Crop Response to Chiseling and Irrigation in Soils with a Compact A2 Horizon

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SHALLOW rooting is characteristic of most crops grown in sandy soils containing a compact A2 horizon located just below the tillage zone. Crops are subjected to frequent short droughts in these coarse-textured soils with low water-holding-capacities, because of poor rainfall distribution and the shallow root system.

The soils of the Southern Coastal Plains have an Ap horizon about 20 cm thick, representing the primary tillage zone. The texture ranges between a loamy sand and a sandy loam and contains less than 3 percent organic matter. The more compact A2 horizon, 1 to 30 cm thick, contains very little organic matter and is slightly higher in silt and clay than the Ap material. The bulk density of the A2 horizon ranges from 1.6 to 1.9 g/cc depending upon textural composition and previous tillage history. The B horizon is sandy clay in texture, often reddish brown in color, and has a better structure than the surface layers.

Campbell et al. (1974) have shown that these soils are most readily compacted when the water content is in the plant growth range and that if the bulk density exceeds 1.65 g/cc very few roots will pernetrate this A2 horizon. During wet periods we have observed that the compact A2 horizon restricts downward water flow from the Ap to the B horizon, and during dry periods restricts the upward capillary flow from the B to the Ap horizon. Miller (1969) observed similar flow restrictions in layered soils. Since root development into and through the compact A2 horizon is limited, plants must obtain most of their water from the Ap horizon. Most crops require more water than can be stored in the typical Ap horizon during drought or low rainfall periods.

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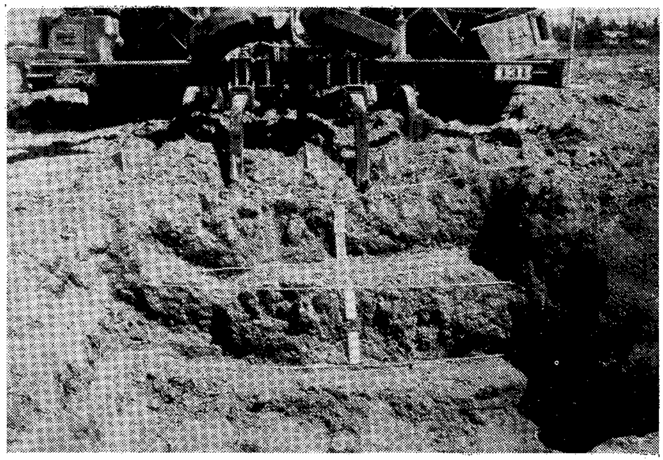

FIG. 1 Chisel plow used to disrupt the soil profile to a depth of 38 cm.

The objective of this study was to determine the yield of millet and sweet corn under four soil-water management regimes and to evaluate yield differences in terms of oxygen stress, depth of rooting, and soil water status in a coarse-textured soil with a compact A2 horizon.

PROCEDURE

The experiment was conducted on a Varina sandy loam (*Typic Paleudult*) soil with a slope of less than 1 percent. Millet (*Panicum Milliaceum var.* Pearl) was grown as a test crop in 1969 and 1970 and sweet corn *(Zea mays L. var.* Silver Queen) was grown in 1972 and 1973. The split-plot experiment consisted of two primary tillage treatments as main plots, with and without furrow irrigation. The experiment contained four replications and each subplot was 6.1 m wide by 7.6 m long. The check treatment main plots were moldboard plowed in 1969 and 1970 and disked in 1972 and 1973 to a common depth of 15 cm. The chiseled treatment main plots were tilled at a right angle and diagonally (Fig. 1) every year to a depth of 38 cm to disrupt the A2 layer. Following the plowing and chiseling operations the secondary disking, harrowing and cultivation operations were the same for all plots. Irrigation water was measured volumetrically, delivered to the plots through manifolds and applied in furrows with the ends blocked. Water (2.54 cm) was applied when approximately 50 percent of the available water was removed from the upper 60 cm of the soil profile. Henceforth, the treatments will be referred to as check, check + irrigation, chiseled and chiseled + irrigation.

Rainfall runoff was measured from two replications in underground tanks connected to four surface inlets in each plot. In the irrigated plots, the furrow ends were opened after each irrigation to allow rainfall runoff.

The millet was fertilized with a total of 571 kg/ha of nitrogen (N), 465 kg/ha of potassium (K) and 75 kg/ha of phosphorus (P), in 1969. The N was applied in four applications and the K in two applications. In 1970, 799 and 641 kg/ha of N and K, respectively, were applied in seven applications and 47 kg/ha of P was applied at planting. In 1972 and 1973, the fertilizer was broadcast at the rate of 84, 75, and 139 kg/ha of N, P, and K, respectively, prior to planting. Additional N as a slow release fertilizer was applied at the rate of 168 and 244 kg/ha in 1972 and 1973.

Tensiometers were installed in the row 15, 30 and 45 cm deep in all plots

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and recorded at least three times weekly. Additional tensiometers were installed in two replications at the 60-, 90-, and 120-cm depths. Soil water content was determined gravimetrically, corresponding to the time the millet was cut and to specific growth periods of the sweet corn. Pan evaporation and rainfall were recorded at the experimental site.

The oxygen content of the soil atmosphere was determined at the 25-cm depth. Gas diffusion chambers, 10 cm in diameter and 1 cm deep, equipped with small bore access tubes and capped with rubber septa were placed in the row. Gas was sampled with syringes at strategic times throughout the growing season and analyzed for O_2 content.

The millet was harvested when the plants within any treatment reached an average height of 76 cm. Dry matter yields were recorded by cutting periods and cumulative annual yields determined. Rainfall and pan evaporation between cuttings were used to define wet and dry periods. The sweet corn was harvested at the roasting ear stage and the annual dry matter yield determined as the total weight of ears and forage, each sampled, dried and weighed separately. Millet and corn were cut from a 4.6-m length of the four center rows (12-row plots) and the fresh weight determined. Sub-samples were dried at 70 C and dry matter calculated.

The water balance equation is represented as

$$ET = ET^* \pm F = P + I - R \pm S \pm F \qquad [1]$$

where precipitation, P, irrigation water applied, I, runoff, R, and change in soil water storage in the 0 to 120-cm depth, ± S, were measured. And, evapotranspiration, ET, and the net water transferred across the assumed lower boundary of the root zone at 120 cm, ± F, were not measured. An estimate of ET was made from the evapotranspiration-yield relation reported by Hanks et al. (1969) for millet and for corn from Harrold et al. (1959) and compared to potential ET from pan evaporation. Estimates of the value of F were determined from the water balance. ET* is defined as the algebraic sum of P, I, R, and S and differs from ET by ± F, i.e. when F = 0, $ET^* \equiv ET$.

Assuming F = 0, the test was made as to whether or not the dry matter yields were proportional to ET* by comparing ratios of treatment yeild, Y_i, to the maximum yield, Y_m, and the ratio of ET* to ET^*_m, where ET^*_m and Y_m are the maximum determined values for any one year.

TABLE 1. DRY MATTER YIELDS OF MILLET FOR DIFFERENT WET AND DRY PERIODS. A PERIOD WAS CONSIDERED "DRY" WHEN PAN EVAPORATION EXCEEDED RAINFALL AND VICE VERSA FOR A WET PERIOD.

	Cutting Periods—Date, Year				
	Dry			Wet	
Water Measurements	7/2-29/69	5/8-6/11/70	6/24-7/15/70	7/29-8/26/69	7/15-8/13/70
	centimeters				
Rainfall	16.38	2.72	0.00	13.56	16.36
Pan evaporation	18.84	25.68	15.95	11.68	11.61
Treatments	M.Tons/ha				
Check	1.90 a*	1.01 a	0.92 a	1.37 ab	3.94 a
Check + irrig.	3.63 b	2.49 bc	2.35 b	0.49 b	3.14 b
Chiseled	2.02 a	1.81 c	1.32 a	2.02 a	4.19 a
Chiseled + irrig.	2.24 a	2.78 b	2.55 b	1.37 ab	3.05 b

*Yields followed by the same letter within the same period are not significantly different at the 5% level.

RESULTS

Comparison of Yields

Millet yield data presented in Table 1 are arranged to show differences between treatments during periods in which rainfall was less than pan evaporation (drought) and during periods when rainfall exceeded pan evaporation (wet period). During droughts the irrigated millet produced more dry matter than nonirrigated millet and the millet yield from the chiseled plots exceeded those from the check treatment. However during wet periods following the droughts, irrigated millet produced less than nonirrigated millet. At the end of each wet period the highest yield was harvested from nonirrigated-chiseled plots.

However, the total annual dry matter yields are more convincing proof of the beneficial results of chiseling, Table 2. Chiseling the soil 38 cm deep provided an improved rooting environment that gave greater yields than the check treatment each year, and yields comparable to the check + irrigation treatment 3 of the 4 years. Specifically, soil chiseling produced yields equal to those produced when 13, 18, and 13 cm of irrigation water was applied to the check + irrigation treatment in 1969, 1972, and 1973, respectively. But in 1970, a dry year, a total of 38 cm of irrigation water resulted in a significant yield increase in the check + irrigation treatment over that of the chiseled treatment. Although short-term yields were increased considerably by irrigation during drought periods, these increases were not significant when considered over the full growing season. Over the 4-year period the average percent increase in dry matter yields above the check treatment was 18.5 percent for the check + irrigation, 17.1 percent for the chiseled treatment, and 25.6 percent for the chiseled + irrigation treatment (Table 2).

The costs of tillage and irrigation were estimated based on results of

TABLE 2. ANNUAL DRY MATTER YIELDS FROM THE CHECK AND CHISELED TREATMENTS WITH AND WITHOUT IRRIGATION.

	Yields				4-Year Percent Increase Over Check
	Millet		Sweet Corn		
Treatment	1969	1970	1972	1973	
	M. Tons/ha				
Check	8.22a*	10.17a	9.25a	11.11a	——
Check + irrig.†	9.34ab	13.84c	10.64ab	12.10a	18.5
Chiseled	9.50ab	11.74b	10.77b	13.42a	17.1
Chiseled irrig.†	11.00b	14.18c	10.80b	12.75a	25.6

*Those yields followed by the same letter within each year are not significantly different at the 5% level.
†There were 13 cm of irrigation water applied in 1969, 38 cm in 1970, 18 cm in 1972, and 13 cm in 1973.

TABLE 3. ESTIMATED NET VALUE OF CROPS PRODUCED AFTER THE EXPENSES FOR TILLAGE AND IRRIGATION WERE SUBTRACTED.

	Net Value of Crops			
	Millet* Silage		Sweet Corn† Roasting Ears	
Treatment	1969	1970	1972	1973
	Dollars/ha			
Check	352	437	1 742	1 011
Check + irrig.	344	489	1 322	1 520
Chiseled	386	485	1 883	1 661
Chiseled + irrig.	395	483	1 774	1 833

*Based on $44 per m. ton for dry matter.
†Based on a price of $0.042 each for marketable ears greater than 15 cm long.

McMartin and Bergan (1968) for gated pipe furrow irrigation and based on charges for custom tillage noted by Williamon (1972). The cost of plowing (check treatment) was $10.50 and the cost of chiseling (three passes) was $32.00 per ha per year. The cost of irrigation was $57.00 per ha in 1969 and 1973, $109.00 in 1970, and $62.00 in 1972. The estimated net values of the crops after the costs of tillage and irrigation were subtracted are shown in Table 3. The chiseling treatment had a larger net return than the check treatment each year, and more than the check + irrigation treatment in 3 of the 4 years. Net crop values of the check + irrigation increased over the check treatments in 1970 and 1973, but decreased in 1969 and 1972. The chiseled + irrigation treatment increased net crop value over the chiseled treatment in 1969 and 1973. These data indicate that chiseling alone to disrupt the A2 horizon resulted in a net return equal to supplying irrigation water in the layered soils of the Southern Coastal Plains.

DISCUSSION

Over the 4-year period improved soil aeration during wet periods and the increased soil-water available during dry periods were related to the increased crop yields from the chiseled treatment over those of the check treatment.

Soil Aeration

The O_2 content of the soil air at the 25-cm depth of the check treatment was lower than that of the chiseled treatment (Fig. 2). Plants in the irrigated treatment showed greater O_2 stress than those in the nonirrigated treatment when rain followed irrigation. Data from our O_2 studies at this location showed that when the oxygen content of the soil at the 25-cm depth became less than 12 percent, the growth rate decreased. Essentially no growth occurred when the oxygen content decreased below 5 percent. The O_2 content in the soil at the 25-cm depth remained below 12 percent for about 14 days in the check + irrigation treatment and for about 10 days in the check treatment during a wet period in June 1973. But the O_2 content in the chiseled + irrigation treatment dropped below 12 percent for only 3 days during this same period. The O_2 content of the soil air in the chiseled treatment did not drop below 13.2 percent at any time during the growing season. Oxygen stress was less in the chiseled treatment than in the check treatment during each wet period throughout the study. This indicates that drainage proceeded faster through the chiseled soil than through the nonchiseled soil (Campbell et al. 1974).

Rooting

The effect of chiseling on rooting patterns of sweet corn in 1972 is shown in Fig. 3. Many roots were 76 cm deep in the chiseled treatment soil, but most of the root system in the check treatment was in the upper 30 cm, above the A2 horizon.

Soil water suction was greater at the 90- and 120-cm depths, in the chiseled than in the check plots (Figs. 4 and 5). For example, about a 30- and 45-centibar suction increase was observed at the 90- and 120-cm soil depths, respectively, of the check treatment during the drought period and under millet in June 1970 (Fig. 4). But the suctions in the chiseled treatment increased about 75 centibars at the 90-cm depth and about 50 centibars at the 120-cm depth. Under corn the soil water suction changed more at the 90- and 120-cm depths in the chiseled treatment than in the check treatment; data for 1973 shown in Fig. 5. Suctions in the check + irrigation and chiseled + irrigation treatments at these soil depths (data not shown) almost paralleled those of the check treatment. These data show that the nonirrigated plants in the chiseled

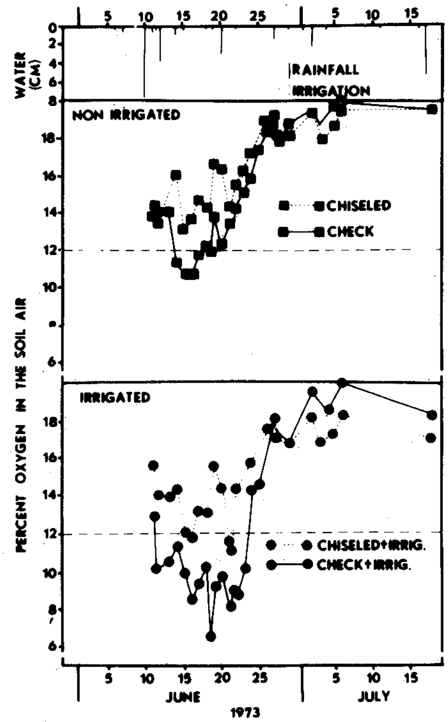

FIG. 2 Percent oxygen in the soil air, rainfall and irrigation versus time during June-July 1973.

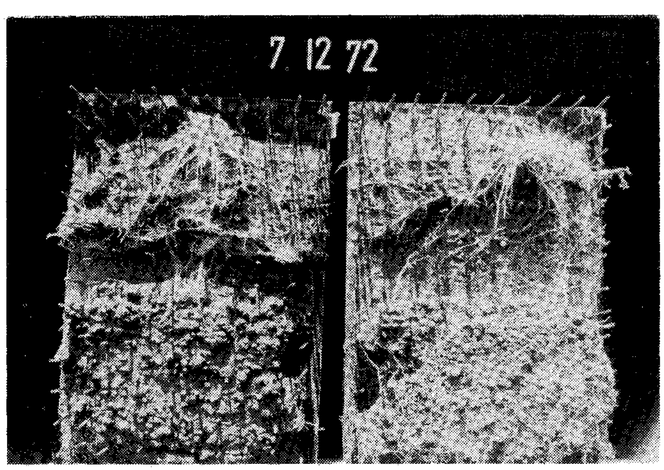

FIG. 3 Partially washed soil monoliths, 50 x 76 cm, of corn roots. Left, check treatment and right, chiseled treatment.

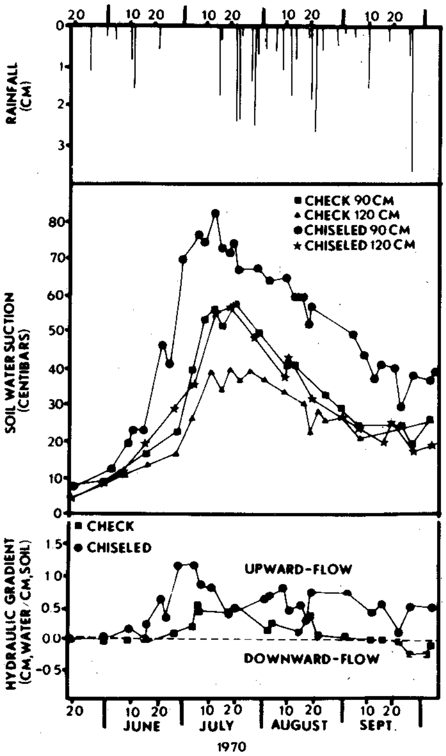

FIG. 4 Rainfall, soil water suction and hydraulic gradient between 90- and 120-cm depths versus time for the check and chiseled treatments for the 1970 millet growing season. Herein a positive gradient indicates an upward flow of water and a negative gradient seepage out of the root zone.

treatment had more active roots in the subsoil than the check treatment.

Soil Water Status

During drought periods plants on the chiseled plots withdrew more water from the soil profile than those on the check plots. For example, from May 18 to June 11, 1970, the total change in water storage within the soil profile of the check treatment was 3.5 cm, and 5.1 cm from the chiseled treatment. Therefore, the plants on the chiseled treatment removed 1.6 cm more water from the soil profile than those on the check treatment (shown by the cross-hatched area, Fig. 6). However, using the yield-ET relation from Hanks et al. (1969) and the measured dry matter yeilds produced, the calculated water used by the plants on the chiseled treatment was 3.2 cm more than those on the check treatment during the May 18 to June 11 period. The additional water used by millet on the chiseled treatment was likely greater than the additional water extracted from root zone soil storage (Fig. 6) because of a probably influx of water from below the root zone.

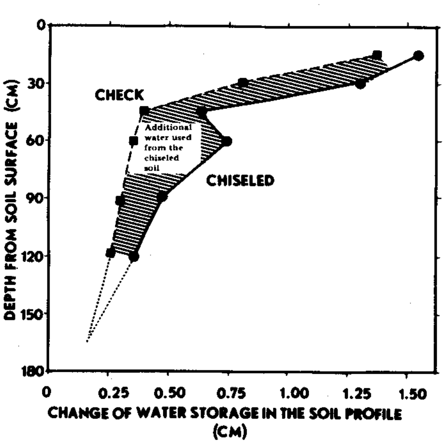

FIG. 6 Change in soil-water storage by millet in the check and chiseled treatments during a drought period, May 18 to June 11, 1970.

The hydraulic gradient (flow direction) between the 90- and 120-cm depths, calculated from tensiometer data (Fig. 4), 1970 and (Fig. 5) 1973, for the full growing season indicate an upward flux of water in the chiseled soil. In 1970 (Fig. 4) the chiseled treatment had an upward flow gradient almost the entire growing season. But the check treatment indicated downward flow until about June 20. The upward direction of flow from June 20 to September 10 on the check treatment had somewhat less gradient than the chiseled treatment. The hydraulic gradient on the check treatment indicated downward flow from about Sept. 20, until the end of the season.

In 1973 (Fig. 5) the flow direction in the chiseled treatment became positive, indicating upward flow, on about June 20, approximately 10 days after 8 cm of rain. But, the check treatment flow direction did not become positive until about July 16, almost a month later. And then the gradient was small. But the chiseled soil treatment had a large positive hydraulic gradient, which indicated water movement upward into the root zone.

Relative-Yield, Relative-ET

The linear relationship between relative-yield Y_i/Y_m and relative-ET, ET^*/ET^*_m, is shown in Fig. 7 (refs. 3, 4, 8, 9). The data for the check treatment (line A) fit a straight line given by the regression equation:

$$\frac{Y_i}{Y_m} = 0.47\frac{ET^*}{ET^*_m} + 48.2, \quad R^2 = 0.95 \qquad [2]$$

Scofield (1945) indicated the relationship to be proportional (line B). The assumption was made that any increase in dry matter yield was considered attributable to the difference in available water in the root zone. Data points above or to the left of the lines (Fig. 7) indicate additional water supplied to the root-zone to produce a larger yield increase, and points below the lines indicate seepage out of the root-zone, thus, decreased yields. Most of the data points for the chiseled treatment fall above lines A and B indicating additional water supplied to the crops from sources not measured, probably the cumulative upward flux from below the

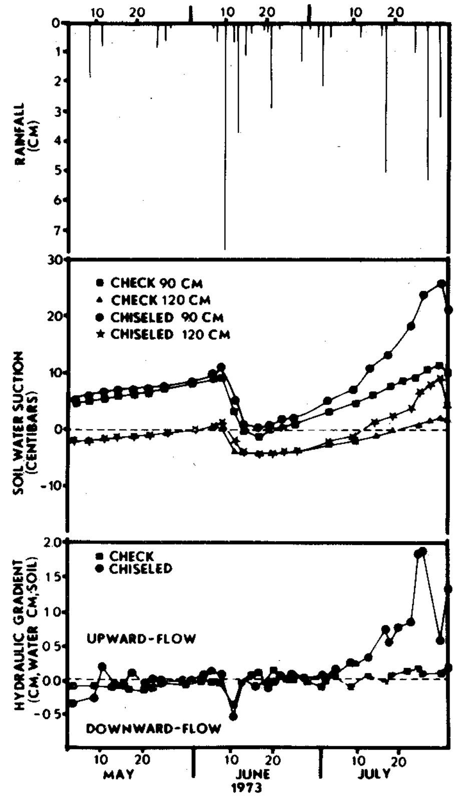

FIG. 5 Rainfall, soil water suction and hydraulic gradient between the 90- and 120-cm depths versus time for the 1973 corn growing season. Herein positive gradient indicates an upward flow of water and a negative gradient seepage out of the root zone.

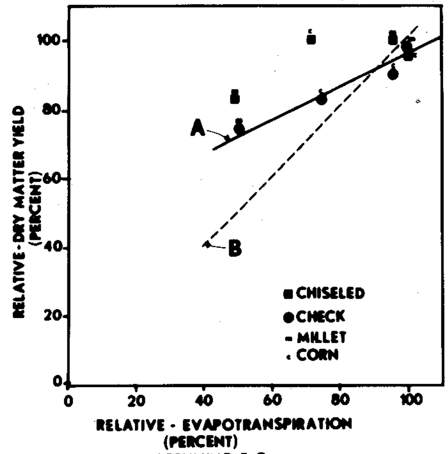

FIG. 7 Relationship of relative-yield to relative-evapotranspiration.

defined root zone, i.e., a positive (F) in equation [1]. Therefore, (F) in equation [1] is not zero. The results indicate a greater upward flux in the chiseled soil treatment than in the check treatment. Regardless of where the relative yield-relative-ET line falls, these data indicate more water was available for plant use in the chiseled than in the check treatment.

Stewart and Hagan (1973) studied plant response to water deficit on a deep Yolo silt loam profile with a deep water table where values of F, in equation [1], were always negative (e.e., drainage out of the root zone). However, where the water table is within 3 meters of the surface F can be either positive – an upward flux into the root zone, and/or negative – a downward flux (seepage) out of the root zone.

TABLE 4. WATER BALANCE FOR GROWING SEASON BASED ON EVAPOTRANSPIRATION RATIOS, CROP DRY MATTER YIELD AND MEASURED WATER.

Growing Season, Year	Crop	Treatment	Water Balance
			RF + I - RO ± ΔS ± F* = ET
			cm
5/8 to 10/7, 1970	Millet	Check	35 + 0 - 4 + 3 + 6 = 40
		Check + irrig.	35 + 38 - 6 + 1 - 14 = 54
		Chiseled	35 + 0 - 5 + 4 + 12 = 46
		Chiseled + irrig.	35 + 38 - 10 + 2 - 10 = 55
4/24 to 7/25, 1973	Corn	Check	33 + 0 - 8 + 7 + 5 = 37
		Check + irrig.	33 + 13 - 9 + 3 + 1 = 41
		Chiseled	33 + 0 - 10 + 8 + 14 = 45
		Chiseled + irrig.	33 + 13 - 9 + 5 + 1 = 43

*F is the balance term and has a plus or minus sign. F includes drainage below 120 cm and the cumulative influx of water into the root zone. A plus value shows the cumulative influx of water into the root zone to be greater than deep seepage. A minus value shows deep seepage out of the root zone greater than the water influx.

Seasonal Water Balance

Potential evapotranspiration estimated from pan evaporation was 58 cm in 1970 for millet and 43 cm in 1973 for corn. These values are in agreement with the ET values presented in Table 4 for the irrigated plots. The ET values presented in this table were determined by multiplying millet yield by the factor 3.89 (Hanks et al. 1969) and by 3.35 cm H_2O/m. ton/ha for corn (Harrold et al. 1959). Values of F were then calculated by combining the measured values of (P + I - R ± S) and ET. Residual errors in the measured components of the water balance equation are included in F. However, errors in F are likely to be systematic and therefore should not affect differences between treatments. Negative F values for the irrigated plots in 1970 indicate a net water loss by deep seepage which correlates with the high rainfall period after the drought (Fig. 4). In the nonirrigated treatments the upward flux (positive F values) in the chiseled plots were 2 and 2.8 times greater than the check plots in 1970 and 1973, respectively. This indicates that when needed water was not supplied by irrigation, the plants in the chiseled soil were able to use more water from below the 120-cm depth than those in the check treatment.

SUMMARY AND CONCLUSIONS

Chiseling the soil 38 cm deep was used to enhance deeper rooting in a soil with a compact A2 horizon. Irrigation water was applied to compensate for the low water holding capacity of these soils. This report compares two tillage treatments and two water management treatments applied annually for 4 years.

Irrigation increased yields during drought periods, but yields were less on irrigated than on nonirrigated plots during periods when the rainfall exceeded pan evaporation. The irrigated plants showed greater oxygen stress when heavy rains followed an irrigation, than those on nonirrigated plots. The probability of receiving enough rainfall to saturate the top 30 cm of soil several times during the growing season is high, and this excess soil-water causes poor root aeration. When excess rain falls on previously irrigated soil, plant growth may decrease significantly from the resulting low soil aeration. Thus, the unpredictable rainfall distribution in the Southern Coastal Plain may hinder adoption of irrigation practices unless new procedures for water application (Phene and Beale 1974) or a system for combining irrigation and drainage (Doty et al. 1974) developed.

However, chiseling the compact A2 horizon increased the rooting depth and plant water availability in the soil profile. Oxygen levels in the chiseled soil were also greater during wet periods than in conventionally tilled irrigated soil. During dry periods chiseling provided a soil environment in which roots proliferated to a greater depth and extracted enough water to eliminate or minimize water stress. During wet periods, the chiseled soil permitted water to infiltrate and percolate to greater depths, thus avoiding saturated conditions in the root zone. Also, relative-yield versus relative-evapotranspiration, water balance and hydraulic gradient data indicated that chiseling increased upward movement of water into the root zone. Chiseling the soil to a 38-cm depth provided a rooting environment which produced significantly more dry matter and larger net crop values than nonchiseled soil with yields and net returns comparable to those on irrigated-nonchiseled soil.

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