Soil and Plant Response to Three Subsoiling Implements

W. J. Busscher,* D. L. Karlen, R. E. Sojka, and K. P. Burnham

ABSTRACT

Many Southeastern Coastal Plain soils require deep (>0.45 m) inrow tillage or subsoiling to disrupt dense tillage/traffic pans and/or eluvial (E) horizons. Three subsoiling implements [Super Seeder (SS), ParaTill (PT), and Kelly (KE)] were compared on Norfolk (Typic Paleudult) loamy sand to assess their effectiveness in developing and maintaining a proper rooting environment for corn (*Zea mays* L.). Soil strength (cone index) for the implements was evaluated with and without conventional surface tillage (disking). All three subsoiling implements effectively disrupted the E horizon regardless of surface tillage, but the 67% stand establishment in nondisked treatments was significantly lower than for disked treatments (92%). However, yields were not significantly different. Significant differences in soil strength were measured among subsoiling implements at the beginning of each growing season. In 1985 mean profile soil strength was lower ($P \leq 0.10$) for SS and PT than for KE. In 1986, soil strength was lower ($P \leq 0.10$) for SS than either PT or KE. The consistent difference between SS and KE occurred because SS disrupted a larger area than the thinner-shanked KE. Nondisked treatments had mean soil strength that was 0.32 MPa lower within the row than disked treatments, but disked treatments had mean soil strength that was 0.37 MPa lower between the rows. Soil strength results suggest that Coastal Plain soils, which have been subsoiled, are less likely to restrict root development regardless of implement with, or without, prior surface tillage.

***Additional Index Words: Zea Mays* L., Corn, Soil strength, Minimum tillage, Deep tillage, Soil compaction.**

Root-restricting strength of shallow subsoil layers has prevented proper utilization of soil water and nutrients in the Southeastern Coastal Plains (Campbell et al., 1974). Deep profile disruption, usually in the form of subsoiling, promotes penetration of roots into and below the restricting zone primarily by loosening the soil (Campbell et al., 1974; Trouse and Reaves, 1980; Box and Langdale, 1984). Increased yields have been attributed to deep disruption that increases root exploration (Gerard et at., 1982; Ide et al., 1984; Peterson et al., 1984). To maintain profitable yields, any management system, even conservation tillage, needs some sort of deep disruption on at least a biennial and very likely on an annual basis (Busscher and Sojka, 1987).

Corn yields have often been lower with minimum surface tillage treatments than with conventionally disked treatments (Karlen and Sojka, 1985). Karlen and Sojka attributed this to erratic germination and seedling emergence. They are unsure, however, whether this was a result of land preparation, soil characteristics, or a combination of the two.

Several subsoiling implements are now commercially available for use in either minimum or conventional surface tillage. Though specific strengths for root penetration have been studied (Taylor et al., 1966; Vepraskas et al. 1986), the effect of specific implements in loosening subsurface horizons, encouraging germination, achieving stand establishment, and maintaining penetrability for root growth throughout the growing season has not been assessed. In this study, it was hypothesized that measurably different mechanical impedance profiles result from the range of currently available subsoiling implements and that these profiles may differ with surface tillage treatment. Three different subsoiling implements along with their associated presswheels, strip tillers, etc. were evaluated with and without surface tillage (disking) and compared to determine their relative ability to provide a seedbed and a soil profile with strength that is a suitable rooting environment for corn.

MATERIALS AND METHODS

This field study was conducted in the spring and summer of 1985 and 1986 on a Norfolk loamy sand soil (fine, loamy, siliceous, thermic, Typic Paleudult) located at the Pee Dee Research and Education Center of Clemson University near Florence, SC. The experimental field design was split plot with the three subsoiling implements randomly split within the two surface tillage treatments. Whole plots, which were approximately 26 by 46 m, were split into two surface tillage treatments (conventional and minimum tillage) described below. Subsoiling implements were evaluated in subplots that were 4.6 by 26 m. Since this did not use the entire plot, the remainder was planted by the Superseeder[1] in the manner described below. Neighboring sets of plots that were in a corn-soybean (*Glycine max*) rotation were used in 1985 and 1986. Measurements were made in the corn plots. Soybean stubble had been left in the field for the winter prior

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[1] 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.

to planting corn (Dekalb-Pfizer T1100 in 1985 and Dekalb-Pfizer 748 in 1986) in 0.76-m rows at a population of approximately 56 800 plants ha $^{-1}$ on 29 Mar. 1985 and 1 Apr. 1986. Treatment 1, the conventional surface tillage treatment, was disked twice and leveled with a tined field cultivator with rolling baskets within 2 weeks of the combined subsoiling and planting operation. Treatment 2, the minimum surface tillage treatment, was deep-till planted through the soybean stubble. After planting, all treatments were sprayed with 2.2 kg a.i. ha $^{-1}$ alachlor [2-chloro-2′-6′-diethyl-*N*-(methyoxymethyl) acetanilide] and 1.7 kg a.i. ha $^{-1}$ atrazine [2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine] for residual weed control. In the same operation, Treatment 2 was also sprayed with Paraquat [1.1′-dimethyl-4,4′-bipyridium] to kill green vegetation.

All three subsoiling implements combined the deep tillage and planting operations. The in-row subsoiling shank design, presswheels, and strip tillers are described as:

1. The Brown-Harden Superseeder (Brown Manufacturing Corp., Ozark, AL) (SS) which has a 50-mm wide subsoil shank angled forward nonparabolically with a 73-mm wide shoe and strip tiller at the side of each shank in the form of fluted cutting coulters.
2. The Tye Paratill (The Tye Co., Lockney, TX) (PT) which has a serrated coulter followed by a leg 25-mm wide, a 0.94-m beam to ground clearance, and a 45° bend (left row to right and right row to left) 0.685 m from the beam. The points are 0.76-m apart and 64-mm wide. Legs of the PT are 0.254 m and have an adjustable shatter plate just above and behind the point to provide lifting of the soil. In 1986, an ACRA Cyclo 800 trash whipper (ACRA-Plant Sales Inc., Garden City, KS) was included to provide in row tillage.
3. The Kelly No-till System (Kelly Manufacturing Co., Tifton, GA) (KE) which has a 45° forward-angled subsoil shank 32-mm wide with a 32-mm point following a 0.508-m serrated, adjustable, spring tension coulter. This is followed by a twin, fixed-tilt, adjustable angle 4:00 by 8 pneumatic rubber tire to squeeze the walls of the ripper slot and form a smooth level seedbed for the planter unit.

These three implements were used because of the difference in width of the subsoil shanks between the SS and KE and because of the new design of the PT. For all of the subsoilers, John Deere Flex-71 type planters (Deere & Co., Moline, IL) were used in 1985 and Case-IH 800 Early Riser planters (Case-IH, Racine, WI) in 1986. In both years, tension was adjusted to provide a 4-cm constant seeding depth.

Soil strength readings (cone indices) were taken for four replicates on 1 and 2 Apr. 1985 and 3 Apr. 1986 just after planting and on 15 and 16 Aug. 1985 and 5 to 8 Aug. 1986 just before harvest. Measurements were taken with a 13-mm

Table 1. The analysis of variance for soil strength (cone index) with a split plot design for the surface tillage treatment (surf) and subsoiling implements (subs).†

Source	df	Date 4/85	8/85	4/86	8/86
Surf	1	***		***	
Rep	3	*			
Surf × rep (error 1)	3				
Subs	2	**		**	*
Subs × surf	2				
Rep (subs × surf) (error 2)	12				
Position²	1	**	*	**	**
Depth	1	**	**	**	**
Position² + depth	1		*	***	**
Depth × surf	1	*	**	**	*
Depth × subs	2	*		**	**
Position² × surf	1				
Position² × subs	2				**
Total number of samples	5304				

*,**,*** Significantly different at the 0.05, 0.01, and 0.10 levels, respectively.

† Depth into the soil and position across the rows were treated as continuous variables.

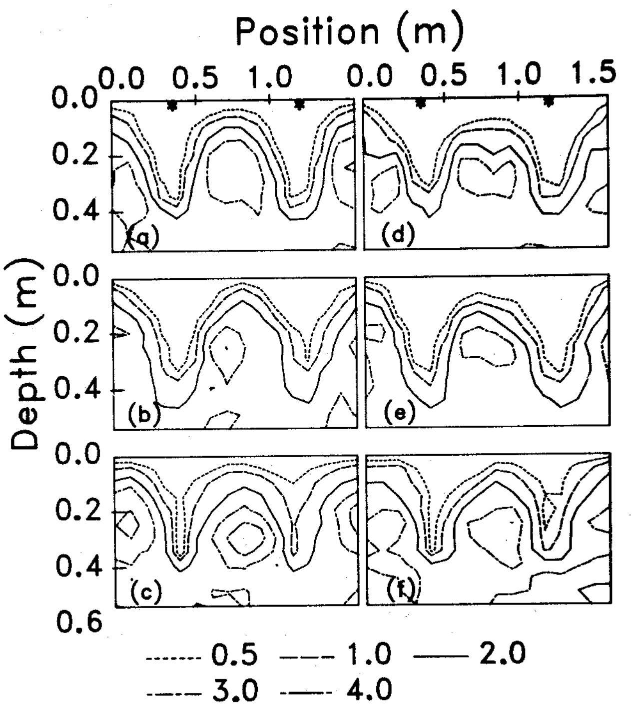

Fig. 1. Cross sectional view of the soil strength patterns for SS (a), PT (b), and KE (c) of the minimum surface tillage treatment and the SS (d), PT (e), and KE (f) of the conventional surface tillage treatment for April 1985. Each diagram is the average of four replicates. The asterisks show the positions of the rows.

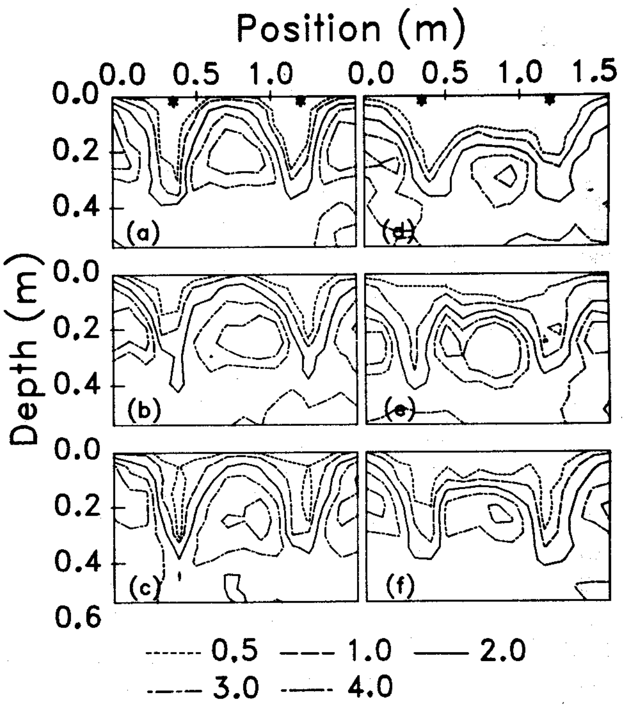

Fig. 2. Cross sectional view of the soil strength patterns for SS (a), PT (b), and KE (c) of the minimum surface tillage treatments and the SS (d), PT (e), and KE (f) of the conventional surface tillage treatment for April 1986. Each diagram is the average of four replicates. The asterisks show the positions of the rows.

Table 2. Mean soil profile strengths for each of the implements at both dates of sampling and for both conventional (Conv) and minimum (Min) tillage.

Date	Surface tillage	Subsoiler soil strength SS	PT	KE	Mean
		MPa			
Apr. 1985	Conv	1.69	1.63	2.08	1.80b†
	Min	1.87	1.81	2.16	1.95a
	Mean	1.78b	1.72b	2.12a	
Aug. 1985	Conv	2.19	2.15	2.46	2.27a
	Min	2.05	2.12	2.02	2.06a
	Mean	2.12a	2.14a	2.24a	
Apr. 1986	Conv	2.06	2.41	2.16	2.21b
	Min	2.40	2.52	2.52	2.48a
	Mean	2.23b	2.47a	2.34a	
Aug. 1986	Conv	3.10	3.65	3.95	3.57a
	Min	4.39	3.86	4.35	4.20a
	Mean	3.74b	3.76ab	4.15a	

† Data for each date was analyzed separately. Means with the same letter are not significantly different.

diam, 30° cone tip, hand-operated, analogue recording penetrometer similar to that of Carter (1967). Soil strength was measured to a depth of 0.6 m at 0.05-m depth increments at width intervals of 0.1 m across two planted rows. At each width interval, three probings were taken to be averaged. Data were then entered into the computer using the method of Busscher et al. (1986b). Data consisted of cone indices for the two surface tillage treatments split by the three subsoiling implements for 13 depths at 17 positions across the two rows. Before analysis, the cone indices were log transformed as suggested by Cassel and Nelson (1979).

Soil strength was statistically modeled using both the general linear models procedure (GLM) and the regression procedure (REG) of SAS. Table 1 lists the design for GLM. A separate GLM was performed for each date of measurement. Since strength was not expected to vary linearly with position, see Fig. 1 and 2, position squared was used in the GLM procedure. Significance up to and including the 10% level was considered.

For the regression procedure a formula was developed to model the strength as a function of depth into the soil and position across the rows using the two rows as duplicate readings. The regression formula included the first four orders of the depth and position and the first and second order interaction terms. A regression was performed for each subsoiling implement of each surface tillage treatment of each date of measurement and for selected combinations. This permits a comparison of the selected combinations of profiles for the surface tillage treatments and/or subsoiling implements. Significance was determined by calculating an F statistic from the error mean squares of the selected combinations and the appropriate individual treatments as shown in Draper and Smith (1966). A 10% level of significance was used with the Bonferroni adjustment for multiple comparison procedures (Draper and Smith, 1966). Individual comparisons were not made if the treatments were not statistically significantly different in the GLM table.

The regression procedure basically simulates the strength as a function of the position and depth and compares the simulations. If the simulations significantly describe the data (as they do in all of these cases), a simple F statistic can be calculated from the mean squares and degrees of freedom (Draper and Smith, 1966) reported in the REG procedure which describes the fit. Since there was an abundance of samples (5304), there was not a problem with degrees of freedom. The Bonferroni adjustment for multiple comparisons in this case essentially divides the significance by 100. To achieve a 0.10 level of significance a 0.001 table must be used.

Table 3. Monthly rainfall for 1985 and rainfall and irrigation for 1986.

Month	1985 Rain	1986 Rain	1986 Irr
	mm		
Apr.	15.2	7.6	33.0
May	66.0	35.6	91.4
June	132.1	19.1	137.2
July	135.9	52.1	124.5
Aug.	158.8	141.0	–

In the GLM and REG procedures, for mechanical impedance of the subsoiling implements to be statistically similar they would have both similar strengths and similar patterns of disruption. One does not preclude the other. For example, although the strength averages of the SS and KE with conventional tillage in 1986 are similar, see Table 2, their differences lie in the patterns of shattering of the soil produced by the two implements (Fig. 2).

Gravimetric soil water contents were taken at 0.1-m depth intervals for treatments on all sampling dates. A simple analysis of variance at the 5% level using GLM was used for analysis of the data. In 1986, South Carolina experienced its driest year on record. Supplemental watering, see Table 3, was used on the plots to preserve the study.

Residue cover of all plots was measured one week after planting using the Line Transect Method of Laflen et al. (1981). These measurements were made to quantify differences observed in the amount of surface disturbance caused by the various subsoiling implements.

Stand establishment was determined by counting plants that had emerged after 21 d in 60 m of row within each plot. There was no indication of disease or insect damage. The counted numbers were divided by the expected number of plants. Yield was determined by harvesting the middle two rows with a mechanized, computer-assisted plot combine. Moisture was determined from a 0.25-kg subsample from each plot with a Steinlite moisture meter used to correct calculated yields to a water content of 155 g kg^{-1}. Data from plant sampling was analyzed using simple analysis of variance and a 5% level of significance.

RESULTS

Strength differences between the surface tillage treatments ($P \leq 0.1$) and among the subsoiling implements ($P \leq 0.01$) were significantly different at the beginning of the growing season for both 1985 and 1986. At the end of the season there were no differences between the surface tillage treatments and no difference in 1985 and reduced difference ($P \leq 0.05$) in 1986 among the subsoiling implements, see Table 1.

When analyzed by the REG procedure, soil strength for all subsoiling implements combined increased significantly during the 1985 and 1986 growing seasons by an average of 0.29 MPa and 1.54 MPa, respectively. When analyzed by the REG procedure on an implement by implement basis, all showed an increase in strength except for the minimum-tilled Kelly unit in 1985, see Tables 2 and 4. Although the Kelly had one of the smallest F values, it showed a significant decrease. This is an anomaly since there was no tillage in the plots throughout the season and no other factors were identified which could reduce the strength.

As shown in Tables 1 and 2, soil strength for the conventional surface tillage treatment was signifi-

Table 4. *F* values for comparison of strengths of the subsoiling implements, individually and combined, between the two sampling dates of each season.

Year	Surface tillage	*F* values for subsoiler			
		SS	PT	KE	All 3
1985	Conv	22.6†	29.1	7.4	4.8
	Min	24.0	22.1	4.3	5.1
1986	Conv	9.7	15.2	18.3	43.9
	Min	22.1	18.0	16.4	45.1

† A significant *F* value ($P \leq 0.10$) is greater than or equal to 2.7.

cantly lower ($P \leq 0.10$), than that for the minimum tillage treatment for April of both 1985 and 1986. Strength differences would be at least partially due to differences in disruption. This is not surprising since the conventional tillage treatment is disked as well as subsoiled, and the disk pan is broken up by the subsoiler (Fig. 1 and 2). The difference could also be due partially to a difference in soil water content. In 1985, soil water in the conventional tillage treatment averaged 2.4% more water on a dry weight basis than in the minimum tillage treatment ($P \leq 0.05$). In 1986, water was also different although not significantly. The soil-water difference (1.8% more for the conventional surface tillage system) was less than in 1985, although the strength difference between the conventional and minimum surface tillage treatments was greater in 1986 than in 1985. This indicates that not all of the difference in strength could be due to water content differences. In August, conventional vs. minimum surface tillage did not differ significantly.

Soil profile strengths for subsoiling implements were different ($P \leq 0.01$) except for SS and PT with conventional tillage in 1985, the PT and KE with conventional tillage in 1986. In August, soil strength of the implements were not significantly different except for the SS and KE in 1986. This is not surprising since KE has a thinner subsoiling shank and disrupts a thinner zone of soil (Fig. 1 and 2).

A simple analysis of variance showed no significant difference among the moisture contents at the 5% level for conventional vs. minimum surface tillage treatments in 1986 or the August sampling dates in 1985. The moisture content of the conventional tillage treatment was significantly higher than the minimum tillage treatment (11.8% vs. 9.4%) in April 1985. On both

Table 6. Percent stand establishment and yield for the subsoiling implements in both the conventional and minimum surface tillage treatments.

Year	Residue mgmt.	Stand for implement type			
		SS	PT	KE	Mean
		%			
1985	Conv	103†	88	89	93
	Min	91	58	85	78
1986	Conv	85‡	89	96	90
	Min	38	64	65	56
		Mg ha^{-1}			
1985	Conv	6.53	5.83	6.03	6.13
	Min	5.54	5.24	6.22	5.67
1986	Conv	5.84	5.52	4.40	5.25
	Min	5.42	5.91	4.58	5.30

† LSD (0.05) is 9. A stand establishment > 100% compared to the targeted stand is the result of seed double drops.
‡ LSD (0.05) is 3.

Table 5. Mean soybean residue cover for conventional tillage treatments and for each of the tillage implements in minimum tillage treatments.

Implement	Residue cover for the years	
	1985	1986
	%	
Conv	5.8a†	3.5a
SS	73.4b	73.2c
KE	76.0b	81.1c
PT	83.1c	50.4b

† Grouped by Duncan's test ($P \leq 0.05$) for each year separately. Means with the same letter are not significantly different.

dates in 1985, the soil was at or near field capacity since there was no crop actively transpiring and both followed periods of relative wetness.

Residue cover was used as an indicator of the level of surface disturbance or seedbed preparation. Residue cover was 73% for the conventional surface tillage treatment vs. 5% for the minimum tillage treatments (Table 5). The lower value for the PT in 1986 is a result of the trash whipper that was used to provide a seedbed. Since 1986 was such a hot, dry year, no implication of its effect was attempted.

Plant stand establishment (Table 6) was 67% for the minimum surface tillage treatments which is lower ($P \leq 0.05$) than the 92% achieved in conventional tillage treatment. Differences in yield were not significant.

DISCUSSION

Zones of significantly different strengths ($P \leq 0.02$) were found between the conventional and minimum surface tillage treatments for each of the subsoiling implements, see Table 7. Lower strengths for minimum tillage were found in-row for SS and 0.1 to the right of the targeted row position for PT and KE.

These differences were plotted in Figure 3. They show the higher strengths between the rows for the minimum surface tillage treatment but lower strengths below the rows. This is a definite advantage for the minimum tillage treatment since the roots would be able to penetrate the restrictive horizon easier and proliferate in the B horizon. The B horizon is higher in clay content and higher in water holding capacity than the A_1 or E (Campbell et al. 1974). The advantage for conventional tillage treatment, however, is that the surface soil horizon will provide a more uniform root medium.

Table 7. Strength differences (conventional minus minimum surface tillage) for in-row and mid-row locations from the combined data of April 1985 and April 1986.†

Implement	Row position	Difference, MPa
SS	Mid-row	−0.539*
	In-row	0.189*
PT	Mid-row	−0.112‡
	In-row	0.517*
KE	Mid-row	−0.460*
	In-row	0.244*

* Statistically significant at the 0.02 level.
† PT and KE "in-row" differences were 0.1 m to the right of the targeted row position.
‡ Not statistically significant.

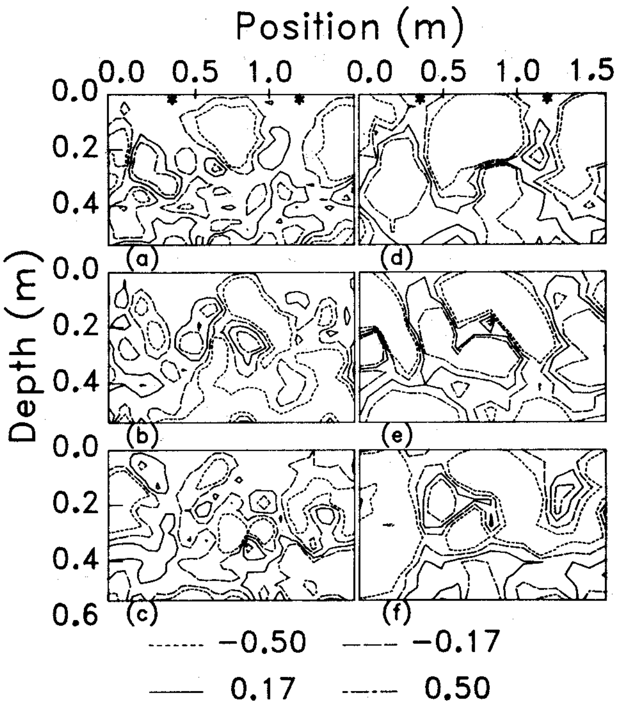

Fig. 3. Cross sectional view of the difference (conventional minus minimum surface tillage treatment) of the soil strength patterns for SS (a), PT (b), and KE (c) in April 1985 and the SS (d), PT (e), and KE (f) April 1986. Each diagram is the average of four replicates. The asterisks show the positions of the rows.

Figures 1 and 2 shows lower strengths for the conventional surface tillage treatment within the top 0.1 m of the profile. In a year of evenly-spaced and adequate rainfall distribution, roots could proliferate in the upper part of the profile and support plant growth (Karlen and Sojka, 1985). However, because this zone is shallow (about 0.2 m) and the soil is sandy and low (4 to 10% on a dry weight basis) in available water-holding capacity (Campbell et al. 1974), it is unlikely that the plants can be productive without deep profile disruption.

Although there was no significant interaction between surface tillage treatment and subsoiling implement (see Table 1), it is interesting to note that the April mean profile strengths of each of the subsoiling implements for the conventional tillage treatment were lower than for the minimum tillage treatment.

The decrease in significance of the effects of the surface tillage and subsoiling implement, as seen in Table 1, and the increase in strength over the growing season, as shown in Table 2, indicate that the different treatments are probably reconsolidating or settling to a common profile. This partially substantiates the need for annually subsoiling to maintain a proper growth medium (Busscher et al., 1986a).

The significantly poorer stand establishment of the minimum surface tillage treatment is at least partially caused by lack of seedbed preparation and, therefore, poor seed-soil contact (Karlen and Sojka, 1985). Despite this, yield differences were not significant. Neither the subsoiling component nor an interaction between the surface tillage and the subsoiling implement appears to be causing the lower yields for this soil under minimum tillage. This was partially confirmed by failure to obtain statistical significance for yield differences for subsoiling implement or the interaction between surface tillage and subsoiling implement. Therefore, no one implement significantly and consistently yielded better for either of the surface tillage treatments.

Although results can be expected to vary with soil type and may have varying economic impact in different cropping systems, in this study the SS provided a larger area of disruption of the profile and a lower overall soil strength than the KE for both the conventional and minimum surface tillage treatments. The KE provided a narrower area of disruption but of comparable strength. The advantage of the larger area of shattering would be a larger area for the roots to explore and penetrate through to the softer subsoil. The advantage of the smaller area is a lower power requirement for the pulling tractor and, therefore, a lower energy cost. Each can have a significant economic impact. If the narrow disruption is deep enough and subsoil strengths are not limiting, it will provide a path for the roots to explore the deeper horizons (Elkins and Hendrick, 1983; Campbell et al., 1984).

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