STUDY OF EVAPORATION FROM SOIL SURFACES

PROGRESS REPORT NO. 6

Colorado Contributing Project

to

Western Regional Project W-32

Basic Hydrologic Factors Relating to Water Conservation

COLORADO AGRICULTURAL EXPERIMENT STATION
Fort Collins, Colorado

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OBJECTIVES

The project is a comprehensive study of evaporation from soil surfaces. The specific objectives of the study for the past year have been twofold:

1. To determine the effect of cyclic ambient conditions on evaporation from soils in contact with a water table.

2. To begin a systematic study of the effects of gravel mulches on evaporation from soils not in contact with a water table.

THE EFFECT OF CYCLIC AMBIENT CONDITIONS ON EVAPORATION

Results of Experiments Conducted with Cyclic Ambient Conditions:

In previous years the study has dealt with a steady-state evaporation from a soil in contact with a water table * (1,2). In these studies the ambient conditions of temperature, relative humidity, and incident radiation were maintained at a constant level for any particular run. It was found that under severe evaporation conditions an inverse relationship could exist between the rate of evaporation from a soil in contact with a water table and the rate of evaporation from a free-water surface.** This phenomenon has been explained in a qualitative manner through a hysteresis hypothesis (3).

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* Numbers in parentheses refer to appended references.

** In this report, as in previous years, the rate of evaporation from a column of sand in which the water table is maintained at the surface is called the rate of evaporation from a "free-water surface", and is given the symbol e_f.

During the past year experiments have been conducted to study this inverse relationship under cyclic ambient conditions simulating those found in the field. In the field the severe evaporating conditions exist for only a short part of the diurnal cycle. The simulation of the cyclic ambient conditions found in the field was accomplished by modifying the control equipment so that temperature, relative humidity, and incident radiation in the environmental-control chamber automatically underwent a diurnal cyclic variation (4,5). The equipment and experimental procedure have been described previously (4).

The range of the ambient variables and the method used for increasing the rate of evaporation from the free-water surface (e_f) are shown in Table 1. For example, Table 1 shows that for Run No. 8, the ambient temperature range was 75 to 105 degrees F, and the range of the relative humidity was 10 to 20 per cent. The amount of radiant energy applied to the soil surface was progressively increased, and the wind velocity across the top of the soil surface was approximately 10 feet per second for evaporation rates from the free-water surface (e_f) equal to 3.07 and 4.37 inches per day.

The rates of evaporation from the soil (e_s) and from a free-water surface (e_f) were measured for a variety of ambient conditions. Fig. 1 shows e_s plotted as a function of e_f for the eight runs described in Table 1. From examination of Fig. 1 it can be seen that for some conditions an increase in e_f resulted in a decrease in e_s. The value of e_f for which this phenomenon occurs is called a "critical e_f". It will be noted, for example, that for Run No. 8 the critical value of e_f is 1.6 inches per day for the 27-inch depth to the water table.

These critical values of e_f for the 27-inch water table depth and related data for the 1.2 hour period in which maximum evaporation occurred from the free-water surface are shown in Table 2.

TABLE 1. Ranges of ambient variables and methods used for increasing e_f during studies of the effect of cyclic variation of ambient conditions on evaporation from soils in contact with a water table

Run No.	Temp. Range	R.H. Range	Rad. Level	Wind Velocity
8	75 - 105°F	10 - 20 %	Increasing	Approx. 10 fps at e_f = 3.07 and 4.37 in/day
9	50 - 80°F	25 - 50 %	Increasing	Approx. 10 fps at e_f = 2.28 and 3.62 in/day
10	65 - 95°F	20 - 40 %	Increasing	Approx. 10 fps at e_f = 2.76 and 3.84 in/day
11	Increasing from 45-75°F to 75-105°F in 5° increments	25 - 50 %	Constant	None
12	Decreasing from 75-105°F to 50-80°F	25 - 50 %	Constant	None
13	60 - 90°F	25 - 50 %	Constant	Increasing from 0 to 20 fps
14	Control problems were encountered so that no useable data were obtained. Run was planned similar to Run No. 10 but with water table depths of 25, 26, and 27 inches.			
15*	60 - 90°F	25 - 50 %	Increasing	Approx. 10 fps at e_f = 2.86 and 4.08 in/day
16	60 - 90°F	25 - 50 %	Constant	Increasing from 0 to 25 fps

* Water table depths for Run No. 15 were 24, 25, and 26 inches. For all other runs the water table depths were 18, 24, and 27 inches.

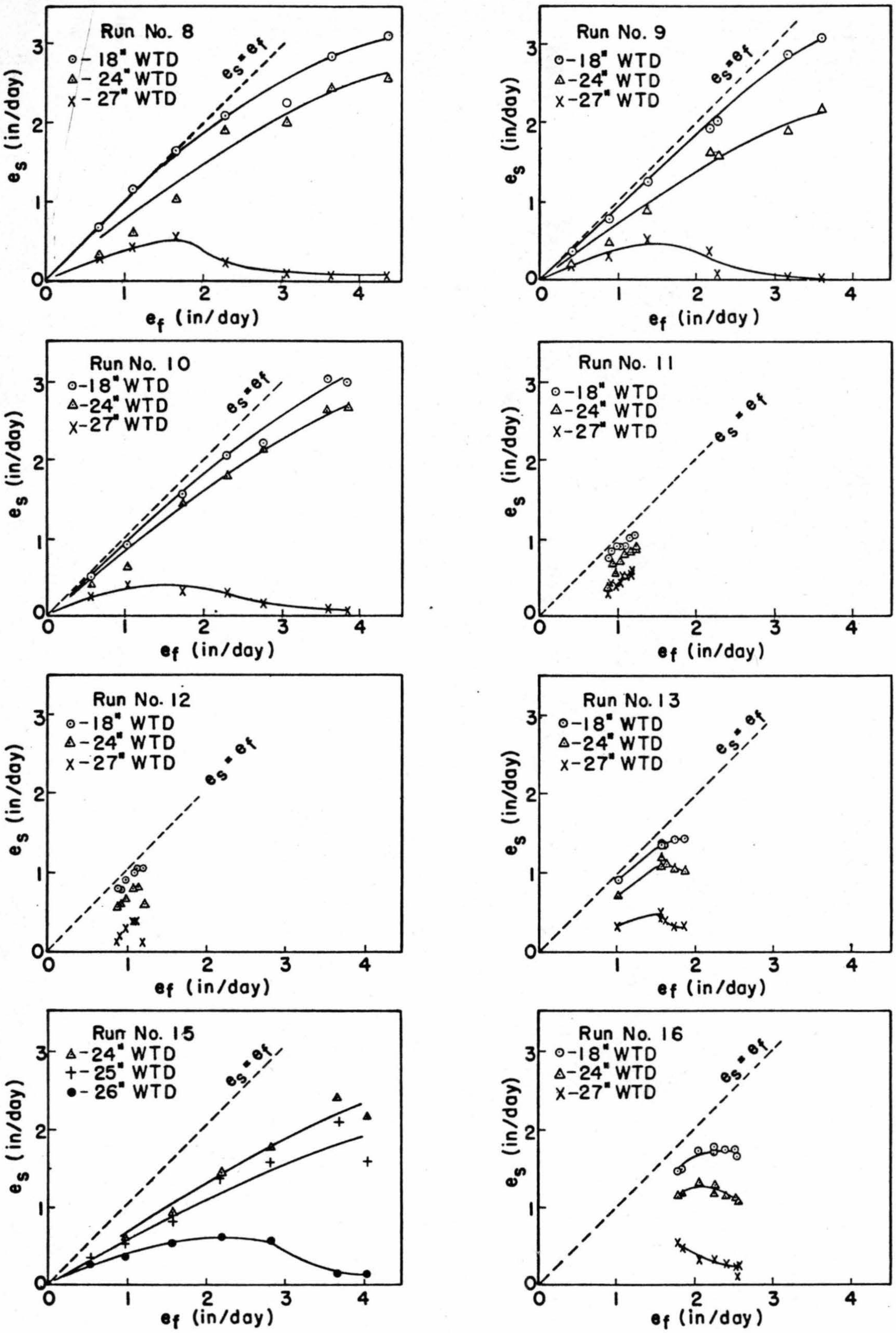

FIG. I. Relations between evaporation from a sand with water table at the surface (e_f) and from Loveland fine sand (e_s) for various water table depths. Ambient conditions and method of changing e_f are specified in Table I.

Discussion of Results of Cyclic Experiments:

From examination of Fig. 1 and Tables 1 and 2, several factors may be noted:

1. A critical value of e_f was reached only for water-table depths greater than 24 inches.

2. The inverse relation between e_s and e_f was noted only for conditions of increasing radiant energy (Runs 8, 9, 10 and 15) or for conditions of increasing wind velocity (Runs 13 and 16) in each of these runs e_f exceeded about 1.5 inches per day. The inverse relation was not noted for conditions such that e_f did not exceed about 1.2 inches per day (Runs 11 and 12). This result appeared to be independent of whether the ambient temperature range was increased or decreased with time (Runs 11 and 12).

3. The critical value of e_f was approximately 1.5 inches per day for the 27-inch depth to the water table. The corresponding value of e_s was about 0.5 inch per day.

4. Soil surface temperature and the temperature of the free-water surface were erratic and appear to follow no consistent pattern in relation to critical values of e_f .

5. A critical value of e_f can be produced under cyclic ambient conditions.

TABLE 2. Critical values of e_f and related data for the 1.2-hour period in which maximum evaporation occurred

Run No.	Critical e_f for depth to water table of 27 inches	Corresponding e_s	Temperature of the surface of the soil	Temperature of the free-water surface
	(In /day)	(In /day)	Deg. F	Deg. F
8	1.6	0.55	127	115
9	1.5	0.5	110	106
10	1.5	0.4	104	102
11	*	*	*	*
12	*	*	*	*
13	1.5	0.5	92	79
14	*	*	*	*
15	2.3**	0.6**	138**	119**
16	1.8 or less	0.5 or more	135	121

* Inverse relation between e_s and e_f not observed during these runs.

** Depth to the water table of 26 inches.

THE EFFECTS OF GRAVEL MULCHES ON EVAPORATION

Surface Treatments for Reduction of Evaporation:

A limited study of the effect of surface treatments on the evaporation from a soil was performed in previous years. It was found (6, 4) that treating the surface of the soil with a surfactant or covering the soil surface with a layer of gravel gave a significant reduction in the amount of water lost by evaporation. Since treatment with surfactants appears to be prohibitive in cost at present prices, a systematic study of the effect of gravel mulches on evaporation from soil was begun.

Procedure for Experiments on Gravel Mulches:

The study is being conducted in the environmental-control chamber (2). Soil samples are contained in 3-1/2" I.D. lucite cylinders 8-1/2" long. The samples are saturated by soaking approximately 48 hours. They are then covered with an air-tight cover and allowed to drain overnight. The samples are then placed on the turntable and the evaporation loss recorded by weighing periodically.

The variables selected for study are shown on Fig. 2 and Table 3.

Preliminary Findings on the Effect of Gravel Mulches:

The results of one run are shown on Figs. 3 and 4 and Table 4. (Results on the Greeley loam are very similar to those shown on Fig. 4, and are not reproduced here.) During Run No. 4 the ambient conditions were: Temperature, 92^{0}F; relative humidity, 28 per cent; wind velocity, zero; radiation: two 250-watt heat lamps 26 inches above the soil surface.

In Figs. 3 and 4 it will be noted that the gravel mulch appears to be more effective for the Loveland fine sand than for the Fort Collins clay loam (Fig. 4). Of particular interest is the contrast between Figs. 3 and 4 in the cumulative water loss after about 29 hours. For the Fort Collins clay loam, the thickest application of the finest gravel mulch produced a greater water loss than thinner layers. This effect was not noted for the Loveland fine sand.

TABLE 3. Variables being studied in experiments on the effect of gravel mulches on evaporation from soils

Soils:		
	Loveland fine sand	(LFS)
	Greeley loam	(GL)
	Fort Collins clay loam	(FCCL)
Gravel Layers		
	Thickness:	
	1/4 inch	
	1/2 inch	
	1 inch	
	Gradation: (Uniform size in multiples of the D_{50} size of the soils*)	
	5 (D_{50})	
	20 (D_{50})	
	60 (D_{50})	
Ambient Conditions:		
	Temperature - constant	
	Relative humidity - constant	
	Incident radiation	Various combinations to give evaporation rates up to 1.05 inches per day from free-water surface.
	Wind velocity	

* See Fig. 2.

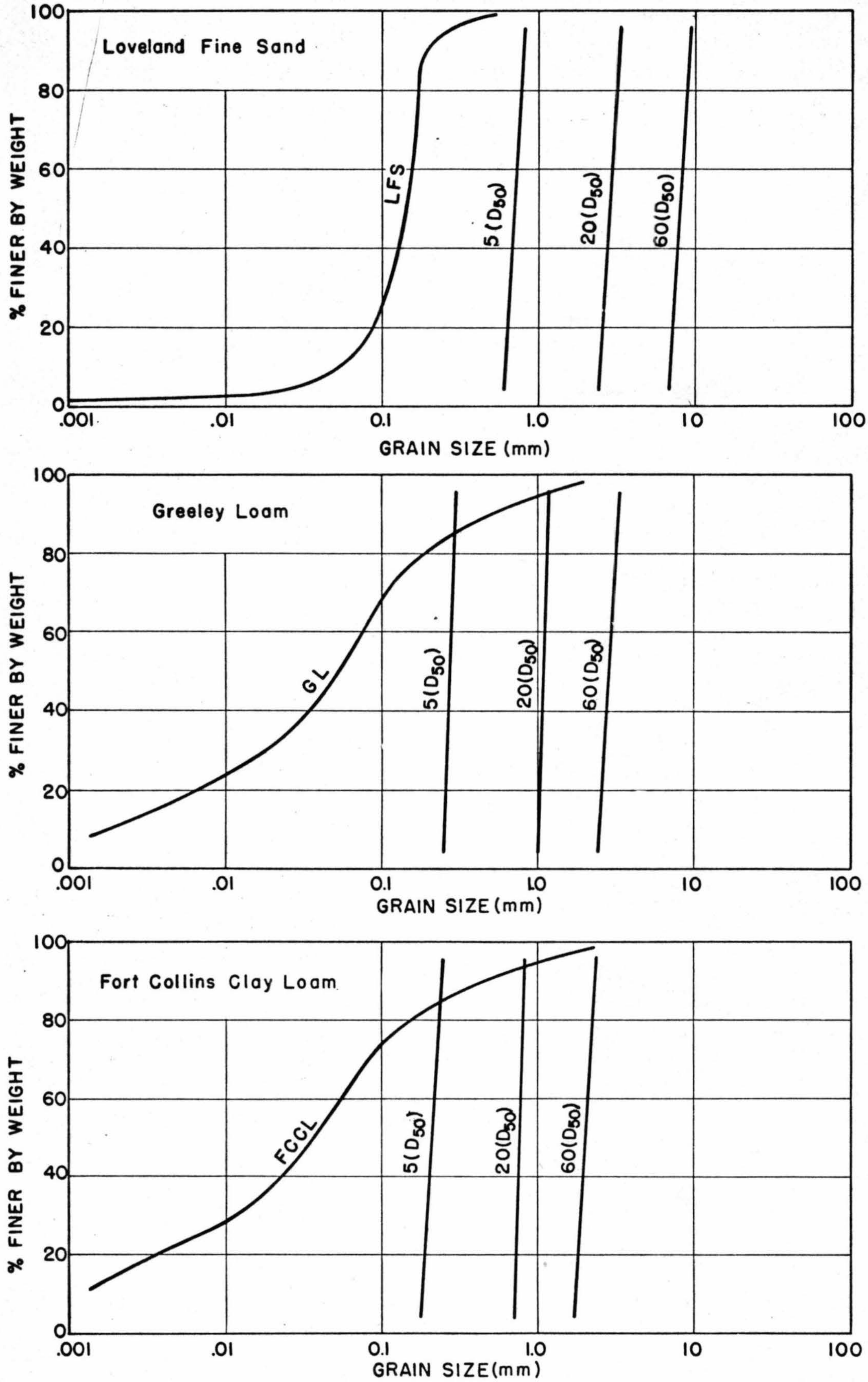

FIG. 2. Gradation of soils and gravel layers used in study of the effects of gravel mulches on evaporation.

Figure 2 may provide an explanation for this behavior. It will be noted that the Loveland fine sand is a very uniform material, and that each of the gravel mulches is coarser than any part of the Loveland fine sand. This is not true for the Fort Collins clay loam. The gravel mulches used with Fort Collins clay loam are smaller in size than the coarsest fraction of the base soil. This fact may tend to cause a flow of liquid water into the gravel mulch covering the Fort Collins clay loam which would have to be evaporated into the atmosphere before the gravel mulch would act as an effective barrier for reducing further evaporation.

Whether or not this is the physical mechanism involved, and the effects of relationships between the gradation curves are questions for which answers will be sought in future studies.

Results of an analysis of variance are shown in Table 4, which shows that the primary source of variation is from the main effects rather than from the first order interactions.

PLANS FOR FUTURE STUDIES

Studies on the effects of gravel mulches on evaporation will be continued during the remainder of the fiscal year. In addition to problems involving the relations between the gradation of soil and mulches, it is planned to utilize gradations of gravel mulches which are independent of the D_{50} size of the soil. An attempt will be made to utilize the coarsest fraction of a soil as the mulch for reduction of evaporation losses.

TABLE 4. Analysis of variance for experiments on the effect of gravel mulches on evaporation from soils (Run No. 4, 96 hours)

Source of variation	df	Sum of squares	Mean square
Main effects			
Soils (s)	2	46,317	23,159**
Gradation (g)	2	1,681	840**
Thickness (t)	2	8,069	4,034**
First order interactions			
s x g	4	1,578	394*
s x t	4	835	209
g x t	4	501	125
Error	8	591	74
Total	26	59,572	

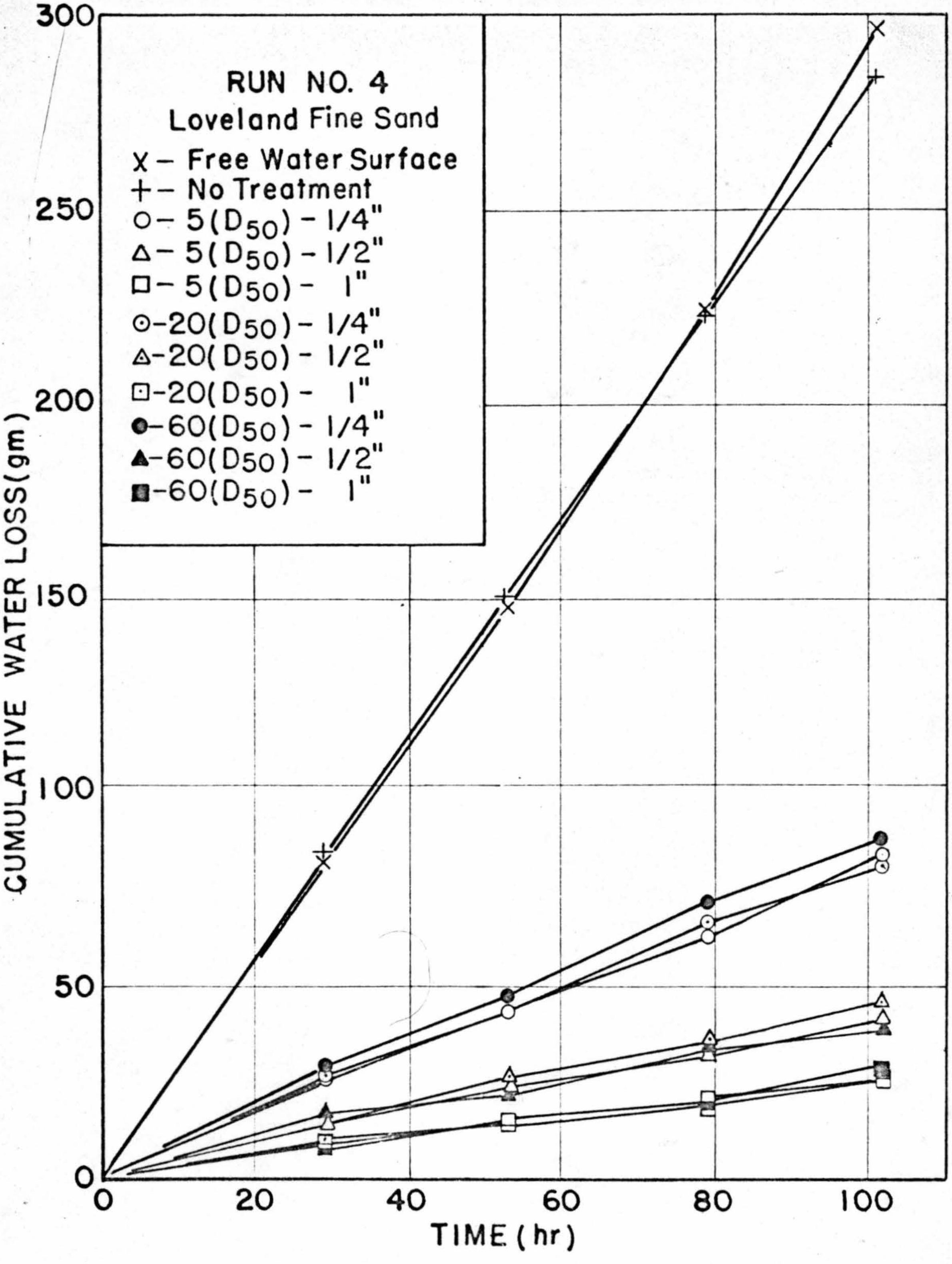

FIG. 3. Evaporation loss vs. time for Loveland fine sand.

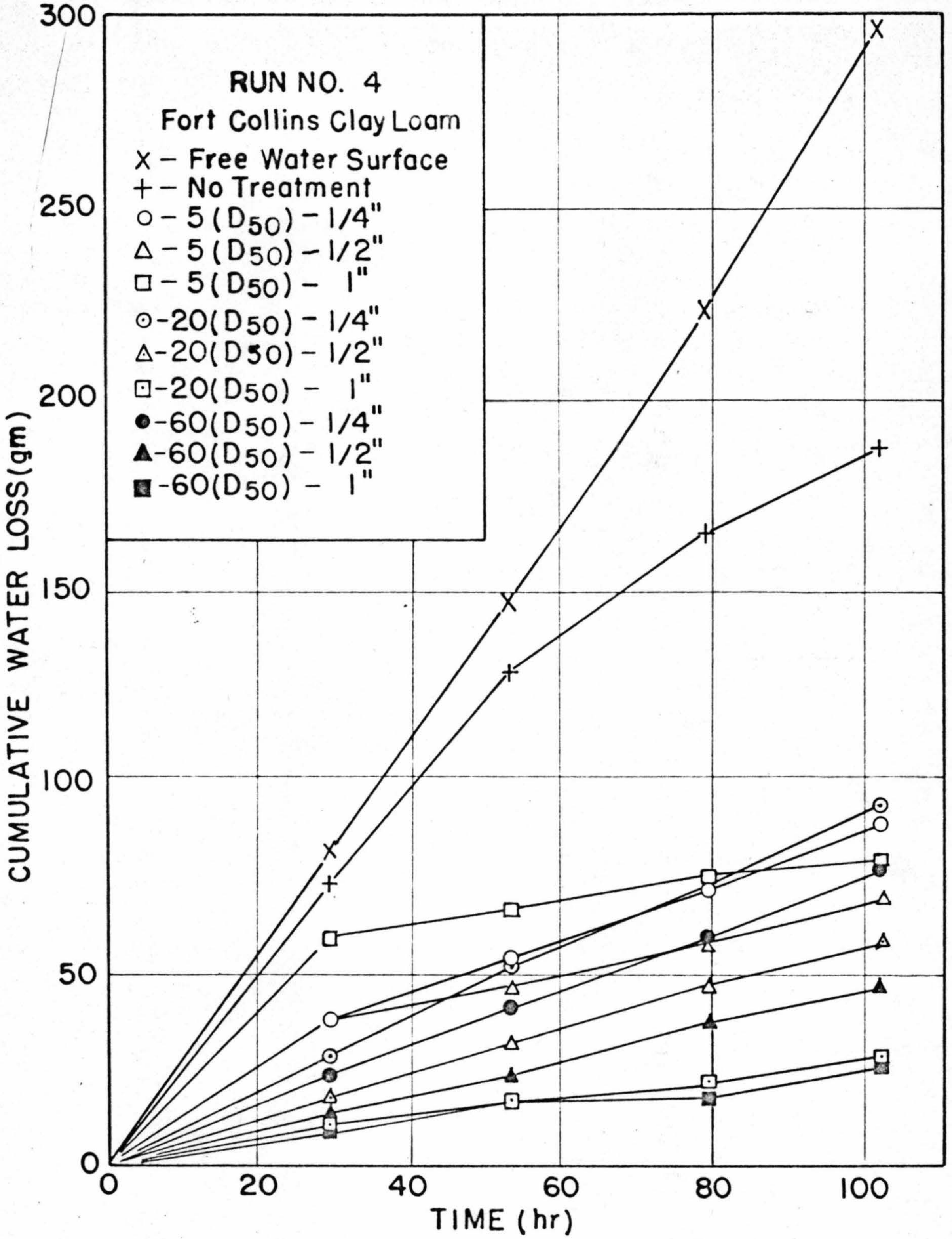

FIG. 4. Evaporation loss vs. time for Fort Collins clay loam.

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1. Progress Report No. 3, Colorado contributing project for W-32. "Study of evaporation from soil surfaces." November 1957.

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4. Progress Report No. 5, Colorado contributing project for W-32. "Study of evaporation from soil surfaces." November 1959.

5. Schleusener, R. A., and King, L. G., "Modification of bridge controls." Agricultural Engineering 41, 7:450-1, July 1960.

6. Progress Report No. 4, Colorado contributing project for W-32. "Study of evaporation from soil surfaces." September 1958.