

THE EFFECTS OF IN-ROW SUBSOIL TILLAGE AND SOIL WATER ON CORN YIELDS IN THE SOUTHEASTERN COASTAL PLAIN OF THE UNITED STATES*

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ABSTRACT

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Soil erosion is a problem in the Southeastern Coastal Plain of the U.S.A. where clean tillage row cropping exists without adequate soil conserving practices. Conservation tillage practices in this region have frequently incorporated in-row subsoiling to overcome root restricting soil layers 0.20 to 0.35 m below the surface. A number of studies have been conducted to determine the benefits of in-row subsoiling and results have been contradictory. The objective of this study was to evaluate the relationships between in-row subsoil and non-subsoil tillage treatments, soil water, and corn grain yields.

The study was conducted for two years on an Orangeburg sandy loam (Typic Paleudult). The study contained irrigated and non-irrigated treatments. The four tillage treatments used were (T₁) in-row subsoiler followed by a double disk bedder, (T₂) double disk bedder, (T₃) fluted coulters followed by in-row subsoiler and slot filler tines, and (T₄) fluted coulters. Tillage and planting were accomplished simultaneously. Each corn (*Zea Mays* L. 'Dekalb XL72B') crop was preceded by fall-planted wheat and the wheat (*Triticum aestivum* L. "Coker 747") was killed with herbicides in the spring before corn planting. Wheat mulch was disked in prior to the bedding treatments and left undisturbed for the two fluted coulters treatments. Corn was planted 0.04 m deep with double disk openers. Soil water potential was maintained above 0.05 MPa in the irrigated corn plots. Forty kg/ha of N was applied at planting and followed 42 days later with eight weekly applications of 50 kg/ha N.

In-row subsoiling and irrigation treatments significantly increased grain yields. Irrigated corn grain yields were 12333 and 7872 kg/ha in 1978 and 1979, respectively. Non-irrigated corn yields were 7697 and 4892 kg/ha in 1978 and 1979, respectively. In-row subsoiled to a depth of 0.36 m and non-subsoiled grain yields were 8577 and 7820 kg/ha, respectively. There was no significant difference between bedding and fluted coulters treatments.

INTRODUCTION

Conservation tillage practices, that improve root penetration and leaves crop residues for surface protection, can minimize erosion, enhance water

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infiltration, and improve crop production. Coastal Plain soils of the Southeastern U.S.A. frequently have root-restricting soil layers 0.20 to 0.25 m below the surface (Reicosky et al., 1977). A large number of experiments have been conducted in the Southern United States to determine effects of root-restricting compacted soil layers and the effects of subsoiling to shatter the compacted zones on crop yield. Results are contradictory. Taylor and Bruce (1968) reported experiments conducted to evaluate the effects of high-strength soil pans on cotton root growth and yield for eight widely separated soil areas in Alabama, U.S.A. At two locations shattering the pans with subsoilers increased yield 40% over yield obtained without subsoiling. At four locations, subsoiling did not affect yield and at two locations, the subsoiled cotton yielded about 30 to 40% less than the non-subsoiled cotton. Parker et al. (1975) found that subsoiling a Marlboro sand (clayey, kaolinitic, thermic family of Typic Paleudult), increased soybean yields the first year but not a second year unless lance nematodes were controlled. Suman and Peele (1974) found that subsoiling without irrigation increased soybean yields 4 out of 6 years. M.B. Parker, C.C. Dowler, and E.D. Threadgill* have unpublished results from a three year study of tillage effects on non-cropped irrigated corn grown on a Tifton sandy loam. All plots had been moldboard plowed and planted to row crops several years prior to study initiation. Their three treatments (a) moldboard plowed to 0.25 m, (b) subsoiling to 0.40 m just prior to planting, and (c) no-till planted used a fluted coulter ahead of the planter. They found no yield differences due to treatment the first year, the fluted coulter treatment yielded significantly less the second year, and the fluted coulter and subsoiled treatments yielded significantly less than the moldboard treatment the third year. Langdale et al. (1981) found that an in-row subsoil tillage method resulted in significantly higher corn grain yields compared with a fluted coulter method at N rates of 200 to 400 kg/ha.

Higher crop yields have been associated with deeper root penetration of the soil profile (Campbell et al., 1974; Trowse, 1978). Root penetration in the soil can be influenced by the soil bulk density, water content, oxygen concentration, temperature, and pH (Barley et al., 1965; Camp and Lund, 1968; Campbell et al., 1974; Eavis et al., 1971; Gill and Miller, 1965; Pearson et al., 1970; Taylor and Gardner, 1963). Taylor and Gardner (1963) and Campbell et al. (1974) have related root penetration to soil water content. Soils with a high strength A₂ horizon can be managed by using water management practices that keep the surface layers in the low strength range. Eavis et al. (1971) have demonstrated that lowered oxygen concentrations reduced root growth. Tackett and Pearson (1964), studying cotton root growth and activity in a Norfolk sandy loam, reported that mechanical impedance was more detrimental for root growth than low oxygen when the subsoil bulk densities exceeded 1.5 Mg m⁻³. At lower bulk densities root growth was depressed at oxygen levels below 10%, and there was a strong interaction between oxygen and bulk densities.

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Phene and Beale (1976), determined for a Varina sandy loam an optimal soil-water potential range of 0.02 to 0.04 MPa which was based on soil oxygen diffusion rate, soil strength, and soil water desorption characteristics.

The objective of this study was to evaluate the relationships between in-row subsoil and non-subsoil tillage treatments, soil water, and corn grain yields.

MATERIALS AND METHODS

This study was conducted during 1978 and 1979 on an Orangeburg sandy loam (Typic Paleudult) site located at the Soil Conservation Service's Plant Materials Center, Americus, GA. The experimental design was a 2×4 factorial with four replications. The two soil water treatments were main plots and for tillage treatments were subplots. Each soil water treatment area had three soil characterization sites which were equally spaced. Duplicate soil bulk densities were taken from the 0–0.15, 0.15–0.28, 0.28–0.53, and 0.53–0.60 m depths at each site within the study area. Average bulk densities and standard deviations for these four depths were 1.485 ± 0.103 , 1.783 ± 0.094 , 1.655 ± 0.101 , and $1.632 \pm 0.032 \text{ Mg m}^{-3}$. The soil textures for the four depths were sandy loam, heavy sandy loam, sandy clay loam, and sandy clay loam for the respective depths. Undisturbed soil cores 0.076 m diameter \times 0.05 m height were taken. Soil water contents using the pressure-plate extraction method were determined at: 0.0005, 0.001, 0.002, 0.005, 0.007, 0.010, 0.015, 0.020, 0.030, 0.040, 0.100, 0.200, 0.500, and 1.500 MPa pressures. Undisturbed cores were allowed to saturate from the bottom prior to placing in the pressure plate apparatus. Plates with bubbling pressures 0.04, 0.25 and 1.70 MPa were

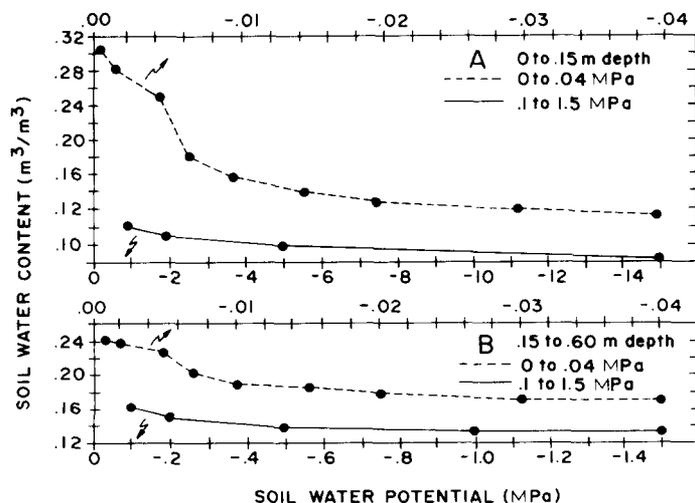


Fig. 1. Soil water desorption curve for an Orangeburg sand loam soil.

used for the 0.0005 to 0.03, 0.04 to 0.20, and 0.50 to 1.50 MPa ranges, respectively. After comparing all data it was concluded that the desorption curves shown in Fig. 1, A and B, are adequate to described water retention at this site. These desorption curves represent the 0 to 0.015 and 0.15 to 0.60 m depths, respectively. The 0.15 to 0.60 m depth curve was also used to calculate soil water in the 0.60 to 1.20 m depth range since soil textures and bulk densities were the same.

Solidset sprinkler irrigation was used to maintain the desired soil water level in the irrigated plots. Sprinkler heads were spaced on an 18.3 m square grid and along the length of the four contiguous replications. The sprinkler heads were arranged such that one was centered in each border between plot lengths and replications. Sprinkler distribution was tested and found to be uniform, and line pressure was monitored during application to assure that proper pressure was maintained.

The University of Georgia soil test recommendations were used as a guide to supply plant nutrient quantities (except N) necessary for high corn production in Georgia. Initial soil samples tested were high in P (69 kg/ha), medium in K (155 kg/ha), and with a pH of 5.4. Nutrient application rates and times (except for N) are shown in Table I. Plant nutrients shown in Table I, except dolomitic limestone and the 13 Oct. 1977 fertilizer application, were applied in solution form. Manganese tested high (40 kg/ha). Forty kg/ha of N was applied at planting and followed 42 days later with eight weekly applications of 50 kg/ha N. The initial N application was in solution as ammonium nitrate and the remaining applications were 0.002 m ammonium nitrate pellets.

Wheat (*Triticum aestivum* L. "Coker 747") was planted in 0.15 m drill rows following moldboard plowing 0.20 m deep on 13 Oct. 1977, and disk harrowing 0.10 m deep on 23 Oct. 1978, respectively. Ammonium nitrate was broadcast just prior to planting at the rates of 38 and 24 kg N/ha in 1977 and 1978, respectively. Wheat was not harvested for grain to permit March corn planting. Herbicides were used to kill approximately 2.5 metric tons/ha of wheat and control weeds. A herbicide tank mixture

TABLE I

Fertilizer application during the study period

Date of application	Plant nutrients (kg/ha)							
	P	K	Ca	Mg	S	Zn	Cu	B
13 Oct. 77	49	186	515 ^a	134 ^a				
27 Feb. 78	20	56			13	5.6	0.6	1.1
23 Oct. 78	31	118	151 ^a	134 ^a				
1 Mar. 79	4	9			13	5.6	0.6	1.1

^aEstimated from 2240 kg/ha application of plowed-down dolomitic limestone.

consisting of 1.68 kg of atrazine [2-chloro-4(ethylamino)-6-(isopropylamino)-s-triazine], 1.26 kg of alachor [2-chloro-2'-6'-diethyl-N-(methoxymethyl)acetanilide], and 0.28 kg of paraquat (1,1'-diethyl-4,4'-bipyridinium iron) per hectare was applied in a pre-emerge manner*.

The four tillage treatments used were (T₁) in-row subsoiler followed by a double disk bedder, (T₂) double disk bedder, (T₃) 0.05 m wide fluted coulters plus in-row subsoiling, and (T₄) 0.05 m wide fluted coulters. Wheat mulch was disked in prior to the two bedding treatments and left undisturbed for the two fluted coulters treatments. The 0.064 m wide subsoiler points were operated 0.036 m deep. Tillage treatment T₃ used two spider-type slot filler tines immediately following the subsoiler tool to firm the trench for seeding. Planters were mounted on a tool bar behind the tillage tool. Each tillage treatment plot contained 8 rows that were 9.14 m long and with 0.76 m spacings. The four center rows, except for 1.53 m on row ends, were harvested for plot yields. Corn (*Zea Mays* L. 'Dekalb XL72B') planting rate was approximately 80,000 seed/ha on 20 and 7 March 1978 and 1979, respectively. Plants were thinned to 74,000 plants/ha after a stand was established. Furadan (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) was applied at planting time at the rate of 2.2 kg/ha active ingredient.

Soil water was monitored in both the non-irrigated and irrigated corn plots. Delmhorst cylindrical gypsum blocks were installed in the non-irrigated plots in 1978 and 1979, and the irrigated plots in 1979. One set of blocks were installed per plot at 0.15, 0.30, 0.45, 0.60, 0.90, and 1.20 m depths. Gypsum blocks were calibrated in the pressure plates to determine the relationship between block reading and soil water potential. Curves in Fig. 1 were then used to convert the data to soil water content. Tensiometers were installed in eight randomly selected irrigated plots and at 0.15, 0.30, and 0.45 m depths. Moisture blocks and tensiometers were generally read on Monday, Wednesday, and Friday. Sufficient water was applied to the irrigated plots to keep soil water potential above 0.05 MPa at the 0.30 m depth.

RESULTS AND DISCUSSION

Rainfall and irrigation for 1978 and 1979 are shown in Figs. 2 and 3, respectively. Total rainfall during 65 days of the corn growing period from tasselling to maturity was 0.166 m in 1978 and 0.156 m in 1979. Irrigated plots received a total of 0.237 and 0.263 m water in 1978 and 1979, respec-

*This paper reports the results of research only. Mention of a pesticide does not constitute a recommendation for use by the USDA nor does it imply registration under FIFRA as amended. Trade names and company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product by the USDA.

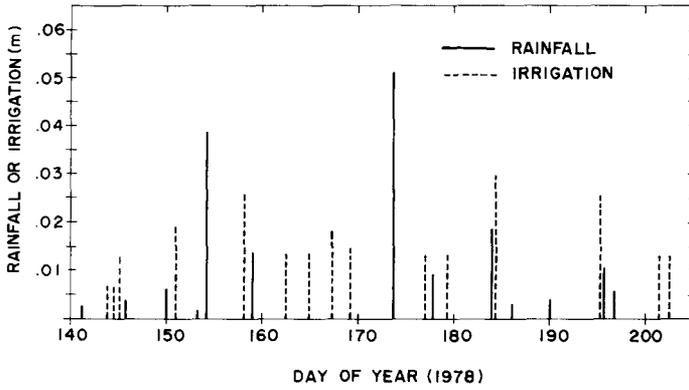


Fig. 2. Rainfall and irrigation during 1978.

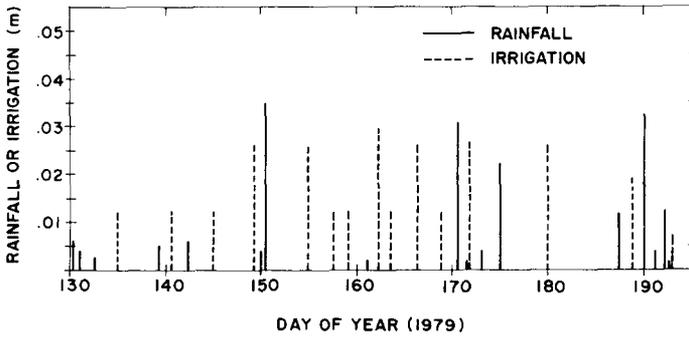


Fig. 3. Rainfall and irrigation during 1979.

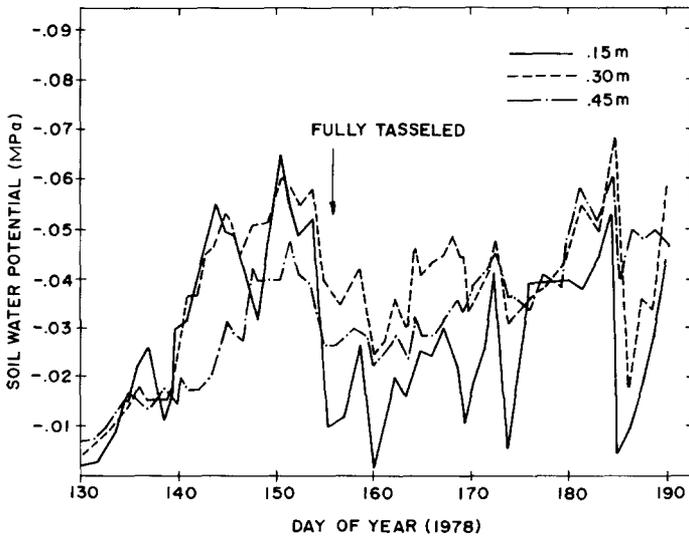


Fig. 4. Soil water potential in irrigated treatments at 0.15, 0.30 and 0.45 m depths, and during 1978.

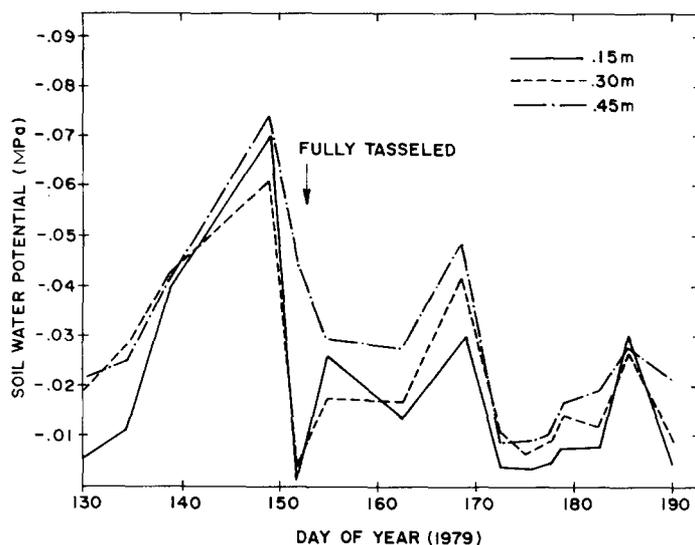


Fig. 5. Soil water potential in irrigated treatments at 0.15, 0.30 and 0.45 m depths, and during 1979.

tively. Irrigated treatment tensiometer readings are shown in Figs. 4 and 5. Gypsum block data for non-irrigated soil water status are shown to a depth of 1.20 m at various days during the corn growing seasons of 1978 and 1979, respectively; Figs. 6 and 7, respectively. Roots were most active in soil water extraction to a soil depth of 0.60 m. Soil water depletion did occur to a depth of 1.20 m.

Corn grain yields are given in Table II. Soil water treatment affected

TABLE II

Corn grain yields (kg/ha; corn grain moisture content = 15%) as affected by tillage and soil water treatments^a

	1978 ^b		1979 ^b	
	Irrigated ^d	Non-irrigated ^d	Irrigated ^d	Non-irrigated ^d
T ₁	12,669	8,149	8,605	5,151
T ₂	12,028	7,262	7,109	4,412
T ₃	12,607	7,995	8,198	5,248
T ₄	12,037	7,382	7,575	4,757
Mean	12,323	7,697	7,872	4,892

^aStatistical model $R^2 = 0.97$, coefficient of variation = 9.5%.

^bYears significantly different at 0.001 level.

^cT₁ = disk harrow, in-row subsoil 0.36 m and bedded; T₂ = disk harrow and bedded; T₃ = fluted coulter and in-row subsoil 0.36 m; and T₄ = fluted coulter immediately followed by planting. T₁ plus T₃ versus T₂ plus T₄ significantly different at the 0.002 level.

^dIrrigated versus non-irrigated significantly different at the 0.0001 level.

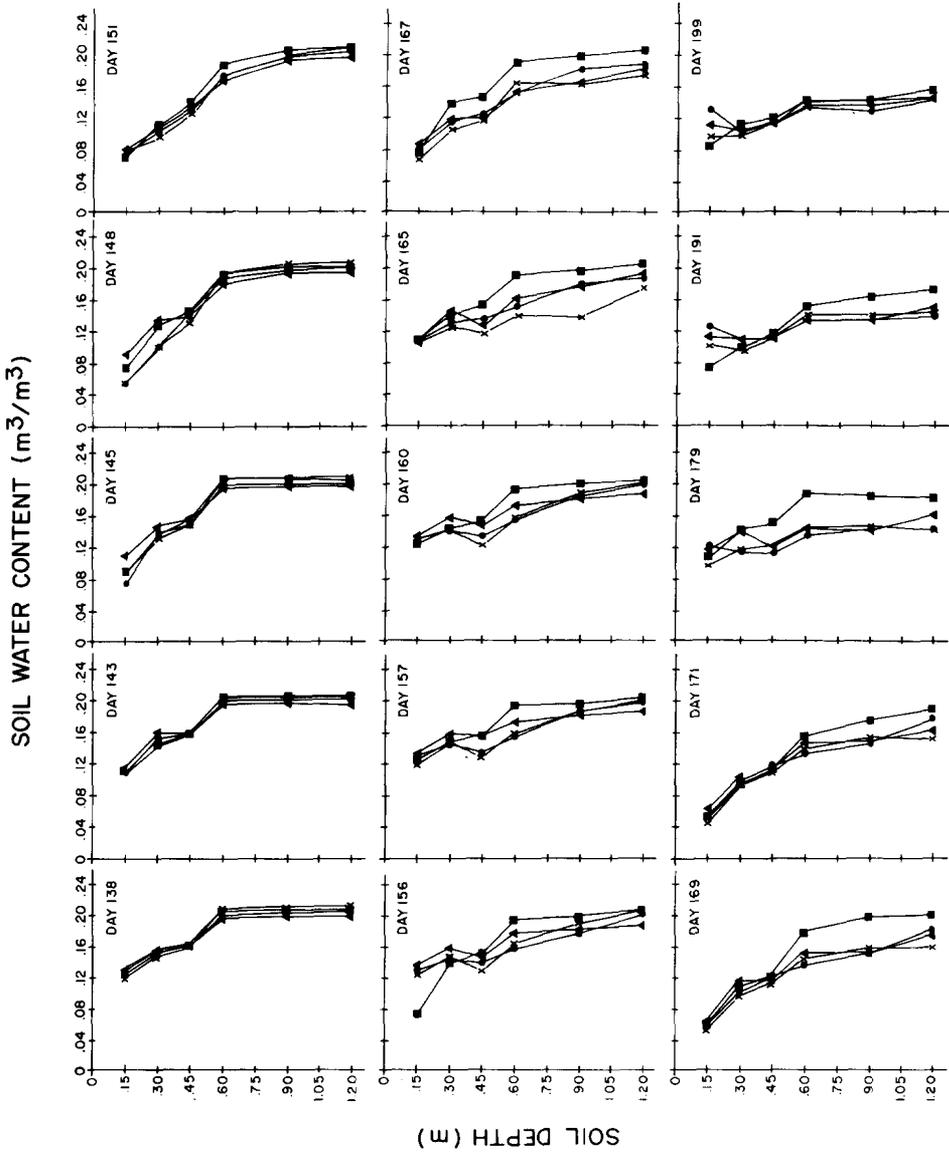


Fig. 6 Soil water content in non-irrigated treatments at selected days in 1978 and for tillage treatments T₁ (x, bed + in-row subsoil to 0.36 m), T₂ (•, bed), T₃ (▲, fluted coultler + in-row subsoil to 0.36 m), and T₄ (■, fluted coultler).

grain yields both years. The 1979 irrigated tillage treatment T_2 had significantly less grain than T_1 , T_3 , and T_4 . However, grain yields for replications 1 through 4 in this treatment were recorded as 7,135, 8,403, 7,575, and 5,322. Replication 4 is 2382 kg/ha less than the average of the other three replications. We suspect that an error occurred in the data tabulation of replication 4.

A general linear model procedure described by Barr et al. (1976) was used to test statistical significance of the grain data. The model R^2 was 0.97 and the coefficient of variation was 9.6. Grain yields were significantly different both years ($PR > F$, 0.0001). The best year of grain yield was 1978. The climate was hot and dry during corn anthesis in 1979. Several studies have shown (Denmead and Shaw, 1960; Howe and Rhoades, 1955; Robins and Domingo, 1953) that plant water stress at anthesis will markedly depress grain yields. Irrigation response was significant both years ($PR > F$ 0.0001). Tillage treatment was significantly different ($PR > F$, 0.006), but there was no significant interaction between soil water treatment and tillage. When T_1 plus T_3 versus T_2 plus T_4 were tested using the Type III means square for soil water*replication*tillage as an error term they were found to be significantly different ($PR > F$, 0.002). The T_1 plus T_3 and T_2 plus T_4 means were 8577 and 7820 kg/ha, respectively. The least significant difference at the 0.05 level is 441 kg/ha.

Even though subsoiling resulted in grain yield increases in this study the margin for yield improvement by reducing plant water stress with subsoiling may not be large enough to assure grain yield increases more than 50% of the years. Using day 138, 1978, Fig. 6, as the maximum retention soil water condition and day 171, 1979, Fig. 7, as the maximum soil water extraction condition, there is 0.072 m of plant available water in the 0 to 1.20 m depth and 0.23 m in the 0 to 0.3 m depth. Subsoiling potentially increases plant available soil water by 0.049 m. Even though plant available soil water is tripled by subsoiling the probability for plant-damaging drought is still high. Ten to 12 days without rainfall and evapotranspiration of 0.005 m per day can cause yield limiting drought. Drought is a condition in which sufficient soil water is not available in the root zone for plant growth and development. Van Bavel and Carreker (1957) have shown that there is a 80% chance of having 20 drought days between March and October in the Coastal Plains of Georgia, U.S.A., when the soil holds 0.075 m of plant available water. In 5 out of 10 years there are 40 drought days during this period, and there is a 45% probability of having 5 consecutive drought days in a 10-year period. This helps explain the erratic yield results with subsoiling experienced by Taylor and Bruce (1968), and Suman and Peele (1974). In those regions and/or years that plant available soil water can be made equal to or exceed daily evaporative demand during the growing season, with increased infiltration from no-till mulching practices and/or increased rooting volume with subsoiling, crop yields may be improved.

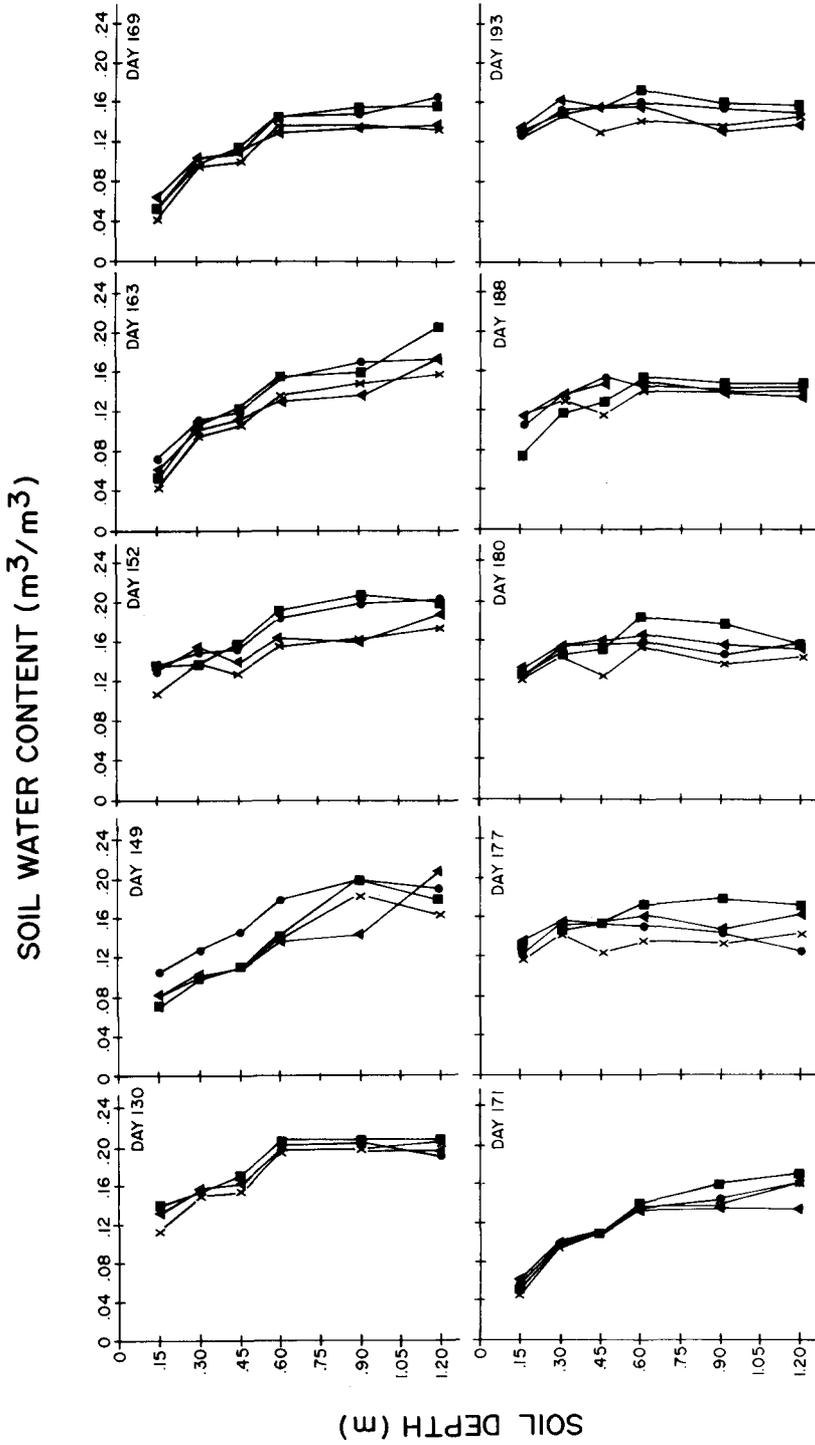


Fig. 7. Soil water content in non-irrigated treatments at selected days in 1979 and for tillage treatments T₁ (x, bed + in-row subsoil to 0.36 m), T₂ (•, bed), T₃ (▲, fluted coultler + in-row subsoil at 0.36 m), and T₄ (■, fluted coultler).

The effect of in-row subsoiling for the 1978 crop year can be seen in Fig. 6. From day 138 to 151 there were no apparent differences in soil water extraction from the root zone. Between days 150 to 159, 0.070 m rain fell and on days 156–159 the soil profile had been recharged. On days 160 through 169, treatment T₄ lags in soil water extraction. By day 171 the drought had been long enough for soil water in all tillage treatments to be equally depleted. At this point an extended drought would be equally damaging to all plants. In 1979, Fig. 7, on days 149, 152, and 163, soil water depletion lagged in the non-subsoiled treatments, T₂ and T₄, but by day 171 the soil water profile was basically the same for all treatments. Again, extended drought at this point would have been equally damaging to plants in all tillage treatments.

The 1978 corn growing season was excellent in that total rainfall was both adequate and well distributed. There was a 20-day period from day 151 to 171 in 1979 when there was a 5-day drought, Figs. 3 and 7. This drought occurred during and immediately following anthesis and is probably responsible for reducing grain yields in 1979.

We conclude that the T₁ and T₃ tillage treatments permitted deeper rooting, and thus had a positive impact on corn grain yields.

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