

Water Requirements and Water Table Variations for a Controlled and Reversible Drainage System

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ABSTRACT

A water mound can be built by controlling the head above the tile outlet. The approximate shape of the mound above three tile spacings, the water requirements, head requirements, and the yield relations to tile depths and spacings are presented.

INTRODUCTION

Erratic rainfall distribution in the Southern Coastal Plains can cause excessively wet soil during one period and excessively dry soil during another. The water-holding capacity of the sandy soils is about 2.25 cm/30 cm of soil, enough to supply crop water needs for 5 to 7 days. Controlled water table levels maintained close enough to the soil surface will allow the plant roots to withdraw water from the capillary fringe above the water table and reduce plant-water stress during droughts.

Recently, farmers, scientists, and water management engineers have become concerned with overdrainage, particularly in sandy soils. In sandy soils of the Carolina Bays, soybean yield was higher for surface drainage than for subsurface drainage (Doty, 1973). Although extensive drainage is needed in the Florida Everglades for flood control, over-drainage can cause drought which will affect land, wildlife, and towns (Ward, 1972).

The relationship of water table to yield of many field crops has been investigated. Doty et al. (1975) found that silage yields of field corn increased by 0.5 t/ha for each additional day the water table was maintained at less than 100 cm from the surface in a sandy Coastal Plains soil. Rogers and Harrison (1974), Williamson and Gray (1973), Hiller et al. (1971), Campbell and Seaburn (1972), and Williamson and Kirz (1970) showed the best crop response when the water table was maintained between 60 and 100 cm from the surface in lysimeters filled with sandy soils. In a field experiment, Follett et al. (1974) reported that yields were maximum in plots over a shallow water table, 60 to 90 cm below the surface. Irrigation of the crops over the shallow water table resulted in no increase in yield.

These findings show that controlling the water table could possibly increase crop production in the Coastal Plains area. According to the Soil Conservation Service

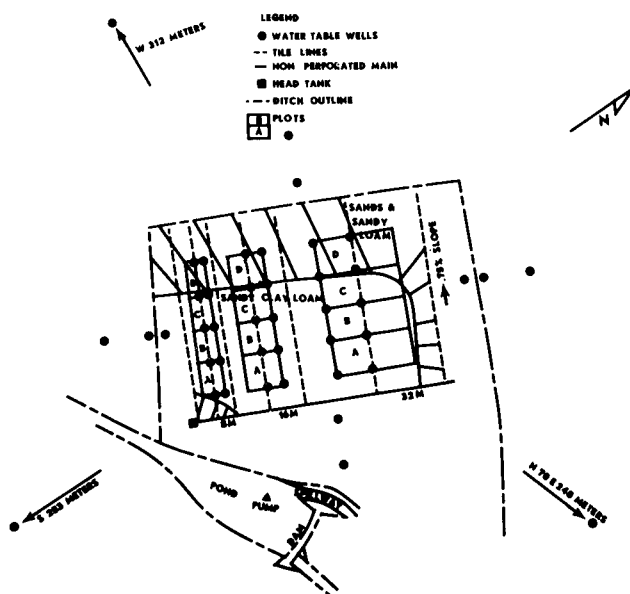


FIG. 1 Sketch of controlled and reversible drainage research site showing relation to pond, tile layout, yield plots and soil textures.

(SCS), an estimated 2 million ha of sandy and sandy loam soils in the Southern Coastal Plains have a seasonal high water table that can be controlled.

Controlled and reversible drainage systems (CaRDS) have worked well in highly permeable sandy soils (Doty et al., 1975, and Follett et al., 1974). However, a water mound must be built above the tile drains for the system to operate satisfactorily in the heavier upland soils with the water table fluctuating from 0.5 to 3 m below the surface. After a water mound has been developed and maintained, a crop can obtain water from the capillary fringe area above the water table and from water movement into the root zone. Reicosky et al. (1976) showed that sweet corn produced better yields on chiseled soil when the water table came to within 0.8 m below the surface.

The objective of this paper is to show that a "water mound" can be built by controlling the head above a drain outlet. The approximate shape of the mound above three tile spacings, the water and head requirements, and the yield responses to the tile depths and spacings are presented.

THE EXPERIMENTAL DESIGN AND PROCEDURE

The experimental area (Fig. 1) consisted of 1.7 ha of land area, whose surface sloped 0.75 percent, parallel to the subsurface conduit direction and no side slope. The cuts, during grading, did not exceed 12 cm. The composite soil map of the area, where the water table fluctuates between 45 and 150 cm below the surface, is shown in Fig. 1. The soil textures include sands, sandy loams, and sandy clay loams. The sands and sandy loams

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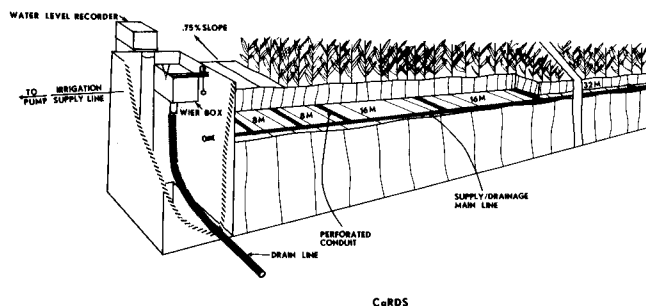


FIG. 2 Sketch of controlled and reversible drainage system.

were classified by SCS soil scientists from soil cores taken on 30-m square grids as Brogdon (*Phenthic paleudults*), Johns (*Aquic hapludults*), Chipley (*Aquic quartzipsaments*), and unclassified. The sandy clay loam was Goldsboro (*Aquic paleudults*).

Seven perforated, coconut-fiber wrapped, 8-cm diameter, corrugated PVC conduits were installed with a laser-controlled drain-tube plow at spacings of 8, 16, and 32 m (Fig. 2). The gradient was 0.2 percent toward the outlet. The depth to the conduit was 90 cm at the lower side and 130 cm at the upper side of the pregraded plots. The seven perforated conduits were connected to a non-perforated 20-cm diameter mainline that ran perpendicular to the perforated laterals (Fig. 2). The mainline was connected to a constant head tank, which controlled the amount of water entering or leaving the plots (Figs. 1 and 2). Water was supplied to the head tank by an electrical pump submerged in an adjacent pond. The amount of water pumped, measured by a 10-cm flow meter, was read daily.

The constant head tank was equipped with a V-notch weir box connected to the tank drainline with a flexible tube. The height of the weir box was adjustable to control the water head at any elevation within the tank. The float control was mounted on the weir box so that when the weir was raised or lowered the float control was appropriately adjusted. With the weir in position, water flowed into the field through the main line and the perforated drain conduits. When the water level in the tank dropped about 6 cm the float-controlled electrical switch activated the pump and refilled the tank to the bottom of the V-notch weir. Drainage was accomplished by lowering the weir box. In 1975, the weir box was lowered to drain the tile lines; but in 1976, no drainage was allowed through the supply drainage mainline. Drainage from the tile system was measured through the V-notch weir (Fig. 2).

Rainfall and pan evaporation were measured with a standard weather-bureau recording rain gage and screened evaporation pan near the site. The water table level was measured continuously with FW-1 water level recorders at 30 locations in the Plots and at 10 locations outside, but within 40 m of the plots. The water table at three locations, 312, 248, and 253 m from the center of the site (Fig. 1) was measured manually each week.

The natural water table was defined as the plane that intersected the water table elevation (measured weekly) at the three wells (W312, N70E248, and S253), located farthest from the experimental site (Fig. 1). The water mound was defined as the free water surface that asymptotically approached the natural water table outside the plot area.

For comparison with the actual water applied to CaRDS,

the irrigation requirements were estimated by the following equation:

$$S_n = S_{n-1} - ET^* + R - L \quad \dots \dots \dots [1]$$

where

- S_n = soil water storage for day n, in cm
- S_{n-1} = soil water storage for day n-1, in cm
- ET^* = estimated evapotranspiration for day n, in cm, obtained from screened pan evaporation multiplied by a factor, ranging from 0.2 to 1.1, depending upon the corn's growth stage†,
- R = rainfall, in cm,
- L = estimated water lost to runoff, deep seepage, and/or lateral subsurface flow, in cm
- L = $\begin{cases} 0, & \text{if } S_n \leq S_{max} \\ S_n - S_{max}, & \text{if } S_n > S_{max} \end{cases}$
- S_{max} = Available water capacity of the top 100 cm of soil

It was estimated from equation [1] that irrigation was needed and applied in the model when $S_{max} - S_n > 2.5$ cm.

A full-season hybrid corn was planted each year. Fertilizer was broadcast over the entire area at rates recommended by Clemson University, based on soil tests. The yields, measured in each 1-m row on each side of the tile lines, were averaged and graphed against the distance from the tile line. The sloping surface on the field provided a variation in depth to the tile line on the nine plots (Fig. 1, A, B, and C for each drain spacing) of sandy clay loam soil. The average yield for each plot was compared with the depth to the drain line.

The yield data for the sandy clay loam soils were analyzed as a non-replicated $2 \times 3 \times 3 \times 2$ factorial. The factors were, left and right sides of the tile, tile spacings, depth to the tile, and years. A non-replicated $2 \times 3 \times 2$ factorial was used for the sandy loam soils because of only one depth to the tile line. In both cases, the high-order interaction was used as the error term. We also assumed that the factors were independent.

RESULTS AND DISCUSSION

The CaRD System successfully formed a water mound over the tile lines in a sandy clay loam soil. The water mound varied somewhat and was not always maintained at the desired level. The water mound, perched above the natural water table, fluctuated with the natural water table (Figs. 3 & 4). For example, on July 16, 1975 (Figs. 3 and 4 A), the natural water table was 0.1 m below the tile lines, and the water mound averaged 0.3 m above the tile lines, thus providing a water mound 0.4 m high. But on August 27, 1975 after 35 days without rain (Fig. 4B), the natural water table dropped to 0.8 m below and the water mound to 0.2 m below the tile line for an average water mound height of 0.6 m. Difficulty in maintaining the desired water mound elevation was probably caused by flow restrictions, the low hydraulic conductivity of the soils, or some other restriction in the system. This is shown by the fact that the amount of water pumped increased as the natural water table decreased, but the maximum pumping capacity (>5 cm/day) was never

†Irrigation Water Requirements, Tech. Release No. 21, U.S. Department of Agriculture, Soil Conservation Service, 1970.

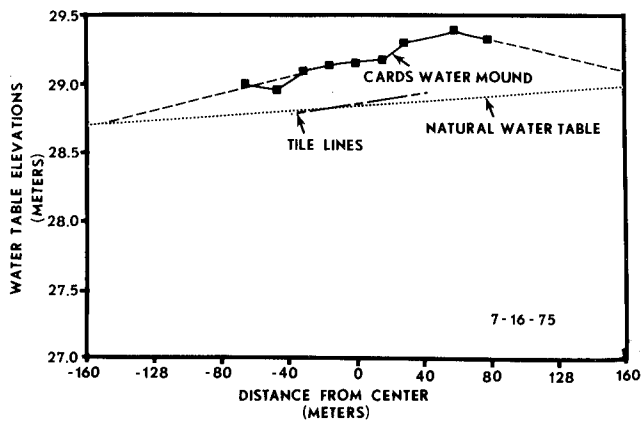


FIG. 3 Water mound - a cross section through the center of the plot parallel to the tile lines on July 16, 1975.

reached. The pumping rate averaged 0.36 cm/day on July 15, 16, 17, 1975, and 0.43 cm/day on August 26, 27, 28, 1975. Even though the pumping rate increased and the height of the water mound increased from 0.4 to 0.6 m above the natural water table, the water flow rate into the soil was not sufficient to maintain the water mound at the desired elevations above the tile lines.

After several large rains in June and July 1976, the natural water table was estimated to be above the tile lines, but the water mound did not rise as high as expected (Fig. 4 C) even though the water level in the head tank was maintained above ground level. Large amounts of runoff were observed during heavy rainfall, which may account for the small rise in the water mound because the natural water table rose faster outside the area than in the research site. The 0.75 percent slope and the saturated profile produced conditions for large amounts of runoff. The water elevation in the constant head tank, the estimated elevation of the natural water table at the center of the CaRDS site, the water mound elevation, and the rainfall are shown for 1975 and 1976 in Fig. 5 A and B, respectively.

Considerable head was required (the difference in elevation of the water level in the head tank and the elevation of the water mound, 30 cm from the tile line) to maintain the water mound. The head required was about 0.75 m during the early part of the 1975 season and about 1.3 m in August and September (Fig. 5 A). During 1976, the water level in the head tank was held constant, and the required head varied from an average of about 0.65 m until July, and increased to about 1.25 m at the end of the season, when the natural water table dropped to about 1.1 m below the tile lines (Fig. 5 B). However, the water table in the field (30 cm from the 16-m spaced tile line) was controlled within 0.35 m of the desired elevation in 1975, a year with less-than-normal rainfall. In 1976, the rainfall was above normal and with the water level in the head tank held constant, the water table in the field remained within +0.2 and -0.4 m of the desired elevation.

Water Requirements

Total estimated irrigation needs for 1975 and 1976 were 38 and 26 cm, respectively, while the water pumped into the CaRD system was 41 and 26 cm, respectively. In 1975, the total water input to the CaRD system (rainfall and water pumped) was 75 cm, and the screened pan evaporation was 71 cm (Fig. 6). Very little excess water was added to the system during the 1975 growing season

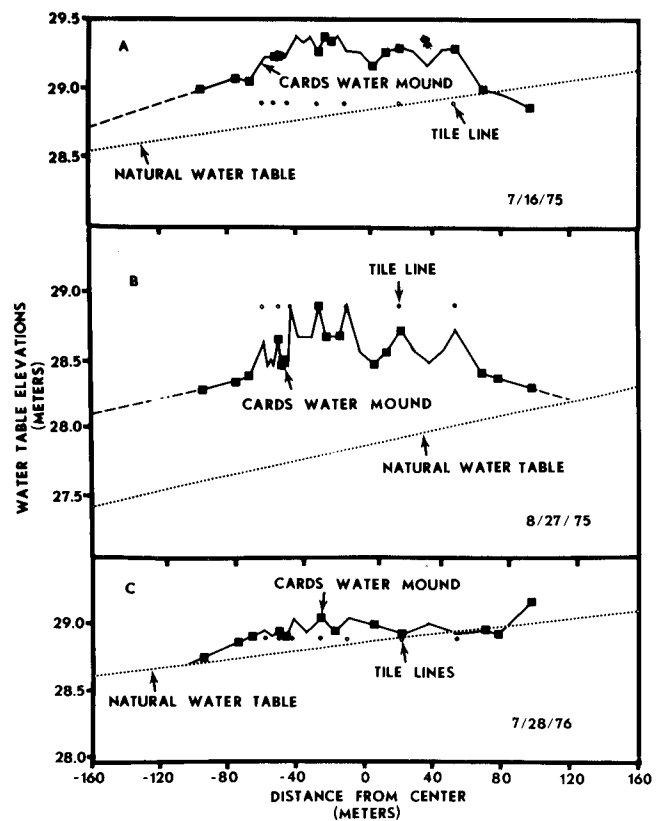


FIG. 4 Water mound - a cross section through the center of the plot perpendicular to the tile lines.

- A. Natural water table near drain lines.
- B. After 35 days without rain.
- C. After high rainfall period in 1976.

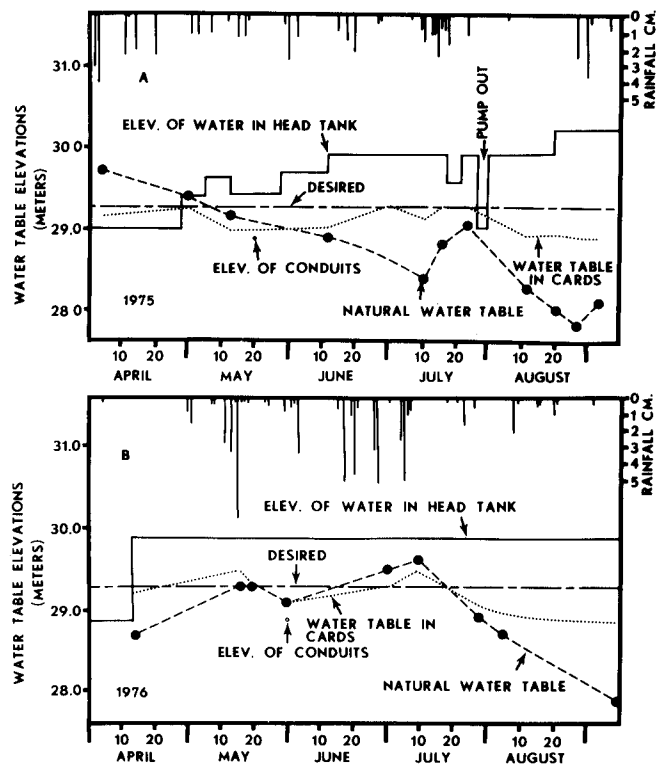


FIG. 5 Rainfall, water level in constant head tank, CaRDS water table and natural water table estimated for the center of the plot.

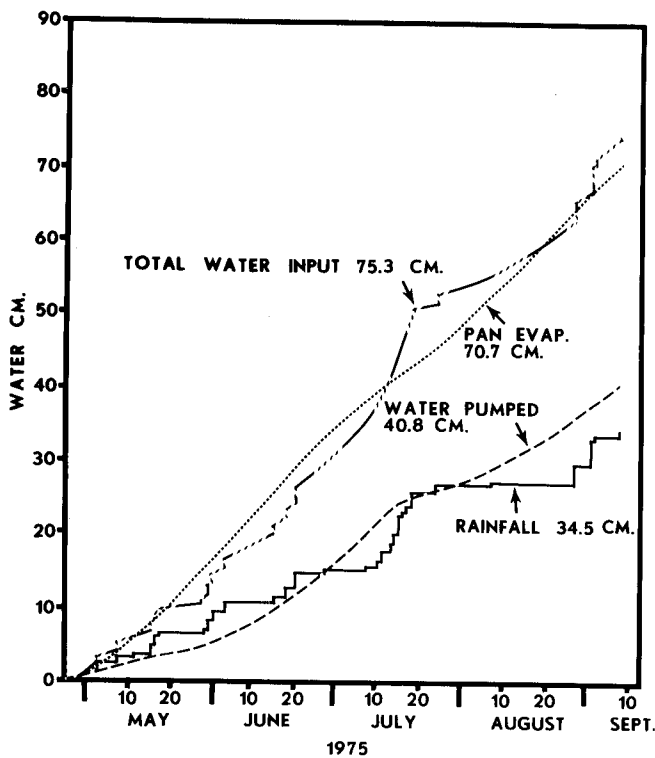


FIG. 6 Accumulated rainfall, water pumped into the system, and pan evaporation measurements for 1975.

with 34 cm of rainfall. However, in 1976, with 61 cm of rainfall during the growing season, the total water input (rainfall and water pumped) was 87 cm, and the pan evaporation was 65 cm (Fig. 7). Excess water was estimated as 10 cm in 1975 and 30 cm in 1976. Because of the high intensity rains in 1976 (Fig. 5 B), our visual observations and the established row slope of 0.75 percent, we assumed that most of the excess water left the plot as surface runoff.

Generally, the CaRD system provided sufficient water for corn production. There were only 2 days in August, 1975 and 1 day in August, 1976 when the system did not supply enough water to meet the estimated evapotranspiration demands of the corn crop.

Yields

Since there are two soil textures in the site, yield and

TABLE 1. SUMMARY OF SHELLED CORN YIELD ON SANDY CLAY LOAM SOIL (A) BY YEAR AND DEPTH TO TILE LINE, (B) BY YEAR AND TILE SPACING

(A)	Drain line depth (m) NS			
Year**	0.9	1.0	1.1	Mean
	-----t/ha-----			
1975	8.2	8.1	7.1	7.8
1976	6.8	7.1	6.9	6.9
Mean	7.5	7.6	7.0	7.4
(B)	Tile spacing (m) NS			
Year**	8	16	32	Mean
1975	8.5	7.4	7.5	7.8
1976	6.6	6.9	7.3	6.9
Mean	7.6	7.2	7.4	7.4

NS - Nonsignificant

**Significantly different at the 99 percent level.

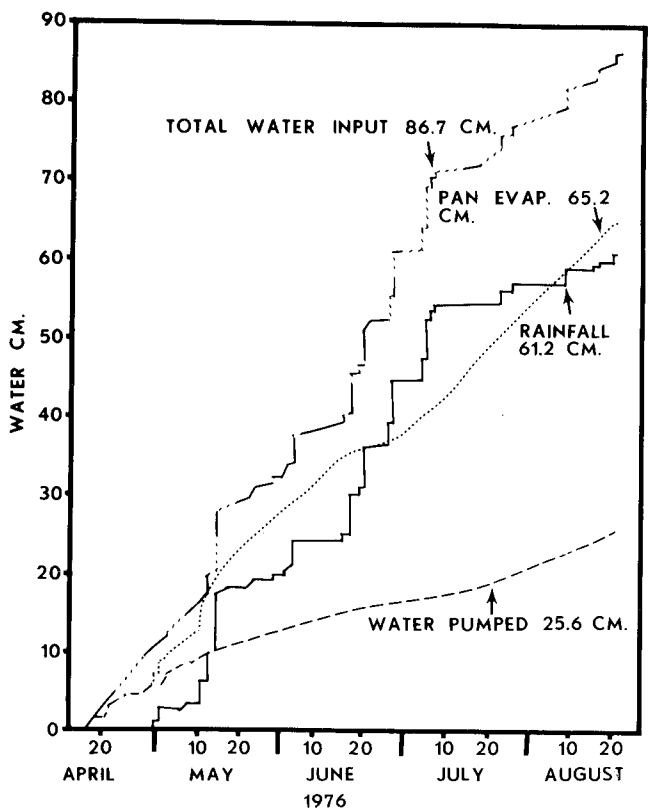


FIG. 7 Accumulated rainfall, water pumped into the system, and pan evaporation measurements for 1976.

related data must be separated into two groups — (1) those from sandy loam soil and (2) those from sandy clay loam soil. The difference in yield of shelled corn, due to year, was significantly different for both soil textures (Tables 1, and 2). Yields from the sandy clay loam soils were not significantly different among drain depths, or tile spacing (Table 1A & 1B). The significant interaction between year and tile spacing is shown in Fig. 8.

Corn yield means for the sandy loam soil were significantly different for both years and tile spacing (Table 2). The yield for 32-m tile spacings was greater than those for either 8- or 16-m spacings in 1975. However, yield for the 16-m tile spacing was highest in 1976.

Yield difference between years can be explained by the rainfall. In 1975, the daily rainfall was about 2 cm or less (Fig. 5A) and the CaRD system supplemented the soil moisture to produce yields of 7.8 t/ha. But in 1976, much more rainfall occurred (Fig. 5B) and the water in the head

TABLE 2. SUMMARY OF SHELLED CORN YIELD BY YEAR AND TILE SPACINGS FOR A SANDY LOAM SOIL WITH THE TILE AT 1.2 m BELOW THE SOIL SURFACE

	Drain line spacings (m)*			
Year**	8	16	32	Mean
	-----t/ha-----			
1975	8.2	9.3	10.0	9.2
1976	6.8	7.8	7.6	7.4
Mean	7.5	8.6	8.8	8.3

*Significantly different at the 95% level.

**Significantly different at the 99% level.

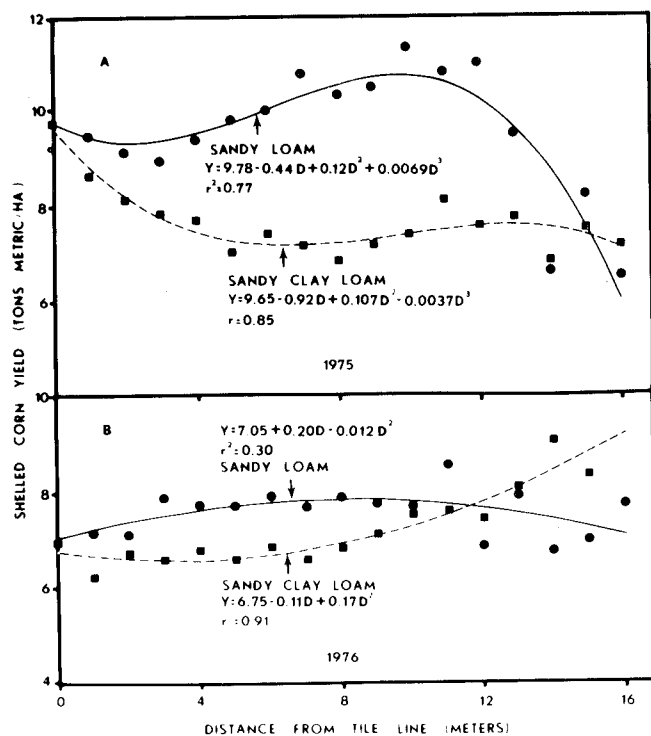


FIG. 8 Relation of yield of shelled corn to the distance the row was from the tile line in a sandy clay loam and a sandy loam soil. (Average of all drain line spacings).

tank was maintained at a constant level. Drainage from the tile lines was prohibited, which caused a high water table in the field, adversely affecting corn growth especially in the sandy clay soils where the tile lines were closer to the surface. This shows the importance of management of the water table and providing proper drainage.

Variations in corn yield, with distance from the drain line for both soil textures, and all drain tile spacings, are shown in (Fig. 8). Corn yields for sandy loam and sandy clay loam soils were almost the same for rows over the drain line where the soil was disturbed by the drain-tube plow. Regression analysis of corn versus the distance of the row from the tile line, explained 85 percent of the yield variation in 1975, and 91 percent in 1976 for the sandy clay loam soils. The corn yields generally decreased at greater distances from the tile line in 1975, but increased at greater distances from the tile line in 1976 (Fig. 8). These data and the strong interaction between year and tile spacing in Table 1 showed a lack of water table control in the sandy clay loam soil. As shown in Fig. 4, the water table was farther from the soil surface 16 m away than near the drain line. With the water mound receding as the natural water table receded in 1975, soil water was not available for maximum production. During 1976, there was enough soil water from rainfall to produce top yields without water table control.

Yield for the sandy loam soils did not correlate as well with distance from the drain line. Regression analysis showed that 77 percent of the yield variation was due to distance from the tile line in 1975, but only 30 percent in 1976.

The 32 m tile spacings produced the highest average yields (Table 2). The 1.2 m drain depth in the sandy loam plots was also important. The water under the positive pressure of the head tank caused a water

table in the sandy loam soil at the up-slope end of the plot to rise (Fig. 3) and apparently provided sufficient water to produce better corn yields than in the sandy clay loam soils.

SUMMARY AND CONCLUSIONS

A controlled and reversible drainage system was designed, instrumented, and operated for 2 years. Rainfall was below normal in 1975 and above normal in 1976.

A water mound was formed above the estimated natural water table, but could not be maintained at the desired elevation because of flow restrictions in the soil and/or in the conduit system.

A positive head was required to produce the water mound. Drainage is necessary to produce maximum yields with the controlled and reversible drainage system. About the same amount of water was required by CaRDS as estimated for a normal surface-applied irrigation system. Losses of water from CaRDS to deep seepage and/or lateral subsurface flow did not seem to be excessive. The total water input to CaRDS was 5 cm more than pan evaporation in 1975 and 22 cm more in 1976. There were only 2 days in 1975 and 1 day in 1976, all in late August, when water was not available to meet estimated ET from corn crop.

The highest yields (2 year average) were produced between tile lines spaced 32 m apart on both sandy loam and sandy clay loam soils; however, difference in yields for the 8-, 16-, and 32-m spacings were significant only at the 85 percent level.

Regression of yield on distance from the tile line accounted for 85 percent to 91 percent of the yield variation. There was an interaction between years and yields on sandy clay loam soils, which was probably attributable to the different rainfall patterns of the 2 years and to no drainage occurring from the tile lines in 1976, when rainfall was above normal. The data indicated that controlled and reversible drainage can be accomplished with drain lines spaced 32 m apart for sandy clay loam soil, if drainage is provided during excessive rainfall. In sandy loam soils, 32-m spacings produced the highest yields. Therefore, 32 m or wider spacings can be used in sandy loam or more permeable soils. Doty et al. (1975) reported satisfactory results from drain line spacings of 40 m or more in sandy soils.

The advantages and disadvantages of the controlled and reversible drainage system (CaRDS) were discussed by Doty et al. (1975). This study adds information on sandy clay loam soils. Although these results are favorable, we are not ready to recommend "CaRDS" for irrigation alone. However, if a drainage system is needed for sandy clay loam soils, we would certainly recommend adding a control structure to the system. This could be done at a small cost and would save water for possible drought periods.

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