The *Journal of Cotton Science* 2:130-135 (1998)

ENGINEERING

Using In-Row Subsoiling to Minimize Soil Compaction Caused by Traffic

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INTERPRETIVE SUMMARY

At the conclusion of a 5-year long study with the USDA-ARS Wide-Frame Tractive Vehicle, the resulting soil condition was investigated with extensive penetrometer samples. The penetrometer was used to assess recompaction of subsoil slots caused by traffic. Four tillage treatments were evaluated. These included a conservation tillage practice that included in-row subsoiling, a conventional surface tillage system with no deep subsoiling, a conventional surface tillage system that was initially completely subsoiled, and a fourth tillage practice that included both in-row subsoiling and a conventional surface tillage system. Comparisons were also made between plots receiving traffic and those on which all traffic was eliminated. The beneficial effects of the conservation tillage practice are especially noteworthy. Besides the environmental benefits of maintaining surface residue, this treatment decreased the degree of soil compaction beneath the row. Traffic tended to reduce the available growing zone for plants, but did not greatly restrict the rooting depth immediately beneath the row when the in-row subsoiling treatments were used. If in-row subsoiling is used in a conservation tillage system in coastal plains soils, traffic beside the row does not appear to be detrimental to the soil condition beneath the row.

ABSTRACT

Soil compaction due to traffic and natural reconsolidation limits the ability of crop roots to expand into deep zones of moisture availability. This study was conducted to determine whether the total absence of traffic substantially improved the resulting soil condition. Extensive cone index measurements were used to evaluate the soil strength resulting from 5 years of a cotton (*Gossypium hirsutum* L.)-wheat (*Triticum aestivum L.*) double cropping experiment. Four cotton tillage systems, including a conservation tillage practice of in-row subsoiling and planting into wheat residue stubble, and two traffic systems were analyzed. The USDA-ARS Wide-Frame Tractive Vehicle was used to control traffic in the experimental plots. Contour graphs of cone index were used to determine differences in tillage and traffic systems. Traffic was found to reconsolidate soil that was initially completely disrupted to a 0.51 m depth into a soil condition similar to one that had never received a subsoiling treatment. Traffic was also found to decrease the total soil volume estimated for root growth using a 2 MPa limiting cone index value, but not the maximum rooting depth beneath the row, when an annual in-row subsoiling practice was used.

Soil compaction plagues many parts of the world and affects many different crops. In the southeastern part of the United States, cotton has been found to be particularly susceptible to soil compaction (Cooper et al., 1969). Where soil compaction is a problem, subsoiling has been found to help alleviate it (Campbell et al., 1974). Subsoiling severely compacted soil provides increased rooting depth that helps the plants withstand short-term drought conditions prevalent during the growing season in the southeastern United States. Soils in this region are subsoiled to a depth of between 0.3 and 0.5 m on an annual basis. This is necessary because of wheel traffic and natural forces that cause this soil to reconsolidate. Identifying the major cause of soil compaction is difficult because of the interaction of wheel traffic and natural forces.

The use of the Wide Frame Tractive Vehicle (Fig. 1) (Monroe and Burt, 1989) at the National Soil Dynamics Laboratory allows experiments to be conducted to determine the amount of soil compaction caused by wheel traffic versus the amount of soil compaction caused by natural forces.

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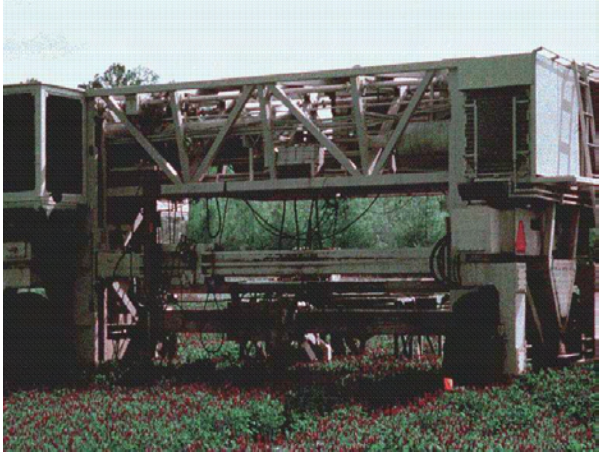

Figure 1. Wide-Frame Tractive Vehicle used at the USDA-ARS National Soil Dynamics Laboratory to study the effects of traffic-free zones on soil compaction.

This machine spans a 6-m growing zone that can then be kept completely free of wheel traffic unless a traffic treatment is specified. This vehicle operates on raised traffic paths and facilitates research to determine the effects of traffic and tillage on soil condition without confounding effects from nearby traffic.

MATERIALS AND METHODS

An experiment was conducted between 1987 and 1991 on coastal plains soils at the Alabama Agricultural Experiment Station, Auburn University, Agricultural Engineering Research Farm at Shorter, AL. The soil used was a Cahaba-Wickham-Bassfield sandy loam complex (Typic Hapludults) that contained a well-developed 0.08 to 0.15 m thick hardpan at a 0.2 to 0.3 m depth. The Cahaba soil is a fine-loamy, siliceous, thermic Typic Hapludult. The Wickham soil is a fine-loamy, mixed, thermic Typic Hapludult. The Bassfield soil is a coarse-loamy, siliceous, thermic Typic Hapludult. Prior to starting the experiment, wheel traffic was run in a moldboard plow furrow incrementally across the field at a 0.2 m depth to reduce the natural variation in the depth and thickness of the hardpan.

A split-plot experiment using cotton and wheat as a double crop was designed with four replications. The main plots were (i) conventional traffic and (ii) no traffic. The subplots contained various common cotton tillage systems including: (i) complete surface tillage (disked and field cultivated) and annual in-row subsoiling to a 0.4 m depth and planting (disk, field cultivate, in-row subsoil and plant); (ii) initial complete disruption of hardpan in 1987 (but with no annual subsoiling thereafter), complete surface tillage, and planting (complete disruption in 1987, disk, field cultivate, and plant); (iii) complete surface tillage, and planting (disk, field cultivate, and plant); and (iv) in-row subsoiling to a 0.4 m depth (strip-tillage) with no surface tillage (in-row subsoil and plant). The initial complete disruption treatment (complete disruption in 1987, disk, field cultivate, and plant) was accomplished by using a V-frame subsoiler on 0.25 m centers operating to a 0.51 m depth. A KMC[1] in-row subsoiler planter was used to plant cotton into the wheat stubble/residue in the strip-tillage treatment (in-row subsoil and plant) and to plant the annual subsoiling treatment. The same planter with the subsoilers removed was used to plant the remaining tillage systems.

The Wide Frame Tractive Vehicle was used for all tillage treatments, even in plots that received traffic. All traffic treatments were applied with a John Deere 4440 or a high clearance sprayer. These machines would have been used had the Wide Frame Tractive Vehicle not been available. All plots were eight rows in width and four-row equipment was assumed to apply the correct traffic treatments. Recommended weed and insect control practices were used throughout the growing season for all plots. Cotton (McNair 220) was planted in 0.76 m rows at 220 000 seeds/ha.

At the end of the 5-year experiment, penetrometer readings were taken with an automatic recording penetrometer to determine changes in soil condition during this time. The penetrometer with base area of 130 mm^2 (ASAE, 1991), and mounted on the Wide Frame Tractive Vehicle was used to sample each subplot at five different locations. At each location, five penetrations were made, starting from the row middle on the untrafficked side of the row, and moving in 0.19 m increments across the row into the trafficked row middle (corresponds to traffic middle in treatments that received traffic). This sampling procedure allowed both tillage and traffic treatments to be analyzed. Four replications

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[1] Use of a company name does not imply USDA approval or recommendation of the product or company to the exclusion of others which may be suitable.

x two traffic main-plot treatments x four tillage subplot treatments x five locations within the subplots x five positions across each location were sampled to give a total of 800 penetrometer sets of force-distance data. Cone index data were taken at every 0.003 m depth down to an approximate maximum depth of 0.7 m.

The cone index data were averaged in depth increments of 0.05 m for all replications and locations using SAS software (SAS Institute, 1990). Contour graphs extending from the untrafficked row middle across the row to the trafficked row middle were then created from this data using SURFER contouring software (Golden Software, 1989). These contour graphs show the potential root-impeding layers of compaction that are present in the soil profile.

Soil moisture and bulk density samples were also taken from beneath the row at a shallow depth of 7.6 cm (Raper et al., 1994). The depth to the hardpan was also measured and soil moisture and bulk density samples obtained at this depth. Three locations within each subplot were sampled.

RESULTS AND DISCUSSION

Comparison of contour graphs from the no-traffic plots (Fig. 2, 3, 4, and 5) illustrate the beneficial effects of subsoiling. Only the no-traffic plot shown in Fig. 4 has had no subsoiling. The shallowness of the 1 MPa profile differs substantially from the other figures. Figures 2 and 5 also show the presence of the annual in-row subsoiler channel.

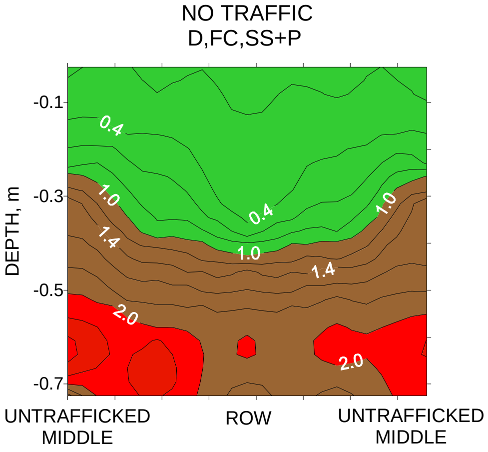

Figure 2. Cone Index Profiles (MPa) across the row for the disk, field cultivate, in-row subsoil and plant tillage treatment with no traffic.

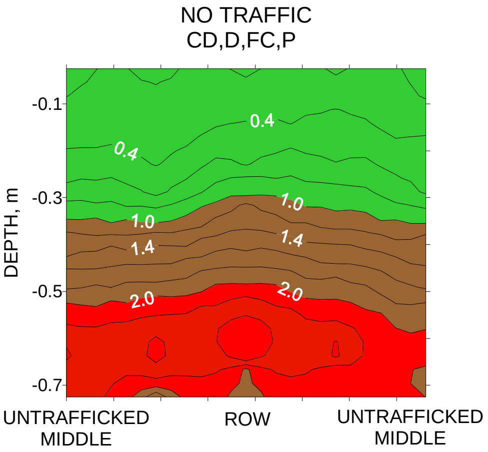

Figure 3. Cone Index Profiles (MPa) across the row for the initial complete disruption, disk, field cultivate and plant tillage treatment with no traffic.

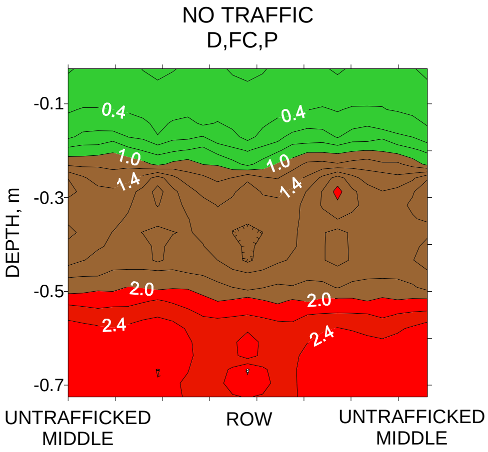

Figure 4. Cone Index Profiles (MPa) across the row for the disk, field cultivate, and plant tillage treatment with no traffic.

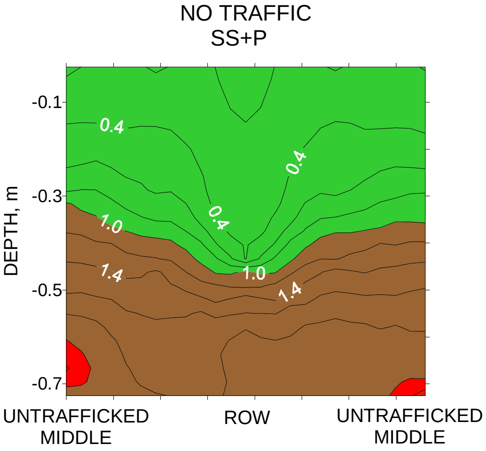

Figure 5. Cone Index Profiles (MPa) across the row for the in-row subsoil and plant tillage system with no traffic.

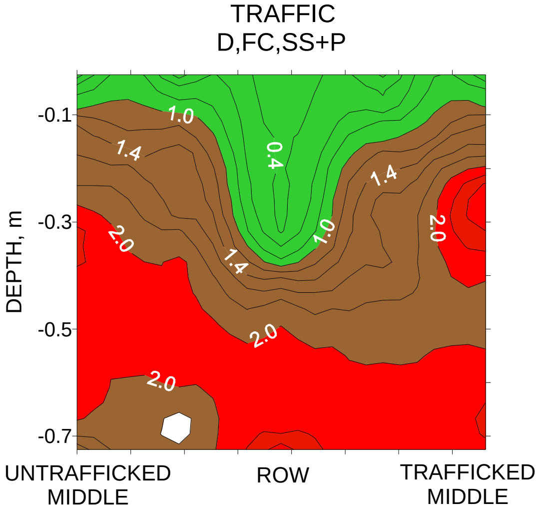

Figure 6. Cone Index Profiles (MPa) across the row for the disk, field cultivate, in-row subsoil and plant tillage system with traffic.

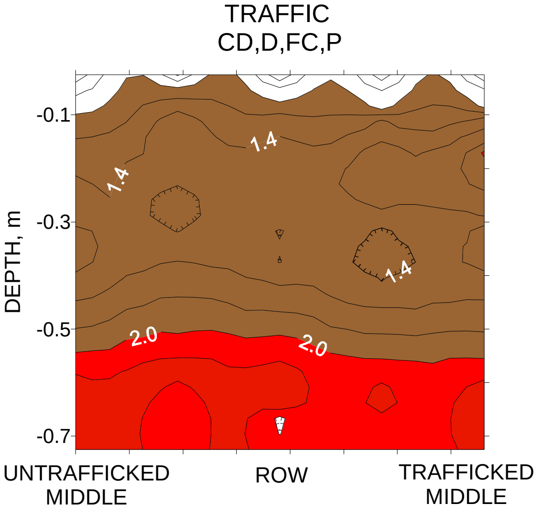

Figure 7. Cone Index Profiles (MPa) across the row for the initial complete disruption, disk, field cultivate and plant tillage system with traffic.

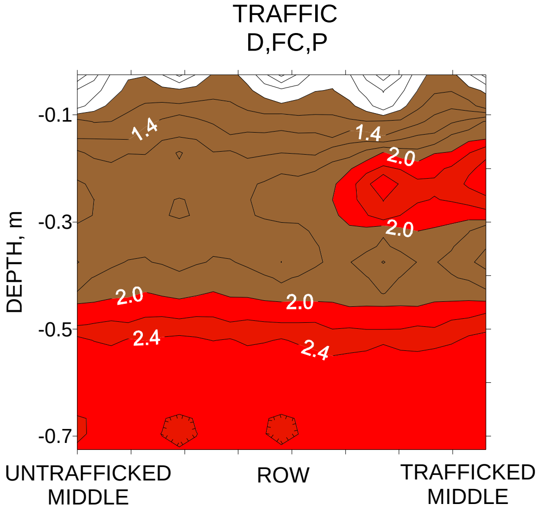

Figure 8. Cone Index Profiles (MPa) across the row for the disk, field cultivate and plant tillage system with traffic.

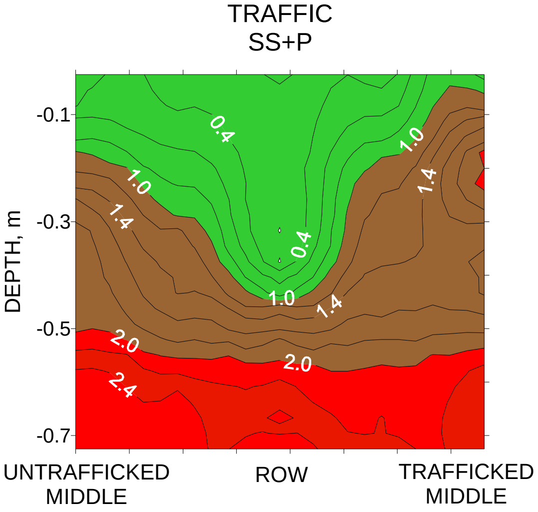

Figure 9. Cone Index Profiles (MPa) across the row for the in-row subsoil and plant tillage system with traffic.

The contour graphs from the traffic plots (Fig. 6, 7, 8, and 9) differ greatly from the contour graphs from no-traffic plots. In each graph, higher magnitude cone index profiles are much closer to the soil surface. An area of high soil compaction is noted beneath the surface in the trafficked row middle. Also, the in-row subsoiler slot is much easier to detect because of the soil recompaction near the slot.

An interesting comparison can be made between Fig. 3 and 7 which illustrates the effect of traffic on plots that were initially completely disrupted. A drastic change has occurred in these plots due only to the effect of traffic. The 1 MPa profile moved 0.2 m closer to the soil surface. The soil volume above this 1 MPa profile is near zero. Comparison of Fig. 7 and 8 shows that the effect of the initial disruption in 1987 has almost disappeared and the soil condition is similar to that tillage system that received no subsoiling treatment.

Table 1. Soil measurements in the row and cotton yield

Treatments	Surface † bulk density	Surface † moisture content	Depth to hardpan	Hardpan bulk density	Hardpan moisture content	1991 † Cotton yield
	Mg/m^3	%	m	Mg/m^3	%	kg/ha
No traffic						
D,FC,SS + P‡	1.36	15.8	0.37	1.63	16.8	977
CD,D,FC,P	1.42	16.6	0.28	1.62	17.3	1022
D,FC,P	1.42	15.9	0.23	1.67	16.3	1070
SS + P	1.28	19.9	0.42	1.56	20.0	1072
Traffic						
D,FC,SS+P	1.48	14.3	0.37	1.63	15.7	890
CD,D,FC,P	1.51	16.8	0.18	1.58	16.5	881
D,FC,P	1.57	15.1	0.18	1.69	14.6	913
SS+P	1.41	17.8	0.41	1.55	20.0	1096
$LSD_{0.05}$(tillage)	0.08	2.7	0.05	0.08	2.8	93.4

† From Raper et al. (1994).

‡Tillage treatment key:

D,FC,SS + P = disk, field cultivate, in-row subsoil and plant.

CD,D,FC,P =complete disruption, disk, field cultivate, and plant.

D,FC,P=disk, field cultivate, and plant.

SS + P= in-row subsoil and plant.

The effect of traffic on subsoiling in a conventional farming system can also be investigated by comparing Fig. 2 and 6. The one major difference in these two figures is that the subsoil slot is much narrower in trafficked plots. The total volume of soil that is in a zone of minimal cone index is much greater in Fig. 2, but the overall depth of the subsoil slot is almost the same. This result is also echoed by contrasting Fig. 5 and 9, the conservation tillage system without and with traffic, respectively. The depth of the subsoil slot is greater in these latter two figures, but the trend is similar.

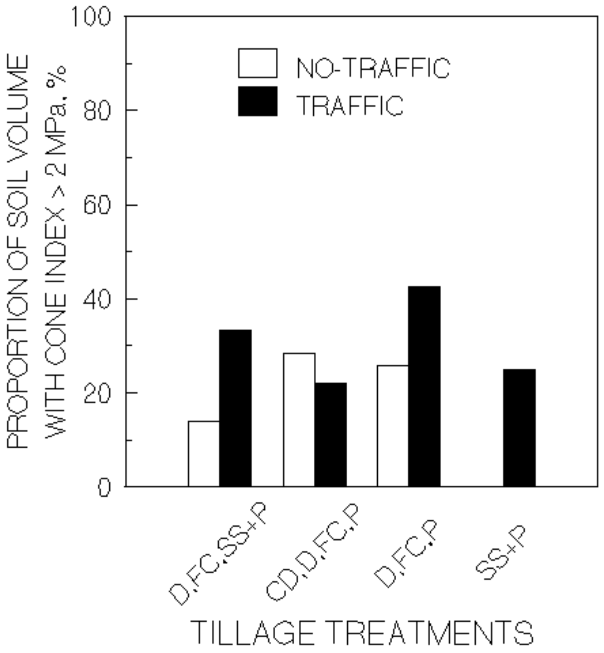

Figure 10. Effect of tillage and traffic treatments on the proportion of soil volume beneath row and wheeltracks with cone index greater than 2MPa.

These contour graphs can also be used to estimate the soil volume available for proper root growth. According to Taylor and Gardner (1963), a cone index of >2 MPa can negatively affect crop yields. Figures 2 through 9 were each analyzed to determine the total soil volume that had a cone index >2 MPa, which is indicated in these figures by the color red. The results are given in Fig. 10. With the exception of the initial complete disruption system (complete disruption in 1987, disk, field cultivate, and plant), traffic decreased the soil volume for root growth in each system. In the initial complete disruption tillage system, traffic negatively affected the soil volume between 1 and 2 MPa, but not above this limit. A significant difference is attributed to traffic in the in-row subsoil and plant and plant tillage treatment. In this conservation tillage treatment, only a very small portion of the total soil volume had a cone index >2 MPa in the untrafficked plots. However, the amount of soil volume available to plant roots may not be as important as the overall soil depth available for rooting. Results reported by Raper et al. (1994) showed that the conservation tillage practice of in-row subsoiling and planting (in-row subsoil and plant) had superior cotton yields in plots that received traffic as opposed to plots that received no traffic (Table 1).

Analyzing the depth to the hardpan measurements showed statistically significant results for both tillage ($P \leq 0.0001$) and traffic ($P \leq 0.0244$). The tillage treatments that incorporated in-row subsoiling showed hardpan depths much deeper than those that did not have in-row subsoiling treatments (Table 1). Traffic did not negatively affect the depth to the hardpan in those plots with in-row subsoiling treatments. In the other plots without in-row subsoiling treatments, the effect of traffic was found to dramatically decrease the depth to the hardpan.

Surface bulk density measurements showed statistically significant effects of tillage ($P \leq 0.0058$) and traffic ($P \leq 0.0154$). Reduced values of bulk density were found in those plots with in-row subsoiling treatments, especially when traffic was eliminated (Table 1). Traffic beside the row during the growing season did not completely recompact soil underneath the row that was loosened by in-row subsoiling. This is especially true when the conservation tillage practice of in-row subsoiling and planting (in-row subsoil and plant) was practiced.

The effect of traffic on bulk density measurements in the hardpan is negligible ($P \leq 0.5925$), but the effect of tillage is significant ($P \leq 0.0237$). All values are quite similar except for the conservation tillage practice of in-row subsoiling and planting (in-row subsoil and plant) (Table 1). The bulk density measurements obtained in these plots show decreased values of bulk density below those of all other tillage plots.

CONCLUSIONS

1. Traffic caused soil in plots initially completely disrupted with a V-frame subsoiler in 1987 to reconsolidate into a state similar to soil in plots that had never been subsoiled.

2. Traffic alongside the row did not significantly change depth to the hardpan or hardpan bulk density beneath the row in plots that received subsoiling treatments.

3. The best soil condition resulted from the conservation tillage practice of in-row subsoiling and planting. This practice produced the lowest cone index, the deepest hardpan depth, and the lowest surface and hardpan bulk densities of any of the practices studied, even in trafficked plots.

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