



The influence of different soil types and treatments on the loss of moisture from fallowed lysimeters
by Bernard L Brown

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

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Abstract:

Moisture efficiency of four Montana soils and five treatments on one soil type was determined in a lysimeter study between May 3 and October 31, 1957. The effect of soil properties on infiltration and evaporation was studied and an efficiency percentage calculated.

Evaporation, infiltration, and moisture stored in the soil volume are controlling factors in moisture efficiency. High infiltration contributes to high efficiency, whereas high evaporation provides low efficiency. Both evaporation and infiltration were influenced by the moisture stored in the soil.

Seasonal influences were noted among soils and soil treatments. Soil properties which were desirable during one period were frequently undesirable during other periods.

During the experimental period, the Huffine soil evaporated less and infiltrated more water than other soils under study, having an efficiency of 20.5%. This is 41.4% more efficient than the Bridger, 14.3% more than Manhattan, and 300.0% more than Huntley.

High storage capacity and low permeability probably accounted for the low efficiency of the Huntley soil.

Among the soil treatments, the rock mulch was outstanding, having a season-long efficiency of 60.4%. During three weeks of warm, wet weather in June, 79.8% of the moisture passed through the 4-inch layer of soil. Throughout the season, the rock mulch was more than three times as effective in infiltrating moisture as the next best treatment. In comparison, all other treatments were relatively ineffective although coarse aggregates stabilized with VAMA were slightly better than the other treatments.

THE INFLUENCE OF DIFFERENT SOIL TYPES AND TREATMENTS
ON THE LOSS OF MOISTURE FROM FALLOWED LYSIMETERS

by *20*

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ABSTRACT

Moisture efficiency of four Montana soils and five treatments on one soil type was determined in a lysimeter study between May 3 and October 31, 1957. The effect of soil properties on infiltration and evaporation was studied and an efficiency percentage calculated.

Evaporation, infiltration, and moisture stored in the soil volume are controlling factors in moisture efficiency. High infiltration contributes to high efficiency, whereas high evaporation provides low efficiency. Both evaporation and infiltration were influenced by the moisture stored in the soil.

Seasonal influences were noted among soils and soil treatments. Soil properties which were desirable during one period were frequently undesirable during other periods.

During the experimental period, the Huffine soil evaporated less and infiltrated more water than other soils under study, having an efficiency of 20.5%. This is 41.4% more efficient than the Bridger, 14.3% more than Manhattan, and 300.0% more than Huntley.

High storage capacity and low permeability probably accounted for the low efficiency of the Huntley soil.

Among the soil treatments, the rock mulch was outstanding, having a season-long efficiency of 60.4%. During three weeks of warm, wet weather in June, 79.8% of the moisture passed through the 4-inch layer of soil. Throughout the season, the rock mulch was more than three times as effective in infiltrating moisture as the next best treatment. In comparison, all other treatments were relatively ineffective although coarse aggregates stabilized with VAMA were slightly better than the other treatments.

INTRODUCTION

All life depends on water. In the early white settlement of the New World, major areas of population were along the coast. When these areas became overcrowded, there was a major population influx toward the inland areas. The main path of settlement followed along the rivers, which not only presented an accessible highway but furnished an ever-ready supply of water.

Eventually man was forced to settle in the more arid areas. Again water was a prime factor in settlement. Usually an adequate supply was available for human consumption, but frequently the supply was inadequate for satisfactory crop production.

Moisture is the limiting factor in crop production in most non-irrigated areas of Montana. It has been estimated (16) that 20 to 25% of the moisture that falls is used by crops. Usually less than 5% of the precipitation is lost through runoff in streams and underground reservoirs. Seventy to 75% is returned to the atmosphere through direct evaporation.

Many people have been interested in the moisture utilization in cultivated areas. Attempts to alter moisture efficiency have met with limited success. Moisture changes during a drying cycle have not received much attention, and only very limited attempts have been made to devise soil treatments to increase moisture utilization.

The present study was undertaken to determine the differences in moisture storage efficiency of four Montana soils and five treatments on one of these soil types.

REVIEW OF LITERATURE

Lysimeter studies have been used throughout the world to study many soil properties. While many of these studies have involved some aspect of nutrition, moisture utilization has frequently been included. Kohnke, et al., (21) has discussed the construction and performance of lysimeters.

Three general types of lysimeters have been used, as discussed by Harrold and Dreibelbis (14).

- (a) The fill type with vertical walls, open top, and perforated bottom. This type does not retain the original profile as the soil is usually screened and mixed before filling.
- (b) The Ebermeyer type in which a pan or funnel is inserted at desired depths in the soil. There is unrestricted lateral flow, as this type has no walls. Water is percolated through the soil into the pan or funnel and measured.
- (c) The monolith or undisturbed soil block type. A casing of vertical walls is built around an undisturbed soil block. A perforated pan or sheet is placed under the undisturbed block for water percolation.

Most of the lysimeter work done has been on nutrient balance in the soil. Smith (30) used a lysimeter in a study of nitrogen balance in an irrigated area. The study involved infiltrated moisture. Similarly, Bizzel (6) also was interested in nitrogen balance but under cropping at

different fertilizer levels, but again moisture loss was studied.

A 9-year experiment was carried on by Joffe (18), using Ebermeyer-type lysimeters at different levels to trace cation activity throughout the soil profile. Quantity of precipitation was found not to determine the quantity of leaching or translocation of ions in the soil profile.

Lysimeters offer a means by which comparisons can be made under similar field conditions. Kardos (19) compared nutrient status of cultivated and virgin soils in a subhumid area. Bizzel (5) compared the effect of ammonium sulfate and sodium nitrate in removal of the N and Ca from the soils. Kilmar, et al., (20) used a monolith-type lysimeter to study nutrient and water loss from a silt loam. Differences between cropped and fallowed lysimeters were studied. The influence of slope and associated runoff of water and nutrient status were also studied.

The hydrologic cycle has been of great interest to a number of authors. Colman (8), using a range of tensions, was able to control seepage rates and drainage of a soil column. Richards, et al., (29) working with moisture tensions, found that soil moisture in fallow soils forms a dynamic system which responds rapidly to moisture changes at the soil surface.

Martin and Rich (26), using a monolith-type lysimeter in Arizona, show that most erosion and surface runoff occurred during the summer, while winter precipitation contributed mostly to storage and percolation. Percolation flow data from two soils was studied by Dreibelbis and Harrold (10). Dreibelbis (9), in further studies, determined the soil constituents in drainage water under a 4-year rotation of corn, wheat, and meadows. This rotation was duplicated on two soil types. Losses of both water and

nutrients from the two soils were similar, except for magnesium which varied more with the amount of percolation than with cropping practices.

Fisher and Burnett (13) used lysimeters to determine the proportion of the rainfall that penetrated soils varying in texture and depth. Their data suggested the possibility of using mulches and crop residues to increase the amount of moisture penetration. Evaporation work done at the same location indicated that the rate of moisture loss decreases following surface drying. Additional work on small fallowed areas, diked to prevent runoff, has shown that at least 60% of the rain that fell during a 2-year study was not stored in the soil at the end of the period. Even greater losses by evaporation from the soil surface have been reported on the high plains of Texas by Finnell (12).

Not all work of interest to this problem was done with lysimeters. Buckingham (7) undertook laboratory studies on evaporation. He found that intensive evaporating conditions were responsible for moisture loss exceeding the capillary flow. This formed a dry mulch of soil on the surface area which tended to slow down moisture evaporation.

Veihmeyer and Brooks (35) studied the cumulative loss from bare soil during a 1,547-day period. Moisture lost during this period amounted to 3.65 inches, and one-third of this total was lost the first month. It was found that the higher the water table, the greater the loss of moisture by evaporation.

Working with undisturbed cores of soil, Stanhill (31) compared soil moisture evaporation against free-water evaporation and found evaporation was approximately equal from free water and soil as long as the soil

surface remained moist.

Evaporation of moisture from a soil surface was subdivided into three distinct stages by Hide (16). The first stage is the brief period while the soil has a moisture content above field capacity, the second stage is after the soil surface has reached field capacity but before the surface dries, and the third stage is when vaporization occurs below the dry soil surface.

Hide and Brown (17), working with three selected soils, found that soil properties altered the amount and nature of water lost during a drying cycle. Even after the moisture content of the upper 3 inches of soil became fairly constant, there was a diurnal redistribution of moisture within the layer.

Major emphasis in moisture conservation has been placed on the control of runoff. Increased emphasis has recently been placed on other methods of conserving moisture. In Texas, Porter, et al., (28) found that leaving crop residues on the soil surface is considerably more favorable to moisture storage than plowing them down. This is true for land being continually cropped or alternately fallowed. These same conclusions were drawn by Aasheim (1) in the north-central Montana area. However, in northeastern Montana, surface residues did not influence moisture storage efficiency.

Crop residues have been used as a conservation practice by Duley and Russell (11), who found that straw mulch increased water penetration and decreased runoff. Bare soils compacted under heavy rainfall lost two to four times more water by runoff than straw mulched plots.

Staple and Lehane (32) studied the effect of shelterbelts on evaporation rates. Differences were found to be very small between the sheltered and unsheltered areas. However, the sheltered areas had a slight effect in cutting down the evaporation rate. Meteorological conditions were found to be the sole controlling factor when the soil surface was moist. Soil moisture content and movement of moisture to the evaporating surface limited evaporation after the soil started to dry.

Lemon, et al., (24) studied energy relationships of evapotranspiration from soils with moisture at various tensions and found that losses could not be predicted solely on the basis of meteorological variables. Soil moisture tension had an effect, but the plant itself exerted, either directly or indirectly, variable restrictions on the transfer of water.

Kolasew (22), as quoted by Lemon (23), made field observations on a soil surface that had been treated with a Naptha soap compound. He found that the treated surface dried much quicker than an untreated soil. This action was attributed to the alteration of the wetting angle between the solid soil particles and the liquid. In the same article, Kolasew quoted Sukhovolshaia's (33) work, which showed that a 2% treatment of Naptha soap reduced evaporation six or seven times.

Very little work has been done in the United States with a rock mulch treatment; however, the Chinese (34) have been using such mulches in the more arid areas of China. Whitmore, et al., (36) used a 3-inch gravel mulch and increased plant production by one-third in an area of South Africa. The increase in production was attributed to saving of moisture normally lost by evaporation.

The effect of soil conditioners on structure and water efficiency has been studied. Hedrick and Mowry (15), using these materials, increased water-stable aggregates and infiltration and reduced the loss of moisture by surface evaporation. The soils treated maintained their characteristics over a 32-month period.

Peters, et al., (27) found that soil conditioners had no effect on the permanent wilting point or field capacity. Physical condition was improved, and the increase in available water was probably due to increased infiltration and a deeper, more extensive root system. Martin, et al., (25) also noted improvement in physical condition, but some crops did not respond to the better physical conditions.

Soil conditioners were used by Alderfer (3) on five tobacco seedbeds. They did not produce marked effects on wilting point, total water-holding capacity, or available water-holding capacity. The increases in the total pore space were reflected in a very substantial increase in the aeration pore space.

Lysimeter studies appear to be well adapted to moisture efficiency studies, although most of the available data is for humid areas. Soil treatments are available which affect many physical soil properties, but their influence on moisture storage efficiency has not received much attention.*

MATERIALS AND METHODS

This study was undertaken to determine how soils and soil treatments influence the efficiency of moisture storage under summer-fallow conditions. It was believed that the amount of moisture which penetrates beyond a depth of 4 inches was largely stored in the soil profile for future use by plants or for deep percolation. It appeared that the influence of this upper 4-inch layer could best be studied in lysimeters containing 4 inches of soil. This procedure induced boundary conditions at the lower edge of the 4-inch layer which do not prevail in a normal profile. It was believed that the procedure would measure real soil differences which exceeded the error caused by the boundary condition.

Soils and Treatments

The experiment was designed to study how the properties of four soils influenced their efficiency in storing water. In addition, the influence of six treatments on one of the soils was determined.

Four selected Montana soils were used as follows:

1. Bridger clay loam was used as one of the soils for comparison and all soil treatments were imposed on it.

It is a dark-colored silty clay loam, well drained, and it belongs to the Chernozem great soil group.

It has developed under grass and shrub vegetation on high fans, aprons, benches, and slopes in mountain valleys. It has a well-developed, very fine crumb structure in the surface layer. The sampling site is southeast corner of southwest quarter, Section 15,

Township 2 South, Range 6 East.

2. Huffine silt loam is a Brown soil developed in silty, alluvial materials. It has many properties in common with the Chernozem group but was developed on flat land characterized by imperfect drainage and local accumulations of soluble salts. The structure is somewhat less stable than the Bridger but of a fine crumb nature. The sample was taken from Montana State College Agronomy Field B, Series 1300 at the northeast corner of the block.
3. Manhattan fine sandy loam is a Brown soil, developed in fine sandy lacustrine deposits. The original material consists of windblown, fine or very fine sand which blew into a former lakebed. It is characterized by a high content of fairly-uniform-sized fine sand particles. Samples were taken one mile west of Manhattan, Montana, on the Northern Pacific right-of-way.
4. Huntley alkali soil probably belongs to the Nibbe series which includes slowly permeable Solonchak soils developed in fine-textured, predominantly clay and silty clay alluvium. These occupy stream terraces and valley floors with relatively high water tables. Their parent materials are derived largely from bedrock uplands of late cretaceous shales and sandstones.

The structure is weak, granular, or crumb, except that the surface 1 inch forms a vesicular crust when dry. It is calcareous, including white flakes of free-lime carbonate and other salts. The sample was taken adjacent to the shed on the field used for salinity studies at Worden, Montana, under the supervision of the Huntley Branch Station.

Six treatments as follows were imposed on the Bridger silty clay loam:

- 5.* Gravel mulch. One inch of gravel ranging in size between 1/4 and 1/2 inch was used. Four kilograms of gravel per 1,060 square centimeters of soil surface gave a mulch approximately 1 inch deep.
6. Straw mulch. This was prepared using chopped wheat straw which was mixed throughout the surface 2 inches of soil. It was applied at a 2-ton-per-acre rate. This left a fairly good surface cover.
7. and 9. Soil conditioners. VAMA** was used at the rate of 0.2% by weight, as suggested by Allison and Moore (4). The material was applied when the soil was sufficiently moist to be easily worked. It was mixed thoroughly and allowed to dry. The soil was sieved into two aggregate size groups--4 to 16 mesh,

* Treatment numbers are a continuation of soil numbers.

** Provided by Monsanto Chemical Company.

designated "coarse", and less than 16 mesh, designated "fine". These treatments will be referred to in this article as coarse and fine.

8. Surfactant.* This material was applied at the rate of 0.1% by weight. This was applied to the soil in a powdered condition and thoroughly mixed.

10. Check. No treatment.

Table I provides the lysimeter numbers, treatments, and randomization for the experiment.

Lysimeters and Construction

To facilitate the collection of infiltrated water, a trench 60 feet in length, 10 feet deep, and 4 feet wide was dug, shored up, and covered with 6 inches of soil. The 60-foot length allowed 15 four-foot areas on each side of the trench for lysimeter treatments. A door covered the exposed steps leading into the trench to reduce temperature changes within.

In construction of the lysimeters, the bottom of each box was a square, shallow funnel of galvanized sheet metal with the top edge on each side of the funnel perpendicular to the ground level. This made a lip which fitted between two 1/8-inch sheets of asbestos-board which acted as the lysimeter walls. Asbestos was chosen because of its low water-holding capacity and heat conductivity. The corners of each box were tarred as a deterrent to leakage. The sides were held in place by small angle irons bolted in each corner.

* PR-51 provided by Atlantic Refining Company.

Table I. Lysimeter numbers, treatments, and randomization.

Lysimeter		Treatment	
No.	Soil	No.	Treatment
1.	Manhattan	1.	Manhattan
2.	Bridger	7.	VAMA coarse
3.	Huntley	3.	Huntley
4.	Bridger	9.	VAMA fine
5.	Bridger	8.	Surfactant
6.	Bridger	4.	Bridger
7.	Bridger	6.	Straw mulch
8.	Bridger	10.	Bridger
9.	Huffine	2.	Huffine
10.	Bridger	5.	Rock mulch
11.	Bridger	4.	Bridger
12.	Bridger	6.	Straw mulch
13.	Bridger	5.	Rock mulch
14.	Bridger	8.	Surfactant
15.	Huffine	2.	Huffine
16.	Bridger	7.	VAMA coarse
17.	Bridger	10.	Bridger
18.	Huntley	3.	Huntley
19.	Manhattan	1.	Manhattan
20.	Bridger	9.	VAMA fine
21.	Manhattan	1.	Manhattan
22.	Bridger	6.	Straw mulch
23.	Huffine	2.	Huffine
24.	Bridger	8.	Surfactant
25.	Bridger	5.	Rock mulch
26.	Bridger	10.	Bridger
27.	Huntley	3.	Huntley
28.	Bridger	7.	VAMA coarse
29.	Bridger	4.	Bridger
30.	Bridger	9.	VAMA fine

Table I continued.

<u>Treatment</u> <u>No.</u>	<u>Soils under study</u>
1.	Manhattan fine sandy loam soil
2.	Huffine silt loam soil
3.	Huntley alkali soil
4.	Bridger clay loam soil
<u>Soil treatments under study</u>	
5.	Bridger clay loam + rock mulch
6.	Bridger clay loam + straw mulch
7.	Bridger clay loam + VAMA coarse
8.	Bridger clay loam + surfactant
9.	Bridger clay loam + VAMA fine
10.	Bridger clay loam soil

Stretch metal 1/8 inch thick was cut to the dimension of each lysimeter and placed in the bottom. This was covered with a 1-inch layer of glass wool on which the soil rested.

The lysimeter box was approximately 13 inches square, and the depth from stretch metal to top was 7 inches. The top edge of each individual box was placed 2 inches above ground level. It was decided that each box would contain 4 inches of soil. The soil surface in the lysimeter was approximately at ground level.

One-half-inch copper tubing with a 3-inch funnel soldered in one end connected the individual lysimeters with receptacles in the trench below. The lysimeter boxes were centered over the funnels in the copper tubing. Individual cans in the trench collected leachate which drained from the lysimeter boxes through the funnels and copper tubing.

Each lysimeter was centered within a 4-foot square area on which the soil treatment was similar to that in the lysimeter. Thus each lysimeter was surrounded by a 16.7-inch band of soil similar to that within the lysimeter. This was used to reduce mixing of soil within the lysimeter with untreated surrounding soil due to splash. Treatment of soil within the 4-foot square areas was identical to that in the appropriate lysimeter except where surfactant was used. A water solution of surfactant was sprinkled on the area surrounding the lysimeter, whereas dry surfactant was mixed with the soil in the lysimeter.

A solution balance was placed in a balance house on the north side of the experimental area. A window and hole in the balance house door allowed accurate weighings during windy weather.

An 8-day recording rain gauge was also placed at the experimental area. This assured accurate readings during the small thundershower season.

With this experimental setup, precipitation, infiltration, and increase or decrease in weight of each individual box could be determined. By knowing these factors, evaporation could easily be determined, and with all four factors, efficiency of each soil and treatment could be calculated.

Weighings were made at approximately 3-day intervals when weather permitted.

Figures 1 and 2 show experimental diagram and design.

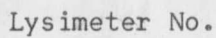


Figure 1. Lysimeter experimental design.

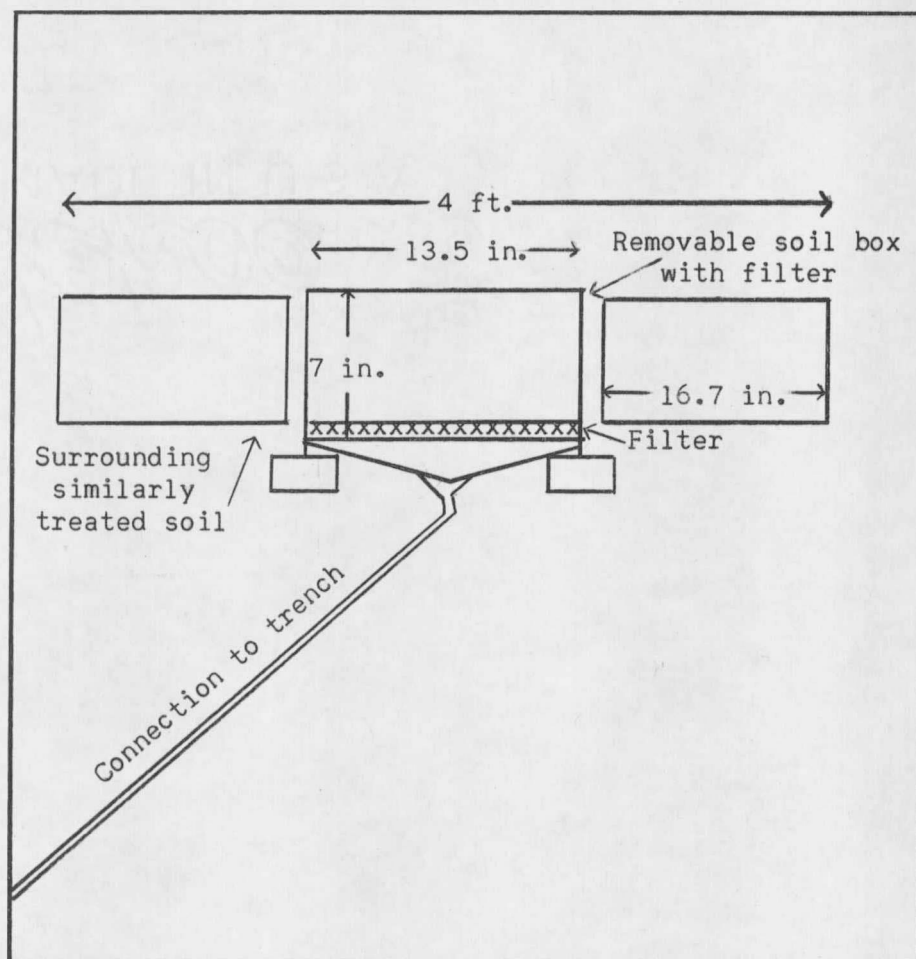


Figure 2. Removable lysimeter soil box.

RESULTS

The experimental period began November 7, 1956, and data was collected throughout a 1-year period. This data included rainfall, periodic records of infiltration and of individual soil box weights.

During the winter period, the soils were continuously frozen and no leachate was collected. The winter snow cover made winter weighings of the lysimeters impractical. It was expected that the spring snowmelt would yield leachate that could be interpreted into winter moisture efficiency. However, the data collected (table II) during the spring snowmelt was highly erratic, and variability between replications was as great as variability between treatments. It is believed that the high variability was caused by water from snowmelt building up on the surface of the lysimeters while the soil was still frozen. Much of this water was lost by spilling over the top of the lysimeter. Thus only the data collected between May 3 and October 31 could be reasonably interpreted.

The moisture that passes through a 4-inch layer of soil must be related to the amount and distribution of rainfall in addition to the amount of moisture which has been lost from the soil by evaporation previous to the incidence of precipitation. Throughout this study, the water which passed through the 4-inch layer of soil is referred to as infiltrated water. Thus the term infiltration is used in a slightly different sense than is common in soils literature. On the basis of rainfall and temperature, the data collected was grouped into periods for detailed study as shown in table III.

Table II. Infiltration from snowmelt for winter and spring months in milliliters.

Soils and treatments	Box No.	Infiltration				Total for period
		11/7/56- 3/11/57	3/11/57- 4/3/57	4/3/57- 4/17/57	4/17/57- 4/26/57	
Manhattan	1	75	13	190	20	298
	19	10	30	150	27	222
	21	30	110	360	30	530
Huffine	9	30	255	435	32	752
	15	90	0	205	27	322
	23	20	100	650	25	795
Huntley	3	0	110	80	10	200
	18	15	5	80	10	110
	27	155	13	220	10	398
Bridger	6	85	3,290	195	25	3,595
	11	33	60	155	18	266
	29	50	30	370	10	460
Rock mulch	10	3	925	210	845	1,983
	13	2	415	45	847	1,309
	25	3	675	1,690	883	3,251
Straw mulch	7	105	2,780	480	5	3,370
	12	0	35	195	10	240
	22	0	70	5	5	80
VAMA coarse	2	55	55	1,245	25	1,380
	16	25	2	145	25	197
	28	75	475	1,110	20	1,680
Surfactant	5	0	1,525	190	20	1,735
	14	15	45	40	18	118
	24	0	50	205	15	270
VAMA fine	4	0	242	105	20	367
	20	3	2	495	27	527
	30	150	355	1,575	24	2,104
Check	8	0	0	342	20	362
	17	3	62	475	15	555
	26	28	15	285	20	348

Table III. Period dates and classification as determined by climatic factors.

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	Warm, wet	4.55	67.5
June 28 - July 31	34	Hot, moist	1.52	81.8
July 31 - Aug. 26	27	Hot, dry	0.00	85.0
Aug. 26 - Sept. 3	8	Warm, wet	1.10	67.3
Sept. 3 - Oct. 30	57	Cool, dry	1.29	62.0

Short Evaporation Periods

For closer examination, three short periods were selected and cumulatively graphed to present evaporation loss in inches as outlined in table IV.

Table IV. Selected evaporation periods and pertinent climatic data.

Period dates	Period classification	Precipitation in inches	Average maximum temperature	Cumulative evaporation
June 18 - June 28	Warm, moist	1.54	72	1.93
July 2 - July 18	Hot, dry	0.30	81	4.81
Sept. 2 - Oct. 2	Warm, dry	0.46	72	5.39

Table V provides the evaporation loss from the four soils between the different observations in relation to that from a free-water surface for the warm, moist period. This information is presented cumulatively in graphic form in figure 3. At the start of this period, the soils were

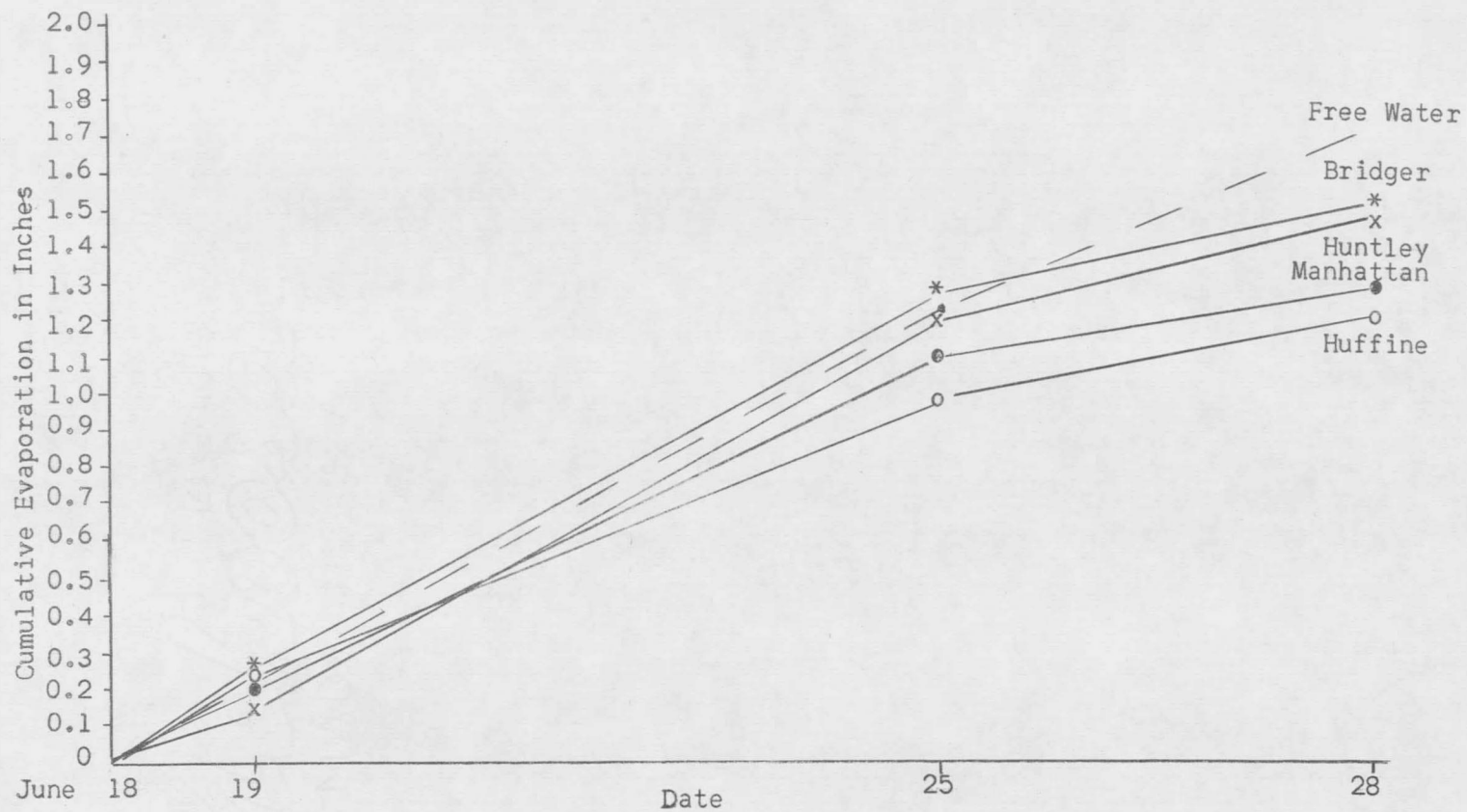


Figure 3. Cumulative evaporation in inches from four soils, June 18 through 28 (warm, moist period).

thoroughly wet from 12 consecutive days during which measurable amounts of rain had fallen (table VI), including a rain of 1.13 inches on June 16. During the first day of the period, all soils except the Huntley lost more water than was lost from a free-water surface. In the following week-long period, evaporation loss from the different soils did not differ greatly from the evaporation of a free-water surface. During this period, Bridger and Huntley soils lost water at approximately the same rate as the free-water surface. Bridger is the darkest colored soil of the group, which probably influenced heat absorption and evaporation. The Huntley soil has very low infiltration capacity and probably remained excessively wet during most of the period. Losses from the other two soils were slightly less than from a free-water surface. While there was a trace of rain on June 26 and 0.15 inch on June 27, it is evident from figure 3 that water loss from the soil slowed down between June 25 and 28. During this period, evaporation loss from all soils became distinctly slower than the loss from a free-water surface. The fact that the lines on the graph during these three days are approximately parallel indicates that during the early stages of surface drying the rate of moisture loss from the four soils is similar.

Table V. Cumulative evaporation loss in inches from four soils and free water, corrected for rainfall and infiltration, June 18 through 28.

Date	Manhattan	Huntley	Huffine	Bridger	Free Water
June 18 - 19	0.199	0.128	0.212	0.23	0.16
June 19 - 25	1.109	1.218	1.032	1.27	1.24
June 25 - 28	1.309	1.508	1.242	1.52	1.76

Table VI. Precipitation in inches, May to October.

Day	May	June	July	August	September	October
1	0	0	0	0	0.35	0
2	0	0	0	0	0	0
3	0.01	0.13	0.33	0	0.05	0
4	0.08	0	0.01	0	0	0
5	0	0	0.04	0	0	0
6	0	0.03	0	0	0	0.04
7	0	0.29	0	0	0	T
8	0	0.39	0.04	0	0	T
9	0.04	0.35	0	0	0	0
10	T	0.31	0	0	0	0
11	0.01	0.02	0.03	0	0	0
12	0.46	0.02	0	0	0.25	0
13	T	0.17	0	0	0.01	0
14	0	0.15	0.18	0	0	0
15	0	0.10	0	0	0	0.54
16	0.01	1.13	0	0	0	0
17	0	0.05	0	0	0	0
18	0.01	0	0	0	T	0
19	0.06	T	0.61	0	0.14	0
20	0.76	0.67	0.12	0	0	0
21	1.01	0.70	0	0	0.01	0
22	0.01	0.02	0	0	0	T
23	0.16	0	0	0	0	0.10
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	T	0	T	0	0
27	0	0.15	0.07	0.04	0	0
28	0.02	0	0	0.03	0	0.30
29	0	0	0	0.09	0	0
30	0.02	0	0.08	0.24	0	0
31	0.14		0.01	0.30		0

Totals	2.80	4.68	1.52	0.70	0.81	0.88

Total precipitation for period, May to October, 1957 = 11.39

The Huffine soil, which had the lowest seasonal loss of moisture due to evaporation, had distinctly less evaporation during the entire period than the other soils. The Huntley and Bridger soils, which had high seasonal evaporation losses, were also high during the period. This lower loss of moisture from Huffine than Bridger soils is in agreement with the findings of Hide and Brown (17) for drying cycles of these soils.

Figure 3 shows the Bridger soil lost the most moisture throughout this period. However, at the last day of this period, it has more available moisture than the Huffine or the Manhattan soil. The Bridger soil is approximately 12.0% above the wilting point, the Huffine is approximately 9.5% above, and Manhattan is 5.0% above the wilting point. At the end of the period, the soils had been dried to approximately half-way between field capacity and the wilting point.

Table VII presents data on evaporation losses from Bridger soil under five different treatments for the three observation periods between June 18 and 28. This data is presented graphically in figure 4. In a general way, the moisture loss from four of these treated soils follows the same pattern as from the untreated Bridger, and variability between treatments is in about the same order as variability between soils.

The outstanding treatment is the rock mulch. This treatment has reduced evaporation loss to less than one-third of the amount lost from any of the other treatments.

Straw mulch slightly reduced the rate of moisture loss due to evaporation. The fine aggregates stabilized with VAMA was the only treatment from which evaporation losses tended to be greater than from a free-water

surface.

Table VII. Cumulative evaporation loss in inches from five treatments on Bridger soil, corrected for rainfall and infiltration, June 18 through 28.

Date	Free water	Rock	Straw	VAMA coarse	Surfactant	VAMA fine	Check
June 19	0.16	0.04	0.16	0.18	0.22	0.22	0.22
June 25	1.24	0.24	0.97	1.10	1.20	1.42	1.15
June 28	1.76	0.37	1.31	1.30	1.40	1.66	1.39

All soils and treatments started this period at a moisture content above field capacity. This is determined by comparing moisture percentages in table VIII with the tension curve of the soil in figure 5. No curve was obtained for the Huntley soil.

Figure 4 shows the rock mulch treatment was the most efficient in controlling evaporation. It was so effective in controlling evaporation that during this period its moisture content was never below field capacity. The straw mulch also remained high in available moisture. Table VIII shows that, at the end of this period, straw mulch is just slightly below field capacity of the Bridger soil as presented in figure 5. The surfactant slightly increased the storage during this period above that of the check. Remaining treatments are close to the check, except for VAMA coarse which was less effective than the check.

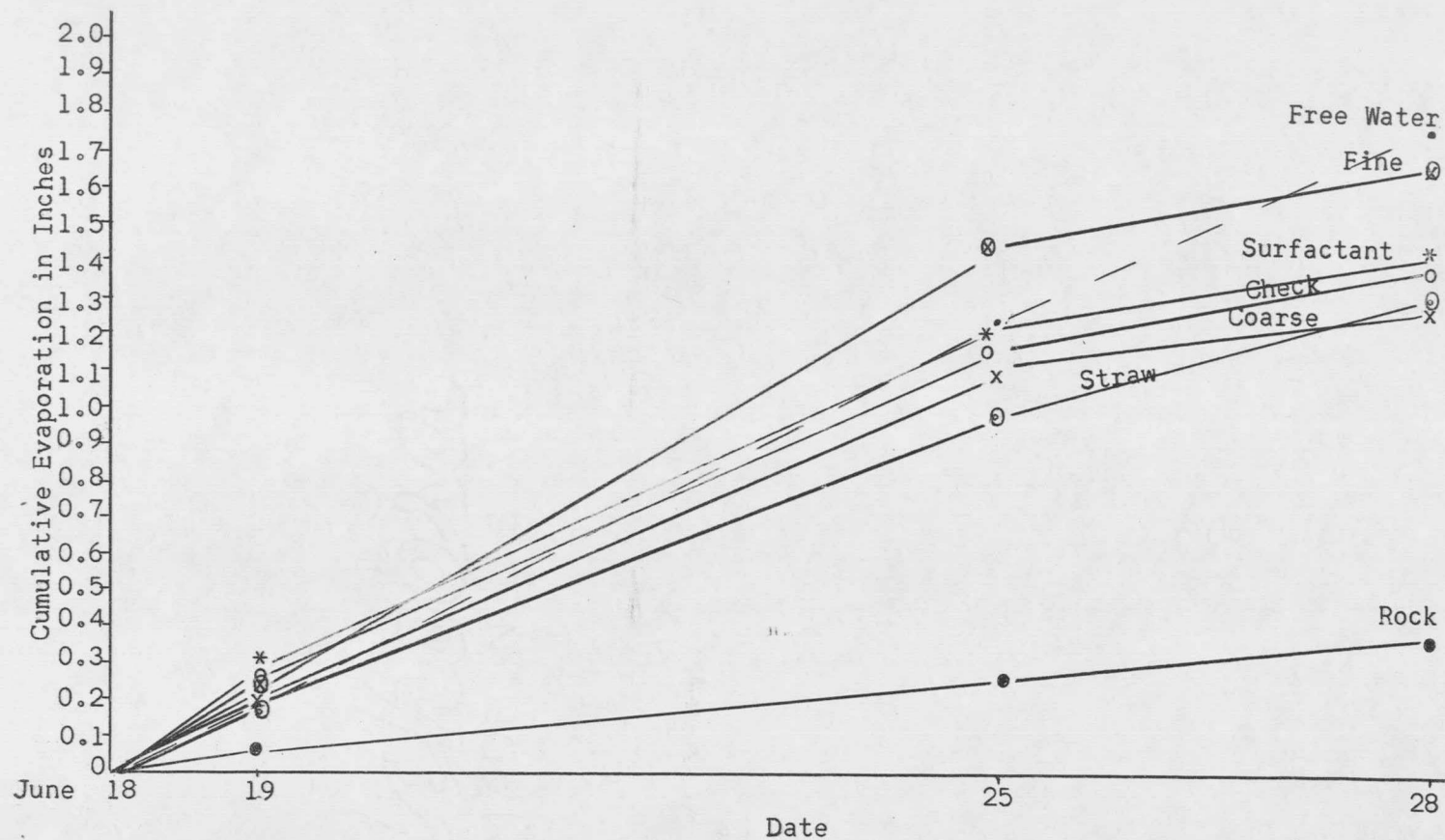


Figure 4. Cumulative evaporation in inches from six treatments on Bridger soil, June 18 through 28 (warm, moist period).

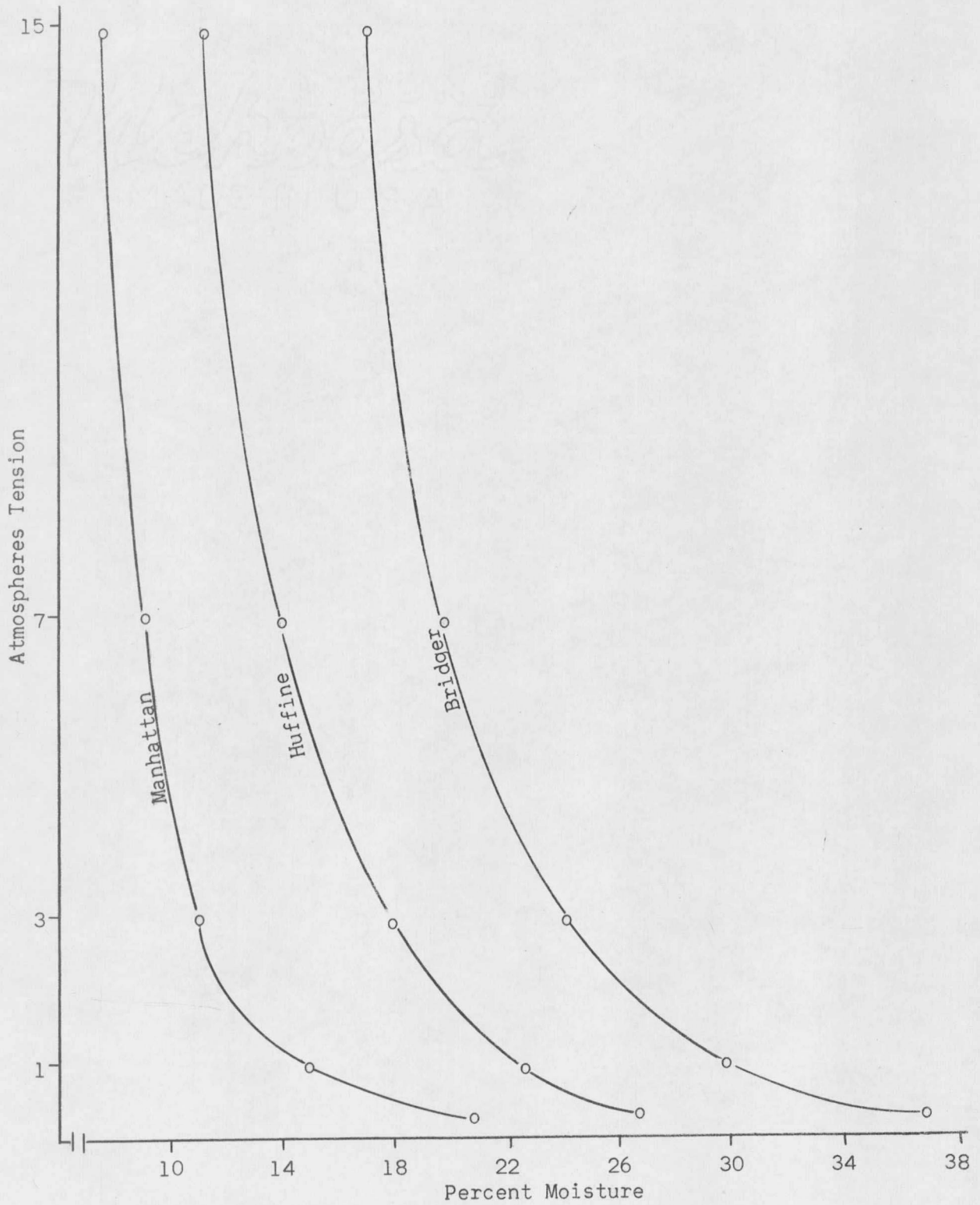


Figure 5. Moisture tension curve of three selected soils.

Table VIII. Moisture percentage of soils and treatments at start and finish of selected evaporating period, June 18 through 28.

Soil-Treatment		Moisture percentage June 18	Moisture percentage June 28
Manhattan	1.	24.1	12.9
Huffine	2.	35.2	21.5
Huntley	3.	51.8	44.7
Bridger	4.	47.8	29.8
Rock mulch	5.	50.9	47.6
Straw mulch	6.	53.7	34.2
VAMA coarse	7.	38.9	25.9
Surfactant	8.	48.7	31.7
VAMA fine	9.	44.2	27.8
Check	10.	44.8	28.1

The second selected short evaporation period is designated as hot and dry. Small amounts of precipitation and fairly hot temperatures characterize this period, as shown in table IV. Cumulative evaporation losses for all soils, treatments, and free water are recorded in table IX.

From the cumulative loss curve for the four soils, as shown in figure 6, it is apparent that evaporation loss is approximately equal for all except the Huntley soil. This soil, as shown in table X, started the period considerably wetter and had much more moisture to lose than the other soils.

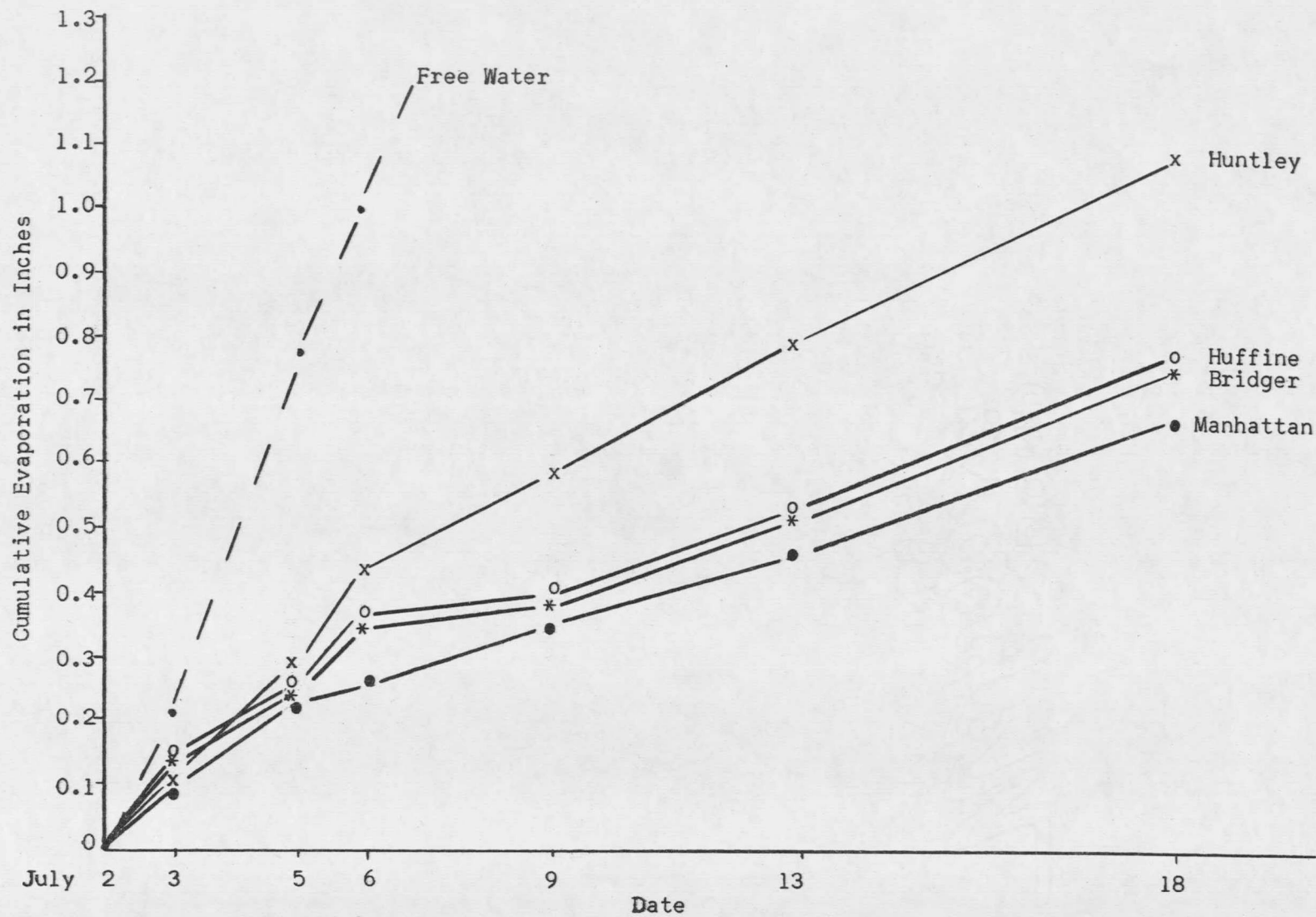


Figure 6. Cumulative evaporation in inches from four soils, July 2 through 18 (hot, dry period).

Table IX. Cumulative soil and free-water evaporation loss in inches, corrected for rainfall and infiltration, July 2 through 18.

Date	Manhattan	Huntley	Huffine	Bridger	Free water
July 2 - 3	.101	.104	.116	.112	.21
July 3 - 5	.227	.286	.254	.255	.78
July 5 - 6	.427	.431	.360	.361	1.00
July 6 - 9	.536	.593	.400	.401	1.84
July 9 - 13	.642	.902	.520	.525	2.96
July 13 - 18	.862	1.292	.760	.775	4.45

Table X. Moisture percentage of soils and treatments at start and finish of the selected evaporating period, July 2 through 18.

Soil-Treatment		Moisture percentage July 2	Moisture percentage July 18
Manhattan	1.	14.6	7.2
Huffine	2.	25.6	12.7
Huntley	3.	42.9	24.1
Bridger	4.	33.7	19.7
Rock mulch	5.	50.3	29.9
Straw mulch	6.	37.6	20.1
VAMA coarse	7.	28.4	15.7
Surfactant	8.	34.7	20.4
VAMA fine	9.	29.0	15.8
Check	10.	31.8	16.2

From field observations made during this period, it was noticed that all soils had become very dry on the surface. Large cracks had formed in the Huntley soil to depths of approximately $3/4$ inch. Moist soil could be seen at the bottom of these cracks, and this accounted for the high evaporation from this soil. From table X and figure 5, it was determined that all soils except the Huntley were at approximately the wilting point at the end of this period.

Treatment effects during this hot, dry period are similar for all soils. Rates of evaporation from the different treatments are considerably lower than from a free-water surface and are fairly uniform, as shown in table XI. This data is shown cumulatively in figure 7. Evaporation during the first 4 days was considerably faster than during the remainder of the period and was approximately one-third as rapid as from a free-water surface. From this point on, the rate of loss from all treatments was considerably reduced. Throughout the period, the straw mulch treatment had either the greatest loss or was in second place. The rock mulch had the lowest loss for the first 3 days of the period but had the greatest loss during the entire period. The check treatment was intermediate among the treatments in moisture loss throughout the period. Surfactant and VAMA coarse and fine behaved similarly throughout the period, and losses were consistently lower than from the check.

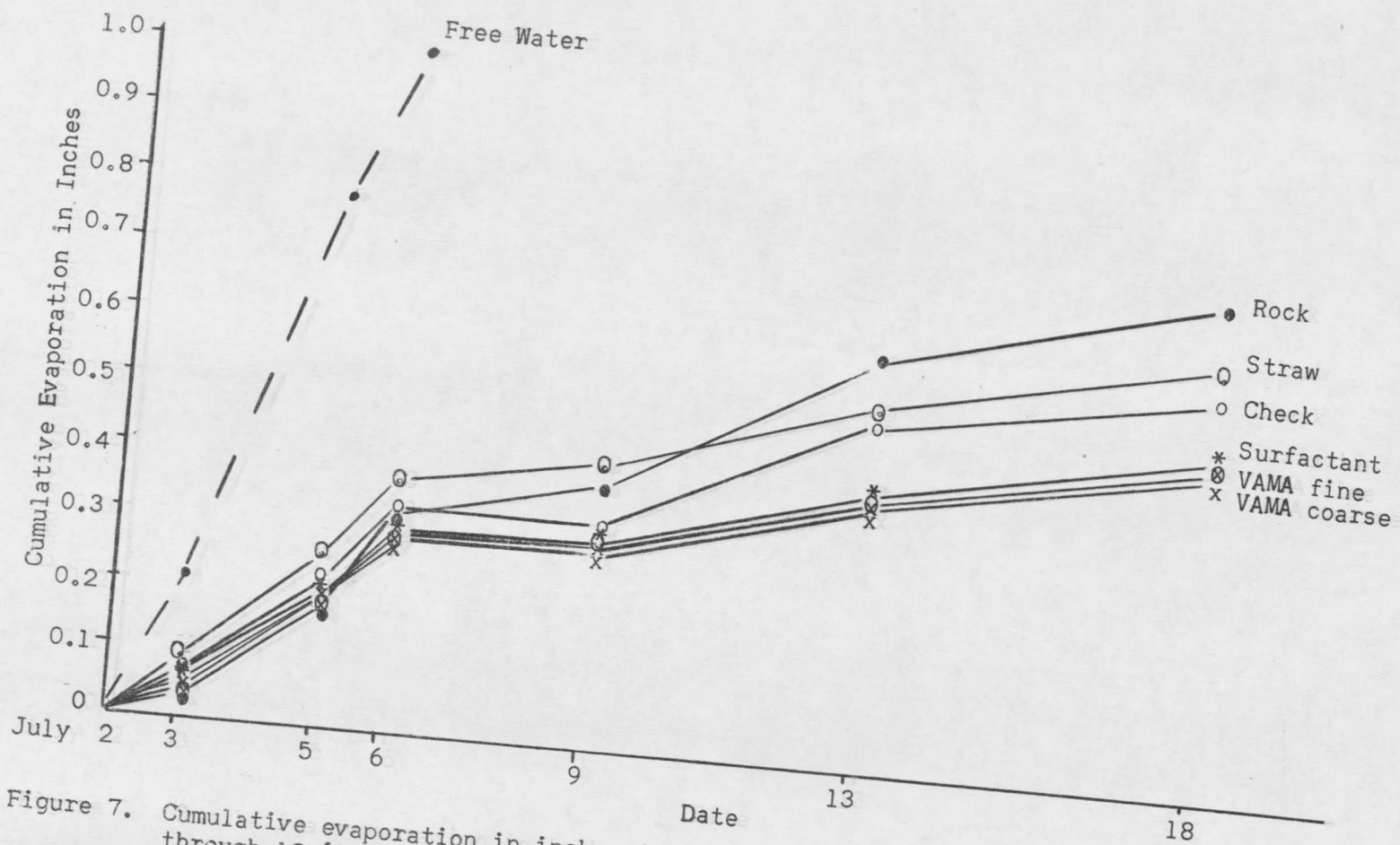


Figure 7. Cumulative evaporation in inches from six treatments on Bridger soil, July 2 through 18 (hot, dry period).

Table XI. Cumulative evaporation loss in inches from five treatments on Bridger soil, corrected for rainfall and infiltration, July 2 through 18.

Date	Free water	Rock	Straw	VAMA coarse	Surfactant	VAMA fine	Check
July 2 - 3	0.21	.03	.08	.06	.06	.06	.07
July 3 - 5	0.78	.19	.25	.19	.20	.19	.21
July 5 - 6	1.00	.32	.37	.30	.30	.30	.32
July 6 - 9	1.84	.39	.41	.30	.30	.30	.32
July 9 - 13	2.96	.60	.53	.39	.41	.40	.51
July 13 - 18	4.45	.90	.73	.66	.68	.67	.76

The third and final selected period of evaporation is somewhat longer than previous periods.

Precipitation had fallen previous to the beginning of this period (table VI), and the average moisture content approximated field capacity. Evaporation from a free-water surface is somewhat lower during this period than in the two previous periods. Cumulative losses for all soils and free water are shown in table XII.

Cumulative losses as graphed in figure 8 show that the Huntley and Huffine soil evaporated moisture at a higher rate during the first 8 days than the other soils. Slope decreased for all soils except the Huntley after the eighth day, and losses were approximately equal for all soils.

At the twelfth day of this period, all soils showed a drastic decrease for a 10-day period extending to September 22. During this period, night temperatures approached freezing, and soil moisture evaporation was greatly affected and losses were small.

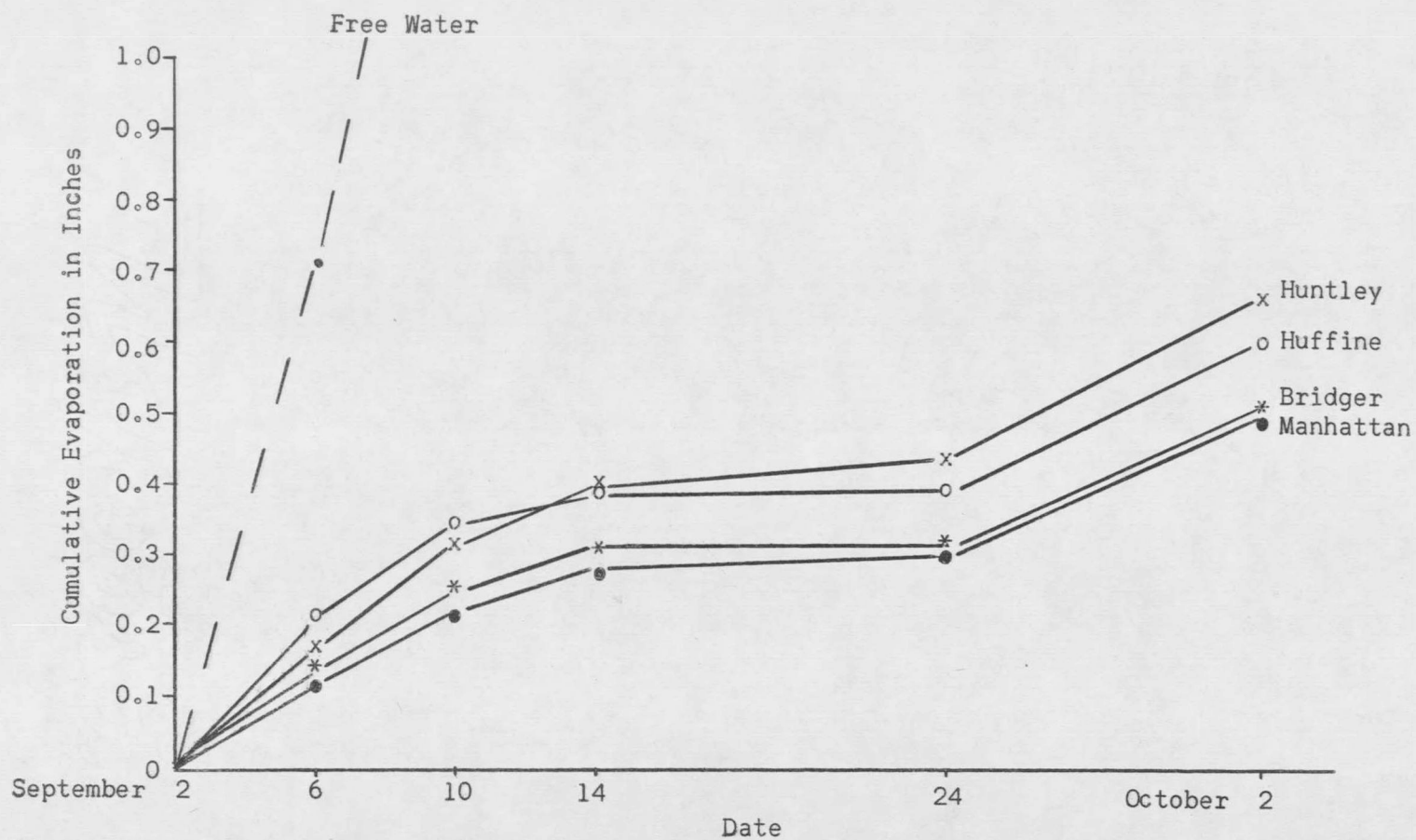


Figure 8. Cumulative evaporation in inches from four soils, September 2 through October 2 (cool, moist period).

Table XII. Cumulative evaporation loss in inches, corrected for rainfall and infiltration, September 2 through October 2.

Date	Manhattan	Huntley	Huffine	Bridger	Free water
Sept. 2 - Sept. 6	.120	.17	.21	.14	0.71
Sept. 6 - Sept. 10	.224	.32	.33	.25	1.62
Sept. 10 - Sept. 14	.284	.40	.39	.31	2.15
Sept. 14 - Sept. 24	.320	.44	.39	.31	3.38
Sept. 24 - Oct. 2	.530	.67	.61	.52	5.26

Temperatures were higher after the twenty-second day, and an increase in evaporation loss occurred for each soil. The cumulative loss from all soils was very small during this period, and moisture percentage lost from each soil was approximately equal except for Huntley, as shown in table XIII. All soils were below the wilting point at the end of this period.

All treatments except the rock mulch followed the soils very closely in evaporation loss for the period. Cumulative losses, as shown by table XIV, are very much like those of the soils (table XII). The cumulative loss of the rock mulch treatment is approximately equal to that of the remaining treatments; however, the distribution of cumulative loss in figure 9 is somewhat different. The lower slope of the rock mulch line indicates greater efficiency than the other treatments during the first 22 days of the period. Also during this period the rock mulch moisture percentage, as presented in table XIII, is the highest of any treatment. As evaporating conditions became more severe, the rock mulch lost more moisture by evaporation, since it had more to lose.

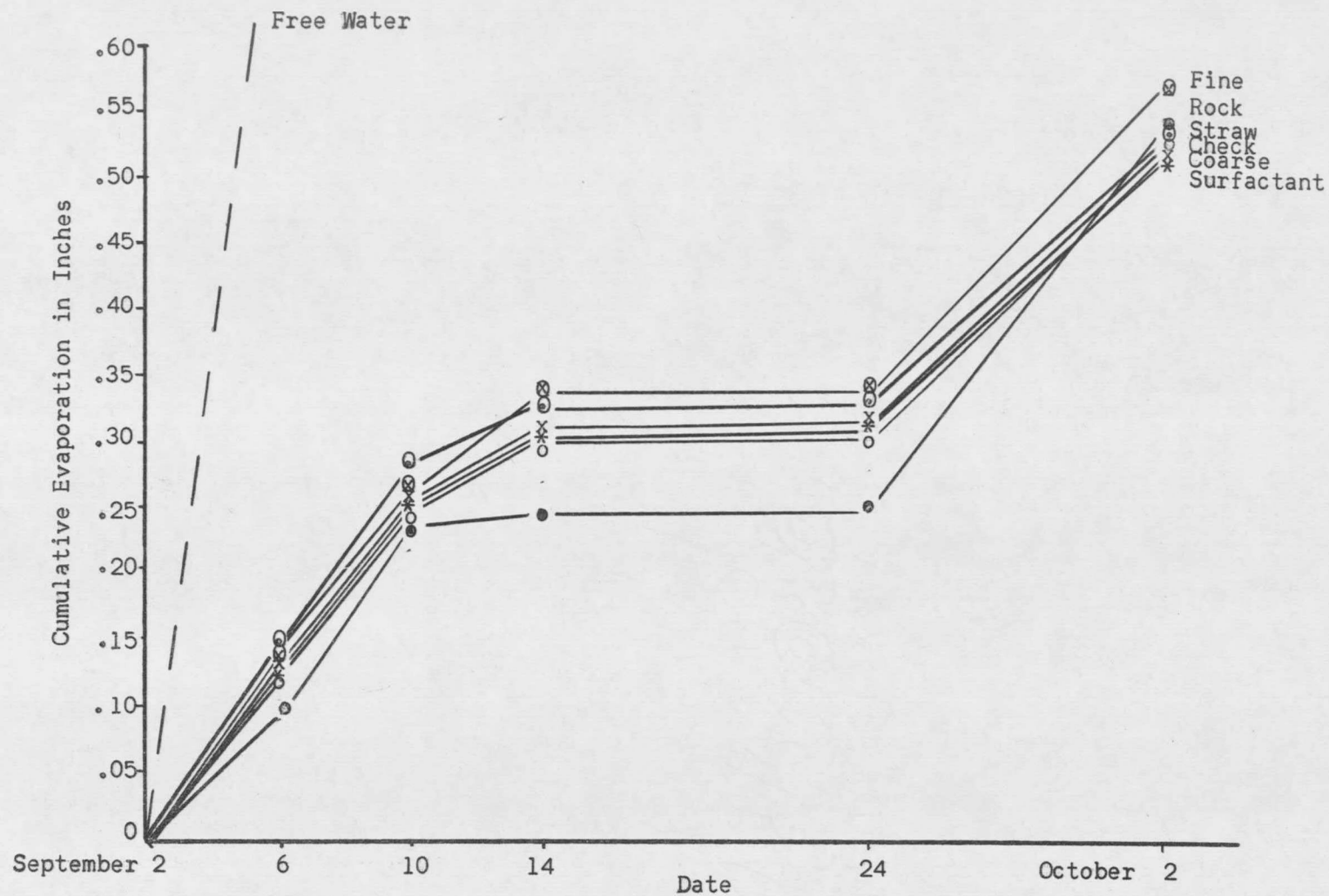


Figure 9. Cumulative evaporation in inches from six treatments on Bridger soil, September 2 through October 2 (cool, moist period).

Table XIII. Percent moisture of soils and treatments at start and finish of selected evaporation period, September 2 through October 2.

Soil-Treatment		Moisture percentage Sept. 2	Moisture percentage Oct. 2
Manhattan	1.	8.2	6.7
Huffine	2.	16.6	14.5
Huntley	3.	15.1	10.5
Bridger	4.	20.7	19.1
Rock mulch	5.	26.2	27.1
Straw mulch	6.	21.5	18.9
VAMA coarse	7.	13.8	10.9
Surfactant	8.	19.2	17.2
VAMA fine	9.	13.4	10.4
Check	10.	19.5	17.8

Again the rock mulch shows a storage efficiency not equaled by any other treatment, since the moisture content of the soil increased during the period (table XIII). All treatments except rock mulch lost moisture from the soil volume as well as all the moisture that fell as precipitation during this period.

Treatments have influenced the moisture retained at the end of the period, as shown in table XIII. The VAMA treatments, both fine and coarse, reduced the moisture percentage far below that of the check. The rock mulch held much more moisture than the check, straw mulch, and surfactant, which were approximately equal.

Table XIV. Cumulative evaporation loss in inches from five treatments on Bridger soil, corrected for rainfall and infiltration, September 2 through October 2.

Date	Free water	Rock	Straw	VAMA coarse	Surfactant	VAMA fine	Check
Sept. 2 - Sept. 6	0.71	.10	.15	.14	.14	.14	.14
Sept. 6 - Sept. 10	1.62	.24	.28	.26	.26	.27	.25
Sept. 10 - Sept. 14	2.15	.25	.33	.33	.32	.34	.31
Sept. 14 - Sept. 24	3.38	.25	.33	.35	.32	.34	.31
Sept. 24 - Oct. 2	5.26	.54	.55	.56	.53	.57	.52

Seasonal Variations in Evaporation and Infiltration

Six seasonal periods were studied for differences in evaporation and infiltration within various soils and treatments. Seasonal differences were determined by climatic factors during the experimental period.

Tables XV and XVI present data on evaporation and infiltration for the period May to October. For presentation, the data was grouped into short periods during which the weather appeared to follow a rather consistent pattern as outlined in Table III. In the following discussion of results, references to evaporation refer to table XV and infiltration to table XVI, but for simplicity, tables are not cited.

Cool, Moist Period

Soils.--During the cool, moist period, the Huffine was the most efficient of the four soils. Its infiltration was high and evaporation low, which indicated that this soil was relatively efficient in moisture retention throughout this season.

The Manhattan followed the Huffine in efficiency, having higher

evaporation and lower infiltration.

Infiltration plays an important role in determining efficiency, as can be seen in this period. During this cool, moist period, the Manhattan evaporated approximately 800 more grams of moisture than did the Huffine. The Huffine infiltrated approximately 800 grams more than the Manhattan.

The Huntley was the least efficient soil of the four, having low infiltration and high evaporation. Here again infiltration was the key to efficiency. Slow permeability left puddles on the surface or a very wet surface from which water evaporated at a greater rate than from drier soil surfaces.

Soil treatments.--During the cool, moist period, the rock mulch was the most efficient of the treatments, followed by the VAMA coarse and VAMA fine. The rock mulch is very effective due to the great amount that infiltrated during this period. The infiltration during the moist periods was the determining factor of the moisture efficiency during the experiment. This can be seen from tables XV and XVI where the straw mulch had high evaporation, low infiltration, and poor efficiency. The straw mulch increased storage capacity which gave a great reserve from which the evaporation process could draw moisture.

Warm, Wet Period

Soils.--During the warm, wet period, the Manhattan soil showed the highest infiltration rate but lost more moisture by the evaporation process than the Huffine soil. Here again the Huffine was the most efficient of the soils in infiltrating moisture. The Bridger soil was not as efficient as the Huffine or Manhattan, but it was more efficient than

Table XV. Evaporation in grams for each climatic period, May to October.

Box		Cool, moist 5/3- 6/6	Warm, wet 6/6- 6/28	Hot, moist 6/28- 7/31	Hot, dry 7/31- 8/26	Warm, wet 8/26- 9/3	Cool, dry 9/3- 10/30	Total
Period No.		1	2	3	4	5	6	
Manhattan	1	5,886	8,577	4,398	3,724	2,203	3,766	
	19	6,654	9,118	4,212	3,680	2,323	3,722	
	21	6,181	8,568	4,212	3,708	2,283	3,677	
	Ave.	6,240	8,754	4,274	3,704	2,277	3,722	28,971
Huffine	9	5,422	8,629	4,354	3,704	2,183	4,462	
	15	5,218	8,617	4,517	3,780	2,188	4,122	
	23	5,552	8,130	4,452	3,771	2,228	4,246	
	Ave.	5,397	8,459	4,441	3,752	2,197	4,277	28,523
Huntley	3	7,773	10,581	5,349	4,934	2,303	3,412	
	18	8,034	11,808	4,867	4,897	2,368	3,612	
	27	7,821	8,768	4,619	4,916	2,323	3,936	
	Ave.	7,876	10,387	4,945	4,916	2,328	3,653	34,105
Bridger	6	6,522	8,528	3,777	3,958	2,223	3,957	
	11	6,984	9,573	4,224	3,954	2,293	3,875	
	29	7,138	9,123	4,397	3,979	2,273	3,992	
	Ave.	6,881	9,075	4,133	3,964	2,260	3,914	30,227
Rock mulch	10	2,170	2,446	3,987	4,818	1,783	2,247	
	13	2,275	2,638	4,147	4,672	1,753	2,252	
	25	2,237	2,345	3,867	4,897	1,728	2,337	
	Ave.	2,227	2,476	4,000	4,796	1,752	2,279	17,530
Straw mulch	7	7,269	7,815	4,774	4,259	1,973	3,397	
	12	7,094	8,054	4,771	4,048	2,203	3,317	
	22	6,814	8,540	4,587	4,111	2,293	3,387	
	Ave.	7,059	8,136	4,711	4,139	2,153	3,367	29,565
VAMA-- coarse	2	5,956	9,078	4,383	4,041	2,338	3,932	
	16	6,162	8,628	3,897	4,016	2,313	3,912	
	28	5,737	9,183	4,389	4,081	2,323	3,824	
	Ave.	5,952	8,963	4,223	4,046	2,322	3,889	29,395
Surfactant	5	6,322	8,897	4,432	4,083	2,293	3,827	
	14	6,845	9,878	4,457	4,021	2,368	3,832	
	24	6,506	9,763	4,427	4,079	2,303	3,842	
	Ave.	6,558	9,513	4,439	4,061	2,318	3,834	30,723
VAMA-- fine	4	6,382	10,161	4,397	4,078	2,343	3,382	
	20	5,953	9,192	4,479	4,130	2,318	3,327	
	30	5,628	9,661	4,279	4,147	2,333	3,215	
	Ave.	5,988	9,671	4,385	4,118	2,308	3,308	29,778
Check	8	6,126	8,763	4,437	3,917	2,238	3,987	
	17	7,068	8,981	4,402	3,958	2,263	4,014	
	26	6,436	8,811	4,610	3,867	2,098	3,927	
	Ave.	6,543	8,852	4,483	3,914	2,197	3,976	29,965

Table XVI. Infiltration for each treatment in cubic centimeters for each climatic period, May to October.

Box		Cool, moist 5/3- 6/6	Warm, wet 6/6- 6/28	Hot, moist 6/28- 7/31	Hot, dry 7/31- 8/26	Warm, wet 8/26- 9/3	Cool, dry 9/3- 10/30	Total
Period No.		1	2	3	4	5	6	
Manhattan	1	2,070	3,720	230	2	0	30	
	19	1,297	3,350	285	6	0	40	
	21	1,730	3,835	310	8	0	70	
	Ave.	1,699	3,635	275	5	0	37	5,651
Huffine	9	2,515	3,345	343	7	0	120	
	15	2,707	3,390	240	1	0	250	
	23	2,432	4,030	175	0	0	115	
	Ave.	2,551	3,588	253	2	0	162	6,556
Huntley	3	23	1,712	88	2	0	120	
	18	8	390	100	4	0	2	
	27	6	3,540	563	0	0	15	
	Ave.	12	1,883	250	2	0	46	2,193
Bridger	6	1,457	3,425	900	7	0	205	
	11	982	2,565	218	6	0	22	
	29	845	2,890	185	2	0	15	
	Ave.	1,095	2,960	434	5	0	81	4,575
Rock mulch	10	6,182	9,875	1,255	8	0	2,210	
	13	6,082	9,645	1,165	4	0	2,010	
	25	6,200	9,850	1,240	4	0	2,270	
	Ave.	6,155	9,790	1,220	5	0	2,163	19,333
Straw mulch	7	735	4,140	143	2	0	0	
	12	889	3,965	140	3	0	25	
	22	1,065	3,680	130	5	0	130	
	Ave.	896	3,928	138	3	0	52	5,017
VAMA-- coarse	2	2,030	3,380	189	5	0	20	
	16	1,864	3,730	715	5	0	20	
	28	2,190	3,260	203	5	0	63	
	Ave.	2,028	3,457	369	5	0	34	5,893
Surfactant	5	1,795	3,390	240	3	0	10	
	14	1,276	2,550	230	5	0	5	
	24	1,630	2,665	200	2	0	0	
	Ave.	1,567	2,868	223	3	0	5	4,666
VAMA-- fine	4	1,784	2,377	150	3	0	25	
	20	2,174	3,130	243	6	0	150	
	30	2,350	2,915	213	4	0	52	
	Ave.	2,103	2,807	202	4	0	76	5,192
Check	8	1,810	3,225	225	9	0	10	
	17	870	3,200	215	3	0	23	
	26	1,532	3,220	263	4	0	95	
	Ave.	1,404	3,215	234	5	0	43	4,901

the Huntley soil.

Soil treatments.--During this warm, wet period, rock mulch was the most efficient soil treatment, followed by straw mulch, in infiltrating moisture. During this period, evaporation and infiltration for the VAMA coarse and the check plot were approximately the same. The VAMA coarse infiltrated more moisture than the untreated Bridger, and the evaporation was proportionately decreased. The remaining treatments had a detrimental effect on moisture efficiency throughout the warm, wet period.

Hot, Moist Period

Soils.--During the hot, moist period, the Bridger soil was more efficient than the remaining soils in infiltrating moisture. Its infiltration is highest and evaporation rate lowest during this period. Following in order are the Manhattan, Huffine, and Huntley.

Soil treatments.--For this period, soil treatments showed efficiencies which were less variable than during previous periods. The rock mulch was high in infiltration but somewhat closer to the remaining treatments in evaporation than during the other periods. The VAMA coarse is the only treatment other than rock mulch which was more efficient than the check.

Hot, Dry Period

Soils.--Infiltration during the hot, dry period was negligible, and the amounts of infiltration measured were attributed to distillation from the lower part of the soil which contained moisture. The Manhattan and Huffine soils lost less moisture by evaporation than the other soils. The loss from Bridger soil was somewhat higher than from the other two soils, and the Huntley again lost more than the other soils.

Soil treatments.--During this period, infiltration from the soil treatments was similar to that from the soils, and evaporation differed from previous periods. The rock mulch was the least effective of the treatments during this period. Low evaporation from the rock mulched lysimeters during the previous periods left the soil more moist than under other treatments, and this condition allowed evaporation to continue at a higher rate.

Warm, Wet Period

Soils.--A short warm, wet period occurred at the end of August, during which no infiltration was noted. This period followed a hot, dry period, and the soils at the start of the period were dry enough to absorb the precipitation within the 4-inch soil layer.

The soils show an increase in weight, but the weight increases during the period did not approach 100% of the rainfall. During this period, the Huffine increased in weight more than the others, and it was the most efficient. Bridger and Manhattan followed closely, with the Huntley again lowest in efficiency.

Soil treatments.--Rock mulch was the most efficient soil treatment, followed by straw mulch and Bridger check. The rock was by far the most efficient during this period and lost only 1,752 grams. This loss was 400 grams less than the next lowest treatment. Remaining treatments were grouped closely with negligible difference. It was noticed that, during this period as in previous periods, some treatments were detrimental.

Cool, Dry Period

Soils.--The last period, which is a long cool, dry one, showed some infiltration which was believed to be a carryover from the previous warm, wet period. The Huntley soil was the most efficient during this period, followed by Manhattan, Bridger, and Huffine. Climatic factors were undoubtedly responsible for the high efficiency of this soil during the period, since this soil was very inefficient throughout the other periods.

Soil treatments.--Among the soil treatments, the rock mulch was again the most effective in conserving moisture. The second most efficient treatment was VAMA fine, but it lost one-half again as much moisture as the rock mulch. Straw mulch was approximately as efficient as VAMA fine.

Moisture Efficiency

The efficiency of infiltration was determined for the different periods by expressing the infiltration as a percentage of the rainfall, and the data is presented in table XVII.

Soils.--During the entire season, Bridger soil infiltrated 14.3% of the rainfall, whereas the comparable figures for Huffine and Manhattan were, respectively, 20.5% and 17.6%. Thus Huffine soil was about 140% as effective in storing moisture over the period as Bridger. In contrast, Huntley soil was less than one-half as efficient in storing moisture as Bridger. It is apparent that the efficiency of storage for the different soils varied considerably for the different climatic periods.

Soil treatments.--The Bridger soil check used in treatment comparisons infiltrated 15.3% of the rainfall throughout the entire season. Remaining treatments except rock mulch and VAMA coarse are very close to the check

Table XVII. Precipitation and infiltration in grams for lysimeter areas and infiltration efficiency expressed as a percentage of total rainfall by periods, May 3 to October 30.

Box		Cool, moist 5/3- 6/6	Warm, wet 6/6- 6/28	Hot, moist 6/28- 7/31	Hot, dry 7/31- 8/26	Warm, wet 8/26- 9/3	Cool, dry 9/3- 10/30	Total
All soils and treatments	Precipitation	7,896	12,262	4,096	0	2,965	3,477	
Manhattan	Infiltration	1,699	3,635	275			37	5,646
	% Efficiency	21.5%	29.6%	6.7%	0	0	1.06%	17.6%
Huffine	Infiltration	2,551	3,588	253			162	6,554
	% Efficiency	32.3%	29.3%	6.2%	0	0	4.70%	20.5%
Huntley	Infiltration	12	1,883	250			46	2,191
	% Efficiency	0.15%	15.4%	6.1%	0	0	1.30%	6.84%
Bridger	Infiltration	1,095	2,960	434			81	4,570
	% Efficiency	13.87%	24.1%	10.6%	0	0	2.30%	14.3%
Rock mulch	Infiltration	6,155	9,790	1,220			2,163	19,328
	% Efficiency	78.0%	79.8%	29.8%	0	0	62.2%	60.4%
Straw mulch	Infiltration	896	3,928	138			52	5,014
	% Efficiency	11.4%	32.0%	3.4%	0	0	1.50%	15.7%
VAMA coarse	Infiltration	2,028	3,457	369			34	5,888
	% Efficiency	25.7%	28.2%	9.0%	0	0	0.97%	18.4%
Surfactant	Infiltration	1,567	2,868	223			5	4,663
	% Efficiency	19.8%	23.4%	5.4%	0	0	0.14%	14.6%
VAMA fine	Infiltration	2,100	2,807	202			76	5,185
	% Efficiency	26.6%	22.9%	4.9%	0	0	2.20%	16.2%
Check	Infiltration	1,404	3,215	234			43	4,896
	% Efficiency	17.8%	26.2%	5.7%	0	0	1.20%	15.3%

plot in infiltration percentage. The outstanding treatment is the rock mulch which infiltrated 60.4% of the moisture that fell. This is a phenomenal 395% increase in storage efficiency over the check. VAMA coarse is also more efficient in storage than the Bridger check, with a 20% increase in efficiency.

All treatments except rock mulch, which was continually the most efficient, varied as did soils in moisture storage throughout the climatic periods of the experiment.

DISCUSSION

Soil Effects

The loss of water in the moisture cycle for these fallowed lysimeters involved only three major factors--namely: surface evaporation, infiltration, and moisture storage within the soil. As mentioned under Results, for the hot, dry period, small amounts of water distilled from the lower boundaries of the soil. It is believed that this was a source of moisture loss during the entire period of the study; however, this loss was considered minor. Distilled moisture was collected as infiltration and no separation of the two sources of water could be made. In a complete soil profile, upward distillation is also a probable source of water to the surface layers of soil. However, the construction of the lysimeter was such that upward distillation into the soil layer could not be expected.

The present study was concerned primarily with soil factors and treatments which influence the amount of water that infiltrated through a 4-inch layer of soil. The soil itself acted as a limited capacity reservoir from which water was lost by evaporation and infiltration. Since the amount of moisture lost from the reservoir between rains determined the amount of precipitation required to refill the reservoir and allow infiltration, the nature and amount of evaporation loss received considerable attention.

It is well established that water loss from a soil by evaporation becomes very slow after the surface has dried to a depth of a few inches. For this study, it was assumed that evaporation losses occurred principally

from the upper 4 inches of soil and that water which passed below the 4-inch depth did not usually return to the surface under fallow conditions. The nature of the drying curve on three of the soils studied (17) indicates that slight moisture losses occurred to a depth greater than 4 inches. However, the discontinuity in the profile at the 4-inch depth in the lysimeters would allow the soil to remain slightly wetter than would occur without this discontinuity. These two errors would partially compensate each other. The three medium-textured soils infiltrated between 13 and 20% of the rainfall. Aasheim (2) found that moisture storage efficiency of fallow during the summer months at Havre, Montana, was 10.7%, and at Culbertson, Montana, it was 15.7%. Thus the amount of moisture which infiltrated through the 4-inch layer of these soils approximated that which was stored under field conditions.

The Huffine soil, which was highest in efficiency throughout most of the experimental period, exhibits a capacity for high infiltration and a reduced amount of evaporation. Previous work with this soil (17) showed a reduced rate of evaporation in comparison with the Manhattan and Bridger soil. This was attributed to a fast surface drying action and the protective mulch formed by the dry surface soil. It was observed that the surface of this soil consistently dried more rapidly than any of the other soils. Buckingham (7) showed that evaporating conditions which induced rapid surface drying reduced total evaporation loss in a drying cycle of soil. This data indicates that soil properties which allow surface drying to occur early in the evaporation period similarly reduce the evaporation loss in each drying cycle.

In a drying cycle, the surface of the Manhattan soil was a little slower to dry than the surface of the Huffine soil. The Manhattan fine sandy loam lost 12% of the moisture as the tension was increased from $1/3$ atmosphere to 15 atmospheres, whereas Huffine silt loam lost 14% of the moisture with a corresponding increase in tension (17). However, the bulk density of Manhattan soil and Huffine soil is, respectively, 1.25 and 1.13, so the two soils did not differ greatly in their storage capacity on a volume basis, and the moisture available for evaporation loss from a 4-inch layer of the two soils was similar.

The Bridger soil was, as expected from previous work (17), the least efficient of the three soils on which supplemental data is available. Surface drying pattern was somewhat slower than the Manhattan or Huffine soil. As pointed out previously, slow surface drying facilitates increased loss of moisture by surface evaporation. The moisture-holding capacity of this soil was greater than the Huffine or Manhattan soils, and with the increased loss by evaporation from the 4-inch layer, storage within the 4-inch soil volume would be greater. This is shown by the decreased infiltration amounts of this soil.

From field observations, it was obvious that the Huntley soil would be very inefficient. The heavy texture plus a high salt content made permeability low on this soil. After periods of heavy precipitation, water was puddled on the soil surface and evaporated rather than infiltrated.

Soil Treatment Effects

Physical properties of soils are very important in moisture efficiency. The treatments used in this experiment were designed to alter these properties and to study the effect of each on a selected soil type.

Previous work done with the soil treatments indicated that each affects the moisture cycle of the soil used. Tsiang (34) pointed out that rock mulches are used in the interior of China as a moisture-conserving measure.

Two different experiments (3)(4) with VAMA-stabilized aggregates found an increase in pore space and infiltration rate with no adverse effects on moisture retention. An increase in growth was noted and attributed to improved condition of the root zone which provided a larger area for root growth. VAMA was chosen as a treatment to study the effects of this conditioner on a fallow soil. It was decided to use this treatment in two aggregate size ranges to better understand the effect of aggregate size on moisture storage.

Lemon's (23) review of the work with surfactants in Russia (22)(33) encouraged the use of this treatment.

The wide use of crop residue mulching justified the inclusion of the straw mulch treatment for comparison with the unmulched soil.

The outstanding treatment is the rock mulch which had an over-all infiltration efficiency of 60% and an evaporation loss of only two-thirds that of the nearest treatment. The rock mulch was very effective in increasing infiltration from this soil. Evaporation was decreased during

every period except the hot, dry one. The high evaporation loss during this period was due to the soil being relatively moist at the start of the period, and consequently, it contained more moisture to lose than the other soils.

The rock mulch on the surface of this soil was very effective in slowing down evaporation and increasing infiltration. The rocks acted as a surface cover which did not disperse and compact as soil would under heavy rainfall conditions. The surface of this treatment was very porous, and water infiltrated readily through the rock layer and into the soil. On the surface of the rock mulch, moisture dried very readily, and it has been shown previously (17) that surfaces which dry rapidly conserve moisture. Since the moisture was stored at a depth of at least 1 inch below the surface, it appears that the storage zone would be cooler than in an unprotected soil. Also the air in the pore spaces between the rocks will usually be unaffected by turbulence and, consequently, will act as a diffusion barrier to water vapor.

VAMA treatments had only moderate effects on the Bridger soil. Infiltration was increased in the coarse treatment to 20% above the check. The fine treatment also showed an increase over the check, although difference was not as great as for the coarser aggregates. Evaporation losses from these treatments approximated those of the check; however, the coarse was slightly more effective in controlling evaporation loss. From data presented, it is evident that the coarse was somewhat more effective in increasing moisture storage than were the fine or the check treatments.

The only treatment which showed a detrimental effect on the Bridger

soil was the surfactant. First period data indicated that it was effective in increasing moisture efficiency. This is in agreement with findings of other workers (22), (23), (33) using a soap or surfactant treatment. After the first period, efficiency dropped below that of the check and remained below throughout the experimental period. A tremendous amount of leaching took place through the winter and spring periods. No analysis was made of the leached material, and it is probable that much of this compound, which is very soluble, passed through the soil volume and into the containers below. There was a residual effect on soil structure as infiltration amount was affected, and evaporation amounts from this treatment were the largest of all treatments. From observing the soil condition, it was noted that surface aggregates were dispersed. It appears that capillarity was affected by this breakdown with an increased amount of moisture reaching the surface area. This in turn was lost by the evaporation process.

The straw mulch reacts very much like the Bridger check, the two treatments having approximately equal infiltration and evaporation. Only during one period was it more effective than the check. During the warm, wet period, it evaporated less and infiltrated more than did the check. It lost more during the hot, dry period as the straw had increased the storage capacity of the soil volume which in turn furnished more moisture for evaporation during hot, dry spells. The increased efficiency during the wet period was enough to offset the inefficiency during the remaining dry periods.

From the data presented, it appears that climatic factors have had

different influences on the drying pattern of the different soils and soil treatments. Evaporation data from soils indicates each soil at one period in the experiment to be more effective in controlling evaporation than the remaining soils. This is true of the soil treatments also. Stored moisture appears to be an important factor in the infiltration and evaporation of moisture from soils and soil treatments. This was pointed out previously in the discussion of the Bridger soil. Soil and soil treatment reaction to climatic factors indicated that a desirable property during one season may change to an undesirable property in a different season.

As noted by the amounts to infiltrate through the soils and soil treatments, a very small percentage of the precipitation that fell during the summer period is stored. Only the rock mulch stored over 25% of the precipitation that fell, and the remaining percentages were in agreement with the estimate of Hide (16), who placed this figure at approximately 20 to 25%. Undoubtedly this figure will vary during seasons and within soils, as shown by work in this experiment.

SUMMARY AND CONCLUSIONS

Moisture efficiency was studied with four soils and five treatments to one soil type. This was carried out in a fill-type lysimeter study which accommodated three replications of each soil and treatment. Each replication contained approximately 4 inches of soil with a surface area of 1,060 square centimeters. Infiltration through each lysimeter was considered stored moisture.

In the discussion, soil types were considered separately from soil treatments. Thus comparisons were between soil types and between soil treatments. Data collected for comparisons consisted of evaporation, infiltration, and percentage of total rainfall collected as infiltration.

Huffine soil had the lowest evaporation loss, followed by Manhattan, Bridger, and Huntley. This was cumulative data for the entire experimental period. The effectiveness of the different soils differed from period to period, depending upon weather pattern during the period.

Infiltration followed a converse pattern to evaporation with cumulative data showing the Huffine to have the greatest infiltration, followed by Manhattan, Bridger, and Huntley. Infiltration efficiency was expressed as the percent of the rainfall which infiltrated through the 4-inch layer of soil. The season-long efficiency for Huffine, Manhattan, Bridger, and Huntley soils was, respectively, 20.5, 17.6, 14.3, and 6.8%.

Since the soil served as a limited capacity reservoir from which water was lost by evaporation and infiltration, it is obvious that there will be a reciprocal relationship between evaporation and infiltration. It was also noted that infiltration data or efficiency varied from month

to month. Not always did the Huffine lead in efficiency. It was, however, the most efficient soil throughout the experimental period.

Evaporation loss and infiltration were influenced by soil treatments as well as soil types. Among the treatments, rock mulch was outstanding and had a season-long infiltration efficiency of 60.3%. This is four times higher than the untreated soil and three times higher than the soil with highest infiltration. Efficiency varied from period to period, with a high of 79.8% for the warm, wet period.

VAMA coarse followed the rock mulch in over-all efficiency of 18.4% and a high of 28.2%. This figure should indicate the great difference between the rock mulch treatment and VAMA coarse. The efficiency of this treatment also varied from period to period.

The remainder of the treatments show very little difference in the over-all cumulative data. The straw, however, during certain periods was very efficient, while at other times it was very inefficient. Its season-long influence on efficiency was negligible.

It is noticeable from the data presented that there is a great seasonal fluctuation in efficiency. This indicates that certain treatments, while very good during one period, lose their effectiveness during another period.

This study, which covered only one growing season, showed that soils differ quite widely in their efficiency in infiltrating water through a 4-inch layer of soil, and this efficiency appears to be closely related to the efficiency of storing moisture under summer-fallow. While soil texture has been assumed to influence moisture storage efficiency, data on

quantitative differences between soils under comparable conditions is extremely limited. Similarly, data on the effect of soil treatments on moisture storage efficiency has received very little attention. While most of the treatments used had rather minor influence on the efficiency of infiltration, the rock mulch was highly efficient. It appears probable that soil treatments can be devised that will greatly increase the efficiency of moisture storage and use.

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APPENDIX

Table I. Evaporation in inches from a free-water surface, May to October, 1957.

Day	May	June	July	Aug.	Sept.	Oct.
1.	.23	.22	.21	.36	.18	.22
2.	.29	.28	.16	.33	.13	.22
3.	.20	.25	.21	.39	.20	.09
4.	.14	.28	.31	.40	.14	.01
5.	.37	.34	.26	.44	.22	.06
6.	.27	.29	.22	.39	.15	.05
7.	.19	.12	.36	.17	.33	.10
8.	.33	.19	.20	.48	.31	.05
9.	.13	.21	.28	.32	.13	.05
10.	.13	.15	.23	.40	.14	.06
11.	.14	.20	.34	.40	.19	.10
12.	.02	.19	.29	.27	.09	.15
13.	.22	.09	.36	.30	.11	.11
14.	.23	.13	.29	.36	.14	.11
15.	.36	.18	.29	.41	.22	.02
16.	.09	.02	.30	.32	.03	.04
17.	.12	.08	.37	.45	.33	.06
18.	.25	.17	.34	.27	.12	.06
19.	.19	.16	.31	---	0	.06
20.	.03	.11	.18	.28	0	.02
21.	---	.11	.28	.30	.03	.04
22.	.12	.25	.29	.47	.12	---
23.	.13	.19	.22	.21	.16	---
24.	.20	.13	.39	.44	.22	---
25.	.19	.29	.35	.25	.18	---
26.	.32	.14	.31	.35	.30	---
27.	.25	.11	.37	.13	.26	---
28.	.29	.27	.27	.17	.31	---
29.	.24	.31	.32	.10	.18	---
30.	.48	.30	.32	.32	.21	---
31.	.19	---	.22	.35	---	---

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