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RESIDUAL EFFECTS OF TILLAGE ON COASTAL PLAIN SOIL STRENGTH[1]

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It has been suggested that different tillage methods create soil physical conditions that persist for various lengths of time in the easily compacted soils of the Southeastern Coastal Plain. To test this hypothesis, plots that had been subsoiled and chiseled were conventionally treated (disk-harrowed) for 1 to 3 yr to observe the residual effect of deeper tillage. In the final season, penetration resistances of all plots were measured at field capacity over a 1.90- × 0.55-m cross-sectional cut of soil perpendicular to the rows. This allowed plotting the isostrength patterns of the soil profile of each treatment. Although some residual subsoil tillage effect could still be identified 2 yr after subsoiling, the increase in soil strength (cone index) to 1.5 to 2.5 MPa even after a single year and the inability to position planters precisely over the previous year's subsoiled rows negated any benefit from the previous year's tillage.

Many soils of the Southeastern Coastal Plain (SECP) are weakly structured, often single-grained or massive, high in bulk density, low in organic matter, and light-textured in the Ap and E horizons (Campbell et al. 1974). These factors produce solid-phase conditions that physically impede root growth (Barley et al. 1965; Campbell et al. 1974; Doty et al. 1975; Reicosky et al. 1977; Trouse and Reaves 1980; Langdale and Box 1984). Although there is some disagreement concerning the precise strength 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 the root is limited by strengths of 1 MPa and restricted beyond strengths of 2 MPa as measured by a flat-tipped penetrometer.

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The current management technique for alleviating the strength problems in soils of the SECP is to disrupt the compacted horizon by deep tillage. In practice, many Coastal Plain farmers either in-row subsoil, chisel, or moldboard-plow every year. Some farmers have questioned the need for profile disruption every year, suggesting that residual effects of a previous year's tillage may suffice for plant growth. Further, Touchton and Johnson (1982) have recently shown that subsoiling of the summer row crop provides significant yield benefit to the subsequent small grain double crop without a second subsoiling operation between crops.

The purpose of this paper is to examine the soil strength characteristics under various tillage practices and determine how they change from year to year.

MATERIALS AND METHODS

This study was conducted between 1978 and 1981 on a Norfolk loamy sand soil (fine loamy, siliceous, thermic, Typic Paleudult) located at the new Pee Dee Research Station of Clemson University in Florence, South Carolina. The experimental design of the field plots was randomized complete block with seven treatments and three replicates. Treatments 1 and 2 were last subsoiled to a depth of about 0.5 to 0.6 m in 1979 and 1980, respectively; Treatments 3, 4 (and 7), and 5 were last chiseled to a depth of 0.4 m in 1978, 1979, and 1980, respectively; and Treatment 6 was moldboard-plowed to a depth of 0.3 m every year (see Table 1). Tillage operations were performed parallel to the rows with a John Deere 3020 tractor using 20-mm wide, angled nonparabolic subsoil shanks with a 65-mm wide foot at 1-m spacings or 20-mm wide chisels at 0.25-m spacings.[3]

During the years plots were not subsoiled or chiseled, they were disk-harrowed to a depth of 0.15 m. In 1981, Treatment 3 was chiseled to 0.4

[3] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA or the S.C. Agric. Exp. Stn. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

TABLE 1
Summary of the tillage treatments

Treatment	Year			
	1978	1979	1980	1981
1	Subsoiled	Subsoiled	Disked	Measured
2	Chiseled	Chiseled	Subsoiled	Measured
3	Chiseled	Disked	Disked	Measured-chiseled-measured
4	Chiseled	Chiseled	Disked	Measured
5	Chiseled	Chiseled	Chiseled	Measured
6	Plowed	Plowed	Plowed	Measured-subsoiled-measured
7	Chiseled	Chiseled	Disked	Measured-subsoiled-measured

m and Treatments 6 and 7 were subsoiled to a depth of 0.5 to 0.6 m. All tillage treatments were performed in the spring with soil moisture at or near field capacity. Between 6 and 9 April 1981, penetrometer readings were taken on all plots before tillage and on two replicates of Treatments 3, 6, and 7 after tillage.

Plots had been planted to soybean (*Glycine max*) in 1978, 1979, and 1980 in 1-m row widths. The field had been harvested but not tilled over winter and was in soybean stubble at the time of the readings. Also, at this time soil moisture was near field capacity (approximately 10, 13, and 18 kg/kg at 30 kPa for the Ap, E, and Bt horizons, respectively), after a somewhat dry winter of 280 mm of rainfall from November to March.

Soil strength measurements were made with a hand-operated recording penetrometer with a 13-mm diameter 30° cone (Carter 1967). Field calibration has shown that 0.5 and 2.5 MPa on this penetrometer compare to the 1- and 2-MPa values of Taylor et al. (1966) and Campbell et al. (1974) for their blunt-tipped penetrometers.

Mechanical impedance was recorded for the top 0.55 m of soil at 0.1-m intervals across two rows from midrow to midrow: 2 m. Three probings were taken at each interval of every plot and recorded by pen tracings on an index card.

Data were read from the cards for each 0.05-m depth increment from 0 to 0.55 m for each tracing by a semiautomated digitization program. Once initialized for the surface, the program automatically moved horizontally to the appropriate position on the card for depth; a cross hair was manually moved vertically over the tracing; and the data were recorded via the digitization process of a Hewlett-Packard 9872A plotter and 87XM microcomputer (Busscher et al. 1985).

Because the three traces on each card crisscrossed freely and were hard to distinguish from one another, they were not digitized in any order. After digitization, the data were averaged to give one set of data per position per plot. Combining the 20 sets of data for a plot gave a cross-sectional view of soil strength of 0.55 m deep and 1.90 m across, with data points every 0.05 m of depth and 0.1 m of width.

These data were averaged over replications and plotted as isostrength contours, using a modified version of a locally written three-dimensional plotting routine. Contours were plotted at 0.5-MPa increments from 0.5 to 3 MPa.

RESULTS AND DISCUSSION

The split-split plot analysis of the cone index data shown in Table 2 was analyzed using a log transformation (Cassel and Nelson 1979). Strength was not significantly different among replications at the 5% level. Treatments were found to be statistically significantly different (at the 1% level). All treatments that were probed one or more years after tillage were not significantly different from each other using a Waller-Duncan *K*-ratio *t* test. They all had average strengths between 1.1 and 1.2 MPa. Plots that were chiseled in 1981 (Treatment 3) and subsoiled in 1981 (Treatments 6 and 7) were significantly different from the above and from each other. Their average strengths were 0.83 and 0.64 MPa, respectively. Strengths interacted significantly with depth for both treatment and position, as would be expected for a soil with a compact E horizon.

Isostrength contours for the 0.55- by 1.90-m

TABLE 2

Analysis of variance with a split-split plot design for the given tillage treatments; position across the rows and depth were treated as continuous variables

Source	*df*
Treatment	9
Reps	2
Treatment * reps (error 1)	15
Position	1
Position * reps (treatment) (error 2)	17
Position * depth	1
Treatment * depth	10
Treatment * position * depth	9
Total number of samples	5040

cross-sectional cut of soil are shown in Figs. 1 to 3. Figures 1(a) and (b) show the disruption of soil strength immediately after subsoiling to a depth of about 0.5 to 0.6 m in plots that had been moldboard-plowed and disk-harrowed in the previous year, respectively (Treatments 6 and 7). Zones of weakness can be seen in the subsoiled trench immediately below rows. In these areas, subsoiling has broken through the E horizon, which extends from the bottom of the Ap horizon to a depth of about 0.3 to 0.5 m. This would enable roots to grow through the E and into the Bt horizon, which is softer (as will be shown later) and higher in available water (Campbell et al. 1974).

Isostrength contours of plots that were subsoiled a year before readings were taken are shown in Fig. 1(c) (Treatment 2). Traces of subsoil trenches can be seen near the 0-, 0.9-, and 1.9-m positions. However, reconsolidation to strengths of 1.5 to 2.5 MPa has occurred, which is at best root-limiting.

Although care by the implement operator was taken during planting to position rows in the same place every year, comparison of Fig. 1(c) with Figs. 1(a) and 1(b) shows that positions were out of alignment by several centimeters. Roots from new plantings in 1981 would miss the zones of weakness and be forced to grow laterally before entering the "softer" soil. Furthermore, it is likely that traffic may pass over at least part of the previous year's trench, thereby leading to some recompaction. It is possible that subsoiling from the previous year may not be beneficial to a crop in the following year for this Norfolk soil.

Soil strengths of plots that were subsoiled 2 yr before characterization are shown in Fig. 1(d) (Treatment 1). Small depressions in the isostrength lines at the 0.3- to 0.4-m depths might suggest that subsoil shanks had broken up the soil at the 0-, 0.9-, and 1.85-m widths. However, it is obvious that the E horizon has reformed, and roots would have difficulty penetrating it to reach the softer subsoil. Compared with the 3-MPa isostrength lines as a reference, the soil is softer above the E horizon and generally softer below it. This has been shown also by Cassel et al. (1978) and Threadgill (1982).

Chiseling was thought by the equipment operator to have reached a depth of 0.4 m. However, as seen in Fig. 2(a) (Treatment 3), the soil was disrupted only to approximately the 0.3-m depth. Strengths between there and the bottom of the plot range between 2 and 3 MPa. The root would have a difficult time penetrating the lower horizons through soil with these strengths and no structure.

Figures 2(b), 2(c), and 2(d) (Treatments, 5, 4, and 3) show the strength conditions 1, 2, and 3 yr after chiseling, respectively. Treatment 7, before subsoiling, was similar to Treatment 4. In all cases, the E horizon has reformed with the lesser strengths above and below. Again, using the 3-MPa lines as a reference for the impeding layer of the E horizon, it appears that in each of these three years, the extent of the layer has enlarged. In fact, the area between the 3-MPa lines of the three graphs increased by 14 and 20% for Figs. 2(b) and 2(c), respectively. This increase is probably caused both by natural reforming processes and by disk compaction. Average depths to 3 MPa of soil strength for the three figures are 207, 205, and 175 mm for

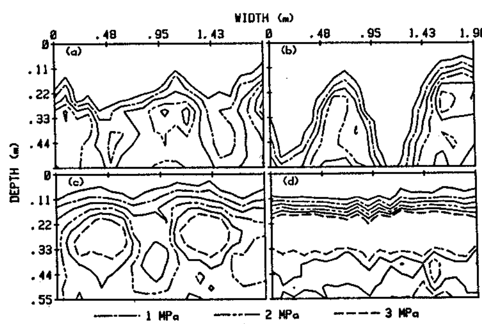

FIG. 1. Isostrength lines at 0.5-MPa intervals for (a) the in-row-subsoiled Treatment 6 that had been moldboard-plowed the previous year, (b) in-row-subsoiled Treatment 7 that had been disked the previous year, (c) Treatment 2 that had been in-row-subsoiled the year before it was measured, and (d) Treatment 1 that had been in-row-subsoiled for 2 yr before it was measured. The solid lines are 0.5-, 1.5-, or 2.5-MPa isopleths.

treatments with 0, 1, and 2 diskings, respectively.

In Fig. 3 (Treatment 6) the isostrength lines are shown for the soil that was moldboard-plowed to a depth of 0.3 m in the previous years. There was no residual trace of the disruption, and the strength of the E horizon had returned.

In Figs. 1(d), 2(c), and 2(d) (Treatments 1, 4, and 3), there had been no tillage since the previous year's disking. Because the disking extended to a depth of only 0.15 m, it cannot be expected to disrupt the E horizon. The shallow depth to which soil strength would favor root proliferation under this tillage explains the general responsiveness of Coastal Plain soils to in-row-subsoiling compared with disking only. This has been determined in previously published yield comparisons (Parker et al. 1975; Peele et al. 1974; and many others).

The cumulative frequency of strength readings is shown in Fig. 4 for treatments that were subsoiled and chiseled in the year that readings were taken and for subsoiling the previous year. Plots subsoiled in 1981 had a higher frequency of readings at lower strength values, indicating that the subsoiling was more effective in breaking up the soil than the 1981 chiseling. It also developed a slot through which roots would be able to grow into the subsurface horizons.

Furthermore, subsoiling consumed less fuel. Doty (1980) showed it was both more effective and less expensive. His economic analysis showed that subsoiling remained profitable even when practiced annually, unlike chiseling, which was not profitable in any year. Finally, he showed that subsoiling every other year was less effective than chiseling annually. This is confirmed here by the fact that the frequency distribution of soil strengths of alternate year subsoiling is even less favorable than chiseling annually (Fig. 4).

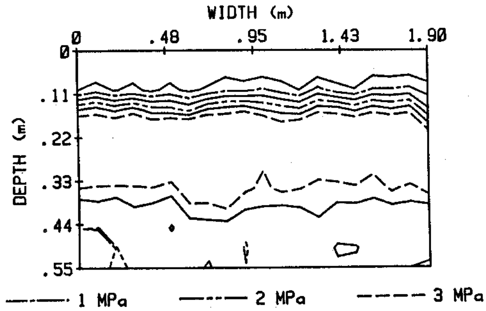

FIG. 3. Isostrength lines for Treatment 6 that had been moldboard-plowed the year before it was measured. The solid lines are 0.5-, 1.5-, or 2.5-MPa isopleths.

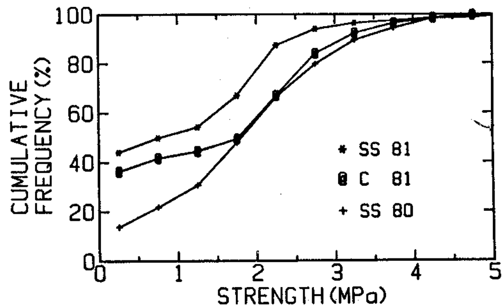

FIG. 4. Cummulative frequencies of the strength readings for Treatments 3, 4, and 2 that had been in-row subsoiled (SS) and chiseled (C) in 1981 and in-row-subsoiled in 1980.

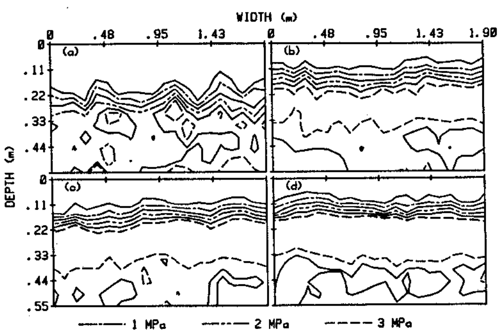

FIG. 2. Isostrength lines for the treatments that had been (a) just chiseled or chiseled (b) 1, (c) 2, or (d) 3 yr before measurement. The plots used were those for Treatments 3 (after chiseling), 4, 5, and 3 (before chiseling). The solid lines are 0.5-, 1.5-, or 2.5-MPa isopleths.

CONCLUSIONS

In the subsoiled plots, residual effects on soil strength patterns could be seen in the year following the tillage. However, the strength in the year-old subsoil trench was considered to be root-limiting (1.5 to 2.5 MPa). Furthermore, it was difficult, in the absence of a sophisticated guidance system, to position rows closer than within a few centimeters of their previous positions. This would demand that roots grow laterally before entering the old subsoil trough. With these drawbacks, it is doubtful that a previous year's subsoiling will ordinarily be of any benefit to a succeeding year's crop.

For treatments that had been chiseled, moldboard-plowed, or disked in the previous years, the strength of the E horizon had reformed to a root-restricting level that would prevent growth into it or the subsurface horizons.

Chiseling did not disturb the soil to the desired depth, even though it took more energy than subsoiling (Doty 1980). Furthermore, it is questionable that chiseling broke up the E horizon enough to encourage root growth into the lower horizons.

As has been previously suggested (Campbell et al. 1984*a*,*b*), annual in-row-subsoiling will have to be an integral part of all cropping systems in the Southeastern Coastal Plain, including all conservation or minimum tillage operations.

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