Corn Plant Water Stress as Influenced by Chiseling, Irrigation, and Water Table Depth[1]

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ABSTRACT

Improved plant water status through improved soil and water management practices can result in efficient crop production and water utilization in the compact layered soils that restrict rooting in the Southeast. The effect of chiseling and irrigation on plant water status was evaluated through leaf water potential, stem diameter, and stomatal resistance measurements. Corn (*Zea mays* L.) was grown on a Varina sandy loam (Typic Paleudult) chiseled to 38 cm and compared with that grown on conventionally tilled plots. In 1972 chiseling had no measurable effect on the daily minimum leaf water potential under the same radiant energy level. At tasseling in 1973, with a water table 80 cm from the surface, chiseling resulted in deeper-rooted corn that enabled utilization of water in the capillary fringe above the water table, and resulted in slightly higher (less negative) daily minimum leaf water potential, lower stomatal resistance, and smaller stem diameter fluctuations. In 1973, plant-water status on chiseled plots was comparable with that on furrow-irrigated plots. The cumulative effects of the small improvement in midday plant water status from chiseling resulted in a 8-metric ton/ha increase in corn ear yields. These findings suggest chiseling of soils with root restricting layers can result in increased corn production, particularly when the water table is approximately 80 cm from the soil surface at tasseling.

Additional index words: **Leaf water potential, Stem diameter, Stomatal resistance, Deep tillage.**

SUBSURFACE irrigation has been suggested as a method of minimizing plant water stress to optimize yield and quality of marketable product (2, 4). The Atlantic coast flatwoods and some soils of the lower Coastal Plain have a natural high water table from which water can be utilized by most crops if rooting barriers are eliminated. The area's flat topography, summer rainfall, and mild climate are conducive to potentially high production levels of vegetables and other important seed and fiber crops.

Inability to control a constant water table under field conditions has resulted in little research in the U.S. on effects of water table depth on plant water status during the growing season. Much of the water table research has been conducted using static water tables in lysimeters. Goins et al. (3) found that in three soils, ranging from a loamy fine sand to a silty clay loam, cornstalk yields increased significantly when the water table depth increased from 15 to 80 cm. They showed that yield for sweet corn was maximum when the water table depth was 80 cm. Hiler et al. (4) indicated that the optimum water table depth in a Travis fine sandy loam for sorghum (*Sorghum bicolor* L.) was 90 cm, at which maximum yields and optimum protein contents were obtained.

Follett et al. (2) used the water table to complement irrigation by providing additional water in the root zone for crop use. They stated that yields of field corn (*Zea mays* L.), sugar beets (*Beta saccharifera*), and alfalfa (*Medicago sativa* L.) were maximum over the shallowest water tables 69 cm from the surface. There was no differential yield response to irrigation for plants grown over the shallow water table. Yields were consistently greatest over the water table that was as shallow as 69 cm early in the growing season. However when the water table was deeper than 92 cm, irrigation early in the season resulted in a much greater crop response and, when the water table was 145 cm deep in the sandy soil, corn and sugar beet yields were highly dependent upon irrigation. Regardless of the amount of water applied, crop yields from the deeper water-table treatment never exceeded those from the shallowest. These results suggest that if rainfall is limited and flooding is not a hazard, water stress can be minimized and yields maximized for plants grown in areas with a high water table.

Some soils in the lower and middle Coastal Plains of the United States have compact horizons that restrict rooting to the surface layer. The soil physical properties that limit deep rooting and water utilization from the water table were discussed by Campbell et al. (1). They reported that chiseling reduced the strength of the root-restricting layers, increased the rooting depth, and increased millet yields. They concluded that the effectiveness of chiseling layered soils largely depended on the duration of the drought and the soil properties that affected root development and that chiseling could have a significant effect on plant water status and yields. This work evaluates the response of corn plant water status to the interactive effects of chiseling, irrigation, and water table depth.

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METHODS AND MATERIALS

Sweet corn (*Zea mays* L. 'Silver Queen') was grown on a Varina sandy loam (Typic Paleudult) near Florence, S.C., in 1972 and 1973. In 1972 the corn was planted on 30 March in 51-cm rows with a spacing of 30 cm within the row. In 1973 the corn was planted on 25 April in 102-cm rows with a 15-cm spacing and thinned to give the same population of 72,000 plants/ha each year. The corn was fertilized according to S. C. Exp. Stn. soil test recommendations. The fertilizer was mixed with the surface soil by disking to the 10-cm depth. South Carolina Exp. Stn. recommendations were followed in applying the herbicide and nematocide.

A split plot experimental design was used with a plot size of 6.5 by 8.2 m. Main plots consisted of tillage treatments and subplots consisted of water control treatments. Treatments were replicated four times. The tillage treatment was either conventional surface tillage to a 10-cm depth (shallow tilled) or chiseling to a 38-cm depth, to disrupt the A2 horizon, followed by conventional surface tillage. The chisels were spaced 25 cm apart. Only the chiseled and shallow tilled treatments stressed at the critical stage (tasseling) will be compared with the irrigated treatment. The term stressed as used here means rainfall withheld intentionally to allow the plants to deplete the soil water. Drought stress was imposed in 1972 by laying 6-mil polyethylene sheets on the soil surface between the plant rows and stapling it around the plant. Rainfall was withheld to create soil water stress starting 8 June 1972 (day 160, 4 days before tassel emergence) and on 19 June 1973 (day 170, 2 days after tassel emergence) using movable shelters activated by 0.05 cm of rainfall. In the irrigated treatment water was applied in 2.5-cm increments by furrow irrigation to the nonstressed plots when the soil matric potential at the 30-cm depth was —0.2 bar.

Plant water status was evaluated by measurements of leaf water potential, stomatal resistance, and stem diameter. Leaf water potential was measured with a modified pressure chamber (7). Stomatal resistance of the abaxial leaf surface was measured using a commercially available sensor designed by Kanemasu et al. (5). Corn stem diameters were measured at the base of the plant using a Trans-Tek model 240[3], DC-DC LVDT (Linear Variable Displacement Transducer) with a 24-V excitation voltage. Stem diameter and microclimate data at the experimental site were recorded hourly as described previously (6).

Soil matric potential was monitored with tensiometers placed in the soil at 15-cm increments to the 61-cm depth and at 30-cm increments to the 183-cm depth. Matric potential data were supplemented with periodic gravimetric sampling and neutron probe data. The depth to the water table was measured in five wells, each 3 m deep, made of slotted aluminum tubes.

Vegetative yields were obtained by periodic sampling during the season and the ears were harvested 17 days after 50% of the silk appeared.

RESULTS AND DISCUSSION

The water table depth and precipitation for the two growing seasons of 1972 and 1973 are presented in Fig. 1 and 2. In 1972 the water table was 152 cm from the soil surface on day 158, just before tasseling, and remained deeper than 152 cm the rest of the season. Rainfall from planting to harvest totaled 32.4 cm in 1972 and 45.2 cm in 1973. In 1973 the water table declined linearly after planting until day 157, then a 4-day accumulation of 11.9 cm of rainfall caused the water table to rise from a low of 247 cm to the highest level, 80 cm from the surface. As the rainfall decreased, the water table declined to the end of the growing season.

The dynamic nature of leaf water potential and its dependence on radiant energy has been reported earlier (6). Table 1 summarizes the daily minimum leaf water potential on selected days in 1972 and 1973. These values are averages of four to 10 readings obtained between 1300 and 1400 hours on the days indicated. In 1972 there was no measurable difference in the minimum leaf water potential for plants grown on the shallow tilled and the chiseled plots in both the stressed and the irrigated treatments. Before tasseling, the stressed plants had a slightly lower minimum leaf water potential (6). While there was no significant difference between the chiseled and shallow tilled treatments in 1972, the leaf water potentials of the plants on the stressed and the irrigated treatments were not appreciably different after tasseling. The difference in the minimum leaf water potential between the stressed and the nonstressed shallow tilled plots in 1973 was small but larger than measurement error with the pressure chamber. On 20 June, when the water table was near the highest level, there was a 2-bar difference in the minimum leaf water potential between the shallow tilled stressed and the irrigated treatments.

Table 1. Midday leaf water potential on selected days during the drought period.

Year	Date	Leaf water potential			
		Stressed		Irrigated	
		Shallow tilled	Chiseled	Shallow tilled	Chiseled
		bars			
1972	15 June	−15.5	−16.0	−16.7	−15.2
	23 June	−16.3	−17.1	−18.5	−17.6
1973	6 June	−18.2	−17.3	−16.8	−17.0
	20 June	−12.7	−12.9	−10.8	−11.8
	6 July	−18.7	−17.6	−16.6	−16.0

Table 2. Midday stomatal resistance on selected days during the drought period.

Year	Date	Stomatal resistance			
		Stressed		Irrigated	
		Shallow tilled	Chiseled	Shallow tilled	Chiseled
		sec/cm			
1972	15 June	28.4	17.6	--	--
	23 June	11.5	16.7	4.7	6.2
1973	6 June	28.9	7.6	3.3	3.6
	20 June	3.6	2.9	2.8	3.1
	6 July	6.4	2.7	2.5	3.0

Table 2 summarizes the midday stomatal resistance data, representing the average of three to seven measurements. The data show large differences in stomatal resistance between the stressed and the irrigated plants. Although no values were obtained at 1400 hours for the irrigated plants on 15 June in 1972, later data on the same day indicated a low stomatal resistance on the irrigated plots, whereas the plants on the stressed plots had severely wilted leaves with a high stomatal resistance. These data suggest that stomatal resistance is a more sensitive measure of plant water stress than midday leaf water potential.

The effect of tillage depth on stomatal resistance was not consistent in 1972, especially after tasseling (6). Part of the difference between the stressed shallow tilled and chiseled treatments may be explained

[3] Trade names are included for the benefit of the reader and do not infer an endorsement or preference of the products listed by the USDA or the S. C. Exp. Stn.

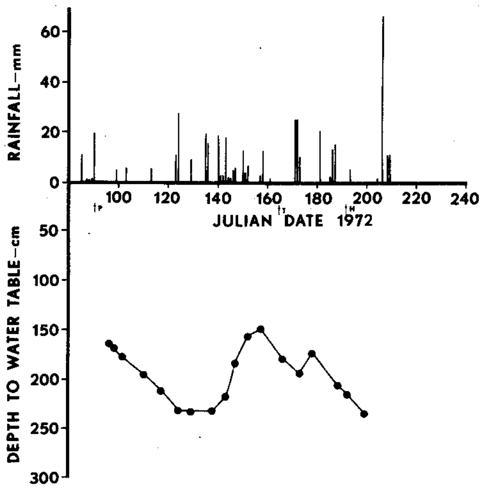

Fig. 1. Rainfall distribution and the depths of the water table during the 1972 growing season at Florence, S. C. P, T, and H are planting, tasseling, and harvest dates, respectively.

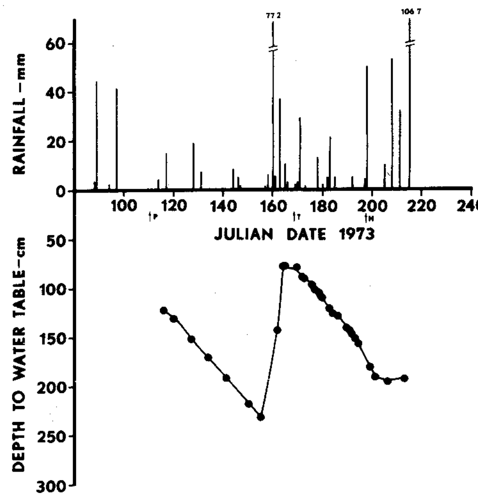

Fig. 2. Rainfall distribution and the depths of the water table during the 1973 growing season at Florence, S. C. P, T, and H are planting, tasseling, and harvest dates, respectively.

by runoff measurements that indicated 0.76-cm additional water infiltrated the shallow tilled plots before 23 June 1972. The 1973 data showed chiseling did affect the stomatal resistance of the stressed plants; e.g., on 6 June the stomatal resistance in stressed shallow tilled plots was several times larger than that of plants in the stressed chiseled plots. On 20 June, with incoming radiation of 35 ly/hour, the difference was not large because of the small evaporative demand indicated by pan evaporation data. On 6 July, a two-fold difference between the stomatal resistance suggests that the plants on shallow tilled plots were stressed more than those on the chiseled plots. There was no difference between plants in the irrigated shallow tilled or chiseled plots. Plants in the stressed-chiseled plots had approximately the same stomatal resistance as the plants in the irrigated plots when the water table was near the surface in 1973.

Examples of the diurnal fluctuations in leaf water potential are shown in Fig. 3 for 6 July 1973. Figure 3A, the diurnal pattern for the shallow tilled irrigated treatment, shows individual points from different plants connected by a solid line drawn through the data points using a 1-2-3-2-1, weighted, running-average technique. The leaf water potential showed a large diurnal change from —1.5 bars before sunrise to approximately —16 bars shortly after solar noon. Although data are not shown, there was no difference in leaf water potential due to chiseling on the non-stressed plants. Diurnal patterns of leaf water potential for the stressed shallow tilled and chiseled plots are shown in Fig. 3B. The individual data points were omitted and only the lines from the weighted running average are shown. In both the shallow tilled and the chiseled plots, plants showed a large diurnal change in leaf water potential from —1.5 bars before sunrise to approximately —18 bars. There was very little difference in the minimum leaf water potential between the shallow tilled and chiseled plants. However the main difference was time response of the leaf water potential at sunset. Plants in the stressed chiseled plots responded to the lower energy flux approximately 2 hours earlier than plants in the shallow tilled plots. Even though the minimum values of the leaf water potential on the stressed treatment were not appreciably different, the differences between the diurnal pattern of leaf water potential indicate the plants on the shallow-tilled plots were stressed longer than those on the chiseled plots.

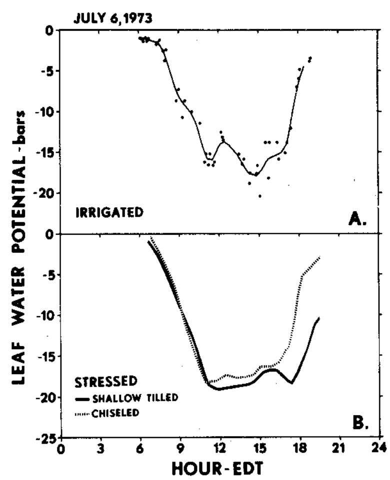

Fig. 3. Diurnal pattern of leaf water potential on 6 July 1973 for shallow tilled irrigated plants (A) and for stressed shallow tilled and chiseled plots (B).

Stem diameter and solar and net radiation data for 4 days during the drying sequence in 1973 are presented in Fig. 4 for stressed and irrigated plants. The stem diameter data are plotted as the relative stem diameter (the difference between existing diameter and the daily maximum diameter, at about 0500 hours, divided by the maximum diameter multiplied by 100). Plants with slightly different diameters can be compared on the same relative basis. Figure 4 shows that stem diameter shrinkage was related to incoming energy and reflected the dynamic nature of the plant water content and indirectly plant water status. The stem shrinkage of the chiseled plants was less than

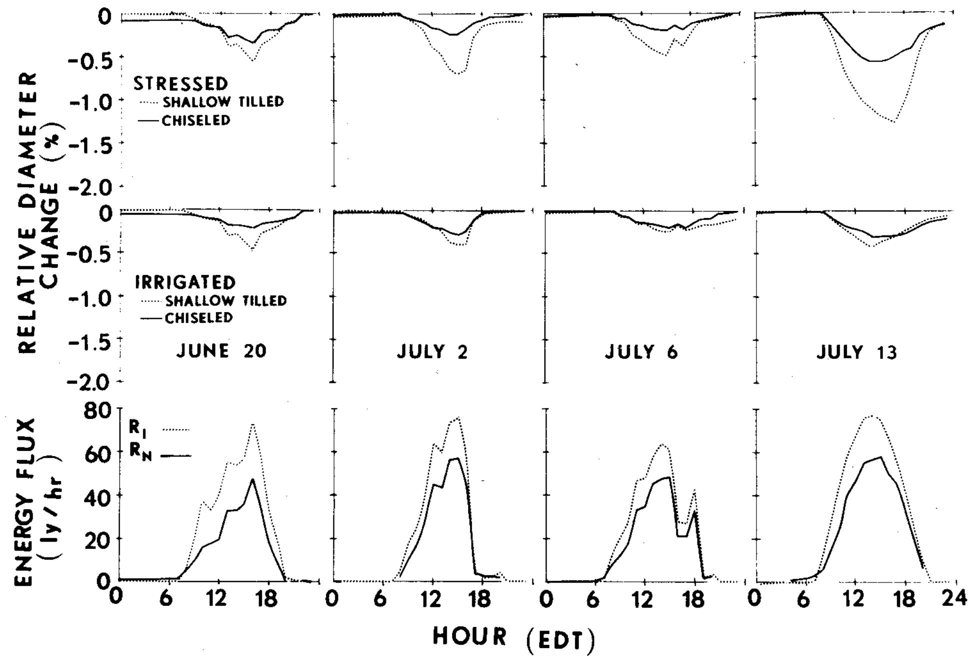

Fig. 4. Relative diam. change for the stressed and the irrigated treatments and energy flux on selected days in the drought cycle in 1973.

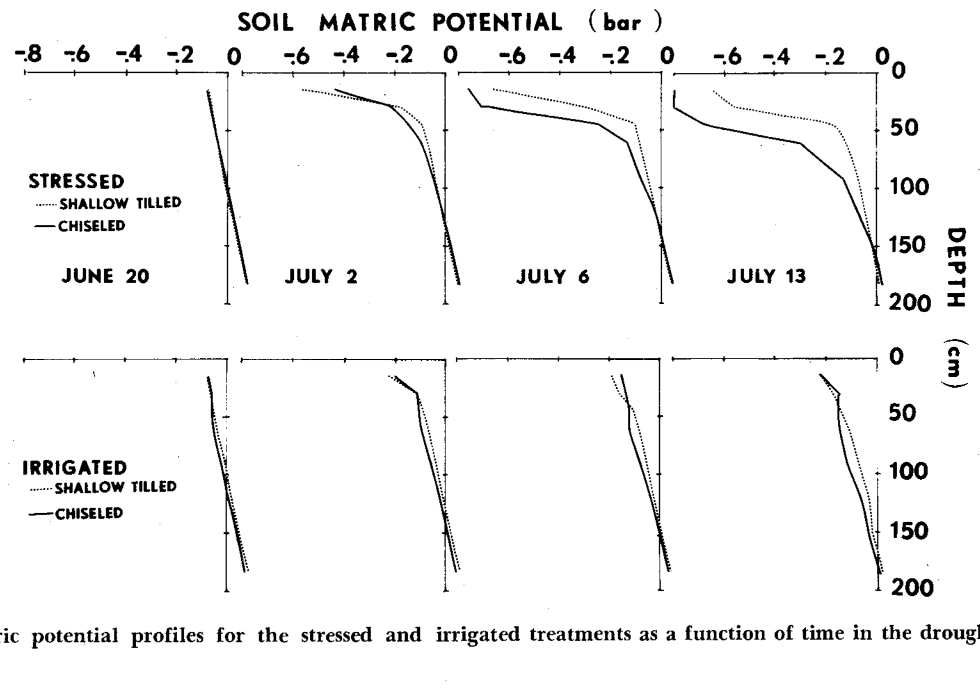

Fig. 5. Soil matric potential profiles for the stressed and irrigated treatments as a function of time in the drought cycle in 1973.

that of the shallow-tilled plants in the stressed plots (Fig. 4). The magnitude of this diurnal fluctuation increased as the drying cycle progressed and reached a maximum on 13 July, which was a clear day with a total incoming radiation of 680 g cal/cm^2. As compared with stressed plots, the stem diameter fluctuations were similar for the irrigated-chiseled and shallow-tilled plots.

The matric potential profiles for the same days, shown in Fig. 4, are summarized in Fig. 5. On 20 June, at the start of the drying cycle, matric potential profiles showed no differences between the stressed and irrigated shallow-tilled and the chiseled plots. However as the drying cycle progressed, the matric potential in the stressed chiseled plots became progressingly more negative with depth and reached —0.3 bar at the 60-cm depth, while that at the same depth in the stressed shallow-tilled plots was —0.14 bar on 13 July. These data and earlier work on rooting patterns (1) indicated that deep-rooted plants in the chiseled plots extracted water from storage and from the capillary fringe. For the irrigated treatments on

Table 3. Sweet corn yield data for the 1972 and 1973 growing seasons.

Year	Tillage	Ear + Husk fresh weight	
		Stressed	Irrigated
		metric tons/ha	
1972	Shallow	11.76 b*	13.96 a
	Chiseled	16.13 a	14.73 a
1973	Shallow	10.18 b	18.31 a
	Chiseled	18.25 a	19.10 a

* Numbers followed by the same letter are not significantly different at the 5% level within each year according to Duncan's multiple range test.

2 July, there was only a small difference in the matric potential at the 91-cm depth as a result of chiseling, however, on 13 July the matric potential was more negative in the chiseled plots. These data suggested that the roots were extracting additional water from this depth, even though the plants were surface irrigated.

Table 3 summarizes the effect on the corn ear yields of chiseling and irrigation. In both years there was no yield difference due to chiseling on the irrigated treatments. However there was a significant difference in yield between the shallow-tilled and chiseled stressed treatments. In 1972, chiseling increased yield 4.4 metric tons/ha over that of the shallow-tilled stressed treatment, while in 1973 yield was increased 1.8 times due to chiseling on the stressed treatment. Since there was no yield increase due to irrigation, our results indicated that when water was adequate there was no benefit from chiseling. The 1973 yields also indicate that, due to the high water table, the plants on the chiseled stressed plots were not really stressed, but obtained sufficient water to produce a yield comparable to those of the irrigated treatments.

In 1972 chiseling had essentially no effect on the minimum leaf water potential and only a small effect on stomatal resistance but irrigating did have some beneficial effect. Soil monoliths showed rooting was deeper and root proliferation greater in the chiseled treatment in 1972 (1). However the water table was about 150 cm from the soil surface, and, even though yield was increased in the chiseled treatment, minimum leaf water potential was not essentially different.

Chiseling slightly affected minimum leaf water potential in 1973, but had much stronger influence on the stomatal resistance and the stem diameter fluctuations. The effect of chiseling on the plant water status in 1973 was also reflected in the yield data. Part of the difference between 1972 and 1973 yield data is explained by the water-table data. In 1973 the water table was within 80 cm of the soil surface, at the critical growth stage for corn, which provided ample water for the deep-rooted plants in the chiseled treatment. The chiseled treatments compared favorably with the irrigated treatments, even when surface water was withheld for approximately 20 days. Our results showed the combined effect of chiseling on increasing root proliferation in the subsoil and the high water table. These two factors resulted in a more favorable plant water status, which in turn increased yields from the chiseled treatments when rainfall was withheld. In 1972, the water table and the capillary fringe was considerably lower in the profile and did not substantially affect plant water status, but did result in a significant yield increase. In 1973 the combined effects of the chiseling and the high water table resulted in yields that were comparable with those from the irrigated treatments. The small differences in midday leaf water potentials were not commensurate with the yield differences measured at the end of the drought. The yield data probably reflect the cumulative effect of the drought and suggest the need for more sensitive and continuous measurement of plant water status. In summary, this work suggests that in the compact layered soils of the Southeastern Coastal Plains controlling water table and tillage interrelationships may be useful in utilizing more subsurface water for increasing crop production.

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