bout
lage
ing,

soil
rgy
her

rch
f.

d
of

n

245

Conservation Tillage and Traffic Effects on Soil Condition

R. L. Raper, D. W. Reeves, E. C. Burt, H. A. Torbert
Member ASAE   Member ASAE

Abstract. *The soil condition resulting from a five-year cotton-wheat double cropping experiment in a sandy loam Coastal Plain soil was investigated using intensive measurements of cone index and dry bulk density. Four tillage treatments including a strip-till (no surface tillage with in-row subsoiling) conservation tillage practice were analyzed. The traffic was controlled in the experimental plots with the USDA-ARS Wide-Frame Tractive Vehicle. Besides the environmental benefits of maintaining the surface residue, the strip-till treatment decreased cone index directly beneath the row, decreased surface bulk density, increased surface moisture content, decreased energy usage, and increased yields. Controlled traffic was beneficial only when in-row subsoiling was not used as an annual tillage treatment. Although differences in soil condition were seen beneath the row middles where traffic occurred, this did not affect the soil condition directly beneath the row.* **Keywords.** *Penetrometer, Strip-till, Bulk density, Controlled traffic, Cotton.*

Soil compaction has long been known to cause root restrictions and yield reductions in many crops, but cotton (*Gossypium hirsutum* L.) is particularly susceptible in the southeastern United States (Cooper et al., 1969; McConnell et al., 1989; Mullins et al., 1992). Two primary techniques have arisen concerning control and management of soil compaction. The first method of controlling 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). Subsoiling is done on an annual basis in some Coastal Plains soils because of their susceptibility to soil compaction. The amount of this compaction that occurs naturally and the amount that is caused by wheel traffic has not been well quantified.

The second method of controlling soil compaction from wheel traffic is by originally preventing it. One method of prevention is to control the traffic patterns in the field (Dumas et al., 1973). If a row could be maintained year after year, then the tractor tire could be kept in the same trafficked area without passing over the growing zone. It was this desire to be able to maintain a traffic-free area that led to the idea of controlled traffic. This concept has been investigated by several researchers (Williford, 1980; Carter, 1985; Carter et al., 1989) who used either conventional tractors with extended axles or specially designed spanner-type vehicles. Most of the studies to date have proposed two major conclusions. The first conclusion is that controlled traffic enhances soil condition for some soils and can enable roots to penetrate to deeper depths, therefore enhancing drought tolerance. The second conclusion is that crop yield is variable and the crop is not able to take advantage of this improved soil condition unless weather patterns exist which cause water stress.

The validity of these two conclusions under different tillage systems was examined in an experiment conducted by a team of researchers from the National Soil Dynamics Laboratory using a Wide-Frame Tractive Vehicle (WFTV). This experiment was conducted from 1987 to 1991 to investigate the effects of crop response to tillage and traffic treatments. The WFTV, as reported by Monroe and Burt (1989), allows a 6-m cropping zone to be kept free of field traffic. Raised traffic paths for the wheels allow the vehicle to completely span this area. This vehicle allows the necessary research to be conducted to determine the effects of traffic and tillage on soil condition without any confounding effects from nearby traffic.

In studies that reported yield results from this research (Reeves et al., 1989; Torbert and Reeves, 1991), the effect of traffic was again variable. Generally, no great advantage resulted from removing traffic from plot areas. Crop yields, however, were largely dependent upon crop species, year, and prevailing weather patterns. Significant tillage effects were noted on crop yields, however, in most years. Therefore, to help explain the variable effects on crop yields, we intensively sampled the soil to determine how the soil condition had been altered due to the imposed tillage and traffic treatments.

Methods and Materials

The experiment to determine the effects of traffic and tillage systems on crop response in Coastal Plain soils was conducted at the Alabama Agricultural Experiment Station,

Article was submitted for publication in October 1993; reviewed and approved for publication by the Power and Machinery Div. of ASAE in March 1994. Presented as ASAE Paper No. 92-1526.

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.

The authors are **Randy L. Raper**, Agricultural Engineer, **Donald W. Reeves**, Research Agronomist, **Eddie C. Burt**, Research Leader, USDA-Agricultural Research Service, National Soil Dynamics Laboratory, Auburn, Ala.; and **H. Allen Torbert**, Soil Scientist, USDA-Agricultural Research Service, Grassland Soil and Water Research Laboratory, Temple, Tex.

Auburn University, Agricultural Engineering Research Farm at Shorter, Alabama. The soil is a Cahaba-Wickham-Bassfield sandy loam complex (Typic Hapludults). This soil contained a well-developed 0.08- to 0.15-m-thick hard pan at a 0.2 to 0.3 m depth. A road grader was operated in a moldboard plow furrow incrementally across the field at a 0.2 m depth in June of 1987 prior to initiating the cropping experiment to reduce the natural variation in the depth and thickness of the hard pan.

A cotton-wheat (*Triticum aestivum* L.) double cropping experiment was designed as a split-plot with four replications. The main plots were conventional traffic and no traffic. The subplots contained various cotton tillage systems* including:

- Complete surface tillage (disked and field cultivated) and annual in-row subsoiling to a 0.4 m depth at planting (designated D, FC, SS+P).
- Initial complete disruption of hard pan (but with no annual subsoiling thereafter), complete surface tillage, and planting (designated CD, D, FC, P).
- Complete surface tillage and planting (designated D, FC, P).
- In-row subsoiling to a 0.4 m depth (strip-tillage) with no surface tillage (designated SS+P).

A V-frame subsoiler on 0.25-m centers and operating to a 0.5 m depth was used in November of 1987 on the plots that received the initial complete disruption of hard pan treatment (CD, D, FC, P). The strip-tilled cotton (SS+P) was planted into wheat stubble with a KMC in-row subsoiler-planter. This planter was also used to plant the annual subsoiling treatment, but in a conventional surface tillage environment.

Cotton (McNair 220) was planted in 0.76-m (30-in.) rows at 220 000 seeds/ha (90,000 seeds/acre) as close to June 1 as possible from 1988 to 1991. All tillage treatments were carried out with the WFTV, even in plots that received the traffic treatments. Immediately after each operation, the trafficked plots received traffic from a John Deere® 4440 that would have been used if the operations had not been performed with the WFTV. All plots were eight rows in width and four-row equipment was assumed during the application of the traffic treatments. Recommended weed and insect control practices were used throughout the growing season for all plots. A high-clearance sprayer was operated in the trafficked plots immediately after each spraying operation with the WFTV. The cotton was hand-harvested each year for yield determination.

The various tillage and traffic treatments were applied to the plots during the years 1987 to 1991. At the end of the five-year cropping experiment, during the fall of 1991, the plots were intensively sampled to determine the changes in soil condition that had occurred during this period of time. A penetrometer (ASAE, 1991), with base area of 323 mm^2, mounted on the WFTV was used to sample each subplot at five different locations. These five locations were distributed at approximately equal distances within the subplot. At each of these locations, five penetrations were made, starting from the row middle on the untrafficked side of the row and moving in 0.19-m (7.5-in.) increments across the row and into the trafficked row middle (corresponds to traffic middle in treatments that received traffic). This sampling procedure should allow changes caused by both tillage and traffic to be noted. Four replications × 2 traffic main-plot treatments × 4 tillage subplot treatments × 5 subsample locations × 5 positions across the row 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 giving 230 data points per dataset. These data were reduced by averaging the data in 0.05-m increments.

Soil samples were also taken from beneath the row at a depth of 7.6 cm and within the hard pan, and their dry bulk densities and gravimetric moisture contents were measured. Three locations within each subplot were sampled.

Results and Discussion

Several analyses were used to determine the effect of traffic and tillage on cone index. First, the data were visually examined for important trends. The most revealing set of soil cone penetrometer data is presented in figures 1 through 4. Figures 1 and 2 are plots of data from beneath the row middle that would have received traffic in the traffic treatment. Figures 3 and 4 are from beneath the row. From these graphs, the original hard pan can be found in the D, FC, P tillage treatment. This hard pan is present both underneath the row and in the trafficked middle and occurs at a depth of between 0.2 to 0.25 m. When traffic is applied, the hard pan is closer to the surface by approximately 0.05 m. Another observation is that when the hard pan is completely removed, as in the CD, D, FC, P tillage treatment, traffic must be controlled or recompaction of this layer can occur.

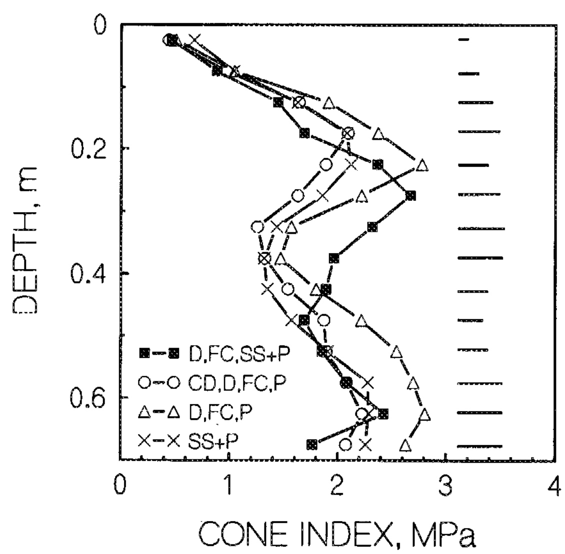

Figure 1–Cone index for the four tillage treatments (see table 2 for key) in the trafficked middle location in plots where traffic was applied. The horizontal bars indicate the $LSD_{0.05}$.

* The tillage treatments are defined by the following key: D (disk), FC (field cultivate), SS+P (in-row subsoil and plant), CD (complete distruption), and P (plant).

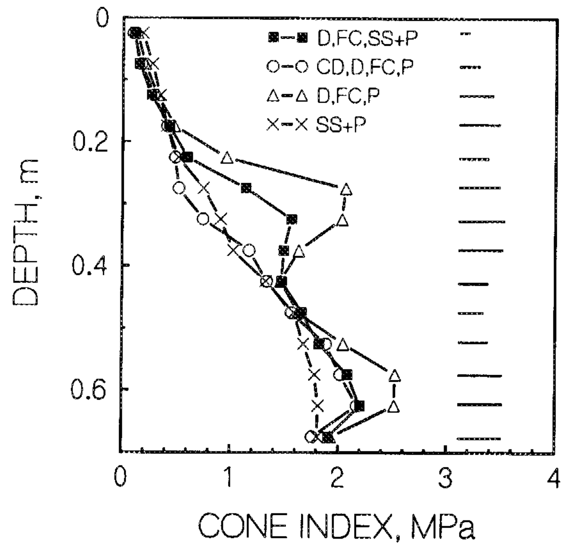

Figure 2–Cone index for the four tillage treatments (see table 2 for key) in the trafficked middle location in plots where no traffic was applied. The horizontal bars indicate the $LSD_{0.05}$.

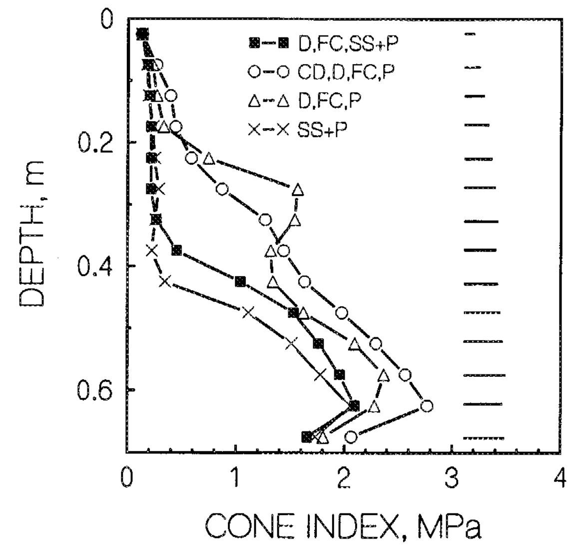

Figure 4–Cone index for the four tillage treatments (see table 2 for key) in the row location in plots where traffic was not applied. The horizontal bars indicate the $LSD_{0.05}$.

If figures 1 and 2 are compared, the overall effect of traffic on soil condition is seen for all four tillage treatments. If a hard pan does not exist, the effect of traffic is to create one. If a hard pan already exists, the soil above it becomes compacted and the pan becomes closer to the surface.

The effect of traffic on soil directly beneath the trafficked middle has been noted. The information that may be more important to plant growth is found directly beneath the row (figs. 3 and 4) where similar traffic effects are found on the nonsubsoiled tillage treatments (CD, D, FC, P and D, FC, P). This trend is not seen, however, when the subsoiling tillage treatments are analyzed (D, FC, SS+P and SS+P). In these tillage treatments, the hard pan is eliminated down to a 0.4 m depth. The dramatic traffic effects seen underneath the tire tracks and in the nonsubsoiled tillage treatments are eliminated when in-row subsoiling is used. The impacts of this trend are worth further discussion.

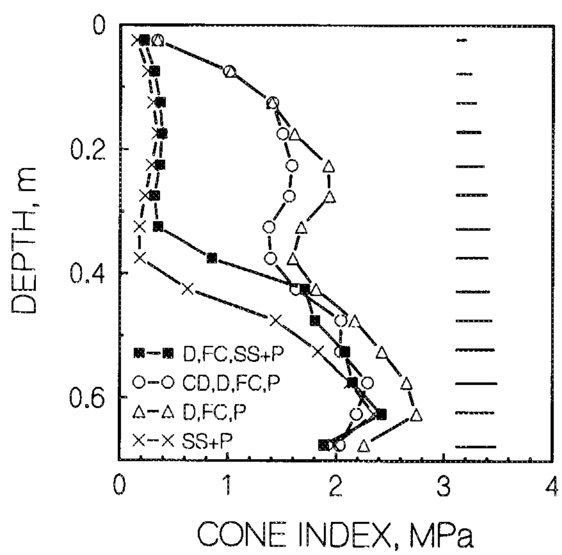

Figure 3–Cone index for the four tillage treatments (see table 2 for key) in the row location in plots where traffic was applied. The horizontal bars indicate the $LSD_{0.05}$.

The depths at which tillage and traffic differences became statistically significant were determined at three locations laterally across the row. Tillage affects cone index beneath the row for depths down to 0.55 m (table 1). The effect of traffic on cone index is particularly strong beneath the trafficked middle, but are also found down to 0.50 m beneath the row, and down to 0.30 m in the untrafficked middle. The explanation for the latter seems to be related to the random traffic that was applied in the fall of the year to the trafficked plots to simulate a cotton harvester and the wheat planting operations. During these operations, traffic was randomly applied throughout the field and not necessarily in the four-row farming patterns.

Immediately beneath the row, traffic and tillage effects are seen at depths down to 0.55 m (table 1). Of particular interest is the depth at which the in-row subsoiler should

Table 1. Effects of traffic, tillage, and traffic by tillage interaction on cone index at the 5% level of significance

Depth (m)	Untrafficked Middle	Row	Traffic Middle
0-0.05	T	T	T,t
0.05-0.10	T	T,t,T*t	T
0.10-0.15	T,t,T*t	T,t,T*t	T
0.15-0.20	T	T,t,T*t	T
0.20-0.25	T,t	T,t,T*t	T,t
0.25-0.30	T,t	T,t	T,t,T*t
0.30-0.35	t	t	t
0.35-0.40		T,t	
0.40-0.45		T,t	T
0.45-0.50		T,t	T
0.50-0.55		t	T,t
0.55-0.60			
0.60-0.65			

Note: T = traffic; t = tillage; T*t = traffic by tillage interaction.

operate, 0.40 to 0.45 m. If cone index is analyzed at this depth only, much greater differences are found between tillage treatments than between traffic treatments (fig. 5). Of special significance, however, is the difference occurring at this depth in the annual subsoiling with surface tillage treatment (D, FC, SS+P). The cone index value in the trafficked plot is almost twice the value obtained in the untrafficked treatment and is almost equivalent to the cone index value in the D, FC, P tillage treatment in which no subsoiling occurred. This trend suggests that the traffic treatment had started to consolidate the loose material that had been tilled at this depth. This same trend is not noticed for the strip-till tillage treatment (SS+P). The superior soil condition relating from the conservation tillage treatment resisted the compactive forces generated by traffic.

The work of Taylor and Gardner (1963) reported that a cone index of 2 MPa prevented proper root elongation and associated crop response for cotton. It therefore seems appropriate to take 2 MPa as the criterion for the hardpan designation. In figure 6, the effect of traffic is seen most obviously between the nonsubsoiled tillage treatments (CD, D, FC, P and D, FC, P). These treatments that use surface tillage without subsoiling are more susceptible to the compactive effects of traffic, however, due to the variation in the data, the effect of traffic is not statistically significant. The two tillage treatments that include the in-row subsoiler (D, FC, SS+P and SS+P) are not statistically different from each other, but are statistically different from the other two tillage treatments (CD, D, FC, P and D, FC, P).

Bulk density measurements taken under the row at a 7.6 cm depth also showed traffic and tillage treatment effects (table 2). Statistically significant differences in surface dry bulk density were found between the nonsubsoiled tillage treatments (CD, D, FC, P), (D, FC, P) and the subsoiled treatments (D, FC, SS+P and SS+P) regardless of traffic. A statistically significant lower surface dry bulk density was also found with the SS+P (strip-till) tillage treatment than the D, FC, SS+P tillage treatment in both the traffic and no-traffic condition. It is also interesting to note that traffic greatly increased the surface bulk density of the soil underneath the row.

When the gravimetric moisture content of these samples was analyzed, differences were found between tillage treatments, but not between traffic treatments. Because

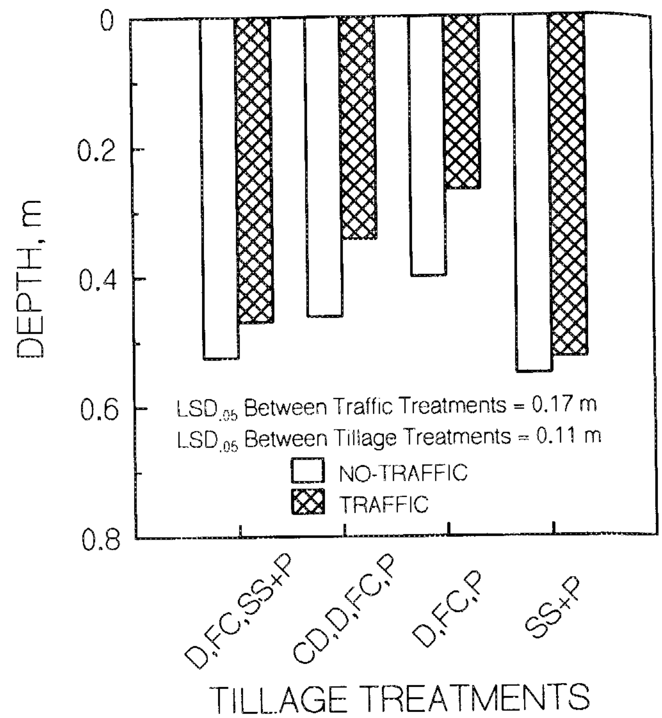

Figure 6–Depth of 2 MPa cone index value beneath the row (see table 2 for key).

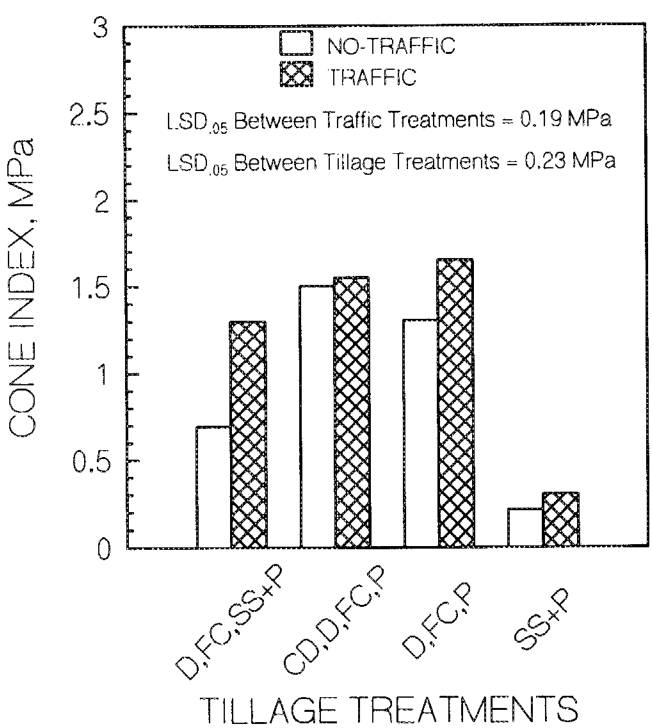

Figure 5–Effect of traffic and tillage treatments (see table 2 for key) on cone index measured beneath the row at a depth of 0.40 to 0.45 m.

Table 2. Surface (7.6 cm depth) bulk density and gravimetric moisture content in the row

Treatments	Bulk Density (Mg/m^3)	Moisture Content (%)
No traffic		
D,FC,SS+P	1.36	15.8
CD,D,FC,P	1.42	16.6
D,FC,P	1.42	15.9
SS+P	1.28	19.9
TRAFFIC		
D,FC,SS+P	1.48	14.3
CD,D,FC,P	1.51	16.8
D,FC,P	1.57	15.1
SS+P	1.41	17.8
$LSD_{0.05}$ (Traffic)	0.08	2.0
$LSD_{0.05}$ (Tillage)	0.05	0.7

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.

these samples were taken in late fall of 1991, the moisture differences that existed were probably due to infiltration and not due to plant soil water depletion. The D, FC, SS+P tillage treatment (annual subsoiling treatment with conventional surface tillage) had the lowest surface moisture content. The SS+P (strip-till) tillage treatment had the highest moisture content, both near the surface and in the hardpan (data not shown) and the lowest bulk density at the 7.6 cm depth. These combined factors could greatly enhance drought tolerance of plants. One possibility is that the SS+P (strip-till) tillage treatment had better infiltration and allowed the subsoil to replenish its moisture supply.

Cotton yield data that was hand-harvested shortly before penetrometer readings were taken in 1991 show interesting trends (fig. 7). Both traffic and tillage effects are statistically significant at the 5% level and the interaction is near the 20% level. It is obvious from these data that the desirable tillage treatment is SS+P (strip-till). Traffic was detrimental in every situation that included conventional surface tillage.

Another reason to consider the SS+P tillage treatment is the energy savings that result from reduced tillage operations. The energy required by various tillage treatments was measured by Burt et al. (1992). One of the results of this article states that "strip-tillage in wheat residue/stubble required about 50% less energy than did the conventional tillage system involving disking, field cultivation, subsoiling, and planting".

Determining the best tillage system from the standpoint of soil condition is not difficult. The SS+P (strip-till) system was by far the most advantageous. This tillage system contained the lowest cone indices of all the tillage systems, regardless of traffic, and allowed roots to penetrate to maximum depths. The SS+P tillage system also minimized bulk density near the surface and increased moisture content throughout the soil profile. The total

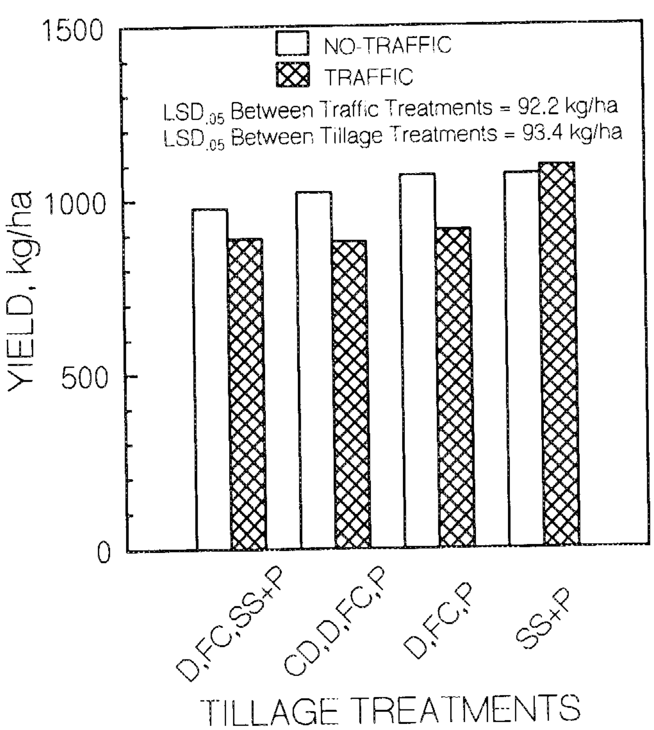

Figure 7–Cotton lint yield data for the year 1991 (see table 2 for key).

energy required for the SS+P tillage system was also less than for any other tillage system. Cotton responded quite well to this tillage system, outyielding all other tillage treatments. In addition to these points, this tillage system leaves the residue on the surface, which reduces soil erosion and increases water infiltration.

As traffic treatments are analyzed, several factors must be considered. Cone index data indicate the effect of traffic is detrimental, especially when in-row subsoiling is not carried out on an annual basis. Annual in-row subsoiling ameliorates the negative effects of traffic on cone index and surface bulk density. The effect of energy input into the system does not suggest that there is any benefit of eliminating traffic. An interesting contrast to these analyses is the yield data. The 1991 cotton yield data, taken prior to these soil measurements, seems to indicate that traffic is detrimental to all tillage systems except SS+P (strip-till). However, it should be noted that traffic in this experiment was kept mostly on row middles of a typical four-row system. Random traffic was only allowed on other locations in the fall of the year. These farming practices do not differ significantly from a normal farming system, but suggest that common sense must be used when operating normal farm machinery with emphasis on staying off the top of the row.

Conclusions

Positive benefits of the strip-till conservation tillage system (SS+P) were found in this study in addition to the environmental benefits of maintaining the surface residue. These include decreased cone index directly beneath the row, decreased surface bulk density, increased moisture content, decreased energy usage, and increased yields.

The positive effects of controlling traffic were significant only when in-row subsoiling was not used as an annual tillage treatment. Although differences existed beneath the row middles where traffic occurred, it did not have a large effect on soil condition directly beneath the row. The strip-tillage (SS+P) treatment was especially capable of withstanding the negative effects of traffic. When annual in-row subsoiling was used and traffic was restricted to row middles throughout the growing season, there was no statistical benefit of completely eliminating traffic.

References

ASAE Standards, 38th Ed. 1991. S313.1. Soil cone penetrometer. St. Joseph, Mich.: ASAE.

Burt, E. C., D. W. Reeves and R. L. Raper. 1992. Energy utilization as affected by traffic in conservation and conventional tillage systems. In *Proc. of the 1992 Beltwide Cotton Conf.*, vol. 3, 1143-1146. Memphis, Tenn.: Nat. Cotton Council of Am.

Campbell, R. B., D. C. Reicosky and C. W. Doty. 1974. Physical properties and tillage of Paleudults in the southeastern Coastal Plains. *J. of Soil and Water Cons.* (September-October): 220-227.

Carter, L. M. 1985. Wheel traffic is costly. *Transactions of the ASAE* 28(2):430-434.

Carter, L. M., B. D. Meek and E. A. Rechel. 1989. Cone index and cotton zone production systems. ASAE Paper No. 89-1542. St. Joseph, Mich.: ASAE.

Cooper, A. W., A. C. Trouse and W. T. Dumas. 1969. Controlled traffic in row crop production. In *Proc. of the 7th Int. Congress of Agric. Eng.*, 1-6, Baden-Baden, West Germany, Theme 1.
Dumas, W. T., A. C. Trouse, L. A. Smith, F. A. Kummer and W. R. Gill. 1973. Development and evaluation of tillage and other cultural practices in a controlled traffic system for cotton in the southern Coastal Plains. *Transactions of the ASAE* 16(5):872-876.
Garner, T. H., W. R. Reynolds, H. L. Musen, G. E. Miles, J. W. Davis, D. Wolf and U. M. Peiper. 1984. Energy requirement for subsoiling Costal Plain soils. ASAE Paper No. 84-1025. St. Joseph, Mich.: ASAE.
McConnell, J. S., B. S. Frizzell and M. H. Wilkerson. 1989. Effects of soil compaction and subsoil tillage of two alfisols on the growth and yield of cotton. *J. Prod. Agric.* 2(2):140-146.
Monroe, G. E. and E. C. Burt. 1989. Wide frame tractive vehicle for controlled-traffic research. *Applied Engeering in Agriculture* 5(1):40-43.
Mullins, G. L., D. W. Reeves, C. H. Burmester and H. H. Bryant. Effect of subsoiling and the deep placement of K on root growth and soil water depletion by cotton. In *Proc. of the 1992 Beltwide Cotton Conf.*, Vol. 3, 1134-1138. Memphis, Tenn.: Nat. Cotton Council of Am.
Reeves, D. W., C. B. Elkins, H. H. Rogers, J. B. Powell and S. A. Prior. 1989. Controlled traffic research with a wide frame spanner for cotton double-cropped with wheat. In *Proc. of the 1989 Beltwide Cotton Conf.*, 519-522. Memphis, Tenn.: Nat. Cotton Council of Am.
Reid, J. T. 1978. A comparison of the energy input of some tillage tools. ASAE Paper No. 78-1039. St. Joseph, Mich.: ASAE.
Taylor, H. M. and H. R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. *Soil Sci.* 96(3):153-156.
Torbert, H. A. and D. W. Reeves. 1991. Tillage and traffic effect on cotton yield and N requirement. In *Proc. of the 1991 Beltwide Cotton Conf.*, 931-935. Memphis, Tenn.: Nat. Cotton Council of Am.
Williford, J. R. 1980. A controlled-traffic system for cotton production. *Transactions of the ASAE* 23(1):65-70.