2.07	2.31
	Post-till	2.17	1.51	1.59	1.51
1985	Pre-till	1.79	2.11	1.74	1.72
	Post-till	1.87	2.12	1.83	1.76

uncorrected (Fig. 3) and the moisture corrected (Fig. 4) cases by an increase in strength between the rows (a traffic pan) and by increases near the bottom of the area of disruption by the subsoiler (a subsoil pan). To say that tillage may have been unnecessary or that it caused more compaction than no tillage would be deceptive since traffic from the planting would increase the soil strength, presumably at a shallower depth than the tillage implement.

For the 1984 tillage treatments, the mean strength of the profiles after tillage are higher for the conventional than the conservation tillage treatments both before and after correction for moisture (Table 2). After correction, the difference is reduced considerably and the two have almost the same strength. However, the conventional treatment has a large area of low strength near the surface and higher strength at depths near 0.40 to 0.50 m while the strength of the conservation tillage treatment is more evenly distributed throughout the profile (Fig. 2). The lower strengths of the conventional tillage treatment near the surface would encourage root growth in that area; the higher strengths below would more easily inhibit root growth than the lower, even strengths of the conservation tillage treatment. It is the purpose of subsoiling to open up an area that is permeable to the roots so that they may grow through it and into the softer subsoil where it can extract water and nutrients. The higher strengths at greater depth would tend to prevent this more in the conventional tillage system.

It is not the purpose of this paper to assess the overall effect on the root growth that would occur with the change in water content or to develop a way to correct for moisture. However, the change of strength caused by the differences in water content is significant and must be considered. Corrections for these changes give an indication of the relative soil strengths if the water contents had been equal.

Although there is some disagreement regarding the precise limits of root growth (Taylor et al., 1966; Camp and Lund, 1968; Campbell et al., 1974; Gerard et al., 1982), the bulk of the existing literature currently indicates that root growth is restricted beyond 2.0 MPa as measured by a flat-tipped penetrometer. This corresponds to approximately 2.5 to 3.0 MPa for the 13 mm, 30 deg cone tip (Busscher et al., 1986). Assuming a cone index of 3.0 MPa as the root-restricting value, the conservation tillage treatment had virtually the whole profile available for plant growth after the 1984 tillage. In fact, most of the profile had strengths less than 2.0 MPa. There were large areas of high strength (>3.0 MPa) for the conventionally tilled soil corrected for moisture content. Nevertheless, the subsoil shank did loosen the soil in one of the two areas of disruption to 2 MPa, as much as it did in the conservation tillage case (Fig. 2). Whether corrected for moisture or not, one of the subsoiled areas of disruption did not loosen the soil below 3 MPa, enough to permit penetration by roots. The zones of high strength here are larger than for the conservation tillage case (Figs. 1 and 2) and would more easily prohibit root growth.

For the 1985 data, the conservation tillage treatment has a higher overall soil strength than the conventional treatment before the correction for moisture content. Here, the strengths after tillage for both of the treatments are low enough throughout the profile to permit root growth except for small islands of high strength (>3.0 MPa) as shown in Fig. 3. The conventional tillage treatments are higher in moisture. Therefore, correction for moisture content changes the strengths of the conservation tillage treatments more than the conventional treatment (Fig. 4, Table 2). In fact, the profile of the conservation tillage treatment is essentially less than 2.5 MPa after correction while the conventional tillage treatment has a 3.0 MPa isoline near the 0.40 to 0.50 m depth. Although this region may or may not be critical depending on the water content, it has a higher strength than the conservation tillage treatment at the same moisture content and, as in 1984, would be more restrictive to root growth if the water contents of the two varied over a similar range throughout the season.

The fact that this could have happened for both years is somewhat confirmed by yield. The yield of the conservation tillage treatment for both years was higher than for the conventional system. The conservation tillage treatment, which had a moister and looser soil after subsoil-planting in 1984, had a higher yield (significant at the 0.15 level) of soybeans (1534 kg/ha) than the conventional treatment (1332 kg/ha). Although the conventional tillage treatment had a higher moisture content at the beginning of the 1985 season, the conservation tillage treatment had the higher yield (6,670 vs. 6.360 kg/ha of the conventional tillage treatment, significant only at the 0.3 level).

CONCLUSIONS

For this study, after correction for differences in moisture content, conservation and conventional tillage had about the same mean strength throughout the soil profile. However, the conservation tillage treatments had a more uniform distribution of strength with depth than conventional tillage. This would provide a medium for the root development that avoids layers of very low or high strength.

Correction of strengths to a single moisture regime for the tillage treatments indicated that the differences were absolute and not merely dependent on increases in profile moisture associated with winter ground cover and tillage.

Disking of the conventionally tilled treatments was probably responsible for at least some of the deep recompaction and reconsolidation of the previous year's zone of disruption from the subsoiler in the first year of the study. This could result in a loss of yield (Touchton and Johnson, 1982).

The average soil strengths (cone indices) of the 1985 tillage treatments were less before tillage than after. However, this was at least partly due to a change in moisture and did not necessarily mean that the treatment did not need to be subsoiled at planting. In fact, Threadgill (1982) and Busscher et al. (1986) found that one year after planting soils can reconsolidate to the point that they can be root restricting. Two years after subsoiling traces of the subsoil slots were hard if not impossible to identify.

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