Crop Water Supplied by Controlled and Reversible Drainage

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THE water-holding capacity of the sandy loam soils of the Southern Coastal Plain ranges from 2 to 5 cm per 30 cm of soil, about enough to supply crop water needs for 5 to 10 days. The rainfall is erratic, ranging from 70 to 194 cm annually and from 3 to 35 cm in July. However, because the natural water table is within 2 m of the surface, some soils need drainage during wet periods. On the other hand, because of the erratic rainfall and low water-holding capacity soils, irrigation is needed during dry periods. A controlled and reversible drainage (CaRD) system could alleviate either stress under these rainfall and water table conditions.

Skaggs (1977) showed that overdrainage could occur in Wagram soils (Arenic Paleudults), and stated that, on the average, "a drain spacing of 43 m would result in 34 or more dry days in 1 year out of 5." He also showed the benefits of a CaRD system with 30-m tile spacings that would provide for adequate trafficability and limit drought stress to only 3 days on a 1-year-in-5 basis.

Doty et al. (1975), Doty and Parsons (1979), Skaggs (1972), and Skaggs et al. (1972) showed that the CaRD system works in Coastal Plain soils. Tovey (1969), Carter and Floyd (1972), and Follett et al. (1974) showed that there was no advantage in supplying irrigation water when the water table was within 1 m of the surface.

This CaRD system was installed on a Goldsboro soil (Aguic Paleudults), a site that would not normally be used for controlled and reversible drainage, to study crop water supplied by a CaRD system in a moderately permeable soil by building a water mound with a head on tile lines.

Doty and Parsons (1979) studied the irrigation water requirements for this same CaRD system, and showed that tile spacing had little effect on crop yield. In 1977, selected plot yields were 3.2, 3.4, and 3.2 tons/ha for 8-, 16-, and 32-m spacings, respectively. Therefore, in this report I have considered the entire CaRD system to report: (a) a method to evaluate water use by crops, (b) the water supplied to a corn crop by a CaRD system in a moderate permeability soil, and (c) a water balance for the entire system.

Article was submitted for publication in October 1979; reviewed and approved for publication by the Soil and Water Division of ASAE in February 1980.

Contribution from the Coastal Plains Soil and Water Conservation Research Center, USDA-SEA-AR, Florence, South Carolina in cooperation with the SC Agricultural Experiment Station.

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Acknowledgements: The author acknowledges the work of Mr. J. E. Parsons, Mathematician, and Ms. Ann Kirby, Biological Technician, in preparing the computer programs and processing the data for this study, and Mr. Vic Rogers, Research Technician, for collecting the data in the field.

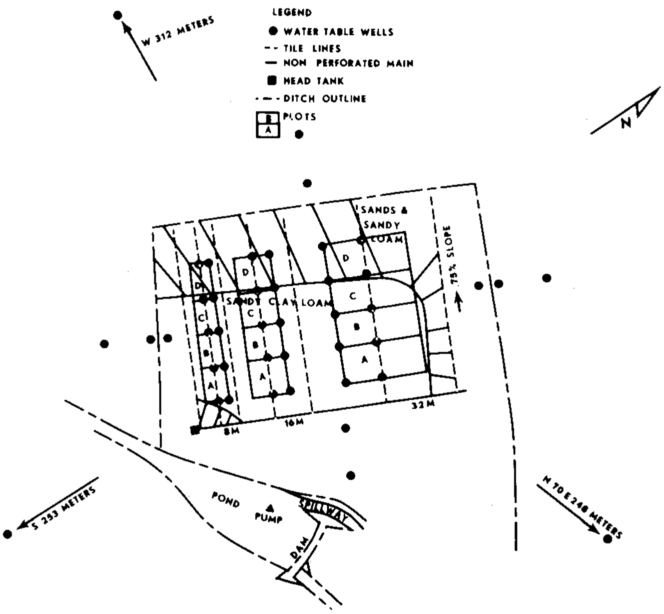

FIG. 1 Plot layout for controlled and reversible drainage system.

EXPERIMENTAL SITE AND PROCEDURE

The experimental area (Fig. 1) consisted of 1.7 ha of land formed to have a 0.75 percent slope parallel to the drain lines and zero slope perpendicular to the drain lines. Perforated, corregated polyvinyl chloride (PVC) coconut-fiber wrapped drain tubes 8 cm in diameter were installed at spacings of 8, 16, and 32 m with a laser-controlled draintube plow. The CaRD system was described in detail by Doty and Parsons (1979). The entire area was planted to corn on 23 April 1975, 7 April 1976, and 26 April 1977.

The CaRD system was operated by controlling the head on the tile outlets about 30 cm below the soil surface. When rainfall raised the water table in the field to within 45 cm of the surface the head was lowered and drainage outflow allowed (except in 1976) until the water table in the field dropped to the desired level about 70 cm below the surface.

The soils in the plot area were classified as Goldsboro (Aquic Paleudults) sandy clay loam, and Brodgon (Plinthic Paleudults), Chipley (Aquic Quartzipsamments), and Johns (Aquic Hapledults) sands and sandy loams. The relation of soils to the entire area is depicted in Fig. 1.

Suction release curves were determined using pressure plate apparatus on undisturbed core samples from three locations in the sandy clay loam soils and two locations in the sandy soils. Soil water storage was determined from tensiometer measurements made three times per week and suction-release curves. Tensiometers were installed

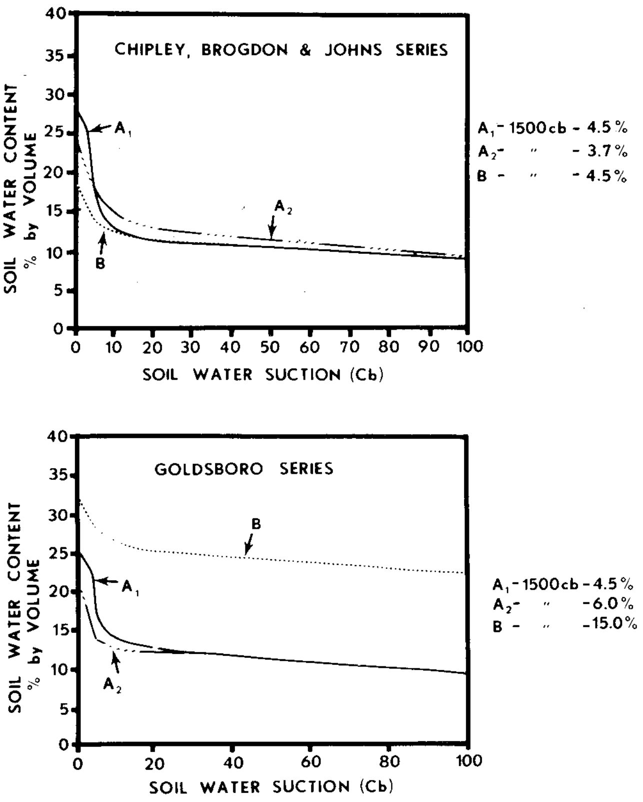

FIG. 2 Suction release curves.

at 15-, 30-, 45-, 60-, and 75-cm depths near the drain tubes and midway between the drain tubes in each plot. Plots A, B, and C (Fig. 1) were in the Goldsboro sandy clay loam soil, and plot D was in sandy soil.

Saturated hydraulic conductivity (K) was measured by the auger hole method at 8 locations within the experimental area and 18 locations around the outside perimeter.

Rainfall (R), screened pan evaporation (SPE), water pumped (P), and water table elevations, from recorder charts at 42 locations, were measured daily. Drain tile outflow (T) from the area was measured with a 30 deg V-notch weir. Rainfall, water pumped, soil-water storage, and drain tile outflow were measured directly. Evapotranspiration was estimated from screened pan evaporation.

The maximum available soil water storage capacity, Smax of the top 92 cm of soil, was calculated from the suction release curves in Fig. 2. Soil water storage was considered to be at the wilting point when soil water suction of the A_1, A_2, and B horizons was 1500 cb, and at field capacity when suction was 5 cb in these horizons of the sand and in the A_1 and B horizons of the Goldsboro soil. Field capacity in the A_2 horizon of the Goldsboro soil was assumed to be at the 3-cb range. The storage was weighted according to percentage of the area represented by each bank of tensiometers to obtain Smax for the CaRD system.

The daily soil water storage in the system and the excess water (E_n) (runoff, lateral loss, and deep seepage) were estimated by the following equations:

$$Sp_n = S_{n-1} + R_n + P_n - ET^*_n - T_n \quad \text{[1]}$$

where

SP_n = Potential soil water storage for day n in cm.

S_{n-1} = Soil water storage for day n−1 in cm.

R_n = Rainfall for day n in cm.

P_n = Water pumped to system for day n in cm.

ET^*_n = Evapotranspiration for day n in cm, obtained from screened pan evaporation multiplied by the cropping factor K_c, (Soil Conservation Service, 1967).

T_n = Tile outflow from the system for day n in cm.

The estimated excess water (E_n) (runoff, lateral loss, and deep seepage) for day n in cm is then defined by:

$$E_n = \begin{cases} 0 & , SP_n \leq Smax \\ Sp_n - Smax & , Sp_n > Smax \end{cases} \quad \text{[1a]}$$

where

Smax = Maximum available soil water storage in the top 92 cm of soil.

The soil water storage in the system for day n (S_n) is then defined as $Sp_n - E_n$ and:

$$S_n = S_{n-1} + R_n + P_n - ET^*_n - T_n - E_n \quad \text{[1b]}$$

where

S_n = Soil water storage in the system for day n in cm.

E_n = Estimated excess water lost to runoff, lateral loss, and deep seepage for day n in cm.

Since the water table was maintained at about the 92-cm depth, I assumed that $E_n \geqslant 0$.

To compare the water applied by the CaRD system to the irrigation water that would have been needed by any other type irrigation system, I calculated the irrigation needs for the corn crop without the CaRD system by the following equations:

$$SIP_n = SIP_{n-1} + R_n - ET^*_n \quad \text{[2]}$$

where

SIP_n = Potential soil water storage under irrigation for day n in cm.

The estimated excess water (X_n) (runoff and seepage) for day n is then defined by:

$$X_n = \begin{cases} 0 & , SIP_n \leq Smax \\ SIP_n - Smax & , SIP_n > Smax \end{cases} \quad \text{[2a]}$$

and the estimated irrigation need (I_n) for day n is defined by:

$$I_n = \begin{cases} 0 & , SIP_n \geqslant 0.5\ (Smax) \\ 2.5\ \text{cm} & , SIP_n < 0.5\ (Smax) \end{cases} \quad \text{[2b]}$$

Since $I_n < 0.5$ Smax (5.90 cm) and irrigation is not needed when $SI_n >$ Smax, there can be no conflict, but I_n

and X_n must be included in the final equation.

$$SI_n = SI_{n-1} + R_n - ET_n^* - X_n + I_n \quad [2c]$$

where

SI_n = Soil water storage under irrigation for day n in cm

and the total irrigation need for the year is:

$$I = \Sigma_o^n I_n \quad [2d]$$

The water balance by weekly intervals were taken from the following equations:

$$\Delta SC_n = S_n - S_{n-1} \quad [3]$$

ΔSC_n = Calculated change in soil profile storage to 92 cm. The available water (AW) is considered that which is available to meet ET. When water is available for crop use AW = ET*. AW is defined as the balance:

$$AW_n = R_n + P_n \pm \Delta SC_n + T_n - E_n \quad [4]$$

These daily values were summed to give weekly values as shown in Table 1.

The water balance in the system for the fallow and cropping period was defined by

$$ET = R + P - T - E \pm \Delta S \quad [5]$$

where

ET = Evapotranspiration in cm, calculated as the balance

ΔS = Change in the system soil profile water storage to a depth of 92 cm based on tensiometer data and suction release curves measured in cm.

R, P, T, and E = Summed valued of R_n, P_n, T_n, and E_n for each period.

RESULTS AND DISCUSSION

In the sandy clay loam soils, the suction, water-release curves for the drying cycle showed much greater water content at all suctions in the B horizon than in the A horizons (Fig. 2). In the sandy soils, the differences between the A and B horizons were small. The maximum available soil water storage, Smax was calculated as 11.8 cm.

The saturated hydraulic conductivity inside the plot area ranged from 0.96 to 1.23 m/day, with a mean of 1.2 and a SD of ±0.2 m/day. The hydraulic conductivity on the parimeter, where some areas were sandy to the depth of the water table, ranged from 0.3 to 1.3 m/day, with a mean of 0.9 and a SD of ±0.3 m/day.

Water Table Control

The water table can be controlled within limits by building a water mount with the CaRD system (Doty and Parsons, 1979). The water table levels ranged from about 0.1 to 1.4 m from the surface. Even though the water table dropped to about 1.4 m from the surface, the plants probably received water if roots were near or within this depth. Roots were found at depths greater than 75 cm when samples for suction release curves were taken. In evaluating water supplied to the crop by the CaRD system, I assumed a rooting depth of 92 cm.

Soil Water Inputs

The 1975 water inputs were 34.5 cm rainfall and 40.8 cm water pumped, for a total of 75.3 cm, which was 4.6 cm more than the 70.7 cm of screened pan evaporation. The estimated irrigation need for 1975 was 38 cm (equation [2d]).

In 1976, 25.6 cm of water was pumped into the CaRD system and rainfall was 61.2 cm, for a total water input of 86.7 cm. Screened pan evaporation was 65.2 cm. The estimated irrigation need for 1976 was 25.6 cm (equation [2d]).

Water input for the 33-day period of bare fallow in 1977 was 5.0 cm of rainfall and 5.3 cm of water pumped, for a total of 10.3 cm. Screened pan evaporation was 18.4 cm for the period.

During the corn growing season of 1977, rainfall was very erratic. Temperatures exceeded 35°C for several days at a time, which caused extreme stress in corn. Rainfall was 52.2 cm, and 21.5 cm of water were pumped into the system for a total of 73.7 cm of total water. The screened pan evaporation was 78.7 cm, 5.0 cm more than the water supplied. The estimated irrigation need for the corn crop was 22.5 cm (equation [2d]).

Corn Yields

The corn yields were excellent (8.2 t/ha) in 1975 and good (7.0 t/ha) in 1976, but because of inadequate stand, replants and worm damage, they were almost a failure (3.7 t/ha) in 1977. However, compared to the yields (0.7 t/ha) from a comparable tillage test about 500 m up slope, the CaRD system increased yields by over 400 percent in 1977. Furthermore, inadequate stand and worms were not factors in the tillage test. There were four possible explanations for the low corn yields in 1977: (a) Extremely high temperatures during pollination; (b) late corn plants did not produce (blackbirds damaged the corn seedlings and corn was replanted twice); (c) army worms attacked the late corn and it may not have used available water as a normal corn crop would; and (d) water may not have been available when needed because of restricted flow from the drain lines due to clogged holes or low hydraulic conductivity of the soil. However, inspection of the drain lines showed very few clogged holes and the measured hydraulic conductivities were about 1.2 m/day. Therefore, high temperatures, late corn, poor stand, and insect damage most probably caused the plants to yield poorly in 1977.

Since no drainage was allowed to leave the CaRD system through the tile lines in 1976, wet soils probably caused the yields to be lower than 1975. Excess water was recorded in June and July (Table 1).

Development of Evapotranspiration Relationship

In order to complete a water balance for the CaRD system, evapotranspiration from the system was determined. Campbell and Phene (1976) reported that screened pan evaporation (SPE) had almost a 1:1 ratio with potential evapotranspiration (PET); therefore, I assumed that SPE was PET. The crop coefficient curve for corn, K_c, was used to convert PET to crop water use or evapotranspiration (Soil Conservation Service, 1976).

TABLE 1. CALCULATED WATER BALANCE BY WEEKLY INTERVALS FOR THE CARD SYSTEM DURING THE PEAK WATER USE PERIOD FOR CORN.†

													Water	
1975	R	+	P	±	ΔSC	—	T	—	E	=	AW	ET*	Deficit	Excess
Week								cm						
6/18-25	2.11	+	2.94	—	0.10	—	0.00	—	0.42	=	4.53	4.53	0	0.42
6/25-7/2	0.50	+	3.42	+	0.08	—	0.00	—	0.00	=	4.00	4.00	0	0.00
7/2-9	0.13	+	4.18	—	0.72	—	0.00	—	0.00	=	3.59	3.59	0	0.00
7/9-16	7.63	+	3.55	—	0.60	—	0.01	—	8.63	=	1.94	1.94	0	8.64
7/16-23	2.61	+	1.00	+	2.42	—	0.00	—	2.47	=	3.56	3.56	0	2.47
7/23-30	1.14	+	1.22	+	1.78	—	0.00	—	0.00	=	4.14	4.14	0	0.00
7/30-8/6	0.00	+	1.59	+	2.96	—	0.00	—	0.00	=	4.55	4.55	0	0.00
8/6-13	0.20	+	2.29	+	0.31	—	0.00	—	0.00	=	2.80	2.80	0	0.00
8/13-20	0.00	+	2.08	+	2.08	—	0.00	—	0.00	=	4.16	4.16	0	0.00
Total	14.32	+	22.27	+	8.21	—	0.01	—	11.52	=	33.27	33.27	0	11.53
1976														
6/18-25	6.22	+	0.58	+	0.53	—	0.00‡	—	5.42	=	1.91	1.91	0	5.42
6/25-7/2	8.51	+	0.48	+	1.27	—	0.00	—	7.08	=	3.18	3.18	0	7.08
7/2-9	9.59	+	0.47	—	1.46	—	0.00	—	5.59	=	3.01	3.01	0	5.59
7/9-16	0.00	+	0.58	+	4.17	—	0.00	—	0.00	=	4.75	4.75	0	0.00
7/16-23	0.36	+	1.52	+	1.97	—	0.00	—	0.00	=	3.85	3.85	0	0.00
7/23-30	2.21	+	1.60	—	0.39	—	0.00	—	0.00	=	3.42	3.42	0	0.00
7/30-8/6	0.00	+	1.41	+	2.33	—	0.00	—	0.00	=	3.74	3.74	0	0.00
8/6-13	2.16	+	1.58	—	0.86	—	0.00	—	0.00	=	2.88	2.88	0	0.00
8/13-18	0.92	+	1.22	+	0.43	—	0.00	—	0.00	=	2.57	2.57	0	0.00
Total	29.97	+	9.44	+	7.99	—	0.00	—	18.90	=	29.31	29.31	0	18.09
1977														
6/18-25	4.82	+	1.37	—	2.35	—	0.00	—	0.00	=	3.84	3.84	0.00	0.00
6/25-7/2	0.94	+	1.17	+	3.02	—	0.00	—	0.00	=	5.13	5.13	0.00	0.00
7/2-9	0.00	+	1.33	+	4.50	—	0.00	—	0.00	=	5.83	5.83	0.00	0.00
7/9-16	2.34	+	1.32	+	2.12	—	0.00	—	0.00	=	5.78	5.78	0.00	0.00
7/16-23	3.18	+	1.12	+	0.68	—	0.00	—	0.00	=	4.98	6.34	1.36	0.00
7/23-30	2.95	+	1.14	—	0.23	—	0.00	—	0.00	=	3.86	6.96	3.10	0.00
7/30-8/6	14.19	+	0.80	—	9.84	—	0.06	—	1.14	=	3.95	3.95	0.00	1.20
8/6-13	0.00	+	0.90	+	3.58	—	0.00	—	0.00	=	4.48	4.48	0.00	0.00
8/13-20	10.87	+	0.73	—	3.98	—	0.32	—	4.51	=	2.79	2.79	0.00	4.83
Total	39.29	+	9.88	—	2.50	—	0.38	—	5.65	=	40.64	45.10	4.46	6.03

†R = Rainfall
P = Water Pumped
ΔSC = Change in soil profile storage to 92 cm as calculated by equation [3]
T = Drain tile outflow
E = Runoff lateral loss and deep seepage calculated by equation [1a]
AW = Available water for ET as a balance
ET* = Screened pan evaporation X Kc
Deficit = ET* - AW
Excess = T + E
‡No tile drainage allowed in 1976.

The daily evapotranspiration, ET^*_n, was calculated using SPE x K_c, and then the daily soil moisture storage to a depth of 92 cm was calculated with equations [1], [1a], [1b], Smax, and the initial soil moisture storage calculated from tensiometer data. The soil water storage calculated by equation [1b] was generally in good agreement with the soil water storage measured with tensiometers (Fig. 3). Equation [1b] tended to show too little water removal in the bare fallow period. During the first 50 days after the corn was planted, agreement between the predicted storage and that measured by tensiometers was good. Equation [1b] apparently overestimated water use during portions of July and August 1977. This is expected because the surface soil water content had decreased below the threshold value (Ritchie, 1972). Also, because of the later poor stand and insect damage, corn may not have used water as rapidly as predicted. However, SPE x K_c and equation [1b] satisfactorily expressed consumptive water use in the CaRD system.

The water balance data (Table 2) indicate that these procedures underestimated evapotranspiration by only

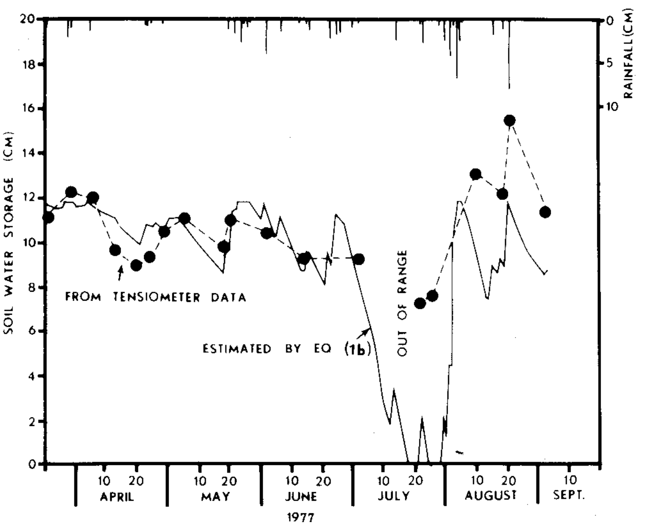

FIG. 3 Soil water storage estimated by equation [1b] as compared with soil water storage determined from tensiometer data for a 92 cm profile depth.

TABLE 2. WATER BALANCE FOR THE CARD SYSTEM IN 1977*

Field cond.	No. days	R	+	P	—	T	—	E	±	ΔS	=	ET	ET*
						cm							
Fallow	33	5.0	+	5.3	—	0.0	—	3.5	—	4.6	=	11.4	7.9
Corn	117	51.9	+	19.3	—	0.6	—	12.6	—	0.5	=	57.5	60.8

*R = Rainfall in cm.
P = Water pumped into the CaRD system in cm.
T = Drain tile outflow in cm.
E = Excess water loses (runoff lateral loss and deep seepage) in cm.
ΔS = Change in soil profile storage to a depth of 92 cm in cm.
ET = Evapotranspiration — balance in cm.
ET* = Calculated in cm.

3.5 cm during fallow periods and overestimated it by only 3.3 cm during the corn growing season. The 3.3-cm difference during the corn growing season is within 5.7 percent—adequate to evaluate the CaRD system.

Moisture Supplied by the CaRD System

In 1975 and 1976, the water supplied during the growing season by the CaRD system for crop use, AW, (equation [4]) was the same as ET*, 57.4 and 53.1 cm, respectively and also during the tasseling and ear fill stages, shown in weekly periods in Table 1. This table shows that the CaRD system furnished ample water for crop production in an area where a water mound was built to control the water table. However, if water had been supplied at the necessary rate by R and P, the soil water storage would have remained constant in both 1975 and 1976. But water was removed from the profile both years as shown by + ΔSC (Table 1).

Rainfall in 1975 was below normal for 35 days during July and August, and during this period, P increased to supply water (Table 1). However, the P increase was not sufficient and the crop withdrew water from soil storage.

Rainfall came at approximately 2-week intervals in 1976. The head tank was not lowered to facilitate drainage through the drain tile. The results were very similar to those of 1975, except that in 1976 rainfall was excessive during the period from June 20 to July 5, and therefore, less water was pumped (Table 1).

The Southeast was a disaster area for corn production in 1977. From June 20 to July 25, the maximum temperature exceeded 35°C, with the exception of two 2-day periods. Minimum temperature during this period ranged from 18°C to 25°C, but was mostly above 21°C. This causes larger daily ET* values than for any other period during the 3-year study (Table 1). The water balance (Table 1) for weekly intervals during June, July, and August showed that deficits occurred from July 16-30. However, the daily accounting showed deficits on July 19, 20, 21, 24, 25, 26, 27, and 28, 1977. Lightning struck the pump that supplied water to the system on July 22 and it was 4 days before it was repaired. This causes deficits of up to 1.15 cm/day from July 24-28. The maximum water pumped during July 19-21 was 0.2 cm/-day. Why the water pumped during this period did not increase as in 1975 and 1976 is not clearly understood. For whatever reason, the result was insufficient water in the system to supply ET* for about 8 days in the latter part of July. After this, there was available water in the system to meet evaporative demands (Table 1).

These data show that water can be supplied as needed to a corn crop using a CaRD system, but some water is taken from soil storage. Also, if the weather is extremely hot and dry during the peak water use period, as in 1977, water cannot be supplied with the present design fast enough to meet plant needs in this soil at a permeability of 1.2 m/day. The mean estimated water use for the hot, dry period, July 16-30, 1977 was 0.95 cm/day (Table 1). The system supplied water at only about 0.2 cm/day during this period. Such a low output of the system indicates some clogging in the system or decreased hydraulic conductivity of the flow path in the soil.

Calculations after Skaggs et al. (1972), using the 16-m spacing and the mean water table elevations for the 14-day hot, dry period in July 1977, indicate that this CaRD system should supply ET at a rate of about 0.44 cm/day which is not enough to meet the 0.95 cm/day, ET. But in a more permeable soil, with a hydraulic conductivity of 3.0 m/day, water can be supplied at about 1.11 cm/day. Therefore, the soil permeability was one limiting factor for this CaRD system in 1977 during the period of high evaporative demands.

SUMMARY AND CONCLUSIONS

Corn was grown for 3 years on a 1.7-ha plot provided with a controlled and reversible drainage system. Data were taken to measure the water supplied to the corn crop. Relationships were obtained from the literature or developed to measure the evapotranspiration from the corn crop and estimate the irrigation needs.

The data on evapotranspiration were checked by using ET* to determine the soil water storage in the soil profile and to compare this with the actual soil water storage determined from tensiometer data and suction release curves. The estimated soil water storage was slightly greater than the actual during the fallow period, and agreed with the actual data during the first 50 days after corn emergence. The estimated soil water storage was less than actual toward the end of the corn-growing season. However, the data were in close enough agreement to measure consumptive use of the corn crop for the 3-year period.

The water pumped into the CaRD system was greater than the estimated irrigation needs for the corn for 1975 and 1976, but was less than the estimated irrigation needs in 1977.

This CaRD system supplied water to meet the daily evaporative demands of the corn crop in 1975 and 1976, but soil permeability or drain spacing limited its effectiveness in 1977, which was hot and dry and the evapotranspiration rates were extremely high. In 1977, evaporative demands of the crop were not met for 8 days, according to the consumptive use rate calculated from screened pan evaporation and the crop coefficient.

Soil permeability may have been one limiting factor in supplying water to the corn in 1977, but poor stand and insect damage were the major factors causing the low yields. However, care should be taken in designing the CaRD system for soils with permeability less than 3.0 m/day, because tile spacings would have to be closer than 15 m in dry, hot years with high evapotranspiration rates.

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