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Grain Sorghum Response to Slit-Tillage on Norfolk Loamy Sand

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Slit-tillage may provide a long-term, less energy-intensive method for disrupting dense, root-restrictive soil layers in many Atlantic and Gulf Coastal Plain soils. The objective of field research conducted during 1986, 1987, and 1988, was to evaluate effectiveness of slit-tillage for grain sorghum [*Sorghum bicolor* (L.) Moench] production on a Norfolk (fine-loamy, siliceous, thermic, Typic Paleudult) loamy sand near Florence, SC. Three-year average grain yields for slit-tillage, in-row subsoiling, and no-tillage were 50, 46, and 39 bu/acre, respectively. Soil pits excavated to a depth of 3 ft in 1988 showed plant roots in slits that had been formed in 1986, 1987, and 1988. Another experiment showed that tillage energy requirements for slit-tillage were lower than for conventional subsoil shanks. A two-row slit-tillage implement had a draft of 3930 lb and required 20.1 horsepower per row. The same implement equipped with parabolic subsoil shanks had a draft of 5215 lb and required 26.7 horsepower per row. Slit-tillage appears to be a viable practice for Coastal Plain soils because it forms very small, macropore-like openings through the restrictive layers that are readily filled with plant roots and thus remain open for more than 1 yr. No problems were identified for the technique suggesting that equipment manufacturers may want to consider further development of slit-tillage tools for Coastal Plain soils.

ROOT RESTRICTING tillage pans or dense eluviated (E) horizons often occur in Paleudult and Hapludult soils throughout the Gulf and Atlantic Coastal Plain. Uncontrolled wheel traffic, excessive surface tillage, low organic matter, and relatively poor physical characteristics of these soils all contribute to a soil-compaction problem (Trouse, 1983; Campbell et al., 1974). Compacted soil layers often prevent crops from achieving full yield potential by retarding root growth and limiting the soil volume available to roots for water and plant nutrient uptake. To alleviate soil compaction problems in this region, a deep-tillage technique known as in-row subsoiling often has been integrated into conventional and conservation tillage systems. This practice has been beneficial even with irrigation (Camp et al., 1984) because it increases the soil volume from which plant nutrients susceptible to leaching (N, K, S, and B) can be accumulated. In-row subsoiling must be repeated annually for many soils because the disturbed zones reconsolidate and increase in strength during the growing season (Busscher et al., 1986; Busscher et al., 1988).

Annual in-row subsoiling has been accepted as a necessary practice for many Southeastern soils (Trouse, 1983), but this practice does require a substantial amount of tillage energy (Elkins and Hendrick, 1983; Garner et al., 1987). Alternate, less energy-intensive practices must be developed to alleviate compaction problems in these soils. Slit-tillage (Elkins and Hendrick, 1983) may be suitable. This technique facilitates root exploration into the subsoil by forming very small, macropore-like openings through the restrictive layers that are readily filled with plant roots,

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and thus remain open for more than 1 yr. Less tractor power is required because the volume of soil disturbed by the slit-tillage implement is much smaller.

Slit-tillage has been shown to be effective on soils with tillage or traffic compaction zones at depths of less than 12 in. (Reeves et al., 1988), but it has not been evaluated previously on soils with E horizons located 8 to 16 in. below the soil surface. The objective of this study was to evaluate the effectiveness of slit-tillage for grain sorghum production on a Norfolk loamy sand that has been shown to restrict root exploration to the Ap horizon unless the E horizon is fractured by subsoiling (Campbell et al., 1984).

METHODS AND MATERIALS

A research study was conducted on a 4-acre field of Norfolk loamy sand in 1986, 1987, and 1988 to compare slit-tillage, in-row subsoiling, and no-tillage for grain sorghum. A randomized complete block experimental design with four replicates was used to evaluate tillage treatments that were 4-rows (10 ft) wide and 60 ft long. Data were collected from two center rows. Two border rows were planted between each treatment. Initial soil-test parameters for the site, which had been chemical-fallowed during 1985, are presented in Table 1. Local weather data were recorded with an automated Campbell Scientific[1] weather station located approximately 1200 ft from the plots.

There was no surface tillage in this study, so weeds were killed with a preplant application of glyphosate or Gramoxone and alachlor. Crop and weed residues were subsequently cut with a flail chopper to provide a uniform surface residue height at planting. Fertilizer supplying 50–22–41 lb/acre N–P–K also was broadcast prior to planting.

Grain sorghum (cv. Savannah 5) was planted in 30-in. rows during mid-June with KMC planters (Kelley Manufacturing Co., Tifton, GA) that were attached to a modified Ro-Till (BushHog Inc., Selma, AL) in-row subsoiling implement. Modifications consisted of: (i) a straight, nonparabolic subsoil shank that loosened soil to a depth of approximately 16 in. below the surface (in-row subsoiling); (ii) a shorter, straight, nonparabolic shank that loosened soil to a depth of 12 in. below the surface and then created a very narrow (0.12-in. wide) slit from the 12- to 16-in depth with a blade that was attached to the foot of the shank (slit-tillage) (Elkins and Hendrick, 1983); or (iii) no subsoil shank (no-tillage). Both deep tillage treatments allowed plant roots to reach the B horizon by either loosening or providing a slit through the E horizon. Rows for all treatments were shifted approximately 8 in. to the right (north) each year. For slit-tillage plots, this added a new slit below the row and slits within the root zone from prior years were not destroyed. The slits were formed at a depth of 12 to 16 in., so even if surface tillage (such as disking) were used, slits from prior years would be preserved. Areas disturbed by annual in-row subsoiling extend to the soil surface and have been previously shown to reconsolidate prior to the next growing season (Busscher et al., 1986).

Table 1. Initial soil-test values for a Norfolk loamy sand where slit-tillage, in-row subsoiling, and no-tillage were evaluated.

Sample depth	Water pH	Mehlich I extractable						Organic matter
		P	K	Ca	Mg	Zn	Mn	
in.		lb/acre						%
0–8	6.1	116	92	450	116	2.6	12	1.0
8–16	5.0	40	122	370	92	–	–	–
16–30	5.2	2	144	630	130	–	–	–

For post-emergence weed control, 2.4 pt/acre atrazine plus 1 qt/acre crop oil were applied with approximately 40 gal water/acre when plants were at the three-leaf growth stage. Gramoxone was applied with a KMC shielded sprayer for additional weed control prior to anthesis. Fertilizer supplying 60 lb N/acre was applied in a band approximately 6 in. from each row using a urea-NH_4NO_3-$(NH_4)_2SO_4$ (25S) solution approximately 4 wk after emergence. Whole plant samples were collected approximately 30 d after planting in 1987 and 1988. Uppermost leaf samples were collected at anthesis (50% bloom) each year. Plant samples were dried at 150 °F, ground to pass a 100-mesh screen, and analyzed for N, P, K, Ca, Mg, S, B, Cu, Mn, and Zn at Clemson University's Soil and Plant Analysis Lab to quantify the nutrient status of the plants.

Plant root proliferation for the three tillage treatments was observed and photographed by excavating soil pits that were approximately 3 ft deep, 2 ft wide, and 6 ft long when approximately 50% of the sorghum heads were flowering. One pit was excavated for each tillage treatment each year. In 1986, pits were located adjacent to field replicate four, while in 1987 and 1988 they were located at opposite ends of field replicate three. These observations enabled us to determine the fracture zone associated with in-row subsoiling, to identify macropores created by slit tillage during the year of observation and in prior years, and to observe relative soil volume being explored by the sorghum roots. Grain was harvested with an Almaco (G.W.C. Inc., Nevada, IA) plot combine. A Steinlite Model SS250 electronic meter (Fred Stein Laboratories, Atchison, KS) was used to measure grain moisture so that yields could be adjusted to a constant 15% water content. Yearly and pooled data were analyzed using Proc GLM (SAS Institute, 1985) to determine cumulative effects of the three tillage systems.

To determine if tillage energy requirements for slit-tillage were lower than for conventional in-row subsoiling on a deep Norfolk loamy sand, a second experiment was conducted in 1986 about 150 ft from the primary study. A two-row, Ro-Till implement with either a standard parabolic shank or a shorter shank with a slitter blade was connected to a John Deere 3020 tractor that was equipped with a three-point hitch dynamometer and microcomputer for conversion of

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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 and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

data from analog to digital format (Reynolds et al., 1982; Garner and Dodd, 1985). Each configuration was operated at a subsoiling depth of approximately 16 in. while measuring forward speed, engine speed, wheel slip, fuel requirement, draft, and drawbar power at a rate of 83 observations per second. Approximately 1755 analog data points were collected for three replicates and analyzed statistically using Proc GLM (SAS, 1985).

RESULTS AND DISCUSSION

Both studies were conducted on very uniform Norfolk loamy sand that has a moderately thick surface, deep water table, and 0 to 2% slopes. The surface layer is brown loamy sand about 7 in. thick with a subsurface eluviated E horizon that extends from 7 to 16 in. in depth and is a pale brown loamy sand (USDA-SCS, 1979). Typical Norfolk soils have approximately 77% sand, 17% silt, and 6% clay in the Ap horizon; 72% sand, 18% silt, and 10% clay in the E horizon; and 63% sand, 17% silt, and 20% clay in the Bt horizon. They have low organic matter levels and bulk densities of approximately 1.6, 1.8, and 1.5 g/cu cm in the Ap, E, and Bt horizons, respectively (Campbell et al., 1974). Deep tillage is required annually because, even without wheel traffic, these soils reconsolidate to very high bulk densities (Busscher et al., 1986). Subsoiling is beneficial even when supplemental irrigation is applied because it allows deeper root penetration and increases the soil volume available for extraction of water and nutrients (Camp et al., 1984). Annual deep tillage operations should penetrate the E horizon for optimum root proliferation, but care must be taken to avoid mixing subsoil material with the upper layers. If mixing occurs, clay particles from the B horizon fill the open spaces and further increase the bulk density (Elkins, 1980).

Early-season plant samples were not collected in 1986, but in 1987 early-season, whole-plant nutrient concentrations (Table 2) showed similar levels for traditional in-row subsoiling and slit-tillage techniques. Both deep-tillage systems increased plant N concentration compared with a no-till treatment, presumably because the volume of subsoil that could be explored by plant roots for water and nutrients was greater. In 1988, N concentrations in whole plants collected approximately 4 wk after emergence from slit-tillage

Table 2. Tillage system effect on early-season nutrient concentrations in whole-plant grain sorghum grown on Norfolk loamy sand near Florence, SC in 1987 and 1988.

	Nutrient									
Tillage system	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn
	%						ppm			
(1987)										
Slit-tillage	3.21	0.31	3.84	0.47	0.44	0.18	8.6	8.6	60	35
Subsoiled	3.24	0.30	3.81	0.50	0.43	0.20	8.6	8.0	62	37
No-tillage	3.05	0.31	3.89	0.51	0.45	0.20	9.2	8.0	59	38
LSD(0.05)	0.10	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	5	11	6	14	14	21	15	15	40	25
(1988)										
Slit-tillage	3.19	0.29	4.02	0.54	0.43	0.14	21	3.8	83	42
Subsoiled	3.00	0.26	3.91	0.54	0.43	0.14	21	1.9	85	38
No-tillage	2.95	0.28	3.93	0.57	0.47	0.14	26	3.2	68	30
LSD(0.05)	0.10	0.01	NS	NS	0.03	NS	NS	0.5	12	4
CV (%)	5	9	8	10	12	9	33	34	25	17

Table 3. Tillage system effect on flag-leaf nutrient concentrations in grain sorghum grown on Norfolk loamy sand near Florence, SC in 1986, 1987, and 1988.

	Nutrient									
Tillage system	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn
	%						ppm			
(1986)										
Slit-tillage	2.42	0.42	1.65	0.16	0.19	0.14	4.0	7.4	28	22
Subsoiled	2.45	0.43	1.64	0.17	0.18	0.16	3.8	7.2	30	22
No-tillage	2.36	0.43	1.68	0.17	0.19	0.15	4.6	7.1	28	22
LSD(0.05)	NS	NS	NS	NS	NS	0.02	NS	NS	NS	NS
CV (%)	7	7	8	15	11	24	45	11	26	12
(1987)										
Slit-tillage	2.82	0.45	1.70	0.26	0.23	0.18	9.6	7.6	36	21
Subsoiled	2.80	0.44	1.75	0.25	0.23	0.19	9.4	6.8	37	21
No-tillage	2.69	0.43	1.76	0.24	0.23	0.17	9.7	6.1	37	20
LSD(0.05)	0.08	NS	NS	NS	NS	NS	NS	0.6	NS	NS
CV (%)	5	8	6	14	14	15	16	16	27	9
(1988)										
Slit-tillage	2.91	0.45	1.70	0.34	0.25	0.16	16	4.0	46	22
Subsoiled	2.88	0.42	1.66	0.33	0.24	0.15	15	3.5	43	22
No-tillage	2.82	0.42	1.61	0.34	0.26	0.15	15	3.3	36	19
LSD(0.05)	NS	0.01	0.04	NS	0.01	0.01	NS	0.5	3	2
CV (%)	5	5	4	8	8	8	22	24	13	12

plots were significantly higher than in plants grown with either in-row subsoiling or no-tillage. Analysis of upper leaves at flowering (Table 3) showed some significant differences among tillage treatments in 1986, 1987, and 1988, but there were no consistent trends and all values were within adequate ranges for grain sorghum (Jones and Eck, 1973).

The relatively late planting date for this study (mid-June) was chosen because in much of the Coastal Plain, grain sorghum is a good double-crop after winter crops such as rapeseed (*Brassica napus* L.), rye (*Secale cereale* L.), or wheat (*Triticum aestivum* L.) (Sojka and Karlen, 1988). Grain yields (Table 4) were similar to other late-planted, non-insect-infested sorghum in this region (Karlen et al., 1989). Higher grain yields in 1987 presumably occurred because seasonal rainfall and temperature (Fig. 1) were more favorable than in either 1986 or 1988. Early-season growth during 1986 was slowed by a drought that resulted in the lowest Palmer Drought Severity Index since 750 AD (Stahle et al., 1988). Slit-tillage sorghum yields were not significantly different than yields measured for in-row subsoiling in 1986, but both deep tillage treatments yielded significantly more than the no-tillage treatment. Slit-tillage yields in 1987 were significantly greater than yields for the in-row subsoiling or the no-till treatment. In 1988, slit-tillage yields were significantly higher than no-till yields, and slightly higher than those with conventional subsoiling. The 3-yr average grain yield showed no significant differences between deep tillage methods but both were higher than for the no-till treatment.

Table 4. Grain sorghum grain yield as affected by in-row tillage practice on Norfolk loamy sand near Florence, SC in 1986, 1987, and 1988.

Tillage practice	Yield			
	1986	1987	1988	3-yr mean
	bu/acre			
Slit-tillage	35.4	68.5	45.1	49.7
Subsoiled	38.3	57.3	42.4	46.1
No-tillage	21.7	57.0	38.7	39.1
LSD(0.05)	10.4	4.8	5.2	5.0
CV (%)	53	14	21	33

Slit-tillage yields were numerically higher than with in-row subsoiling, presumably reflecting persistence of the slits. When soil pits were excavated at anthesis in 1988 (Fig. 2), slits from 1986, 1987, and 1988 were found and filled with plant roots. Decomposition of these dense mats of plant roots presumably stabilizes the slits during the winter and during periods of wetting and drying. Proliferation of roots in the larger volume of soil loosened by standard in-row subsoiling was not as dense (Fig. 3) and therefore this area was not stabilized from year to year. Therefore, as previously shown (Busscher et al., 1986; Busscher et al., 1988), subsoiling must be repeated each year because disturbed zones reconsolidate during the growing season and during the winter. Yields for both slit-tillage and in-row subsoiling treatments were significantly

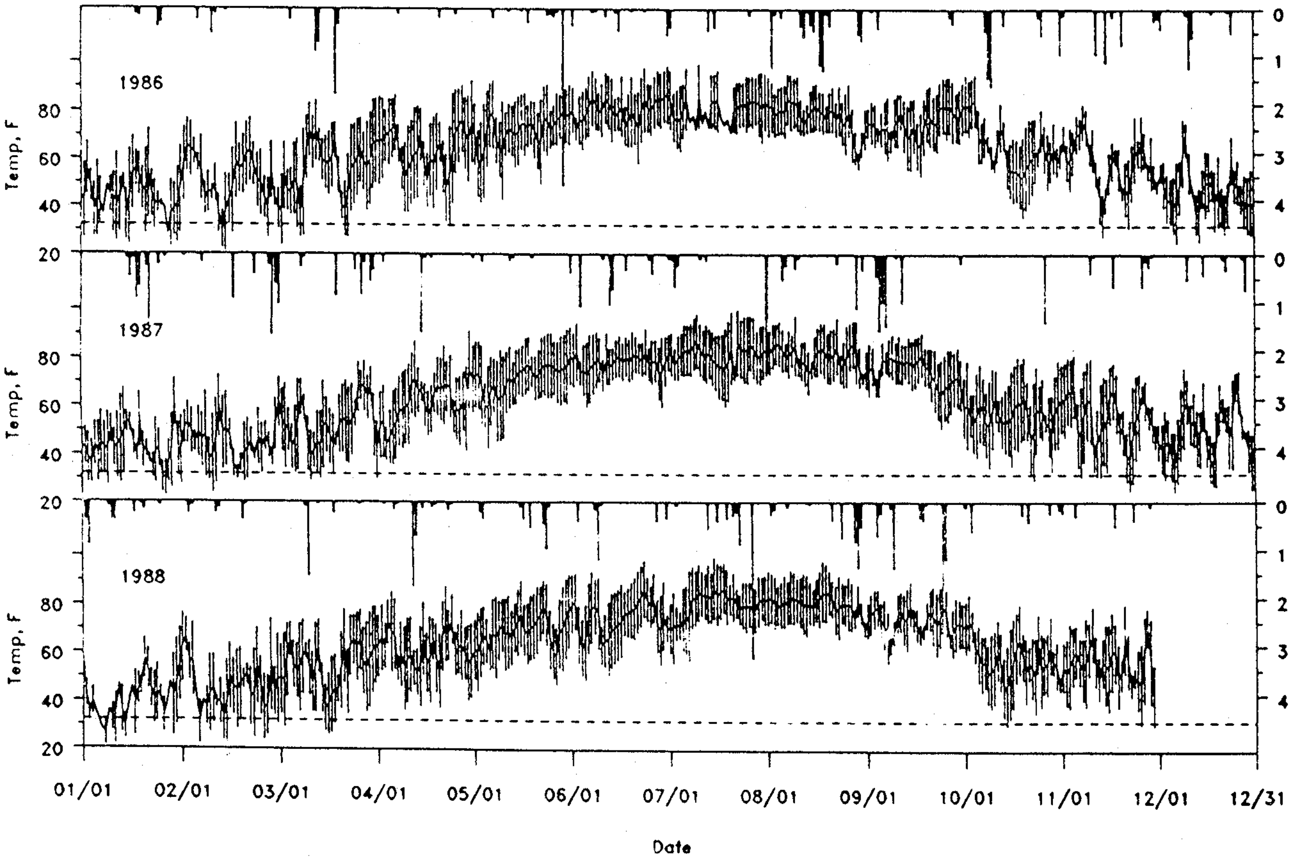

Fig. 1. Rainfall and temperature patterns measured at the experimental site near Florence, SC.

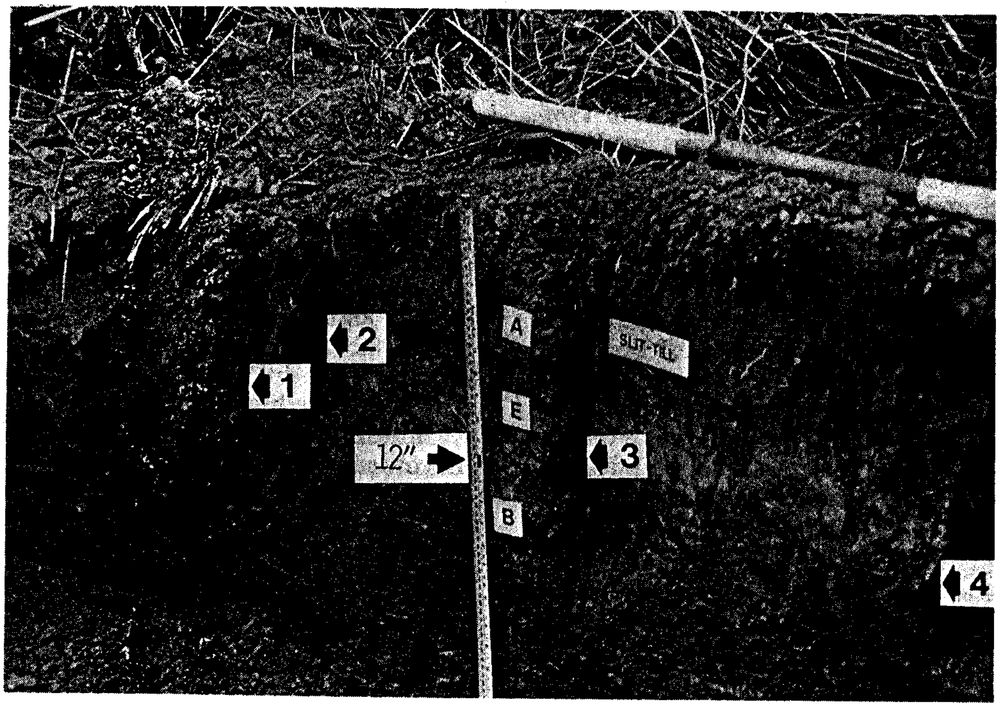

Fig. 2. Persistence of root-filled, macropore-like slits beneath plant rows at anthesis as a result of slit-tillage operations on deep Norfolk loamy sand in 1986 (1), 1987 (2 and 4), and 1988 (3).

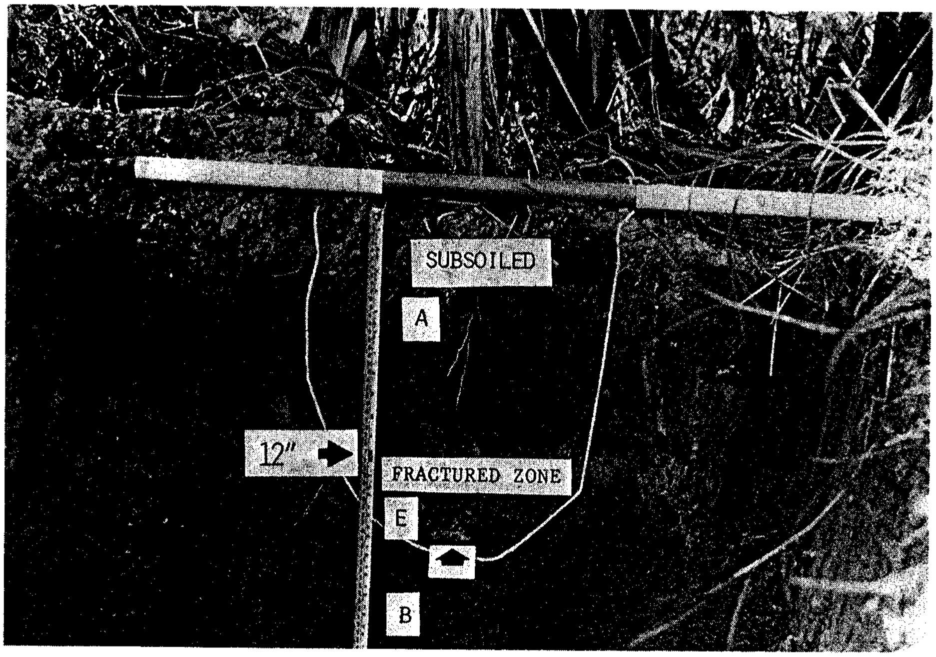

Fig. 3. Fracture zone at anthesis associated with annual in-row subsoiling of a deep Norfolk loamy sand.

greater than for no-tillage treatments. This presumably occurred because roots in no-till treatments were generally confined to the Ap horizon (Fig. 4), and therefore the plants were subjected to more stress during periods of low rainfall and high temperature (Fig. 1).

Elkins and Hendrick (1983) found that cutting a slit through a tillage pan required less energy than subsoiling to the same depth, but tillage energy measurements had not been made on deep Coastal Plain soil with well developed E horizons. Draft and horsepower required to pull a two-row, Ro-Till system with a standard parabolic shank and a shorter parabolic shank with a slitter blade showed that the slit-tillage system had a draft of 3930 lb compared with 5215 lb for the parabolic subsoiler. Power requirements per shank were 20.1 horsepower for the slit-tillage system and 26.7 horsepower for the parabolic subsoiler. Forward speed, engine speed, wheel slip, and fuel requirement also were measured but showed no significant differences for the two deep tillage implement designs.

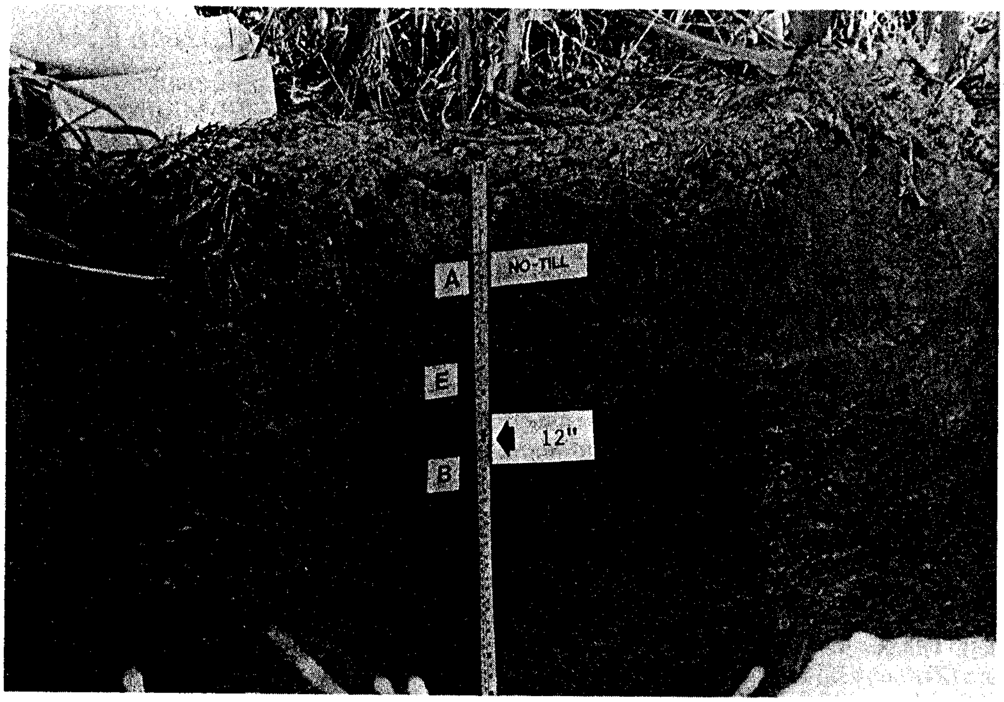

Fig. 4. Proliferation of sorghum roots at anthesis in only the Ap horizon when grown without some form of deep-tillage.

INTERPRETIVE SUMMARY

This study showed that slit-tillage was at least as effective as in-row subsoiling for producing grain sorghum on deep Coastal Plain soils such as a Norfolk loamy sand. Slit-tillage yields were significantly greater than in-row subsoiling yields in one of three years and significantly greater than no-tillage yields every year. The macropore-like slits persist with active root growth recurring for at least 3 yr. This persistence contrasts with previous reports showing that deep in-row subsoiling must be repeated annually because of reconsolidation. Slit-tillage also requires less tillage energy than standard in-row subsoiling. Therefore, slit-tillage would seem to offer an attractive alternative to presently used tillage systems. We recommend that manufacturers of tillage equipment for Coastal Plain soil conditions seriously evaluate slit-tillage as an option for their deep-tillage equipment.

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