The influence of different soil types, treatments, and soil properties on the efficiency of water storage
by Raymond T Choriki

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
Moisture storage efficiency of four soils and five treatments on one soil type was determined during 1958 in a lysimeter study, and comparisons were made between 1957 and 1958 data. The effect of soil differences and soil treatments on percolation and evaporation was studied. In addition, an attempt was made to determine the differences in soil properties that accounted for differences in moisture lost during a drying cycle in Huffine and Bridger silt loams.

Water that falls on the soil can be stored, evaporated, or percolated. Alteration of any one of these variables will have a direct influence on the others.

Seasonal influences were noted on moisture efficiency in 1958 as in 1957.

In 1957 and 1958, Huffine soil evaporated less and percolated more water than the other soils studied, with a storage efficiency of 20.4% in 1957 and 6.2% in 1958. This was followed by Bridger, instead of Manhattan, in 1958. Again Huntley was very inefficient.

Rock mulch repeated as the outstanding treatment with a season-long efficiency of 29.8% in 1958 compared to 60.4% in 1957. The remaining treatments were relatively ineffective in 1958, although the VAMA treatments were slightly better than the other treatments, as in 1957.

The importance of rainfall distribution in obtaining high moisture efficiency is illustrated by comparing the efficiencies in 1957 and 1958. The higher efficiency in 1957 was associated with the distribution of rainfall which was concentrated in the months of May and June and before the soil had lost much of the moisture stored from the winter snow. The amount of rainfall was similar in the 2 years.

The soil properties that were found to be appreciably different were pore size distribution, percent organic matter, and bulk density. Texture, percent aggregation, aggregate stability, and unsaturated and saturated flow were almost alike in the two soils. It is believed that differences in pore size distribution account for the differences in moisture loss between Huffine and Bozeman silt loams, but this hypothesis needs additional testing.

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Approved:

A H Post

Head, Major Department

J. C. Hide

Chairman, Examining Committee

Leon H Johnson

Dean, Graduate Division

Bozeman, Montana
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ABSTRACT

Moisture storage efficiency of four soils and five treatments on one soil type was determined during 1958 in a lysimeter study, and comparisons were made between 1957 and 1958 data. The effect of soil differences and soil treatments on percolation and evaporation was studied. In addition, an attempt was made to determine the differences in soil properties that accounted for differences in moisture lost during a drying cycle in Huffine and Bridger silt loams.

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INTRODUCTION

Because of the importance of moisture in plant growth and crop production, studies are being conducted in an attempt to increase moisture conservation by reducing evaporation. Hide (21) has emphasized the importance of this moisture which is being lost by evaporation. He estimates that 60 to 75% of the total precipitation is lost by evaporation in dryland areas. Peters (29) found that a plastic cover over the soil reduced the water required to grow a corn crop by 50% in the humid areas. Campbell (10) placed enough importance on evaporation to state, "The danger to the farmer from evaporation cannot be estimated.....If there was no water lost or wasted, the deserts would bloom". Considering this, it is surprising to find very few investigations on the many facets of the complex evaporation process.

In relation to these comments, Hide and Brown (22), in 1956, completed a study on the natural drying pattern of three different soil types, of which only two will be discussed, to observe the difference in evaporation cycle. Considerable difference was observed throughout the season. They found that Huffine soil lost water rapidly from the different soil layers in the early stages of the drying cycle, and then loss almost ceased. Bridger soil lost water for a longer period and lost a total of 0.75 inch of water while Huffine soil lost only 0.50 inch of water in a drying cycle.

In 1957, a set of lysimeters was constructed, and the influence of soil types and soil treatments upon moisture storage was studied. Brown (6) submitted a thesis for his master's degree in connection with this experiment. The experiment was continued in 1958, and the present study includes similar data to that obtained in 1957 and a comparison between the 2 years.

In addition to the lysimeter study, work was undertaken in 1958 to determine the factors which cause the difference in the drying pattern of Huffine silt loam and Bridger silt loam. Bridger silt loam was taken from an area classified as Bridger clay loam, but mechanical analysis showed it to be a silt loam.

A knowledge concerning the process of evaporation is desirable because it may aid in devising a method to increase moisture conservation by soil treatment and simultaneously increase crop production.

REVIEW OF LITERATURE

When cultivated agriculture was first imposed on the plains of the United States, there was only very limited information available on growing crops under restricted moisture supplies. At the beginning of the twentieth century, there seemed to be a sprinkling of interest in the study of evaporation in an effort to increase the moisture supply available for plant growth. Buckingham (8) was among the first to study the phenomena of capillary flow. He assumed capillary attraction to constitute a conservative force field and defined capillary potential, the gradient of which was equal to the capillary force. This concept of capillary flow led to the idea that rapid initial loss of moisture reduced later loss by forming a dry mulch.

King (26) presented data showing that a thin layer of dry, loose material decreased water loss. Campbell (10) publicized the importance of this dry layer and developed interest among the workers. King's work, however, was done under a soil condition where a water table was present. Call and Sewell (9) showed that, in the absence of a water table, most of the water that could be lost by evaporation had been lost before the surface was dry enough for cultivation.

When it was found that surface mulches had only limited influence on evaporation loss, studies on evaporation were curtailed. Limited information appeared in the next 20 to 25 years on this subject. Beginning about 1930 and continuing to the present time, there has been an expansion of research on the physics of moisture movement.

Buckingham's concept of capillary flow was used. Gardner and his associates (15) pointed out that Buckingham's potential was closely related to the pressure in the water films. Richards (31) some years later developed an expression which estimated moisture distribution in soils. No real progress, however, was made in developing a method to control evaporation during this period.

An interest has been developing concerning evaporation control, especially in the last 10 years. Various chemicals have been used. Hedricks and Mowry (20) have used HPAN to increase water aggregate stability and create a dry layer by rapid initial loss of moisture. VAMA-stabilized aggregates and HPAN have been used by Allison and Moore (2), and they found an increase in pore space and infiltration rate with no adverse effect on moisture retention.

Hanks (16) used Arquad 2HT, a water repellent material, to reduce capillary flow to the surface and form a dry mulch. Use of Naptha soap similarly seems to reduce evaporation. Soap is used to reduce the surface tension of the wet film around the soil particle to reduce movement of water toward the surface. This was quoted by Lemon (28) from the work done by Kolasew (27). Paints were used by Army (3) to reduce evaporation and to increase the length of time water is held near the surface of the soil and increase seed germination. Tsiang (34) reported that rock mulches have been successfully used in the dry sections of China to reduce evaporation.

Brown and Dickey's (7) evaporation control study on corn shows that plastic used on nonirrigated plots reduced the total water used by the plant. This means that less water was needed because the loss of water was reduced by the cover.

Lemon (28) briefly mentions the review Kolasew made on the effect of stratification which reduces the evaporation loss of moisture.

Some of the work done has been on soil factors that influence evaporation. In 1913, Harris and Robinson (19) quoted Widstoe as saying that evaporation of water from bare soil increased with saturation of the soil. The results are confirmed by Fisher (13) and Keen et al. (23). Evaporation is practically constant at high moisture content. Fortier (14) concluded that the rate of evaporation from soil varies directly with the amount of moisture in the top layer. Stanhill (32) compared soil moisture evaporation with free-water evaporation. There were no differences in evaporation as long as the surface layer of soil remained wet.

King (25) showed that the darker-colored soils absorb more heat and cause a rise in temperature which increases evaporation.

Bowie (5) claims that loss due to wind is caused by the more intimate contact of the air with moist surfaces. An average wind velocity between 2.4 and 4.0 miles per hour and an average water temperature of 70° F. increased evaporation due to wind movement about .5% for each mile of increase in wind velocity.

Water vapor transfer becomes the principal factor involved in water loss once a dry layer is formed. It is necessary that some study be made involving this process. Hanks (17) found that porosity and depth of dry soil influenced water movement. A dry layer of .25 inch will decrease moisture loss considerably. Hanks and Woodruff (18) found that wind velocity of 0 to 25 miles per hour was shown to increase water vapor movement. Three treatments were used, and soil mulch seemed to be the most satisfactory. This is in agreement with Penman (30), who concluded that a dry layer 2 mm. thick will reduce evaporation by about 90%.

Princippi, as quoted by Harris and Robinson (19), found that evaporation from materials with the largest pore space was rapid. Wollny (37) found that capillarity ceases when the diameter of the particle exceeds 2 mm. in size. Harris and Robinson (19) worked with different-sized particles and found decreasing moisture loss with decreasing particle size.

MATERIALS AND METHODS

The lysimeter portion of this study is a continuation of the work reported in a thesis submitted by Bernard L. Brown (6), which presents the method of construction of the lysimeter, as well as soil types and treatments studied.

The 1958 data and previous work indicated that there was a difference in the evaporation cycle of Huffine and Bridger silt loams. It appeared that the physical properties, in addition to the meteorological factors, were involved. In an effort to determine the soil properties that account for the differences, additional determinations were made in 1958.

For the determinations, loose samples were taken from the area surrounding the lysimeter plots. These samples were air dried and screened through a 4-mm. sieve for aggregate analyses and a 2-mm. sieve for the remaining analyses discussed in the thesis. Uhland samplers were used to get the core samples necessary for the permeability and pore size distribution study.

1. Mechanical analyses were run on Bridger and Huffine silt loams, using the pipette method as discussed in Agricultural Handbook No. 60 (36). Prior to this determination, organic material was oxidized with hydrogen peroxide to reduce the cementing material and to obtain better dispersion.

A constant-temperature bath was used to eliminate the change in temperature which would affect the settling velocity of the dispersed particles. Data obtained were reported as percent silt plus clay, percent clay, percent silt, and percent sand.

2. Unsaturated flow.--In an attempt to determine the cause of difference in evaporation of Bridger and Huffine silt loams, water intake rate was studied. The apparatus used for measuring Q, the intake, and dQ/dt, the rate of intake, is shown in figure 1. The water supply (D) passing through the horizontal calibrated burette (E) is drawn from the beaker (B) in which a constant water level is maintained, using Mariotte's principle. The water supply (A) is the source of water which maintains the constant water level. The amount of water passing into the soil (I) is measured by introducing an air bubble (C) with a hypodermic needle into the calibrated tube, and by recording the time, t, required for it to pass through this known volume (.1 ml.), data is obtained to calculate the rate of water entering into the soil. Two stop watches were used during the experiment. One stop watch was used to record the total time, t, elapsed, and the other was used to record the time, Δt, required for the air bubble to pass through the known volume, dQ. The air bubble was collected in a trap (F). Water reservoir (G) was used to flush the air collected in the system. The water applicator (H) has a fine brass screen sealed to the bottom to provide a source of water

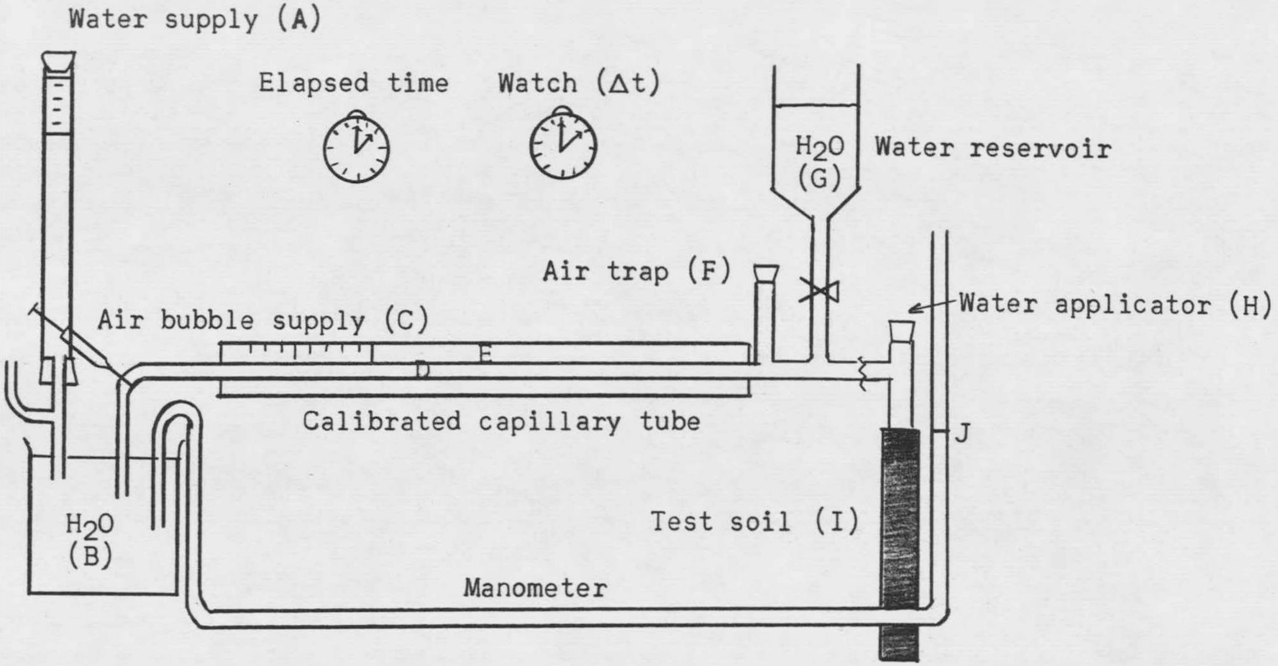

Figure 1. Apparatus for measuring $\Delta Q/\Delta t$ as a function of time.

at a constant head. A manometer (J), connected to the water supply (B), is located adjacent to the test soil to facilitate a determination of the hydrostatic head.

The soil container used consisted of a glass tube 18 inches long (45.7 cm.) with an inside diameter of 25 mm. This tube was closed at the bottom with cheesecloth to let the air escape freely. Only linear flow was considered in this experiment.

Emphasis was placed on the uniform packing of these tubes. Therefore, in filling, a tube smaller in size was placed inside the larger tube. Excess soil was placed inside the smaller tube and pulled out at constant rate to allow the soil to run out. A vibrator was used simultaneously to increase uniformity of packing. These tubes were dropped once from a height of 1 cm. All the tubes were filled and packed in a similar manner.

In measuring the infiltration rate, the soil tube was positioned vertically. Zero pressure was applied throughout the experiment (water level being equal to the surface of the soil).

The distance of the wetted front from the source of water was recorded as a function of time.

Data obtained was computed and presented as dQ/dt and total time. This was put on log-log coordinate graph paper, and the slope of the line was obtained.

3. For degree of aggregation, the method described in Agricultural Handbook No. 60 (36) was used. The method involved measuring the concentration of the suspension of the two samples of each soil. The pipette method was used to give total silt plus clay; and the hydrometer method was used in measuring unaggregated silt plus clay. The water-stable aggregates larger than 50 microns in size were determined by the difference in concentration between the two suspensions. The data obtained was reported as percent silt and clay aggregated into stable aggregates larger than 50 microns in size.

4. Saturated flow and pore size distribution were determined using the Uhland and O'Neil (35) technique. To provide a reservoir, a 1-inch extension was placed on top of the 3-inch cylinders containing the undisturbed soil samples. Cheesecloth was used on the bottom to keep the soil in place and to let the water out freely. A tank, 4 feet x 1 foot x 6 inches, provided a source of water. A constant hydrostatic head was maintained by flowing excess water into the tank which was provided with an overflow. Percolating water was recorded after each hour and continued for 3 hours. The data are presented as "K" values, a permeability constant calculated from the equation, $Q = \frac{Kaht}{l}$, where "Q" = quantity of H_2O percolated, "K" = a value depending upon soil properties, "a" = the area of the

container, "h" = the "head" applied, "t" = the time in minutes, and "l" = the length of the soil column.

The saturated soil samples were placed on a ceramic tension cup and placed at 0, 10, 30, 60, 100, and 150 cm. of water tension for a period of 1, 2, 4, 4, 12, and 12 hours, respectively. This is required for the system to reach equilibrium. The loss of moisture was recorded by weighing after each respective time.

From the data, the minimum pore size drained was calculated for each tension used. The radius of the pore size is calculated using the equation, $\gamma = \frac{1}{2}hdgr$, where γ = the surface tension of water at 25° C., "h" = the height at which the tension cup was placed from the reference point, "d" = the density of water, "g" = acceleration of gravity, and "r" = the radius of the pore space. Percent of the total pores drained between each pair of tensions was computed from the equation, $\frac{(A - B)}{C} \times 100$. (A - B) is the weight loss between two tensions and C is the total grams of water at saturation (weight of saturation minus dry weight of soil).

From these data, a desorption curve was prepared and presented. Information was obtained concerning the water relation in the soil and the amount of water held at various energy ranges.

The apparatus used for this experiment is shown in figure 2.

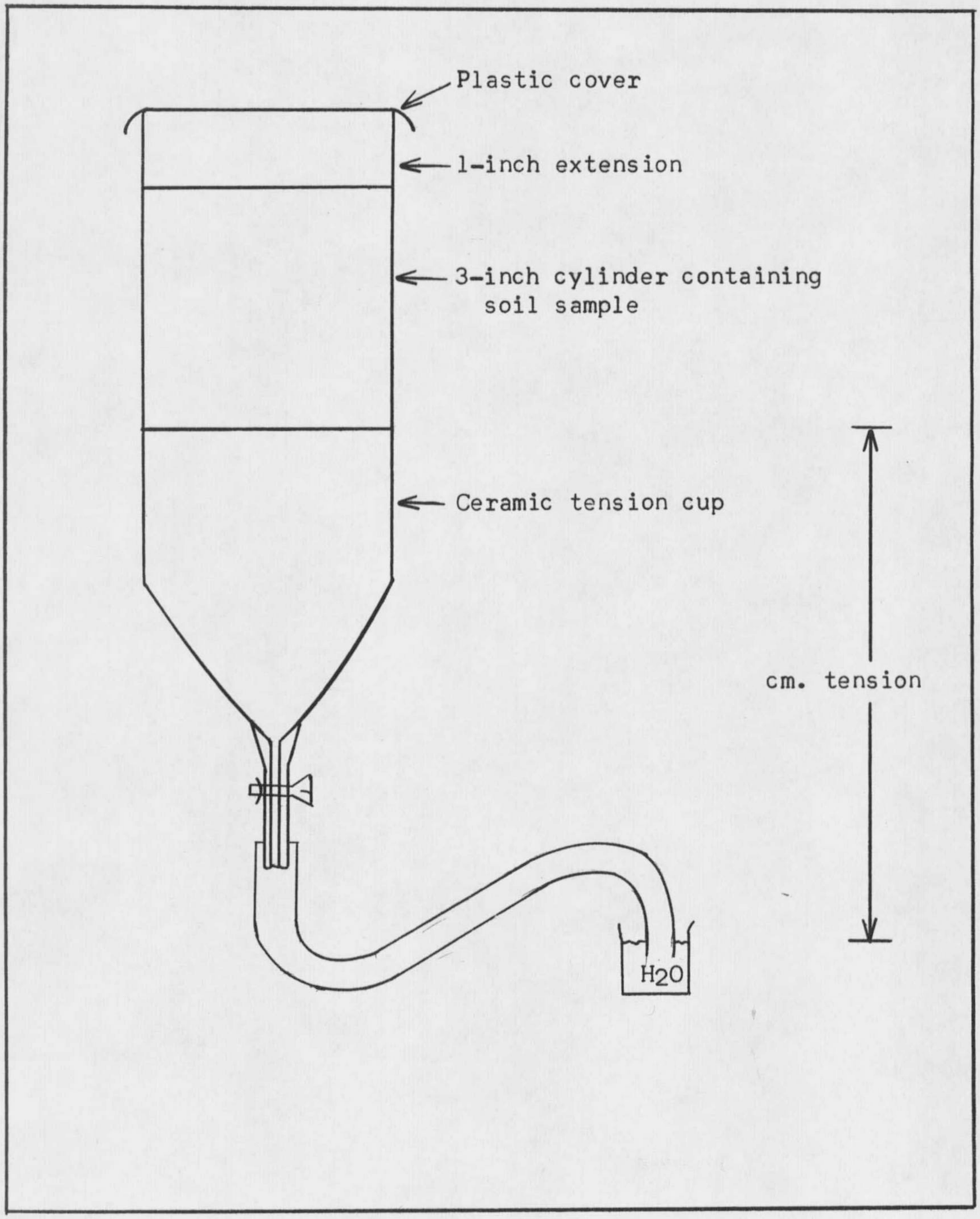

Figure 2. Apparatus for conducting water through a porous membrane to study the moisture characteristics of soil at low tensions.

Effect of Soil Depth on Drying Properties

To assist in evaluating the importance of the discontinuity at a depth of 4 inches in the lysimeter, two sections of tube, 4 and 18 inches long, were filled and packed with each of Huffine and Bridger soil. These tubes were filled and packed similarly by the method discussed in the earlier sections.

In this experiment, the 4-inch tubes filled with soil were saturated with water with the apparatus shown in figure 1. To prevent soil loss during wetting, a filter paper was placed in the bottom of the tube and held in place with a plastic screen. The quantity of water entering into the soil was measured by weighing the soil before water was applied and after saturation. This same quantity of water was placed in the 18-inch-long tube, and the tube was set aside for drying. In the 4-inch tube, paraffin was used to seal the bottom to avoid water loss from the bottom. Moisture lost was determined by daily weighing of each sample. The temperature in the room in which the determinations were made fluctuated from 24° C. to about 30° C.

RESULTS AND DISCUSSION

This study is a continuation of the work initiated by Brown (6), who presented the 1957 data in thesis form. While the major undertaking in the study is a presentation and interpretation of the 1958 data, Brown's (6) data is frequently used for comparative purposes. The 1958 data consisted of rainfall records and semiweekly lysimeter weights and percolation records for each lysimeter.

Only rainfall data was collected for the winter months, since snow-covered ground and frozen soils made the collection of percolation data impractical. Leachate from the spring snowmelt (table I) was collected, but no interpretation of the winter storage efficiency could be made because of the wide variability within the treatments. It is believed that the frozen soil caused the water to accumulate on the surface of the lysimeters which either overflowed the freeboard or evaporated, while the lower soil in the lysimeters was still frozen and prevented percolation.

For convenience in interpretation, the data presented in table II has been summarized by climatic periods on the basis of rainfall (table III) and temperature (table IV). The subdivisions were: (a) cool-wet; (b) warm-dry; (c) warm-wet; (d) hot-moist; and (e) cool-dry, as outlined in table V. The temperature and rainfall ranges used for selecting periods in 1958 differed somewhat from those used in 1957. When Brown's (6) data is referred to, the periods have been reclassified according to present terminology.

These periods were subdivided to aid in differentiating between the drying pattern in the different periods. Not all six periods obtained

Table I. Percolation from snowmelt for winter and spring months (in milliliters), 1957-58.

Soils and treatments	Box No.	Nov. 1, 57– Mar. 26, 58	Mar. 26, 58– Apr. 9, 58	Apr. 9, 58– Apr. 12, 58	Total for period
Manhattan	1	4,730	4,730	42	9,502
	19	68	4,730	10	4,808
	21	0	1,950	170	2,120
Huffine	9	0	4,730	187	4,917
	15	2,675	0	97	2,772
	23	235	525	140	900
Huntley	3	0	4,730	196	4,926
	18	1,000	1,450	52	2,514
	27	1,200	4,730	84	6,014
Bridger	6	100	4,730	160	4,990
	11	1,050	4,730	118	5,898
	29	4,730	4,730	145	9,605
Rock mulch	10	3,000	100	8	3,108
	13	225	4,730	275	5,220
	25	125	4,730	145	5,000
Straw mulch	1	1,925	0	22	1,947
	12	275	0	5	280
	22	4,730	0	157	4,887
VAMA coarse	2	4,730	675	137	5,542
	16	230	0	133	363
	28	0	3,275	111	3,386
Surfactant	5	4,730	0	230	4,960
	14	4,730	4,730	102	9,562
	24	30	0	89	119
VAMA fine	4	0	4,730	62	4,792
	20	460	4,730	43	5,233
	30	4,730	4,730	93	9,553
Check	8	4,730	0	322	5,052
	17	55	4,730	48	4,833
	26	4,730	4,730	376	9,836

Table II. Periods into which data was subdivided and climatic information by periods.

Period	Days in period	Period classification	Precipitation (inches)	Average maximum temperature	Evaporation (inches) from free-water surface	PE index
April 12-May 28	46	Cool-moist	1.54	65.5	9.74	16
May 28-June 16	19	Cool-wet	2.08	67.8	3.44	60
June 16-June 26	10	Warm-dry	0.73	76.9	3.36	22
June 26-August 4	39	Warm-wet	4.43	76.5	10.20	43
August 4-August 28	24	Hot-moist	1.86	83.3	6.47	29
August 28-October 30	63	Cool-dry	2.05	67.3	9.20	22

Table III. Daily precipitation (inches) in 1958 as recorded by the rain gauge located adjacent to the lysimeters.

Day	April	May	June	July	August	September	October
1	0.00	0.00	0.11	0.02	0.00	0.00	0.20
2			.09	.46	.08	.06	
3			.27		.39		
4	.08	.09	.03	.04			
5	.43		T				
6			.05	.08			
7			.16	.48			
8	.24		.02	.06			.04
9	.21		.14	.67	.38		
10	.02		.03				
11			.31	.02	.13	.17	
12			.24				
13			.10				
14			.02			.06	
15		.12				.02	
16		.02		.01	.02		
17				.02			
18	.56			.01	.87		
19					.09	.03	.20
20	.12				.01		.03
21			.09	.05			
22	.20			.05	.22		
23	.06	.06		.47	.03	.63	
24			.60	.02	.04	.34	
25			.04				
26	.10			.43			
27	.14				.02		
28	.07	.02		.21			
29		.06	.11	.41	.27		
30		.32	.18	.16			
31		.11					
Total	2.23	0.80	2.55	3.67	2.55	1.37	0.47

Total precipitation for period April to October, 1958 = 13.64 inches

Table IV. Daily maximum temperature (in degrees Fahrenheit) for 1958 as recorded by the U. S. Weather Bureau cooperative station at Montana State College.*

Day	April	May	June	July	August	September	October
1	53	64	68	68	86	87	49
2	51	69	65	69	89	74	63
3	53	69	57	65	82	75	72
4	49	66	72	65	77	72	75
5	40	73	68	70	77	73	79
6	40	72	73	69	82	77	71
7	46	61	72	65	90	87	64
8	41	68	68	74	90	89	57
9	44	70	64	78	73	82	--
10	46	78	65	78	83	77	60
11	50	78	64	81	89	87	73
12	57	73	59	85	88	80	78
13	68	59	57	86	88	64	75
14	67	63	68	69	88	59	--
15	68	71	72	71	88	61	75
16	63	74	76	80	90	75	67
17	67	73	75	79	87	68	70
18	62	74	75	80	82	67	80
19	55	83	62	79	80	74	72
20	52	84	69	82	77	59	44
21	52	80	80	82	80	76	48
22	42	82	84	85	81	75	50
23	33	80	75	86	76	71	60
24	37	75	69	77	81	45	--
25	47	83	80	82	85	58	46
26	45	82	91	76	85	60	52
27	39	81	88	72	85	69	53
28	39	84	75	85	82	60	52
29	50	51	61	78	75	63	58
30	58	70	--	72	69	54	56
31		67		81	79		--

--Indicates no record available.

* Within one-half mile of experimental site.

Table V. Basis for classifying periods from average maximum temperature and rainfall calculated to 30 days.

Rainfall classification		Temperature classification	
0-1 inch	Dry	<69° F.	Cool
1-3 inches	Moist	70-79° F.	Warm
>3 inches	Wet	>80° F.	Hot

in 1958 were similar to those encountered in 1957. For instance, in 1958, no hot-dry period was encountered, although one occurred in 1957. However, a warm-wet and a warm-dry period prevailed in 1958. Since comparative data for these periods are not available, they are discussed ahead of and separate from the other periods during the presentation of "Effect of Soil Types and Soil Treatments on Evaporation and Percolation for Different Climatic Periods".

Thornthwaite (33) has presented a map on "Climates of the United States", based on the PE index. The PE index, table II, was calculated to decide what climatic type of periods occurred in 1958. According to his classification, the cool-moist, warm-dry, hot-moist, and cool-dry periods are all classified as "semiarid" type of climate. The cool-wet period is "moist, subhumid" climate; while the warm-wet period is classified as "dry, subhumid". This was presented entirely for interest, and no discussion will be made. Evaporation data is shown in table VI.

Effect of Soil Types and Soil Treatments on Evaporation and Percolation for Different Climatic Periods

The following presentation will be a discussion of the results obtained for the 2 years. Table VII shows the results for evaporation during each period, and table VIII shows the amount of percolated water collected for the same period in 1958. For comparison between years, Brown's (6) 1957 data has been included as appendix tables XVI, XVII, and XVIII.

It was believed that, in several periods, small amounts of water distilled from the lower boundaries of the soil. Since no separation

Table VI. Daily evaporation from a free-water surface as compiled from the U. S. Weather Bureau cooperative station at Montana State College.

	Evaporation in inches						
Day	April	May	June	July	August	September	October
1	--	0.24	0.17	0.17	*	0.39	0.02
2	0.28	.27	.17	.29	*	.21	.06
3	.03	.23	.06	.17	1.00	.19	.12
4	.04	.23	.22	.15	0.26	.21	.13
5	--	.27	.25	.27	.30	.20	.17
6	--	.35	.15	.34	.39	.23	.19
7	*	.12	.27	.20	.26	.28	.11
8	*	.15	.20	.15	.39	.27	.15
9	.94	.22	.17	.50	.10	.20	.12
10	.05	.25	.10	.09	.24	.05	.08
11	.12	.33	.26	.44	.28	.34	.08
12	.16	.22	.09	.32	.23	.15	.17
13	.18	.16	.20	.35	.30	.19	.13
14	.22	.33	.01	.23	.33	.12	.08
15	.22	.21	.30	.25	.38	.16	.25
16	.14	.30	.21	.34	.35	.17	.28
17	.18	.31	.27	.37	.28	.20	.11
18	.14	.35	.21	.24	.29	.15	.27
19	.18	.41	.32	.25	.18	.19	.23
20	.14	.29	.11	.27	.21	.20	.01
21	.08	.27	.22	.46	.26	.24	.06
22	.00	.27	.23	.34	.20	.15	.05
23	.10	.29	.31	.39	.29	*	.07
24	.05	.26	.29	.19	.23	*	.05
25	.12	.30	.22	.37	.28	.07	.08
26	*	.34	.30	.17	.32	.10	.09
27	*	.40	.46	.19	.38	.13	.05
28	*	.29	.42	.33	.19	.03	.03
29	.25	.31	.20	.26	.16	.19	.05
30	.08	.15	.10	.13	.23	.13	.06
31		.15		.42	.06		.07
Total	4.11**	8.27	6.49	8.64	8.27	5.14	3.42

Total evaporation for period April 26 to October 30, 1958 = 40.56 inches

--No record available.
* Amount included in the following measurement.
**Adjusted to full month.

Table VII. Precipitation and evaporation (in grams) for lysimeter areas, April 12 to October 30, 1958.

Treatment		Selected period April 12–May 28 Cool-moist	 May 28–June 16 Cool-wet	 June 16–June 26 Warm-dry	 June 26–Aug. 4 Warm-wet	 Aug. 4–Aug. 28 Hot-moist	 Aug. 28–Oct. 30 Cool-dry	Seasonal total
	Precipitation, gms./1,061 cm.^{2}	4,150	5,606	1,967	11,939	5,013	5,525	34,200
Manhattan	Evaporation	8,299	4,393	2,003	11,375	5,452	5,509	37,031
Huffine	Evaporation	7,999	3,936	2,083	10,435	5,501	4,956	34,910
Huntley	Evaporation	9,986	4,049	1,867	10,989	5,589	5,887	38,367
Bridger	Evaporation	8,703	4,012	1,967	10,875	5,512	5,203	36,272
Rock mulch	Evaporation	6,497	2,393	1,827	7,022	4,047	4,295	26,081
Straw mulch	Evaporation	8,829	3,817	2,061	10,249	5,427	5,442	35,825
VAMA coarse	Evaporation	8,757	4,337	1,935	11,192	5,529	5,248	36,998
VAMA fine	Evaporation	8,602	4,234	1,996	11,396	5,499	5,426	37,158
Surfactant	Evaporation	8,427	4,021	1,915	11,218	5,532	5,632	36,745
Bridger check	Evaporation	8,644	3,999	1,982	10,853	5,524	5,150	36,154
Average		8,474	3,919	1,964	10,560	5,361	5,275	35,554

Table VIII. Precipitation and percolation (in grams) for lysimeter areas and percolation efficiency expressed as percent of total rainfall by selected periods, April 12 to October 30, 1958.

Treatment		Selected period							
		April 12– May 28 Cool-moist	May 28– June 16 Cool-wet	June 16– June 26 Warm-dry	June 26– Aug. 4 Warm-wet	Aug. 4– Aug. 28 Hot-moist	Aug. 28– Oct. 30 Cool-dry	1958 Seasonal average	1957 Seasonal average
	Precipitation, gms./1,061 cm.^{2}	4,150	5,606	1,967	11,939	5,013	5,525	34,200	30,696
Manhattan	Percolation	172	32	49	333	197	193	1,026	5,646
	% Efficiency	3.5	0.6	2.5	2.8	3.9	3.5	2.9	17.6
Huffine	Percolation	147	27	51	1,054	159	736	2,174	6,554
	% Efficiency	2.9	0.5	2.6	8.8	3.2	13.3	6.2	20.5
Huntley	Percolation	42	18	13	162	81	68	389	2,191
	% Efficiency	0.8	0.3	0.6	1.4	1.6	1.2	1.1	6.8
Bridger	Percolation	150	18	36	701	169	470	1,668	4,570
	% Efficiency	3.0	0.3	1.8	5.9	3.4	8.5	4.8	14.3
Rock mulch	Percolation	1,511	1,014	196	4,624	1,419	1,683	10,447	19,328
	% Efficiency	30.0	18.1	10.0	38.7	28.3	30.5	29.8	60.4
Straw mulch	Percolation	145	13	35	855	193	473	1,715	5,014
	% Efficiency	2.9	0.2	1.8	7.2	3.8	8.5	4.9	15.7
VAMA coarse	Percolation	115	29	42	387	140	417	1,133	5,888
	% Efficiency	2.3	0.5	2.2	3.2	2.8	7.6	3.2	18.4
VAMA fine	Percolation	152	50	50	220	145	243	861	5,185
	% Efficiency	3.0	0.9	2.6	1.8	2.9	4.4	2.5	16.2
Surfactant	Percolation	124	22	37	346	150	83	762	4,663
	% Efficiency	2.5	0.4	1.9	2.9	3.0	1.5	2.2	14.6
Bridger check	Percolation	137	15	33	653	148	521	1,513	4,896
	% Efficiency	2.7	0.3	1.7	5.4	3.0	9.4	4.3	15.3

between percolation and distillation could be made, any period in which 100 cc. or less water was collected was assumed to be distillation.

Warm-Dry Period -- June 16 to June 26, 1958

Effect of Soil Differences

Throughout this period, the four soils behaved similarly with regard to evaporation. Huntley soil had the least evaporation (1,867 grams) and the least distillation (13 grams). Huffine soil, however, lost the greatest amount of water by evaporation (2,083 grams) and distilled the most water (51 grams).

In three of the soils, evaporation exceeded the total amount of rainfall (.73 inch) which occurred during this period. This was lost at the expense of the stored moisture from the previous period. Distillation increased over the previous period (cool—wet), and it appears that the higher soil temperature in the second period encouraged distillation.

Effect of Soil Treatments

Rock mulch was most effective in reducing moisture loss by evaporation (1,827 grams). This treatment also percolated or distilled 196 grams of moisture. Since 185 grams of this amount was collected in the data taken on June 26, it is assumed that the 185 grams was mostly percolation. The differences among treatments during this period were not large enough to materially influence seasonal efficiency.

Warm-Wet Period -- June 26 to August 4, 1958

Effect of Soil Differences

It was during this period in 1958 that the highest rainfall was recorded (4.43 inches). This period followed a dry period, but there was sufficient rainfall for the soil to absorb the water and still percolate some water. Huffine, during this period, had the highest percolation of 1,054 grams and 440 grams less evaporation than Bridger which was the second highest in percolation. Huntley and Manhattan followed closely behind with less efficiency than Bridger. Huffine seems to have the best properties for reducing evaporation in this climatic pattern. Despite having 4.43 inches of rainfall, almost all of the 11,939 grams of rainfall was evaporated. This high evaporation is probably due to the scattering showers which enabled the moisture to return to the atmosphere without passing through the soil. Only once was there sufficient rainfall in excess of evaporation to saturate the soil and initiate percolation.

Effect of Soil Treatments

In 1958, rock mulch was the outstanding treatment, losing only 7,022 grams of water by evaporation and percolating 4,624 grams. Half of the total percolation for the entire season occurred during this period. Straw mulch was the next most efficient treatment with 855 grams of water percolating for storage and losing 10,249 grams by evaporation. Again the differences in the remaining treatments for evaporation were small, grouped together, and did not differ much from the check. In moisture storage, the remaining treatments showed low capability of percolating water. It may be that some of the treatments are losing their effectiveness. Some soil tends to disperse after treatment, making water more available for evaporation by remaining on the surface, and thus decreasing percolation.

Cool-Moist Period -- April 12 to May 28, 1958

Effect of Soil Differences

The period April 12 to May 28 showed Huffine to have the least evaporation losses (7,999 grams), followed by Manhattan (8,299 grams), Bridger (8,703 grams), and Huntley (9,986 grams). In contrast, Manhattan percolated 172 grams; Bridger, 150 grams; Huffine, 147 grams; and Huntley, 42 grams. When the period started, the individual weights of the lysimeters indicated them to be fully saturated. Most of the evaporation, therefore, occurred at the expense of the moisture stored during the winter months. This was illustrated by the fact that many of the lysimeters evaporated twice the amount of rainfall that occurred during the period.

In 1957, the cool-moist period occurred between May 3 and June 6. Evaporation did not exceed rainfall, but it is believed that some of the moisture was lost prior to this period. However, the pattern of evaporation was similar to 1958, with Huffine losing the least amount of water. Also, Huffine was the most efficient in percolation with 2,551 grams; followed by Manhattan, 1,699 grams; Bridger, 1,095 grams; and Huntley, 12 grams. In 1957, nearly 95% of the total percolation occurred in the months of May and June, while in 1958, it was distributed throughout the season.

Effect of Soil Treatments

Rock mulch has the unusual property of reducing evaporation throughout the season. The initial period in 1958 showed rock mulch to have the least amount of water lost by evaporation (6,497 grams). Of the remaining treatments, surfactant was the only treatment that was more effective than the check. In percolation, rock mulch was the most efficient with 1,511 grams, and the remaining treatments did not differ greatly from the check.

In 1957, rock mulch, for the comparable period, was also the most effective soil, losing only 2,227 grams as compared to Bridger check which lost 6,543 grams. The two VAMA treatments were more effective than the check in 1957. In 1957, rock mulch collected 6,155 grams of percolated water, which was almost four times as much as in 1958. In 1957, straw mulch percolated only about 65% as much water as the check.

Cool-Wet Period -- May 28 to June 16, 1958

Effect of Soil Differences

During this period, the maximum difference in evaporation occurred between Huffine and Manhattan. The losses in excess of that from Huffine were Manhattan, 457 grams; Bridger, 76 grams; and Huntley, 113 grams. There was very little distillation during this period, Manhattan having the highest distillation of 32 grams and Huffine 27 grams. Between weighings, the percolation collected never exceeded 25 grams in any individual lysimeter, and it is believed that this water collected as a result of distillation rather than percolation. The 2.08 inches of water that fell during the period was either evaporated or stored in the soil. This agrees with the data secured for the second comparable period (August 26 to September 3) in 1957, but approximately half of the total 1957 percolation was collected during the first cool-wet period (June 6 to June 28). The cool-wet period (August 26 to September 3) in 1957 followed a hot-dry period, and it is believed that the soils were dry enough to absorb the rainfall within the 4-inch layer. The period from June 6 to June 28 followed a moist period, in addition to receiving a total of 4.55 inches of rainfall during the period.

Effect of Soil Treatments

Rock mulch was the only treatment that allowed an appreciable amount of water (1,014 grams) to percolate, while the small amounts collected under other treatments were considered to be from distillation. Rock mulch lost the least amount of water by evaporation (2,393 grams). The remaining treatments, except straw mulch, exceeded the check in evaporation and amount of distillation collected.

The water lost by evaporation in 1957 agreed with the period occurring in 1958. Half of the entire season's percolation occurred during the period June 6 to June 28, while no percolation was collected for the second cool-wet period occurring from August 26 to September 3, 1957.

Hot-Moist Period -- August 4 to August 28, 1958

Effect of Soil Differences

Bridger was the most effective soil in the hot-moist period of 1957. It had the lowest loss of water by evaporation and the highest percolation among the four soils. Manhattan, Huffine, and Huntley followed in that order.

In 1958, this period occurred in August as compared to July in 1957. Under this condition, Manhattan instead of Bridger (as it was in 1957) was the most effective in reducing evaporation and increasing percolation. Huffine and Bridger had approximately the same efficiency during this period, while Huntley again showed the least efficiency. All the soils lost more water by evaporation than the total amount of rainfall, but some of the water came at the expense of the stored moisture from previous periods.

Effect of Soil Treatments

In the hot-moist period of 1957, rock mulch allowed the highest percolation but was somewhat closer to the remaining treatments in evaporation than during the other periods. VAMA coarse is the only treatment other than rock mulch which was more efficient than the check.

In 1958, rock mulch was again the most effective treatment, and it was the only one to lose less moisture than was received in rainfall. The remaining treatments behaved similarly to the check with very little difference in percolation and evaporation. As it was explained earlier, some of the water lost during this period came from the previous periods, enabling the soil during this period to lose more water than occurred as rainfall.

Cool-Dry Period -- August 28 to October 30, 1958

Effect of Soil Differences

The cool-dry period occurred at almost the same time in 1958 as it did in 1957. The pattern of evaporation differed in both periods. Huffine lost least water by evaporation in 1958, followed by Bridger, Manhattan, and Huntley. In contrast, the 1957 data showed Huntley as the most effective in reducing loss of moisture by evaporation, followed by Bridger, Manhattan, and Huffine. This is a complete reversal of the 1958 period. It is believed that differences in climatic pattern may have been responsible for the differences in behavior in the 2 years. Huffine was the most efficient in percolation in 1958 with 736 grams as compared to 162 grams in 1957. The general pattern behaved similarly for the remaining soils for both years. Differences in stored moisture at the end of the previous period is believed to be responsible for differences in percolation occurring in the cool-dry season of 1958.

Effect of Soil Treatments

Rock mulch was again the outstanding treatment in conserving moisture by reducing evaporation (4,295 grams) and percolating most water (1,683 grams). This pattern agreed with the data obtained in 1957. The remaining treatments in 1957, except surfactant, showed slightly less evaporation than the check. Distilled water collected in 1957 did not vary greatly from the check. In 1958, no treatment except rock mulch was more effective than the check in reducing evaporation. Bridger check collected 521 grams of percolated water, but none of the remaining treatments, except rock mulch, exceeded the check. It is believed that climatic factors were responsible for this behavior, in addition to some deterioration of the stability and effectiveness of some treatments.

Seasonal Moisture Efficiency

Percolation

Table VIII was developed to determine which soil and treatment retained most of the rainfall. The percent efficiency was determined by expressing percolation as a percentage of the rainfall.

Effect of Soil Differences

In 1958, Huffine was the highest in efficiency for the season with

6.2%, followed by Bridger with 4.8%, Manhattan with 2.9%, and Huntley with 1.1%. In 1957, Huffine was the most efficient with 20.5%, followed by Manhattan with 17.6%, Bridger with 14.3%, and Huntley with 6.8%. It is obvious that the efficiency decreased to about one-sixth of that obtained for some soils during the 1957 growing season. It is believed that the rainfall distribution pattern was the major cause of this difference. In 1957, the major portion of the rainfall occurred in May and June, while in 1958, it was distributed in the months of April, June, July, August, and September. In 1957, 6.48 inches of the total 10.49 inches occurring in the entire season fell during May and June. For high moisture efficiency, it is essential that the rains come frequently enough so that the soil does not dry out between rains. Under these circumstances, the rainfall pattern in 1957 was more favorable than the pattern in 1958.

Effect of Soil Treatments

Rock mulch was the outstanding treatment in 1958, with a moisture efficiency of 29.8% as compared to 60.4% in 1957. In 1957, VAMA coarse showed a 20% increase in storage over the check, while the remaining treatments did not vary greatly from the check. In 1958, straw mulch was the only treatment in addition to rock mulch that had a higher efficiency than the check.

A lower efficiency was observed for all the treatments in 1958 than in 1957. Again the rainfall distribution as it was discussed earlier is believed to be the principal cause. In addition, some of the chemicals used may have deteriorated and lost their effectiveness.

Despite the low efficiency obtained in 1957, it is in the range that was presented by Aasheim (1), who studied the moisture efficiency on fallowed soil.

Evaporation

Effect of Soil Differences

Huffine silt loam lost the least amount of water by evaporation in 1958, followed by Bridger, Manhattan, and Huntley. This is a slightly different arrangement than was found in 1957 because Manhattan instead of Bridger followed Huffine soil. This difference is believed to be caused by climatic factors.

In 1958, Huffine was the only soil in which evaporation did not exceed the total rainfall. Moisture stored during the winter months probably supplied the extra moisture for evaporation.

In 1957, Huntley was the only soil in which evaporation exceeded rainfall. The period in 1957 was started on May 3, and it is believed that some of the winter-stored moisture was lost prior to this date.

Effect of Soil Treatments

The rock mulch treatment in 1957 and 1958 was the outstanding treatment with the least amount of water lost by evaporation. It lost 10,073 grams less than the Bridger check soil in 1958 and 12,435 grams less than the check in 1957. Among the other treatments, both of the VAMA treatments and the straw mulch treatment showed some encouragement by having slightly lower evaporation in 1957 than the check. However, in 1958, straw mulch was the only treatment that did not exceed the check in evaporation.

Besides rock mulch, straw mulch was the only treatment that did not lose more water by evaporation than was added by rainfall. In 1957, surfactant was the only treatment which caused the soil to lose more water than the total rainfall received. This is believed to have been lost from previously stored moisture.

Drying Characteristics of Huffine and Bridger Soil and Rock Mulch Treatment

In an effort to predict from climatic data when water storage can be anticipated, the disposition of water from some of the lysimeters was evaluated during the period June 26 to August 4, 1958. Figures 3, 4, and 5 were developed for Huffine and Bridger silt loam and rock mulch treated soil. The data in these graphs include rainfall, percolation, evaporation, and storage weight between weighings. The data below the reference line represent all the water that was lost, while the data above include all the stored moisture.

Following a period of continuous rainfall, field capacity was assumed to be established for these lysimeters, and the average field capacity weights for the lysimeters were Bridger, 18,881 grams; Huffine, 18,283 grams; and rock mulch, 22,595 grams. The average dry weight of each lysimeter was Bridger, 13,842 grams; Huffine, 14,079 grams; and rock mulch, 17,691 grams. From this data, approximately 5,039 grams of moisture was required to induce percolation in the Bridger soil, 4,204 grams for Huffine, and 4,904 grams for the rock mulch treated soil. The lysimeter serves as a reservoir in which the above amounts of water can be stored. Since drying from the three sets of lysimeters proceeds

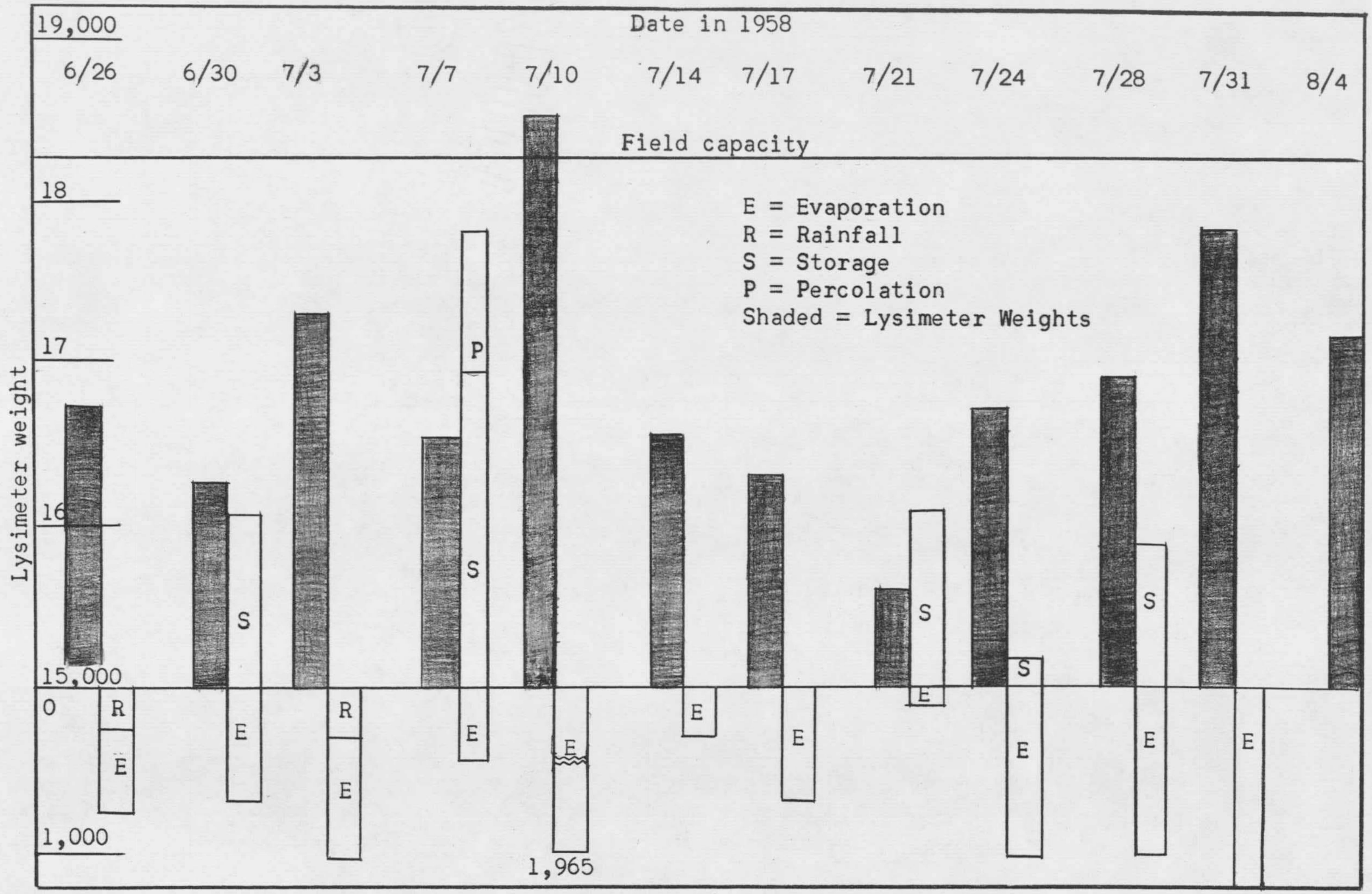

Figure 3. Drying characteristic of Huffine silt loam. (When evaporation exceeded rainfall between weighings, the rainfall was added to evaporation and shown below the base line. Otherwise, rainfall was shown above the base line as stored or percolated water).

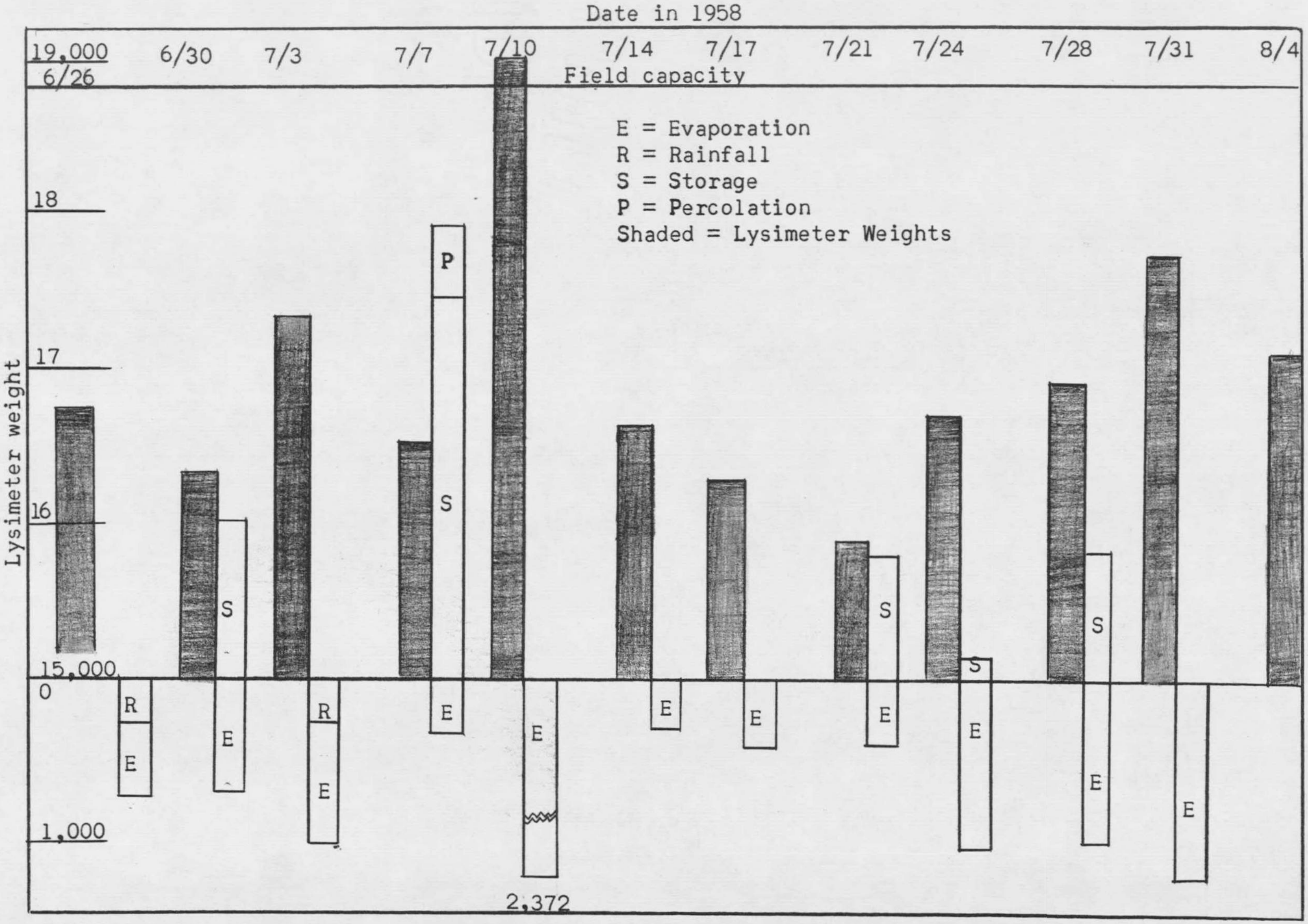

Figure 4. Drying characteristic of Bridger silt loam. (When evaporation exceeded rainfall between weighings, the rainfall was added to evaporation and shown below the base line. Otherwise, rainfall was shown above the base line as stored or percolated water).

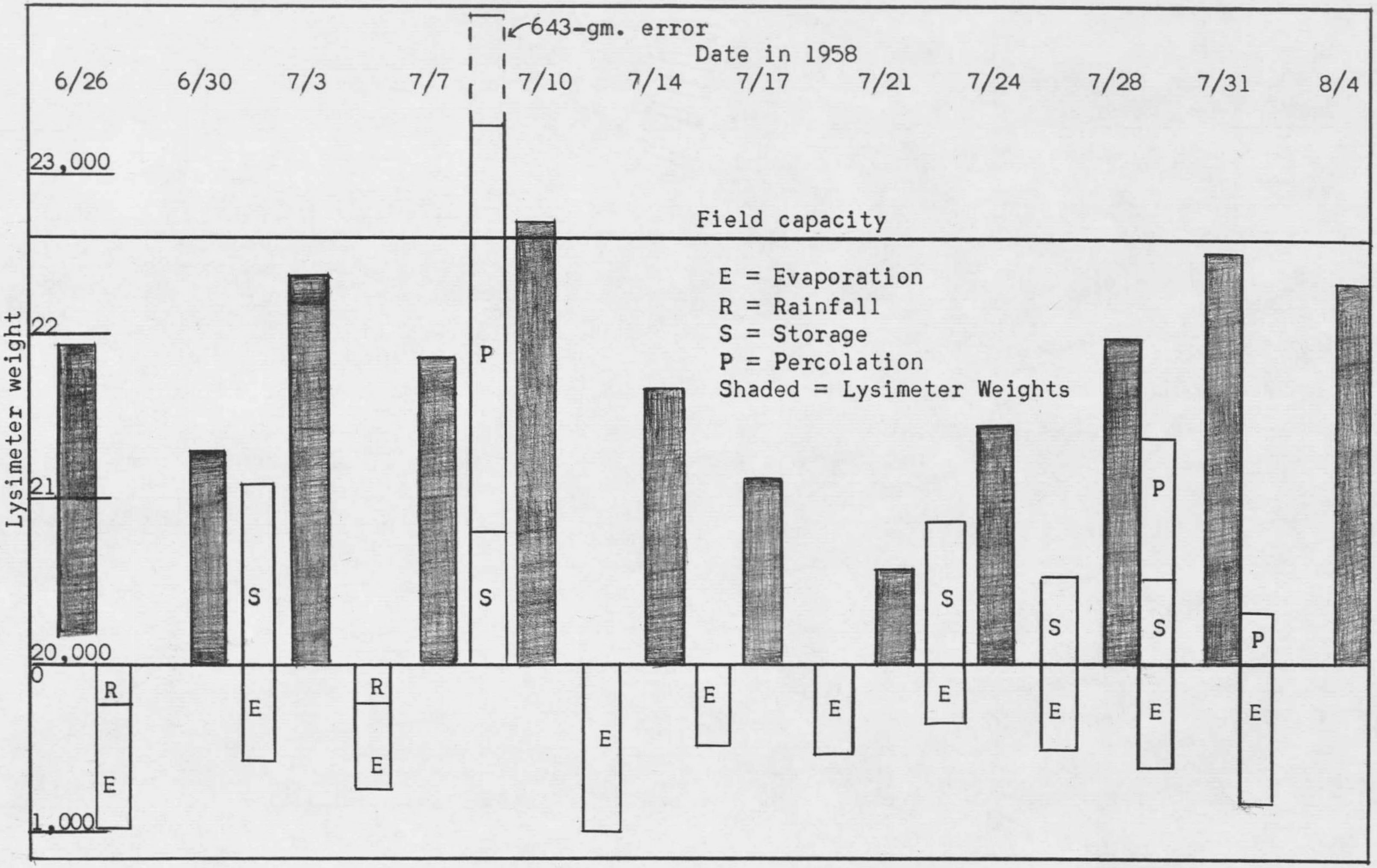

Figure 5. Drying characteristic of rock mulch treatment. (When evaporation exceeded rainfall between weighings, the rainfall was added to evaporation and shown below the base line. Otherwise, rainfall was shown above the base line as stored or percolated water).

at different rates, it is evident that the amount of rainfall necessary to induce percolation on any treatment will be dependent upon the amount of water evaporated from the reservoir since it was last full. Since the rock mulch was quite effective in reducing evaporation, it follows that less rainfall would usually induce percolation on this treatment than for other treatments. Huffine and Bridger evaporated a high percentage of the moisture stored in the lysimeter, and they required more rainfall than was necessary for rock mulch to induce percolation. Huffine in comparison to Bridger required slightly less rainfall because it evaporated less moisture than Bridger.

Only once during this period was there sufficient rainfall to initiate percolation in Huffine and Bridger. Rock mulch allowed percolation of water three times during this period, which indicates again that rock mulch reduced evaporation.

Rock mulch percolated 872 grams between July 28 and July 31 and 302 grams between July 31 and August 4. Continuous records would probably have shown that the lysimeters reached field capacity before percolation was induced, but evaporation again lowered the lysimeter weights below this value prior to the next weighing. Huffine and Bridger did not accumulate sufficient moisture to initiate percolation.

The difference between the weight of a lysimeter at any time and its weight at field capacity indicates the amount of rain necessary to induce percolation.

Physical Properties of Bridger and Huffine Silt Loams

Since Hide and Brown (22) found that the moisture loss associated with different depth layers differed considerably with time in Bridger and Huffine silt loams, an attempt was made to determine the physical properties which account for this difference.

Mechanical Analysis, Organic Matter, and Bulk Density

Mechanical analysis determinations were made using the pipette method, and the results are shown in table IX.

The mechanical analyses show very little difference in texture between the two soils. Kemper (24) also found these two soils to be similar in clay content, although he found somewhat higher clay contents than those presented above. It doesn't seem probable that this small difference in texture would materially affect the evaporation pattern. Mechanical analyses show both soils to be silt loams, although on the soil survey of the area by DeYoung and Smith (11), the Bridger soil is classified as a clay loam. Despite the same clay content, the water-holding capacity of Bridger silt loam is greater than Huffine silt loam, and it is believed that the difference in organic matter in these two soils is responsible for this property.

The organic matter content of Bridger and Huffine silt loams is presented in table X. Bridger (5.1%) has a higher organic matter content than Huffine (2.8%).

The bulk density (table XII) for the two soils differed by about 10%, with Bridger and Huffine having 1.04 and 1.14, respectively. The

Table IX. Mechanical analysis by the pipette method.

Soil type	% Clay	% Silt	% Sand
Huffine silt loam	21.1	58.9	19.9
Bridger silt loam	18.8	63.2	18.0

Table X. Percent clay, percent organic matter, and aggregate stability of Bridger and Huffine silt loams (24).

Soil type	% Organic matter	% Clay	Aggregate stability Vacuum wet	 Immersion
Huffine	2.8	25.1	81.1	24.2
Bridger	5.1	25.4	72.4	22.2

Table XI. Percent silt and clay aggregated in Bridger and Huffine silt loams.

Soil type	% Silt and clay aggregated
Huffine	67.7
Bridger	66.8

Table XII. Bulk density for Huffine and Bridger silt loams.

	Bulk density
Huffine	1.14
Bridger	1.04

difference confirms, however, that Bridger could have a larger storing capacity than Huffine. The higher organic matter content of Bridger probably accounts for its greater amount of pore space and lower bulk density than Huffine.

Degree of Aggregation

Table XI shows the percent silt and clay aggregated (degree of aggregation) for Huffine and Bridger silt loams.

Table X shows Kemper's (24) results of percent clay, percent organic matter, and aggregate stability of Bridger and Huffine silt loams.

Only small differences in aggregate stability were found in the two soils, with Huffine having a slightly higher aggregation than Bridger. Yet the low bulk density of Bridger indicates that it contains a greater amount of pore space. Thus apparently neither degree of aggregation nor aggregate stability provides a good measure of pore distribution. Field observation indicates that the Bridger soil is more porous and has less tendency to crust than the Huffine.

Saturated Flow

In saturated soils, movement of water takes place throughout the soil pore spaces that contain little or no air. For this experiment, assumptions are made that no air is entrapped within the pores.

The results of the water collected and the "K" values calculated for 1-, 2-, and 3-hour intervals are shown in table XIII.

The permeability constant "K" values obtained, as defined by Baver (4), are dependent upon the soil properties--particularly size of particles,

Table XIII. "K" values and infiltration rate (cc.) of Bridger and Huffine silt loams.

	First hour	Second hour	Third hour
		Infiltration	
Huffine*	196	154	147
	242	220	202
Average	219	187	174
K	.061 cm./min.	.026 cm./min.	.018 cm./min.
		Infiltration	
Bridger	261	208	185
	256	191	172
	157	134	120
	332	257	231
Average	252	198	177
K	.069 cm./min.	.027 cm./min.	.019 cm./min.

*Two samples were discarded.

aggregates, and nature of the soil pore space. A small difference occurred only during the first hour of infiltration. Thereafter, infiltration was approximately the same in the two soils. The Bridger soil has a slightly higher infiltration rate for the first hour of infiltration, but in succeeding hours, the infiltration for the two soils becomes similar.

Unsaturated Flow

The problem of infiltration has received much attention by those concerned with irrigation, erosion control, and moisture conservation. Few attempts have been made to find the intimate relationship between water entry under unsaturated conditions and water moving out of the soil to meet the evaporation demands of the atmosphere. The water movement is dependent upon, among other factors, the percent pore space, nature of pore space, particle size, and aggregation. For convenience, the results of the unsaturated flow are shown in figures 6 and 7 and table XIV as parameters A, B, E, and F where B and F are the slope obtained from figures 6 and 7, respectively, A is obtained from the equation $\frac{dQ}{dt} = At^B$, and E is obtained from the equation $S = Et^F$. When $t = 1$, $\frac{dQ}{dt} = AB$, $Q = A$, and $S = E$. Thus, the larger the parameters A and E, the larger the initial infiltration.

Parameters A and B show a small difference in their unsaturated flow characteristics. The slightly larger value of Bridger indicates a higher rate of intake of water initially and a lower intake of water with respect to time. Parameters E and F are slightly different. The larger value of E and smaller value of F indicate the change in soil properties of Bridger with respect to time is greater than in Huffine.

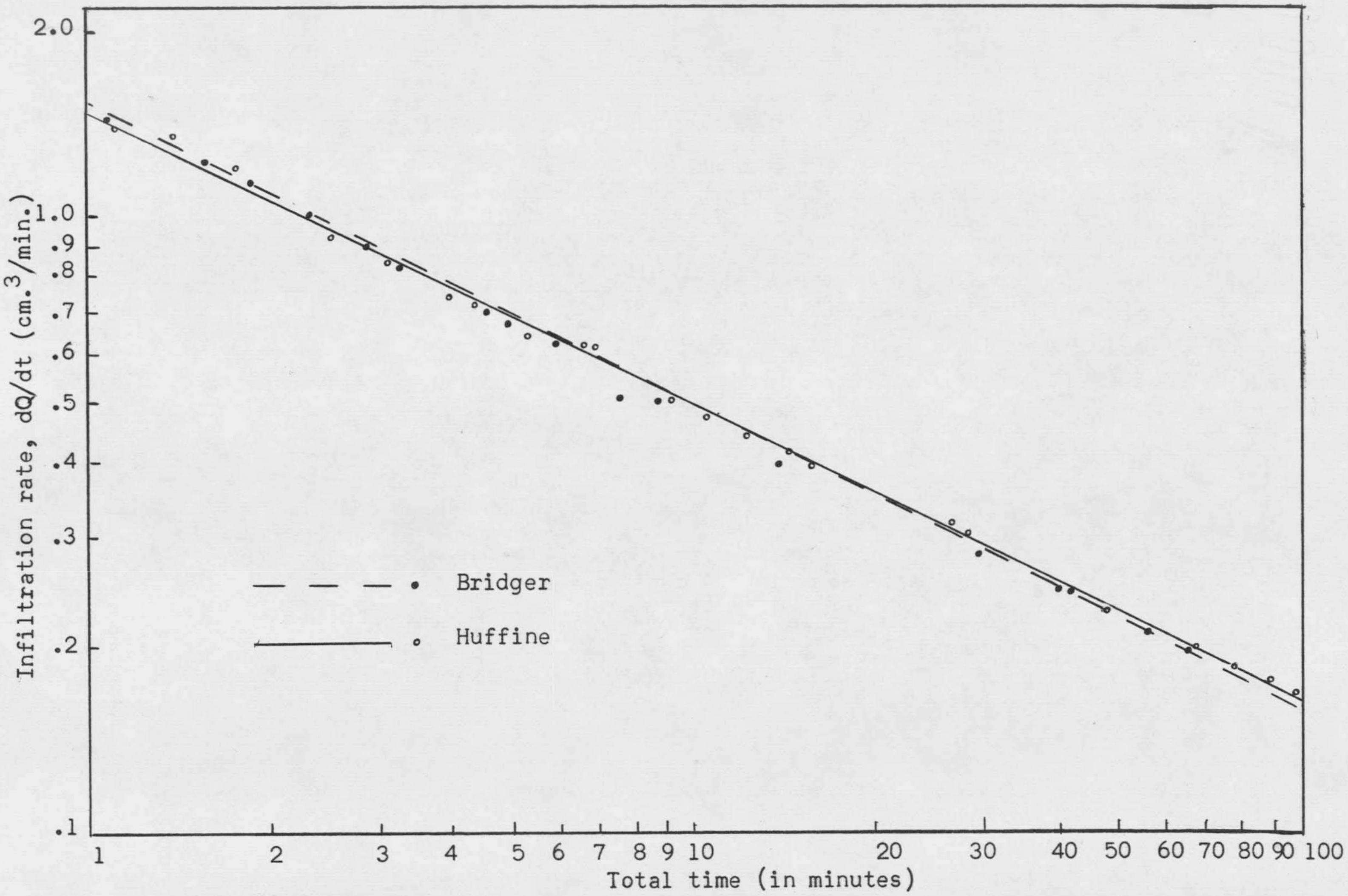

Figure 6. Rate of intake, $\Delta Q/\Delta t$, as a function of time, t, with hydrostatic head as the parameter for Huffine and Bridger silt loams.

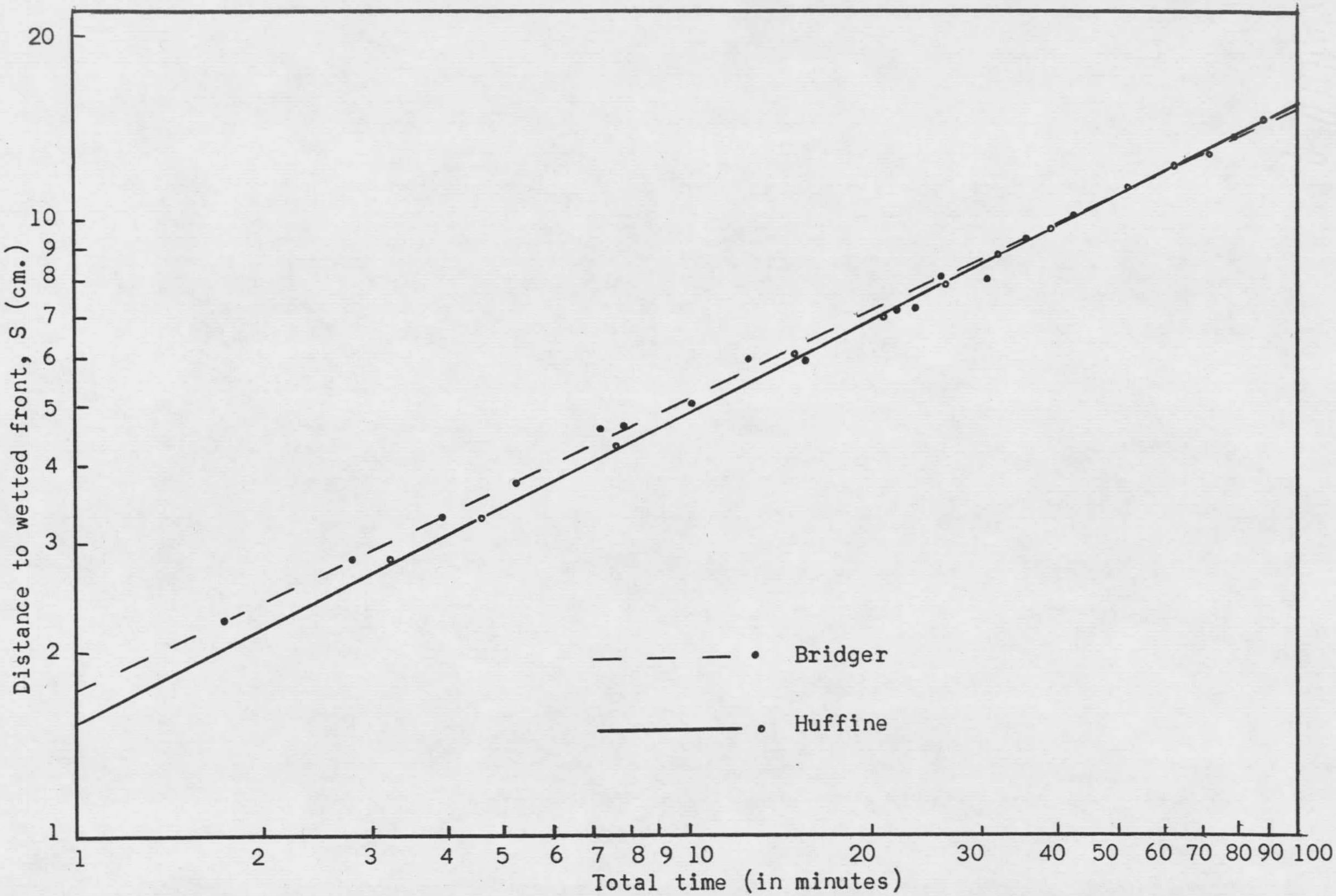

Figure 7. Vertical distance of advance of the wetted front, S, as a function of time, t, with hydrostatic head as the parameter for Bridger and Huffine silt loams.

Table XIV. Parameters A, B, E, and F of infiltration against time.

Soil	A	B	E	F
Huffine	2.9	.49	1.55	.47
Bridger	3.3	.50	1.73	.45

For further evaluation, desorption data was collected. Undisturbed samples were used for the tension range from 0 to 0.150 atmospheres, and disturbed samples were used from 0.150 to 15 atmospheres tension. According to Elrick and Tanner (12), as much as 30% difference can be expected between disturbed and undisturbed samples at tensions below 1 atmosphere. The results obtained for this moisture curve (figure 8) were well within this percent error from the line drawn. This curve indicates that, between 0 and 100 cm. water tension, which is approximately the range above field capacity, Bridger released 14.5% moisture while Huffine released 9.8% moisture. From 100 to 150 cm. water tension, Bridger again released more moisture than Huffine.

The points obtained from the disturbed samples could not satisfactorily meet the points obtained from the undisturbed samples. In order to complete the curve to a higher tension, the dotted line was drawn from 150 to 1,000 cm. water tension, disregarding the point at 1/3 atmosphere. It was in this tension range that the moisture released by the two soils was nearly equal. It is evident from the similarity of the curves (figure 9) between 3 and 15 atmospheres that the two soils were almost identical in the amount of moisture released in this range.

Further work was done to decide what property of Bridger soil caused it to release more moisture than Huffine.

The percent pore space drained for each tension is shown in table XV. There was little difference in the percent pore space drained for the pore size of .0146 to .0015 cm. radius, but the Bridger soil had a much higher percentage of pores in the size range of .0015 to .001 cm.

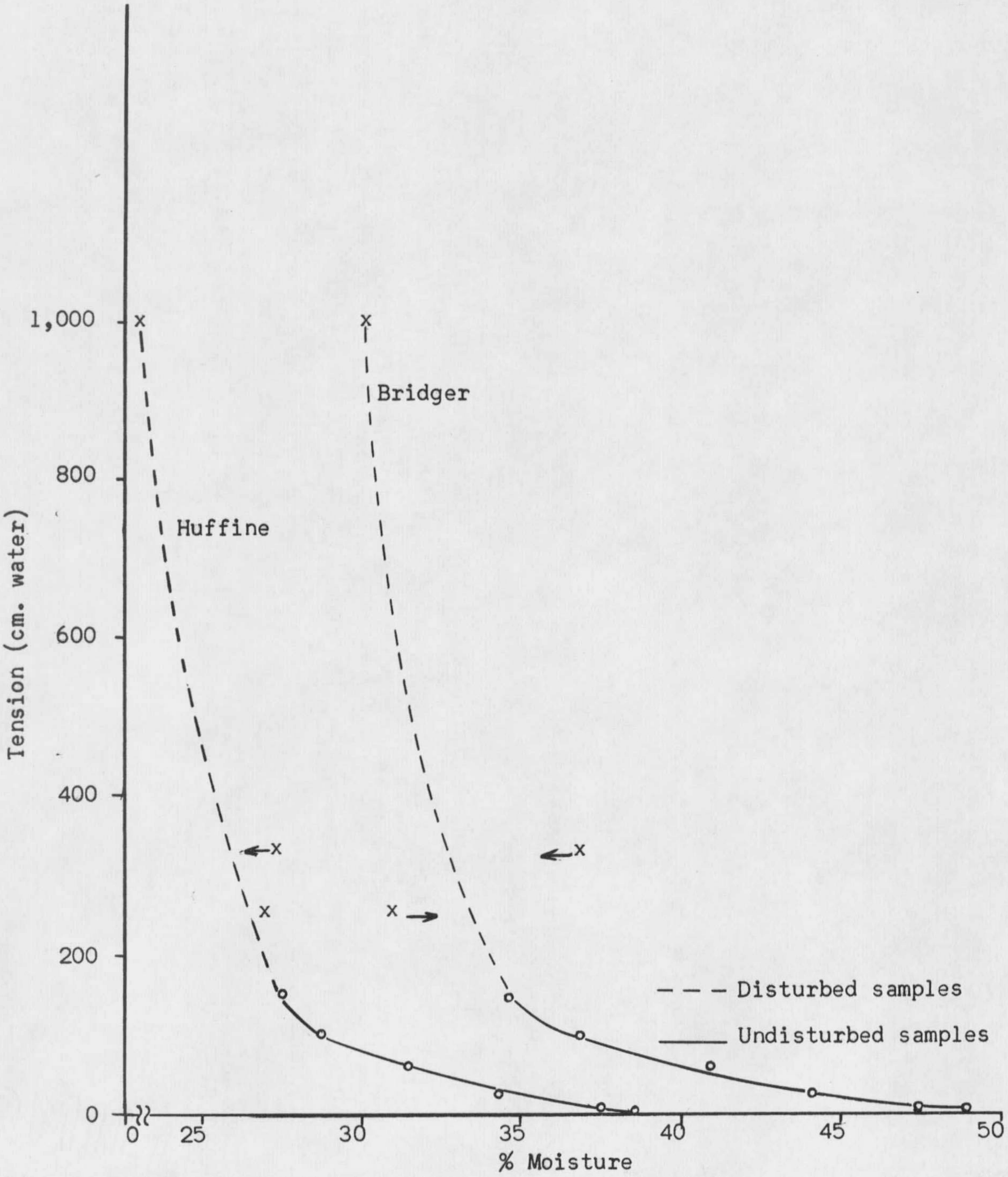

Figure 8. Moisture tension curve for Bridger and Huffine silt loams between 0 and 1 atmospheres tension.

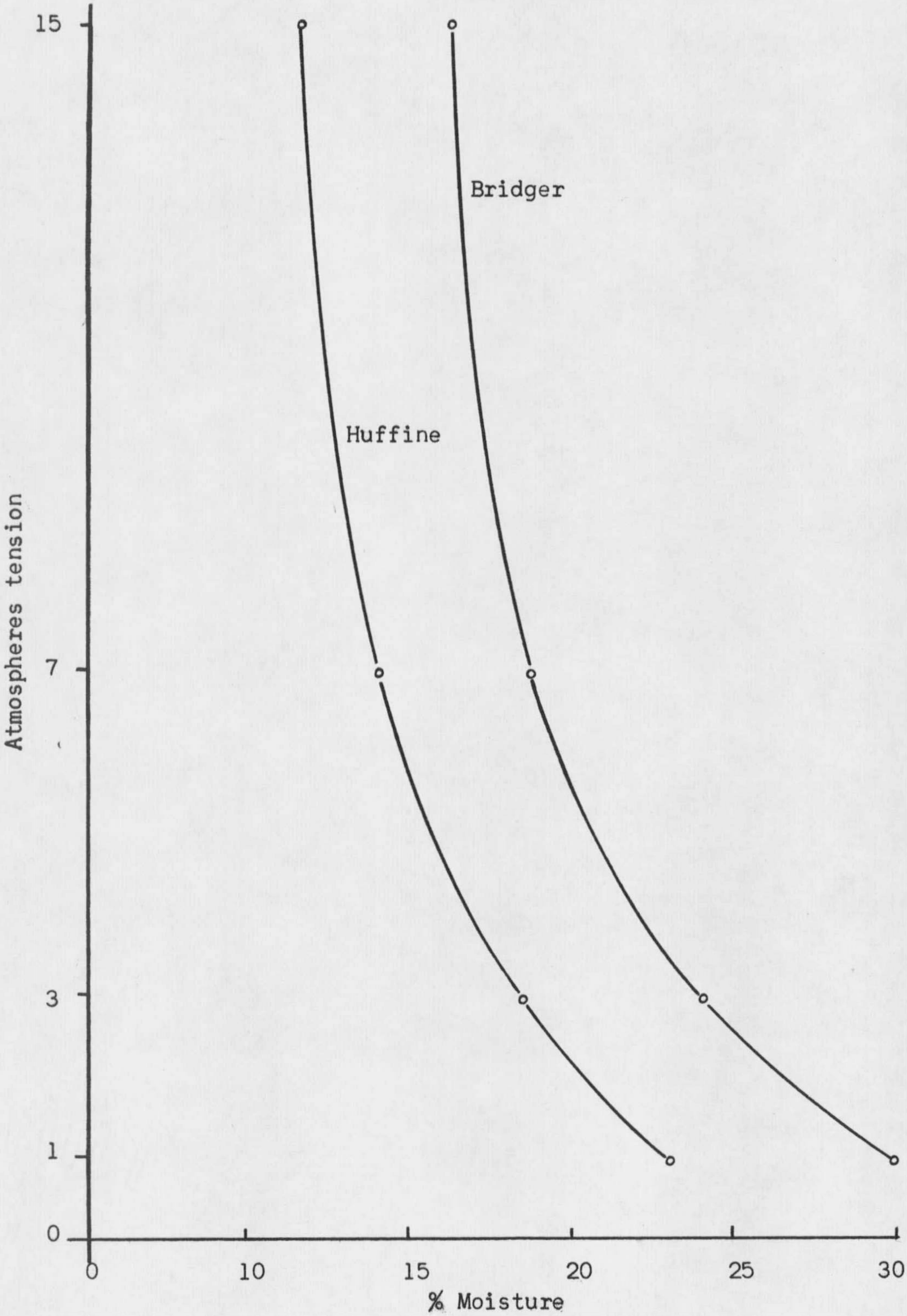

Figure 9. Moisture tension curve for Huffine and Bridger silt loams between 1 and 15 atmospheres tension. Data by Brown (6).

Table XV. Percent pore space drained at various tensions (pore size distribution).

Water tension (cm.)	Radius of pore space in cm.	% Pore space drained	
		Huffine	Bridger
10	.0146	2.9	2.4
30	.0049	8.2	7.6
60	.0024	7.5	6.1
100	.0015	7.2	7.3
150	.0010	2.9	5.8
Total pores coarser than .001 cm.		28.8	29.2

radius. Thus the two soils have similar amounts of large pores, but the Bridger soil has a considerably higher percentage of medium-sized pores. These medium-sized pores which probably do not drain under the influence of gravity may serve as a source of water that can be moved to the surface for evaporation.

Effect of Soil Depth on Drying Properties

A major criticism of the shallow lysimeter approach in determining the seasonal water regime is that the discontinuity at the bottom of the lysimeter may seriously influence the nature of the regime. In an effort to evaluate this limitation, studies of evaporation losses from 4- and 18-inch columns of soil were undertaken in the laboratory. The results are shown in figure 10. For both soils, the 4-inch column tube, representing the lysimeter, evaporated more than the 18-inch tube, which represented the normal soil condition. However, the pattern through which water was lost remained similar in the two tubes. Greater losses from the 4-inch column are due to the fact that water does not drain from the bottom of the lysimeter until the moisture content is raised so that tension becomes essentially zero. In a continuous soil column, the moisture would be moved downward under considerable tension. Thus the 4-inch column contains more moisture when it yields no further percolate than it would have contained had there been additional soil into which this excess moisture could have moved. The fact that more water was lost from the 4-inch columns than was lost from the deep columns indicates that fallow would store more water than percolated through the lysimeters. Thus the data for efficiency as presented would tend to be lower than

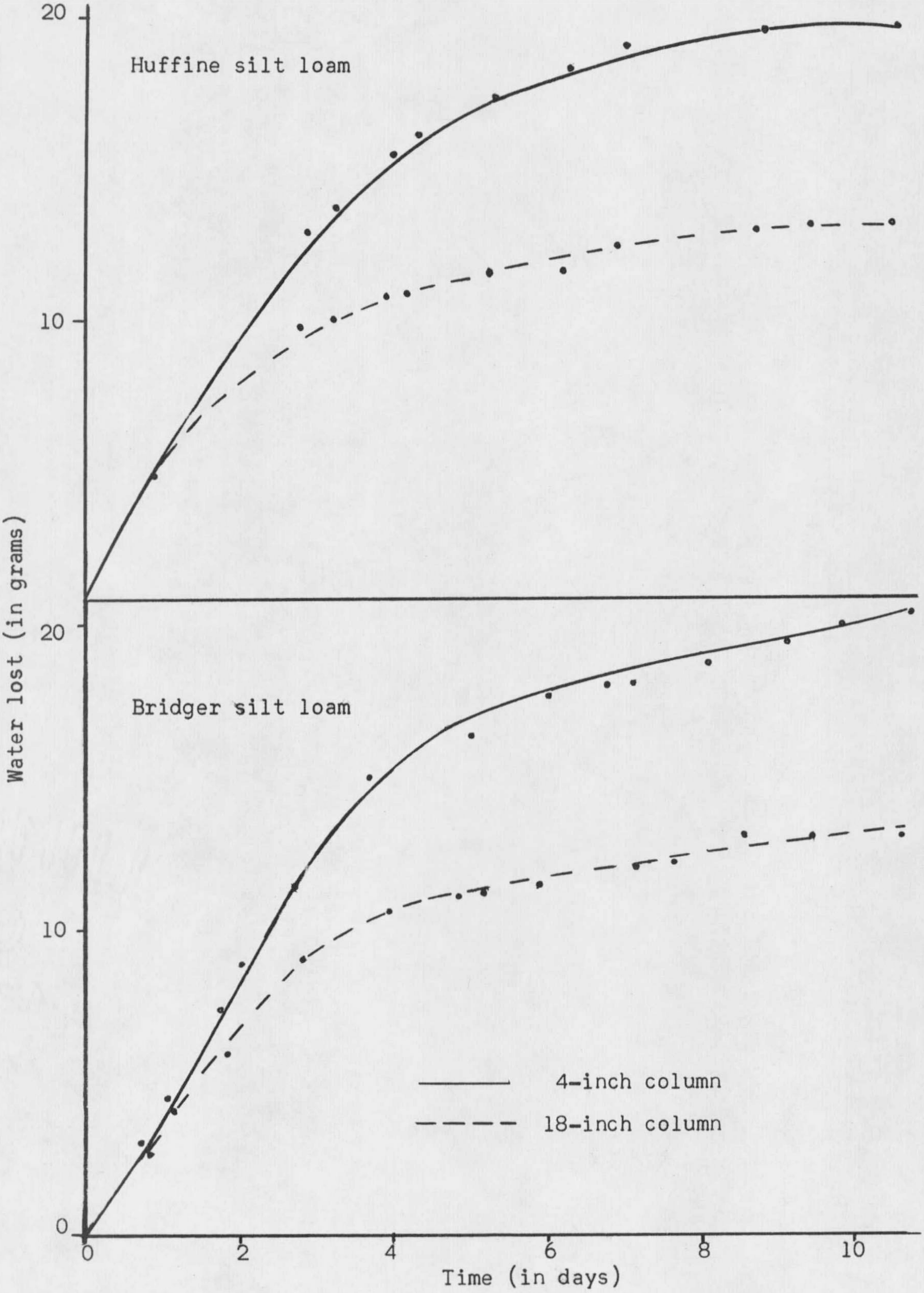

Figure 10. Effect of soil depth on drying properties.

would be encountered in the field.

This condition enables the surface to remain wet longer, which accounts for the greater loss. As long as the surface was wet, evaporation was constant in both the 4- and 18-inch tubes of both soils, but Huffine, during the first 2 days, lost more water than Bridger. After 4 days, both soils were losing about the same amount of moisture; but after 8 days, Huffine had almost ceased losing water while Bridger was still releasing water for evaporation. This continued loss of moisture in Bridger soil, even after 8 days, is the major factor responsible for its evaporating more water than Huffine.

SUMMARY AND CONCLUSIONS

Moisture efficiency was studied for four soils and five treatments on one soil in 1958, and comparisons were made with the data obtained in 1957. In addition, studies of physical properties of Huffine and Bridger silt loams were undertaken in an effort to account for the difference in their evaporation pattern.

Since the lysimeter portion of this study is a comparison between years using the same soils and treatments, the summary and conclusions will be made in a similar manner to that which Brown (6) presented in 1957.

Among the soil differences, cumulative data for the entire period showed that Huffine had the lowest evaporation loss, followed by Bridger, Manhattan, and Huntley. In 1957, Huffine, Manhattan, Bridger, and Huntley followed in this order. The difference is believed to be influenced by climatic differences.

The soils that were low in evaporation were invariably high in percolation, although percolation was much lower in 1958 than in 1957.

Season-long efficiency for 1958 for Huffine, Bridger, Manhattan, and Huntley was 6.2, 4.8, 2.9, and 1.1%, respectively, in contrast to 20.5, 14.3, 17.6, and 6.8% in 1957. The rainfall distribution accounts for the reduced efficiency in 1958.

Both evaporation and percolation for each soil varied from period to period, depending on the climatic pattern. Huffine was not the most effective soil in all the periods; however, it was the most efficient soil throughout the experimental period for the 2 years.

Among the soil treatments studied, rock mulch repeated as the outstanding treatment and had a season-long percolation efficiency of 29.8% as compared to 60.4% in 1957. This is still six times higher than straw mulch and the untreated soil which were the next highest. In 1958, percolation efficiency varied from period to period, with a high of 38.7%, whereas in 1957, it was 79.8%.

The remainder of the treatments were less effective than the check, but during certain periods, straw mulch as in 1957 showed some efficient characteristics, while at other times, it was very ineffective. Most of the treatments used had only minor influence on the efficiency of percolation, but the effectiveness of rock mulch and the differences found between soils encourage continued efforts to devise more efficient treatments.

Among the various physical properties studied, pore size distribution, percent organic matter, and bulk density differed between Huffine and Bridger soils. The texture, aggregate stability, percent aggregation, and moisture movement under saturated and unsaturated conditions did not differ greatly. The differences that were observed, however, do not directly account for the differences that occurred between Huffine and Bridger silt loams in evaporation. It appears that size and volume of pore space are the most probable soil factors to account for differences in evaporation loss in a drying cycle.

A study involving a greater number of soils should be undertaken to establish a definite relationship.

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APPENDIX

Table XVI. Period dates and classification as determined by climatic factors, 1957.

Period dates	Days in period	Period classification	Precipitation in inches	Maximum average temperature
May 3-June 6	34	Cool-moist*	2.93	66.0
June 6-June 28	22	Cool-wet*	4.55	67.5
June 28-July 31	33	Hot-moist	1.52	81.8
July 31-August 26	26	Hot-dry	0.00	85.0
August 26-September 3	8	Cool-wet*	1.00	67.3
September 3-October 30	57	Cool-dry	1.29	62.3

*Data from Brown (6), but classification changed to correspond with that used in 1958.

Table XVII. Precipitation and evaporation (in grams) for lysimeter areas for period May 3 to October 30, 1957.*

Treatment		Selected period May 3–June 6	 June 6–June 28	 June 28–July 31	 July 31–Aug. 26	 Aug. 26–Sept. 3	 Sept. 3–Oct. 30	Total
	Precipitation	7,896	12,262	4,096	0	2,965	3,477	30,696
Manhattan	Evaporation	6,240	8,754	4,274	3,704	2,277	3,722	28,971
Huffine	Evaporation	5,397	8,459	4,441	3,752	2,197	4,277	28,523
Huntley	Evaporation	7,876	10,387	4,945	4,916	2,328	3,653	34,105
Bridger	Evaporation	6,881	9,075	4,133	3,964	2,260	3,914	30,227
Rock mulch	Evaporation	2,227	2,476	4,000	4,796	1,752	2,279	17,530
Straw mulch	Evaporation	7,059	8,136	4,711	4,139	2,153	3,367	29,563
VAMA coarse	Evaporation	5,952	8,963	4,223	4,046	2,322	3,889	29,395
VAMA fine	Evaporation	5,988	9,671	4,385	4,118	2,308	3,308	29,778
Surfactant	Evaporation	6,558	9,513	4,439	4,061	2,318	3,834	30,723
Check	Evaporation	6,543	8,852	4,483	3,914	2,197	3,976	29,965

*Data collected by Brown (6).