Residual Effects of Deep Tillage vs. No-Till on Corn Root Growth and Grain Yield

M. J. Vepraskas,* W. J. Busscher, and J. H. Edwards

Tillage pans occur in many coarse-textured soils and must be ripped by a form of deep tillage to maximize yields. This study compared the longevity of slits produced by subsoiling and slit-till (both to 16 in.) to a no-till treatment, and related slit longevity to corn (*Zea mays* L.) grain yield and root development. The soil was a Typic Kandiudult with a tillage pan. Both deep tillage treatments were last performed in 1989; this study was conducted from 1990 through 1992. Roots were examined at tasselling each year, and in 1992 thin sections were examined to determine the effects of the tillage slits on root penetration. Corn grain yields were not significantly different among the three tillage treatments in any of the 3 yr. Concentrations of roots in soil profiles did not differ significantly among treatments and roots extended to depths >40 in. Root observations indicated that the tillage slits affected root development 2 yr after tillage was performed. Residual effects of both subsoiling and slit-tillage on root growth could be seen for up to 2 yr after tillage was imposed, but the effects were gone by the third year. The residual effects of tillage did not affect yield in any year.

In the southeastern USA, compact soil layers have formed beneath the Ap horizons or plow layers of many agricultural fields having coarse-textured soils (Naderman, 1985). The pans have few or no macropores for roots to grow through, and when dry the pans develop a high mechanical impedance (soil strength) that slows root growth through them (Campbell et al., 1974). As a result, roots are concentrated in the Ap horizons early in the growing season. During dry years, yields are especially low on these soils because the Ap horizons hold little plant-available water (Kamprath et al., 1979).

Farmers managing soils with tillage pans frequently use a form of deep tillage to cut slits in the pans that will enable roots to grow through the pans quickly. Subsoilers, the most common type of plow used for deep tillage, cut slits that are approximately 3 in. (8 cm) wide to a depth of 16 in. (40 cm). Subsoiling has increased yields of corn, soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L.), and tobacco (*Nicotiana tabacum* L.) during dry years, and is an economical form of tillage for these soils (Vepraskas and Guthrie, 1992). The subsoiler slits collapse over time, and currently it is recommended that subsoiling be done every year to maximize its benefits (Naderman, 1985).

When fine-textured B horizons lie within 16 in. (40 cm) of the surface, the subsoiler shank will usually bring clods of this horizon to the surface. These B horizon clods tend to be acidic and will lower topsoil pH values. In addition, if subsoiling is done when soils are excessively dry, large clods brought into the topsoil can result in a poor seedbed and retard or prevent germination of seeds due to poor seed-soil contact.

It has been hypothesized that such problems with subsoiling could be overcome by cutting a very thin (0.1 in.) slit through the tillage pan using a blade rather than a curved shank (Elkins and Hendricks, 1983). The blade would not bring up subsoil material, and the slits may persist longer than those cut by a subsoiler, because they would not fill-in as quickly. Whitely and Dexter (1982) showed that slits made by knife blades are effective in increasing root penetration into the subsoil when compared with soil loosened by tines of more conventional tillage implements. Deep tillage with a thin blade has been termed slit-tillage (Elkins and Hendricks, 1983).

Karlen et al. (1991) compared the effects of slit-tillage, subsoiling, and no-tillage on sorghum [*Sorghum bicolor* (L.) Moench] grain yield over 3 yr on a soil having a tillage pan. The average grain yields over the study period were 50, 46, and 39 bu/acre (3136, 2885, and 2446 kg/ha) for the slit-till, subsoiled, and no-till treatments. They observed that the slit-till slits remained open for more than 1 yr and roots could grow along them as with subsoiler slits. Roots in the no-till treatment were generally confined to the Ap horizon, presumably because they could not penetrate the tillage pan. These results suggested that slit-tillage would be a suitable alternative to subsoiling in these coarse-textured soils.

The objective of this study was to determine the longevity of deep-tillage slits by comparing corn grain yields and root concentrations among a no-till treatment and two deep-tillage treatments (slit-till and subsoiled) for periods of 1, 2, and 3 yr after deep tillage had been performed.

MATERIALS AND METHODS

A 3-yr tillage study was conducted from 1990 through 1992 on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult) at the USDA Coastal Plains Soil and Water Conservation Research Center in Florence, SC. The four-acre (1.6 ha) field was the same one used by Karlen et al. (1991), who imposed all tillage treatments. The site was selected originally because it had a tillage pan below a loamy sand Ap horizon. Subsoiling was considered the best conventional tillage practice for this type of soil because it could break the pan.

From 1986 through 1989, the field was tilled using three tillage treatments arranged in a randomized complete block design with four replications. The tillage treatments

Dep. of Soil Science, North Carolina State Univ., Raleigh, NC 27695; W.J. Busscher, USDA-ARS, Coastal Plains Soil and Water Conserv. Res. Cent., Florence, SC 29502-3039; and J.H. Edwards, USDA-ARS, Auburn Univ., Auburn, AL 36831-0792. Joint contribution from the NC Agric. Exp. Stn. and USDA-ARS. Received 9 Sep. 1994. *Corresponding author (michael_vepraskas@ncsu.edu).

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Table 1. Data for rainfall, corn grain yield, and root concentrations both in the profile and near deep tillage slits for the slit-till, subsoiled, and no-till treatments. Treatments were last tilled in 1989.

Treatment	1990	1991	1992
	June plus July rainfall, in.		
	4.8	11.1	7.7
	Grain yield, bu/acre		
Slit-till	25.5	111	112
Subsoiled	26.4	120	103
No-till	29.1	120	116
Pr > F	NS†	NS	NS
	Profile root concentration, root/sq in.		
Slit-till	0.65	0.91	0.33
Subsoiled	0.78	1.30	0.33
No-till	0.65	1.11	0.33
Pr > F	NS	NS	NS
	Root concentration near slit, root/sq in.		
Slit-till	--‡	3.71	--
Subsoiled	--	3.12	--
No-till	--	0.65	--
Pr > F		0.01	

† NS indicates that the probability of finding a greater F value was > 0.10.
‡ Dash means data were not determined.

were: (i) subsoiling to a depth of 16 in. (40 cm) with a forward-angled, straight subsoil shank; (ii) subsoiling to a depth of 12 in. (30 cm) while cutting a 0.1 in. (3 mm) wide slit from depths of 12 in. to 16 in.; and (iii) no-tillage. Plots were 60 ft (18 m) long and consisted of four rows spaced 30 in. (76 cm) apart. Beginning in 1986, all experimental treatments were repeated on the same plots each year. No surface tillage was used from 1986 through 1992. Weeds were controlled using preplant applications of glyphosate or a mixture of Gramoxone[1] and alachlor. Rainfall was measured daily at the site by a recording rain gauge.

From 1990 through 1992, corn ('Pioneer 3165') was planted no-till into all plots with seeds spaced approximately 8 in. (20 cm) apart along the plant row. Rows were placed within 12 in. (30 cm) of the deep tillage slits each year. Planting occurred between 26 March and 2 April for each of the 3 yr. Following planting, P and K were broadcast over the field at a rate that conformed to soil test recommendations. When plants were approximately 20 in. (50 cm) tall, a solution of urea ammonium nitrate was banded approximately 6 in. (15 cm) from each row at a rate of 121 lb N/acre (135 kg N/ha).

At tasselling, pits were dug in each replicate plot of both sites using a backhoe. Pits were positioned to be perpendicular to a row and were dug to a depth of 60 in. (1.5 m). Root distributions were determined for each plot using the trench-profile method (Vepraskas and Hoyt, 1988). One pit wall that was perpendicular to the row was smoothed until it was 6 in. (15 cm) from the plant stalk. A 40- by 40-in. (102 by 102 cm) grid consisting of 100 4- by 4-in. (0.1 by 0.1 m) squares was placed on the smoothed pit wall. The grid was positioned so that its top was even with the soil surface and its center was below the plant row. Approximately 1 in. (25 mm) of soil was scraped out of each grid square with an awl to expose roots. Roots were counted by assigning one count for each live main root and one count for each live branch root appearing in each square.

In 1991, undisturbed blocks were collected from each plot to determine the numbers of roots entering the slits. The blocks were 6 in. (15 cm) long, 4 in. (11 cm) wide, and 2 in. (6 cm) deep and were encased in aluminum boxes having these dimensions. These samples were collected at a depth of 12 to 18 in. (30 to 45 cm) after roots were described. In the subsoiled and slit-till treatments the blocks included the tillage slits, whereas in the no-till treatment the blocks were collected below the row. Samples were collected by forming a horizontal shelf at the base of the Ap horizon, and then cutting out a block of soil with a knife while slowly sliding the aluminum box over the block as it was gradually exposed by cutting. Samples were wrapped in aluminum foil to preserve moisture.

In the lab, the soil water was removed by an acetone exchange procedure which saturated the soil pores with acetone as water diffused out of the soil (Murphy, 1986). After water was removed, samples were impregnated with an unsaturated polyester resin diluted in acetone. The samples hardened in about 6 wk. Two thin sections were made from each soil block following standard procedures (Murphy, 1986). Each thin section was approximately 2 by 3 in. (6 by 8 cm), and the two thin sections from a block were oriented to lie side by side in the block. Roots were counted by examining each thin section under a

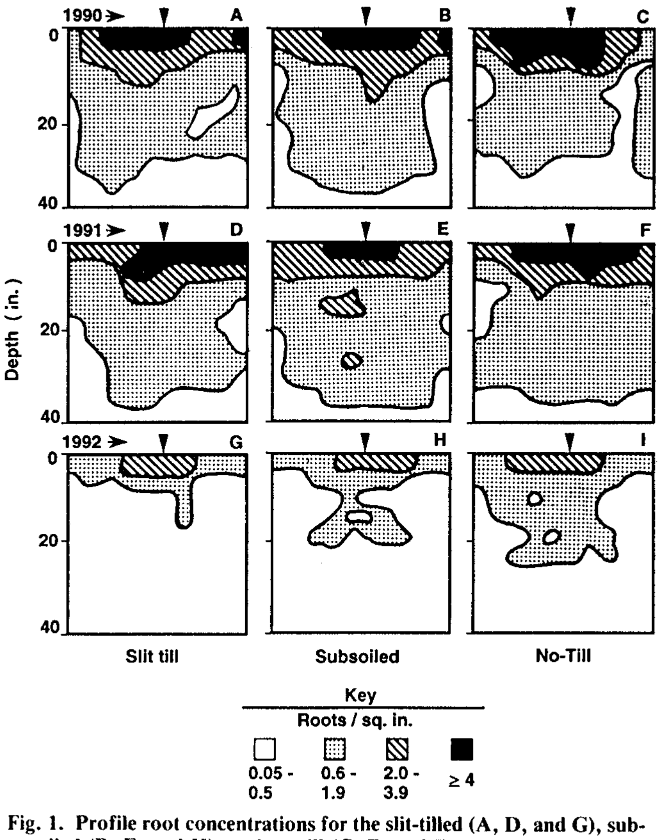

Fig. 1. Profile root concentrations for the slit-tilled (A, D, and G), subsoiled (B, E, and H), and no-till (C, F, and I) treatments for 1990, 1991, and 1992. Deep-tillage was last performed in 1989. Data are means of four replicates. Arrows indicate rows. Plots were 40 in. wide.

[1] The use of trade names in this publication does not imply endorsement by the North Carolina Agric. Res. Serv. or USDA-ARS of the product named, nor criticism of similar ones not mentioned.

microscope with a magnification of 200X. The smallest roots that could be observed at this magnification had a diameter of 0.007 in. (0.18 mm).

On the same day roots were counted by the trench-profile method, undisturbed cores were collected from major horizons from each plot of all three treatments. Samples were collected in cylindrical metal rings (3 in. high by 3 in. diam.) at depths of 6 to 12, 12 to 18, and 18 to 24 in. These depths were selected to correspond to the lower Ap, E, and upper B horizons. Samples in the no-till treatment were collected below the plant row. In the subsoiled and slit-till treatments, samples were collected in a vertical line that included the tillage slits in 1990 and 1991. In 1992, the tillage slits could not be easily seen, so the undisturbed cores were collected below the plant row. The cores were oven-dried (220 °F) and bulk density was determined.

Corn grain yield was determined for the center two rows of each plot by combine harvesting when grain moisture was 0.16 lb/lb. Harvesting was done between 11 and 28 September of each year during the 3-yr study. Harvester traffic was confined to the same interrows each year to limit compaction.

Root data, bulk density, and yield were compared among treatments using analysis of variance procedures for a randomized complete block design (SAS Inst., 1985).

RESULTS AND DISCUSSION

Rainfall, grain yield, and root concentrations are shown in Table 1. Rainfall data are presented for June and July, which include the period of silking and tasselling. The 1990 year was abnormally dry, while adequate rainfall occurred during the two other years. Grain yields varied markedly by year and were lowest in 1990. No significant differences ($\alpha = 0.10$) in yield were found among treatments in any year.

Profile root concentrations (Table 1) are the average concentrations of roots observed from the surface to a depth of 40 in. (102 cm), and include roots found within 20 in. (50 cm) on either side of the plant row. While no significant differences in root concentration were found in any year, the subsoiled treatment tended to have higher average concentrations in 1990 and 1991. By 1992, means for profile root concentrations were identical among treatments.

Root concentrations near the slits of the subsoiled and slit-till treatments were significantly greater than for the no-till treatment (Table 1). This indicated that root penetration of the E horizon occurred around the deep-tillage slits for the subsoiled and slit-till treatments, with the roots basically growing toward the slits.

Profile root observations showed that all treatments had roots penetrating to at least 40 in. (102 cm) in each of the 3 yr of observation (Fig. 1). Lateral root distributions were similar among treatments as well. For 1990 and 1991, the effect of the deep tillage slits can be seen by noting the distribution of roots in concentrations of 2.0 to 3.9, and 0.6 to 1.9 roots/sq in. As shown for 1990, roots in these concentrations extended approximately 4 in. (10 cm) deeper than was found for the no-till treatment. In 1991, the differences among treatments were small, but the subsoiled treatment had more roots extending to 24 in. below the plant row than the other treatments. While the effect of the deep tillage slits on root penetration was evident in 1992 for root concentrations of 0.6 to 1.9 roots/sq in., root penetration in the no-till treatment for these concentrations tended to be greater than for the two other treatments. Thus, the beneficial

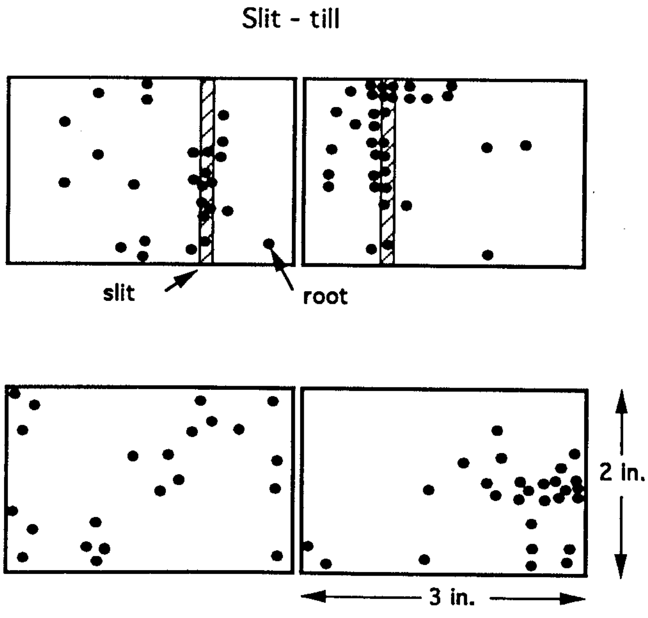

Fig. 2. Distribution of roots found at tasselling in 1991 in the E horizon around the slits made by the slit-till blade and subsoiler. The observations were made from thin sections which were oriented (horizontally, side by side) in the original sample as shown. The gap between sections was produced by the saw used to cut the blocks. Location of the tillage slit is shown for only the slit-till treatment. The subsoiler slit was filled with clods and macropores and extended across both thin sections.

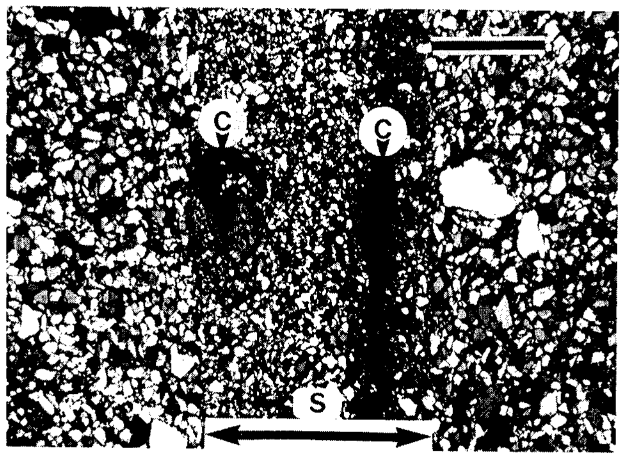

Fig. 3. Micrograph showing how the slit-till slit (S) has filled in with sand in 1991. The original slit was 0.08 in. (2.0 mm) wide and now contains sand that appears to have a smaller diameter than the surrounding material. This suggests the slit filled with sand from an overlying horizon. The black voids are root channels (C) in the slit. The voids are black because the photograph was taken in a petrographic microscope using polarized light and crossed polarizing filters. The scale bar represents 0.04 in.

Table 2. Bulk density values for the Ap, E, and B horizons of each treatment. Samples were collected to include slits produced by the subsoiler or slit-till blade, and for the no-till treatment samples collected below the row.

Treatment	1990			1991			1992		
	Ap	E	B	Ap	E	B	Ap	E	B
	g/cu cm								
Slit-till	1.53	1.59	1.46	1.62	1.64	1.49	1.66	1.74	1.52
Subsoiled	1.56	1.58	1.49	1.59	1.59	1.43	1.71	1.76	1.58
No-till	1.56	1.48	1.45	1.60	1.61	1.45	1.66	1.66	1.59
Prob. > F	NS†	NS	NS	NS	NS	NS	NS	0.02	NS

† NS indicates that the probability of finding a greater F value was > 0.10.

effects of slit-till or subsoiling were best expressed on root development in the first year after tillage was imposed, but were virtually gone by the third year.

Examples of root distributions observed in thin sections from the slits of both deep tillage treatments are shown in Fig. 2 for 1991. In the slit-till treatment, roots tended to be concentrated around the slit, but they were not solely in the slit. In the subsoiled treatment, a single slit was not found. Instead, the slit formed by the subsoiler implement was filled with clods of material from the E and B horizons. Large pores were seen between the clods. Roots tended to be grouped in clusters across the thin sections. The larger area of disturbance created by the subsoiler as compared with the slit-till implement would seem to increase the chance of roots penetrating the tillage pans, but as shown in Fig. 1 and Table 1, there was little difference in root distributions between these two treatments.

All of the slits in the slit-till plots that were visible in thin section were filled in with sand (Fig. 3). The sand appeared to be finer than that in the adjacent soil matrix, and presumably fell into the slit from the overlying Ap horizon. The infilling material contained few large pores, but did not impede roots. Because the slits were not examined in 1991, we can only say that the slits will fill in within 2 yr of their formation, but it may occur within the first year.

Bulk density values are shown in Table 2 for three horizons of each tillage treatment. For a given depth and tillage treatment, bulk density tended to increase over time. There were no significant differences in bulk density among treatments at any depth in 1990 and 1991. In 1992, the no-till treatment had a significantly lower bulk density in the E horizon than the two other treatments, but the bulk density values were within the range commonly found for tillage pans (Vepraskas and Guthrie, 1992).

The high bulk density values found for all treatments in 1992 indicates that compact soil layers had formed in the Ap and E horizons by the third year of this study. The effect of this compaction on root distribution is clearly shown in Fig. 1 where root abundance, both laterally and with depth was less in 1992 than in the preceding years.

The changes in bulk density that occurred over time are related in part to rainfall. The greatest changes in bulk density typically occur when the soils are wet at the time they are trafficked, such as during planting and harvest, which results in compaction (Cassel, 1981). Our bulk density measurements were not made frequently enough to pinpoint which rainfalls resulted in the most compaction, but some general conclusions can be drawn. Because 1990 was a very dry year, little compaction occurred and bulk densities were low in all treatments. Greater rainfall in 1991 and 1992 resulted in wetter soils and increased the likelihood of compaction, which was observed in the form of greater bulk densities in the Ap and E horizons. Had 1990 been a very wet year, it is possible that the bulk densities observed in 1992 would have occurred as early as 1990. The general trend of increasing bulk density across all treatments is believed typical for coarse-textured Coastal Plain soils, and has been observed in previous studies (e.g., Cassel and Nelson, 1985). However, the rate of increase will depend on the amount and distribution of rainfall prior to the time the soils are trafficked.

In summary, this study was done as a follow-up to that of Karlen et al. (1991) who showed that the subsoiling and slit tillage treatments increased sorghum yields as compared with no-till over 3 yr, when the two deep tillage operations were performed every year. Our profile root data and thin section observations showed that the residual effects of subsoiling and slit-tillage on root growth could be seen for about 2 yr, and appeared to virtually disappear by the third year when the soils tended to recompact. We saw that the slits of both deep tillage treatments contained roots each year, but the slits did not significantly affect profile root concentrations. No significant yield increase from deep tillage was found in any of the 3 yr either, even though both wet and dry years were included in the study. Based on the results of this study and those of Karlen et al. (1991), we conclude that the maximum benefit of deep tillage on yield has to occur when subsoiling or slit tillage is done every year. We saw no evidence in this study that deep tillage has any residual effect that benefits yield.

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