Soil Water Tables Under Corn on Tile-Drained Chalmers Silt Loam[1]

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Abstract

Soil moisture in the corn root zone and the depth of the water table on tile-drained Chalmers silt loam near Lafayette, Indiana, were measured under early- and late-planted corn in the 1971-1973 growing seasons. From relations developed between available soil moisture and the drop of the water table, the amount of upward flux of water into the corn root zone was estimated. The upward flux of water from the water table was estimated to range from as little as 1 per cent of the actual evapotranspiration from corn in the first planting in the wet season of 1972 to 11 per cent in the first planting of 1973, a year with several extended dry periods. High corn yields are dependent upon an adequate supply of soil moisture. Shallow water tables which underlie much of Indiana's cropland can furnish a significant part of the water requirement in summers with periods of insufficient rainfall.

Introduction

Artificial drainage is necessary for efficient crop production on nearly ⅔ or almost 9 million acres of the agricultural cropland in Indiana. The soil water table has usually been considered a farming liability, especially in the spring when often, even with drainage tiles, frequent rains may cause the water table to rise to the surface and delay land preparation and planting operations. Occasionally, rains in the fall may again bring the water table to the surface before harvesting operations are completed, although the probability for this is less than in the spring.

During a field experiment to quantify the effect of weather on corn growth and yields at the Purdue Agronomy Farm, it became evident that a soil water table under the experimental plots had a role in the moisture supply for corn roots during the main part of the growing season. More detailed observations of the variation in height of this water table were made in 1971-73 seasons. The results and interpretations reported here indicate that the flux of water upward from the water table can be a significant part of the water supply for evapotranspiration, especially in a dry year. The possible value of this phenomenon can be appreciated when it is realized that a similar water supply probably underlies much of Indiana's 9 million acres of drained cropland.

Review of Literature

The effect of downward percolation on measuring evapotranspiration by soil moisture changes has been recognized in irrigation areas (12). Capillary rise has been studied most extensively in the European lowlands, and with regard to subirrigation (11).

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Several methods of estimating deep percolation have been used. Since it is a type of unsaturated flow in porous media, theoretical methods can be used if pressure gradients and hydraulic properties are known as functions of moisture content (5, 7). van Bavel *et al.* compared soil moisture changes in a lysimeter to those in a regular field and found that as much as 4 mm per day could flow up into a sorghum root zone from a supply which had percolated downward after irrigation (10). Jaworski found a strong diurnal fluctuation in a shallow water table under young poplar trees (6). The water table dropped during the day with maximum evapotranspiration and rose during the night with side inflow and capillary rise.

Many investigators have observed the presence of water tables, and others have studied the relation between water table depths and yields. Harris *et al.* found that the highest yields of maize on a muck soil occurred when the water table was at 80 cm (4). Van't Woudt and Hagan summarized the effect of water tables on yields in different kinds of soils (11). Influences of water tables on corn yields in Indiana were studied indirectly by Galloway and Sisson as yield variation with distance from tile lines in different years and soil (2). Harlan measured the depth of the water table for 1967 to 1971 under Brookston and Crosby soils in central Indiana (3).

Experimental Techniques

A full season corn hybrid[2] was planted on Field 32 of the Purdue University Agronomy Farm, West Lafayette, Indiana, on two planting dates in each of 3 years. To help interpret the soil water measurements with regard to the development of the corn crop the phenological dates are shown in Table 1. Both early and late crops were planted in 85-cm rows and hand-thinned to plant population densities of 62,000 plants per hectare, a typically high commercial stand in Indiana.

The soil was Chalmers silt loam, a Typic Argiaquoll, and probably as level and homogeneous as any soil found on glacial till. Soil bulk density and the water remaining in the soil at 15 atmospheres tension for each 30-cm layer are provided in Table 2. The plots were tiled with the tile lines approximately 19 m apart and 0.95 to 1.05 m deep. The tile lines are shown in Figure 1.

The soil moisture in the corn root zone was measured all three years with a neutron probe.[3] The locations of the neutron probe access tubes are shown for 1972 in Figure 1. Location of instruments and field plot design were similar in 1971 and 1973. There were five (six in 1973) access tubes in each planting and they were located about halfway between drain tiles in 1972 and 1973, but were approximately over the drain tiles in 1971. Observations with the neutron probe were taken by 30-cm increments in the top 1.5 m, and were calibrated with

[2] SX-29 PAG in 1971 and 1972, courtesy of the late Dr. Wayne Whitehead; and Pioneer 3369A in 1973.

[3] Troxler depth probe, courtesy of Mr. Walter Stirm, Advisory Agricultural Meteorologist, National Weather Service, Purdue University, West Lafayette, Indiana.

gravimetric measurements at the time of placing the access tubes. Measurements were taken twice a week in 1971 and once-weekly in 1972 and 1973.

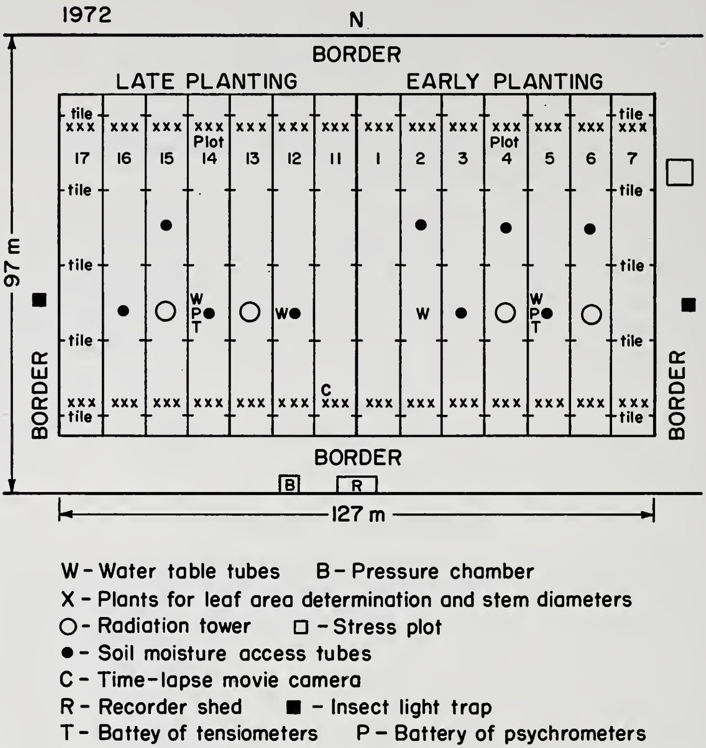


FIGURE 1. *Weather and corn experimental plot layout on Field 32, Purdue University Agronomy Farm, West Lafayette, Indiana, 1972.*

Each year, four 2.5-cm diameter conduit pipes, sealed on the lower end and with small holes drilled in the lower 1 m, were installed to a depth of 2.5 m. Two water table pipes were used in each planting, and on one of the pipes in each planting water stage recorders were mounted for continuous recording of the water table height. The depth of the water table in all pipes was measured with a steel tape and stick at least once weekly.

Results and Discussion

The plant available water—amount above 15 atm retention—in the top 105 cm for both the first and second plantings for 1971, 1972, and 1973 growing seasons is shown as the top set of curves in Figure 2. The top 105 cm represent the depth of the root zone at maximum development. Daily soil moisture amounts between neutron measurements were estimated with a soil moisture simulation program.

TABLE 1. *1971-1973 Purdue Agronomy Farm weather and corn experiment phenological data.*

Season	Phenological Dates				Yield
	Planted	Emerged	Silked	Matured	Bu/acre
1971 First planting	4/28	----	7/16	9/2	167
Second Planting	5/28	6/3	7/27	9/16	156
1972 First Planting	5/3	5/14	7/21	9/11	142
Second Planting	6/1	6/8	8/11	10/4	140
1973 First Planting	5/1	5/13	7/20	9/13	183
Second Planting	5/24	6/3	7/26	9/20	160

With no upward flux of water from the water table, the available soil moisture in the top 105 cm is a direct reflection of the precipitation-evapotranspiration balance. Evapotranspiration causes a gradual decrease in the curves, as moisture is extracted by the corn roots from the entire profile, but preferentially from the top 30 cm with adequate available soil moisture. Precipitation occurrences can be observed on the figures as abrupt increases in the soil moisture content, with the amount of increase equal to the rainfall received less the evapotranspiration for the day of precipitation. The neutron measurements, by 30-cm layers, have been published in the Annual Summary, Indiana, Climatological Data (9) for the specific year.

TABLE 2. *Soil bulk density and water remaining at 15-atmospheres tension for 30-cm layers of Chalmers silt loam, Field 32 Purdue University Agronomy Farm.*

Depth (cm)	Avg. Bulk Density (g/cc)	15-atm Water Retention (mm/30 cm)
0- 30	1.54	47
30- 60	1.48	53
60- 90	1.55	53
90-105	1.68	25
0-105	----	178

The average depths of the drain tiles are indicated by the short horizontal bars along the left ordinate of the figures. Tile lines are all nearer the surface ($\sim$ 95 cm) under the first planting on the east side of the field than under the second planting ($\sim$ 105 cm).

The depth of the water table is shown as the lower set of curves in the same figures. Initially, following winter and spring rains, both the soil moisture and water table levels are high and then decrease with deep drainage and increasing evapotranspiration demands during the growing season. The recharging process came early in 1972, the wettest September on record over much of Indiana, when the water table (Fig. 2b) rose above the tile lines by mid-September. The fall of 1972 will be remembered in Indiana for its high moisture corn and delayed harvesting. It is this dependable winter recharging of soil moisture in the crop root zone, however, which provides the more stable high grain production potentials in the eastern corn belt than in the

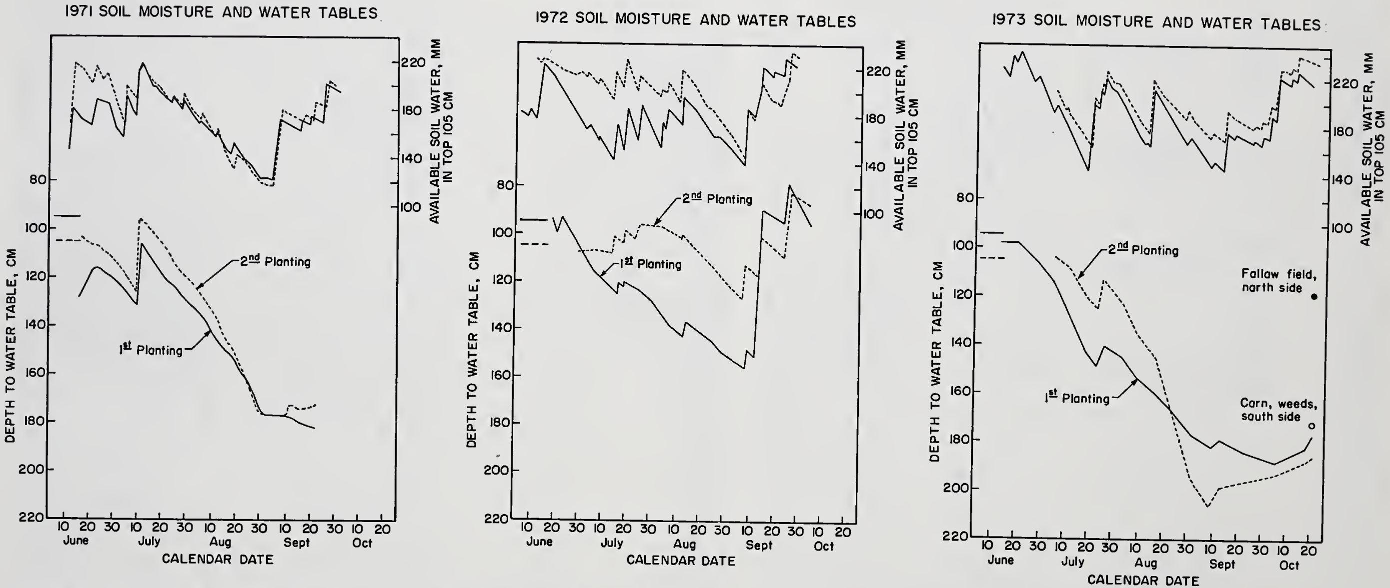
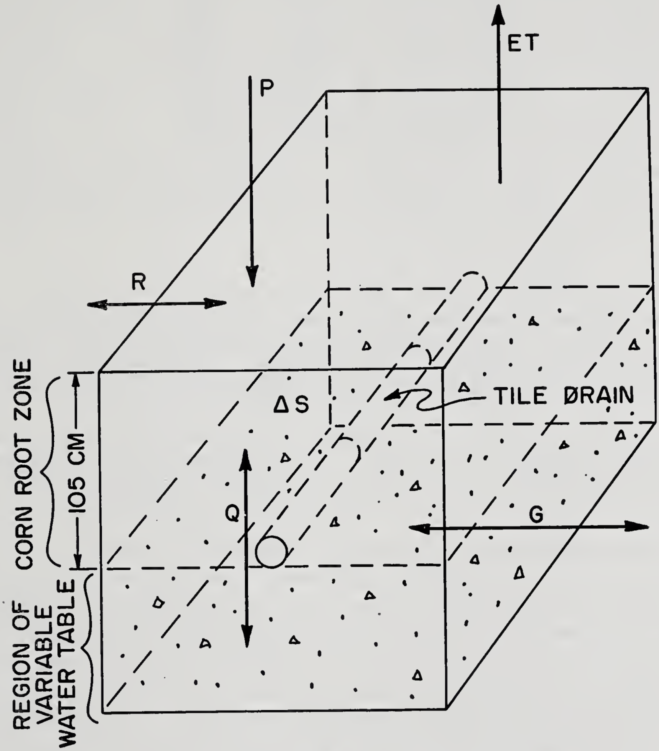


FIGURE 2. *Available soil moisture in top 105 cm and depth of water table under corn for: a. 1971 growing season; b. 1972 growing season; and c. 1973 growing season.*

western corn belt, since precipitation probabilities are very nearly the same over the entire corn belt in the spring and summer (8), when evapotranspiration demands usually exceed precipitation supply.

The problem is to estimate the amount of soil moisture in the corn root zone which has moved upward from the water table for use by plants. The complexity of this problem can be appreciated from the components of the soil water balance sketched in Figure 3. Precipitation (P) can be measured with standard rain gages. The experimental plots are sufficiently level that runoff or runon (R) was observed to be zero. The evapotranspiration (ET) can be estimated for any period as the difference ($\triangle S$) between soil moisture neutron probe measure-



$$\Delta S = P \pm R \pm G \pm Q - ET$$

ΔS = Change in available soil water
P = Precipitation
R = Surface runoff
G = Horizontal ground water flow
Q = Deep percolation
ET = Evapotranspiration

FIGURE 3. *Schematic soil water balance.*

ments at the beginning and end of the period, plus any precipitation, *if there is no other inflow or outflow from the corn root zone.* Although this has been assumed for a first approximation, this assumption is not true.

Even when periods with the water table above the tile lines are not considered, there may be downward percolation, or deep drainage from the corn root zone ($Q\downarrow$), and also water flow upward ($Q\uparrow$) as plant roots remove water and create an upward pressure gradient. The horizontal ground water flow in the unconfined aquifer is designated as G. Under large, level monocultures G can be assumed zero, but in smaller plots this term may be troublesome, especially if adjacent plots do not have the same cropping pattern. For example, in Figure 2a, the 1973 water table curves show rises late in the season when there was insufficient rainfall to explain the rise in water table from surface percolation through the 105-cm profile. Test holes in a fallow field immediately to the north of the experimental plots showed the water table to be about 0.5 m higher while test holes in corn and weed plots to the south showed water table levels similar to those measured in our corn plots. The average of several readings in these test holes late in October are shown in Figure 2c. With this higher hydraulic head to the north, it appears that G was non-zero, at least late in the 1973 season.

The daily rates of water table decrease were determined by dividing the difference between water table depth measurements by the number of days in the interval. When the recorders were operating, hourly rates were summed for the 24 hours ending at 8 AM (to agree with time of climatological observations) for the particular interval. Recorder data showed that water table decreases were generally much greater between 8 AM and 4 PM, but showed no nighttime increases in the 3 years. This latter observation suggests that side inflow (G) is probably small or smaller than any upward flux at night.

To differentiate that part of the water table drop due to internal drainage (leakage) from that caused by flow upwards into the root zone, periods were selected when there was sufficient soil moisture in the top 150 cm to meet evaporation demands, but not excess which would drain freely downward (1). To meet this requirement, *i.e.*, $Q\uparrow = 0$, periods were selected when the available root zone soil moisture was between 150 and 200 mm. To assume that $G = 0$ the other requirement was that the depth of the water not be too far below the tile drains, or be representative of the general water table level in the surrounding area. In this case only periods when the water table depth was between 110 and 130 cm were used. In the six seasons there were 24 cases which met the qualifying conditions. The average drop of the water table for these 24 cases was 8 mm day^{-1} with a standard deviation of 1.3. This "base leakage" rate was assumed constant for all water table depths, and is shown as the dashed line on Figure 4 for the second planting, 1973. The higher rates of water table drop (above this line) represent depleted soil moisture by ET and replenishment ($Q\uparrow$) from the water table. Rates below this line are attributed to some type of water table recharge, either from P or G. It is recognized that the deeper the water table the greater the chance for G to be non-zero.

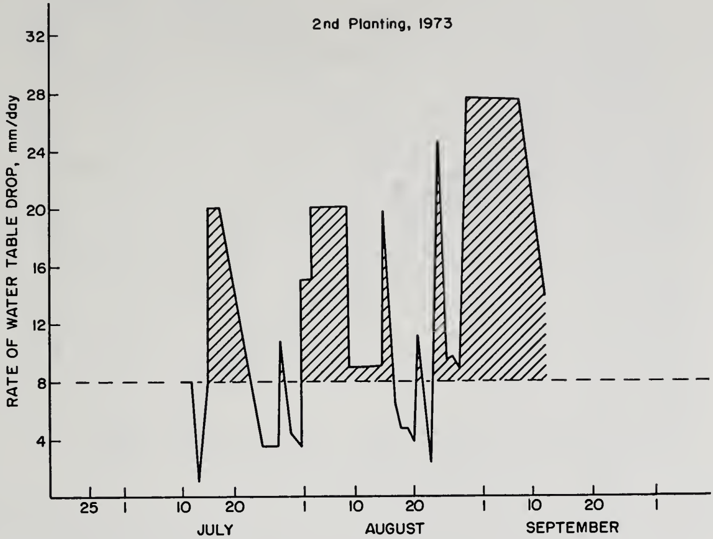


FIGURE 4. *Rate of water table drop under second planting corn, 1973 (average of two wells). Dashed line is estimated average deep drainage rate below tile lines into unconfined, aquifer, 8 mm day^{-1}. Rates above this are caused by evapotranspiration, and rates below this by water table recharge with precipitation, percolation or side flow.*

To obtain some quantitative estimate of Q in relation to changes in the level of the water table, the available soil moisture in the corn root zone was compared to the depth of the water table. As shown in Figure 5 there is high correlation of the available soil moisture in the 90- to 105-cm layer with the depth of the water table. The same relations hold true for other layers where the root zone or parts of it are sufficiently close to free water that depletions can be replaced quickly by capillary rise (Q$\blacktriangle$). The average relation between the available soil moisture in the entire 105-cm root zone and depth of water table is shown by the least squares regression line in Figure 6. The greater scatter is caused by including in this relation the more independent surface layers. Points above the line, say, the cluster near the coordinates, 180,180, represent recent rains in the top of the profile. Points below the line, *e.g.*, that near 120,140, reflect periods where corn roots have extracted soil moisture in the surface layers below the indicated equilibrium condition. The slope of –0.73 indicates that for every 1 cm decrease in the water table, available soil moisture is reduced by an average of 0.73 mm. When ET is zero the change in soil moisture caused by a decrease of 1 cm in the water table would average 0.73 mm through the lower boundary of the root zone, *i.e.*, Q$\blacktriangledown$ = 0.73 mm cm^{-1}. Conversely, with ET but no deep drainage, we assume that 0.73 mm of available water will move into the root zone, Q$\blacktriangle$, and cause the water table to drop 1 cm. In periods where there is a sufficient rate of ET to create a gradient for capillary rise the net Q will be the relative magnitude of the two effects, if we assume no hysteresis.

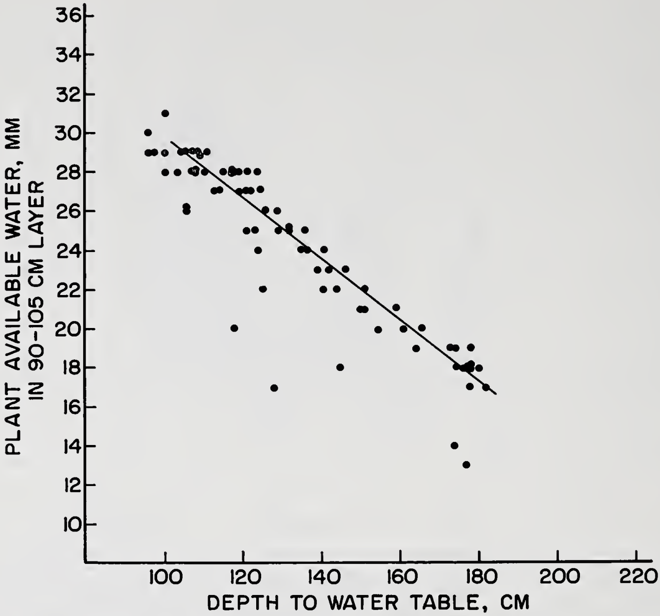


FIGURE 5. *Relation between plant available water in 90-105 cm layer and the depth of water table.*

Using the relationship in Figure 6, and attributing the additional drop in the water table beyond that of the base leakage rate to the decrease caused by capillary use, we can make a rough estimate of the net volume of water which flows into the root zone from the free water below. For example, in Figure 4, Second Planting 1973, if the hatched area is integrated (34 cm) and is multiplied by the average slope, –0.73 mm cm^{-1}, of the Figure 6 relation, the contribution of Q↑ to total ET is estimated as 25 mm. The total ET for the same period (449 mm) is estimated by correcting evaporation pan measurements (used to estimate potential ET) by crop development and moisture stress factors. The ET contribution from the water table is then estimated as 6% of the total ET for the season. The results for the six planting-seasons are shown in Table 3.

In the last 3 years the amount of moisture used by the corn crop from the water table ranged from as little as 1% in the first planting of 1972 to 11% in the first planting of 1973. Although only three relatively wet years are represented, the contribution from the water table is a significant part of the water used, and it may be more than coincidence that the yields shown in Table 1 are proportional to these Q↑/ET percentages.

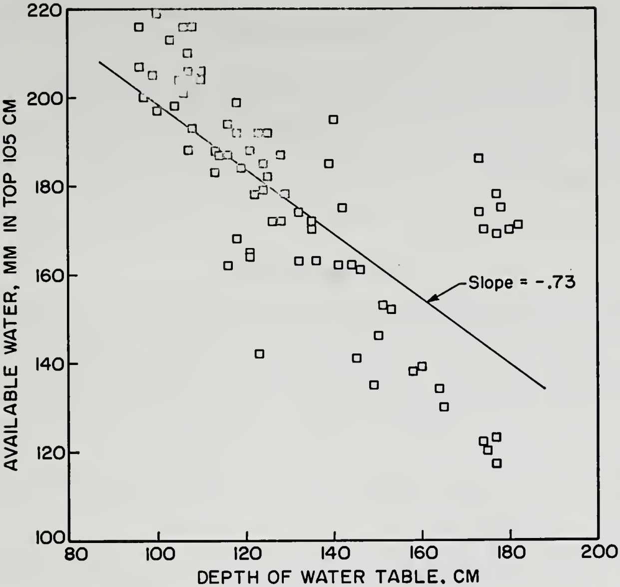


FIGURE 6. *Relation between plant available water (mm) in entire corn root zone, top 105 cm, to depth of water table. Least squares regression slope indicates for each 1-cm drop in water table the plant available water in the corn root zone decreases 0.7 mm.*

TABLE 3. *Percentage of evapotranspiration contributed from water table on tiled Chalmers silt loam, West Lafayette, Indiana.*

Crop	Season	Q↑ (mm)	Est. ET (mm)	Q/ET (%)
1971 First	5/24-9/15	20	482	4
Second	6/4-9/26	24	443	5
1972 First	5/28-9/19	4	418	1
Second	6/19-10/11	6	415	2
1973 First	5/29-9/20	49	446	11
Second	6/3-9/25	25	449	6

Summary and Conclusions

The observed correlation between the depth of the water table and available soil moisture shows that over most of the growing season the corn root zone is in the capillary fringe of free water. The estimates of the amount of water flux up from the free water level into the corn root zone is comparable to values reported in the literature and can be a significant part of the water requirements of the corn crop, especially in a dry year. Harlan's Brookston seasonal water table patterns, including those for the dry summer in 1967, are very similar to those found on Chalmers (3). Should an extensive drought be experienced this valuable water resource might be conserved and more fully exploited by "drainage management", *e.g.*, stopping tile line outlet flow from May to September and utilizing the shallow water table for ET rather than stream flow, or even using the tile lines for subsurface irrigation. Galloway and Sisson came to this same conclusion for poorly-drained soils developed on loess-capped till, like Fincastle, and in depressional areas, like Brookston (2). Generally, on these soils in dry years they found corn yields increased with distance from the tile drains.

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