INFLUENCE OF INORGANIC WATERSHED COVERS ON MOISTURE EXCHANGE IN A VERTICAL DIRECTION ACROSS THE SOIL-AIR INTERFACE

PROGRESS REPORT NO. 1

Colorado Contributing Project

to

Western Regional Project W-73

Hydrologic Processes of Moisture Exchange in Moisture Conservation

COLORADO AGRICULTURAL EXPERIMENT STATION

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OBJECTIVES

The objectives of this project are to determine the effects of inorganic covers on the fundamental hydrologic processes of evaporation and infiltration of moisture across the soil-air interface and to evaluate the effect of these processes on water yield. The specific objective of the work during the past year has been to determine what properties of gravel mulches have a significant effect on their ability to reduce evaporation from soils.

BACKGROUND

The present project has developed from studies (1,2,3) conducted under the regional project W-32. In these studies it was found that gravel mulches constitute a promising method of reducing evaporation from bare soil where water is applied by frequent light rains. The reason for this is that not only do gravel mulches result in a large reduction in evaporation; but also they do not interfere with infiltration; they are not easily blown away by winds; and gravel is usually plentiful and relatively inexpensive. The studies during the past year were undertaken to determine the kind of a gravel mulch that is most suitable under various soil and atmospheric conditions.

PROCEDURE

The study of gravel mulches has been conducted in an environmental-control chamber in which temperature, relative humidity, radiation, and to some extent air movement can be controlled. Three soil types were employed, samples of which were contained in Lucite cylinders, 3½ inches I.D. and 8½ inches in depth.

These soil columns with various kinds of gravel mulches were saturated under vacuum and then allowed to drain approximately thirty-six hours. The samples were then placed upon a rotating table at equal radii from the axis of rotation. This procedure was followed in order to insure that all samples during particular runs were subjected to identical environmental conditions.

The environmental conditions were constant during a particular run but were changed from run to run. The radiation was controlled by infrared lamps, the temperature and relative humidity by an air-conditioning unit, and for some runs the air-movement was controlled by a blower placed to cause a horizontal movement of air across the upper surfaces of the soil columns. When the blower was used, each sample was subjected to the blast from the blower during about 1/5 of each rotation of the turntable. This situation, therefore, was analagous to gusty wind conditions often existing in nature. The wind velocities given in this report are the maximum velocities to which the soil surfaces were subjected.

Loss of moisture was determined by periodically weighing the soil columns. The loss of water from the columns with gravel mulches was compared with that from columns which were not protected by mulches. One column of each of the three soils was not covered by a mulch. A measure of the severity of the evaporating conditions for each run was obtained by measuring the evaporation from one column of sand in which the water table was maintained at the surface. This was accomplished by periodically weighing a Marriotte siphon bottle which supplied water to this sand column under constant head.

Two sets of nine runs each were performed. During the first set of nine runs, the gravel mulches varied with respect to thickness and with respect to the grain-size (Figure 1). Three increments of each were used making a total of nine mulches per soil. A uniform grain-size was used for all the mulches during this set of runs. During the second set of nine runs, the mulches varied with respect to the grain-size and the uniformity of the grain-size distribution (Figure 2). Once again three increments of each variable were employed. All mulches were one inch thick. For both sets of runs, the temperature was constant at 90° F and the relative humidity was constant at 30 per cent. Each successive run in a set was carried out at increasingly severe evaporativity. This was brought about by increasing the number of lamps; and for each level of radiant energy, the wind velocity was varied. Three increments of radiation and of wind velocity were employed, requiring nine runs for each set.

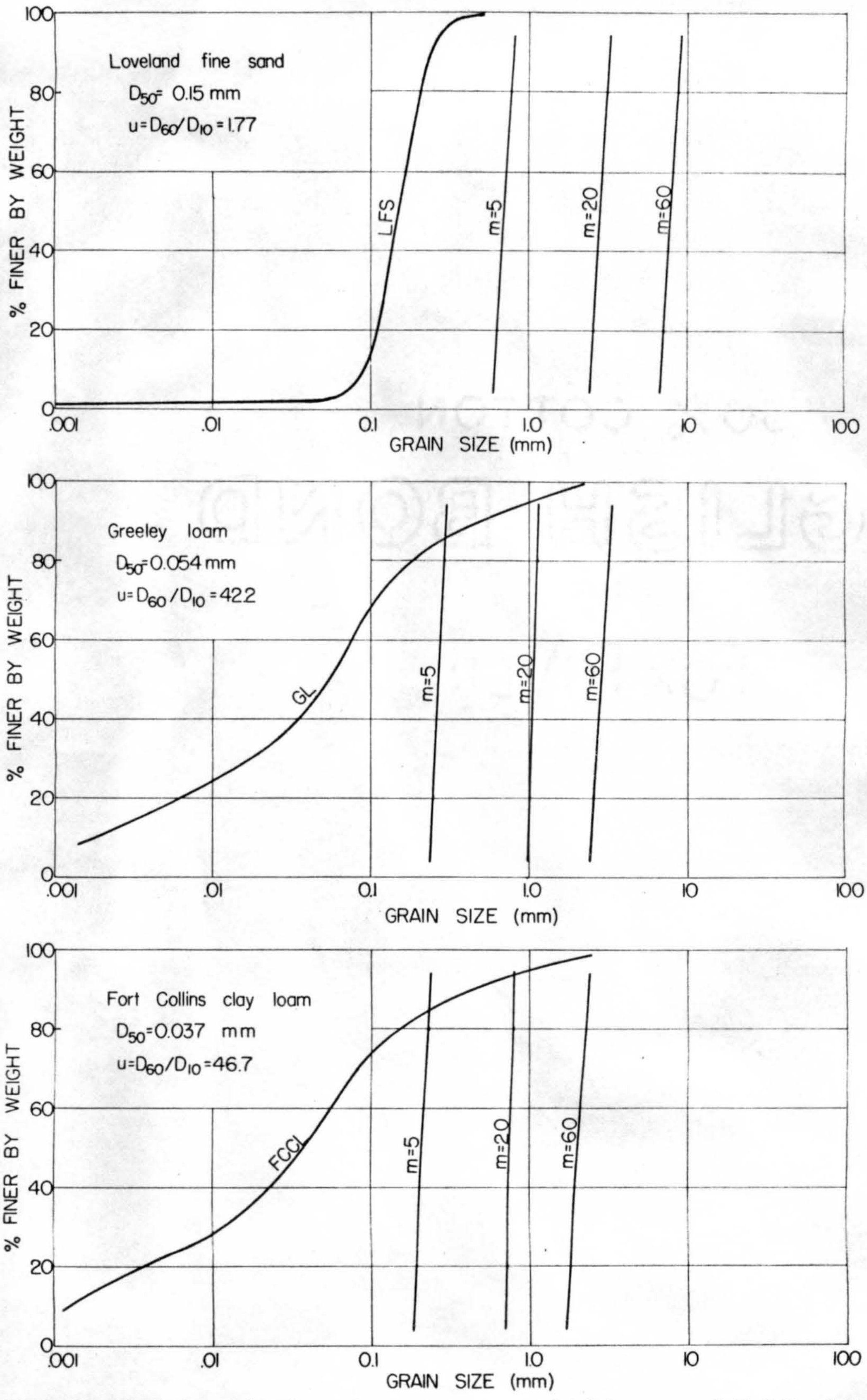


Fig. 1 Size distributions of soils and gravel layers used during runs 3-7, 9-12 of study of the effects of gravel mulches on evaporation.

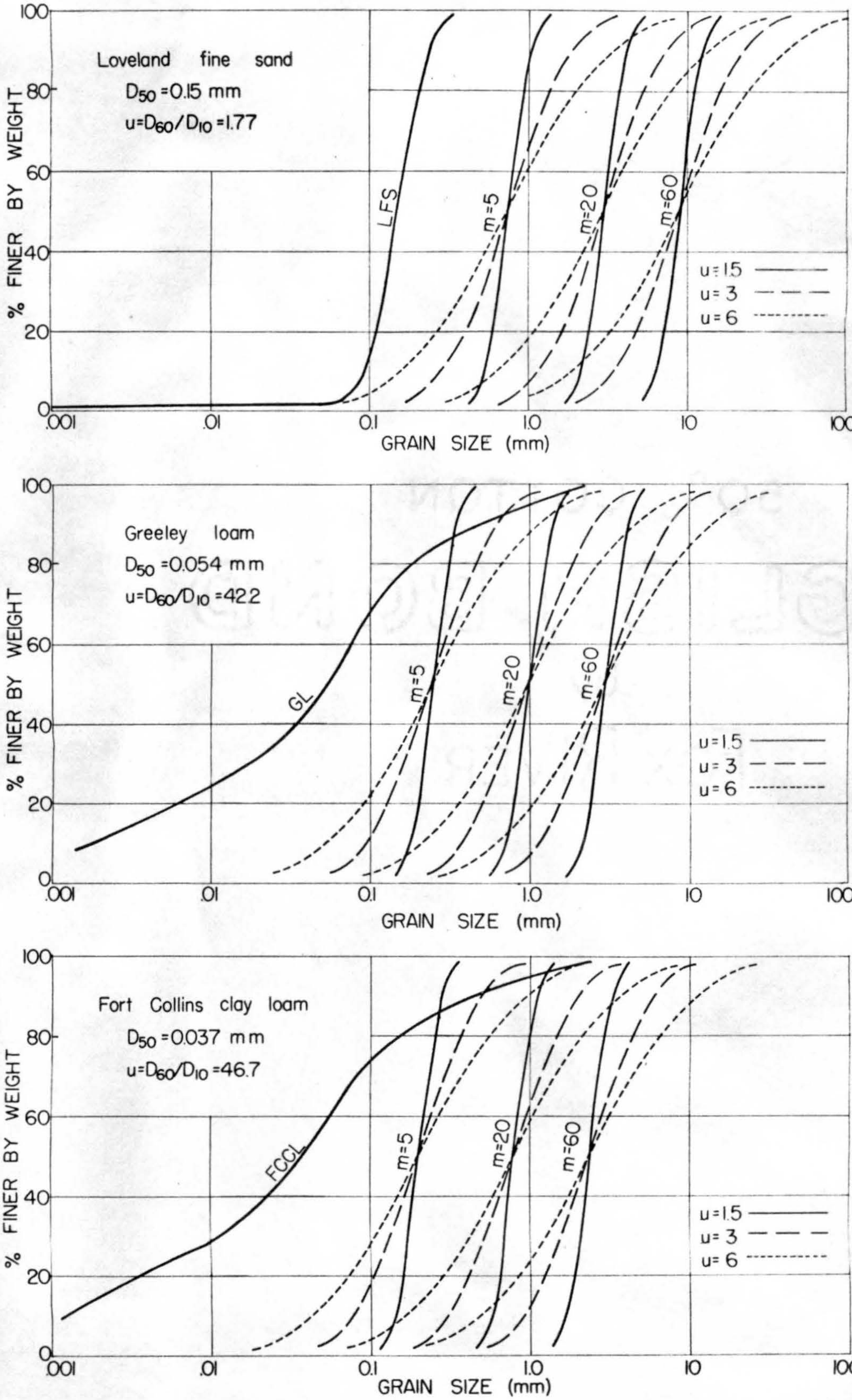


Fig.2 Size distribution of soils and gravel layers used during runs 14-22 of study of the effects of gravel mulches on evaporation.

During each run there were 31 samples on the turntable. There were nine different mulches for each of three soil types and a single sample with no mulch for each soil type and one sand column with the water table at the surface. Tables 1 and 2 describe the experimental design in tabular form. Note that the grain-size of the mulch is expressed as a ratio of median sizes; i.e., the median size of the mulch to the median size of the soil. This procedure was employed because theory and the results of previous experiments indicated that the grain-size is significant mostly in relation to the grain-size of the soil. The grain-size distribution of the mulches along with the grain-size distribution of the corresponding soils are shown in Figures 1 and 2. The increments of the several variables used were chosen (based on experience from previous experiments) to cover the range of greatest practical interest.

The experiments were designed in the manner described in order to permit suitable statistical analyses of the results; i.e., five-variable analyses of variance. In these analyses the dependant variable was the amount of moisture conserved after a specified period of time; i.e.,96 hours. The amount of moisture conserved was defined as the difference between the moisture lost in 96 hours from a soil with a mulch and that lost from the same soil without a mulch.

RESULTS

The two five-variable analyses of variance are shown in Tables 3 and 4 respectively. Both tables show that all main effects are significant. Some of the most significant results are also shown graphically in Figures 3-5.

Figure 3(a) shows the interaction among soils, median size, and uniformity. For all three soils, the combination of a median size ratio of five and a uniformity coefficient of six was very ineffective in comparison to the other mulches. For Greeley loam and Fort Collins clay loam, for median size ratios of 20 and 60, the uniformity of the gravel layer had very little effect on the amount of moisture conserved. For Loveland fine sand the same result was observed for a median size ratio of 20. For the latter soil, the median size ratio of 20 was more effective than the median size ratio of 60, especially for a coefficient of 1.5. For the loam and clay loam, however, there was little difference between the effectiveness of the median size ratios of 20 and 60.

Figure 3(b) shows the interaction among soils, median size, and wind velocity for runs 14-22. For the loam and clay loam, the increase of wind velocity from 0 to 10 ft/sec caused a reduction in the effectiveness of the mulches, but there was very little change in effectiveness as the wind velocity increased from 10 to 25 ft/sec. The latter observation was true of all median size ratios used. For the loam and clay loam, there was little difference between the effectiveness of the median size ratios of 20 and 60, but both were considerably more effective than the median size ratio of five. For the fine sand, for median size ratios of five and twenty, an increase in wind velocity caused

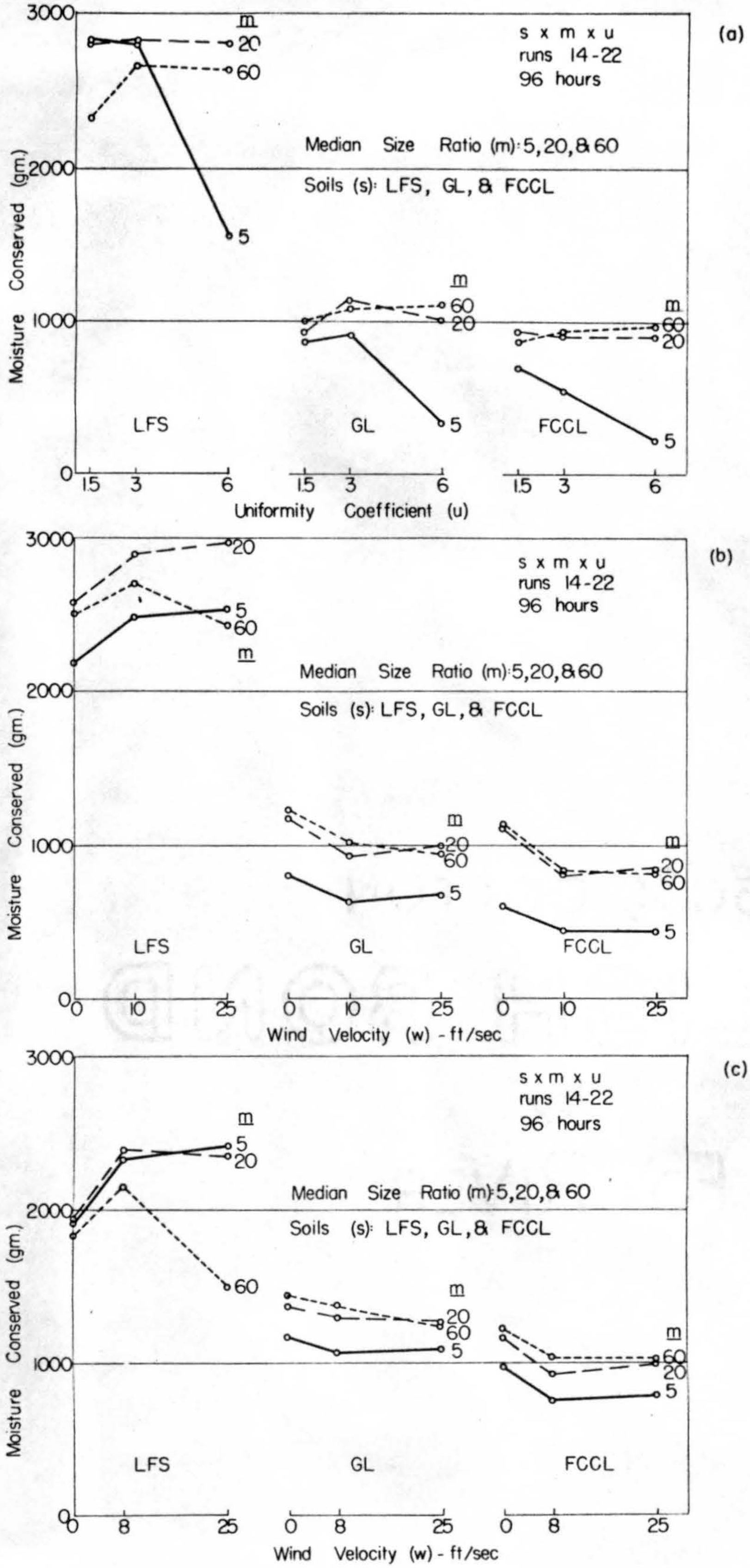


Fig. 3 Some results of the study of gravel mulches.

an increase in the effectiveness of the mulch. For a median size ratio of 60, the effectiveness increased as the wind velocity increased from 0 to 10 ft/sec and then decreased as the wind velocity increased from 10 to 25 ft/sec.

The interaction among soils, median size, and wind velocity for runs 3-7 and 9-12 is shown in Figure 3(c). All the observations previously noted also apply to these runs except that with the fine sand there was little difference in effectiveness between the median size ratios of five and twenty.

Figure 4(a) shows the interaction among soils, median size, and radiation for runs 14-22. An increase in radiation caused a decrease in the effectiveness of the gravel mulch regardless of the median size ratio with the loam and clay loam. With these two soils there was little difference between the effectiveness of the mulches with median size ratios of 20 and 60, but both were considerably more effective than the median size ratio of five. With the fine sand, an increase in radiation caused an increase in the effectiveness of the gravel mulches, especially for the median size ratio of twenty.

The interaction among median size, thickness, and wind velocity are shown in Figure 4(b). For all thicknesses, and for median size ratios of five and twenty, wind velocity had very little effect on the amount of water conserved. For all thicknesses, and for a median size ratio of sixty, there was a marked decrease in the effectiveness of the mulches as the wind velocity increased from 8 to 25 ft/sec. At a wind

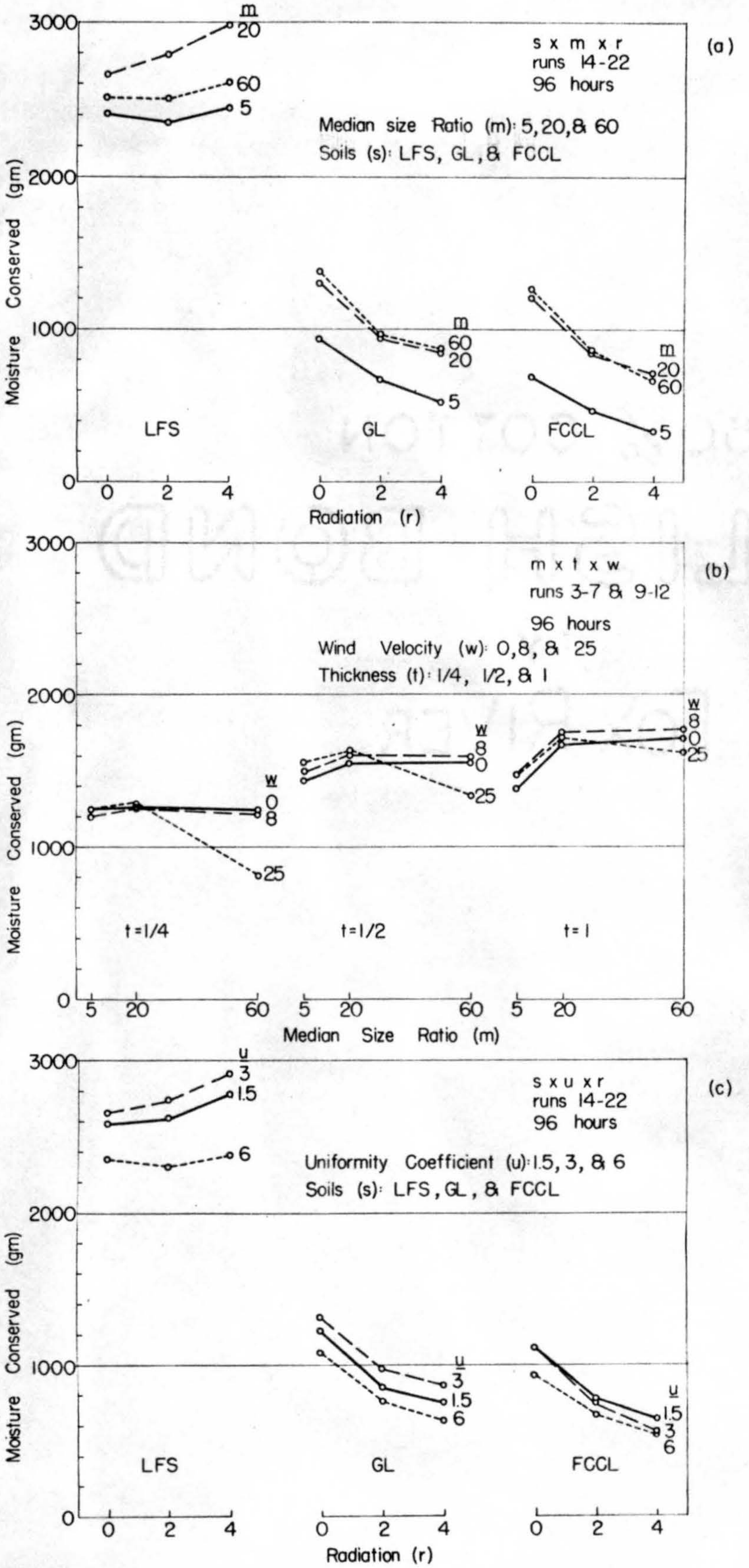


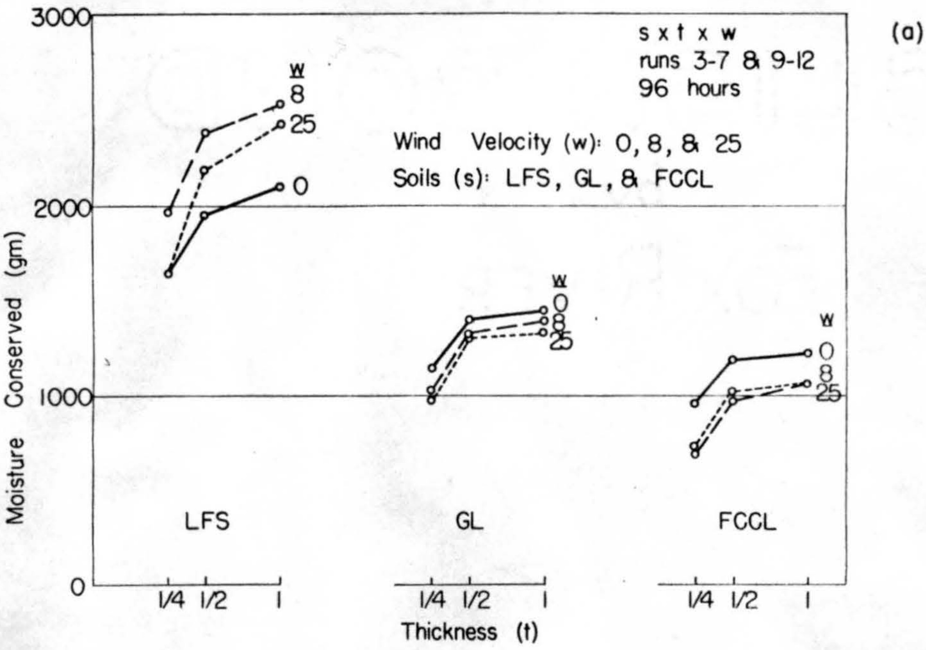
Fig. 4 Some results of the study of gravel mulches.

velocity of 25 ft/sec the mulches with a median size ratio of sixty were significantly less effective than the other mulches. This effect was most pronounced with a mulch thickness of ¼ inch, less pronounced with ½ inch, and still less pronounced with a mulch thickness of one inch.

The interaction among soils, uniformity coefficient of the mulch, and radiation is shown in Figure 4(c). The uniformity coefficient of six was least effective for all three soils at all three radiation levels; this was especially true in the case of the fine sand. The uniformity coefficient of three was most effective for nearly all soils and radiation levels.

The interaction among soils, mulch thickness, and wind velocity is shown in Figure 5(a). For all soils and wind velocities, the relative effect of thickness was the same. A substantial increase in effectiveness occurred as the thickness was increased from ¼ to ½ inch and the effectiveness leveled off at about one inch except on the fine sand in which case the mulches consisted of much larger grains and a thicker layer may have been substantially more effective.

Figure 5(b) shows the interaction among soils, median size, and thickness. For all three soils, with a median size ratio of five, the one-inch mulch was less effective than the ½-inch mulch which is hard to explain unless the loss of water from the mulches themselves was significant in this case. For the fine sand, the most effective layer had a thickness of one inch and a median



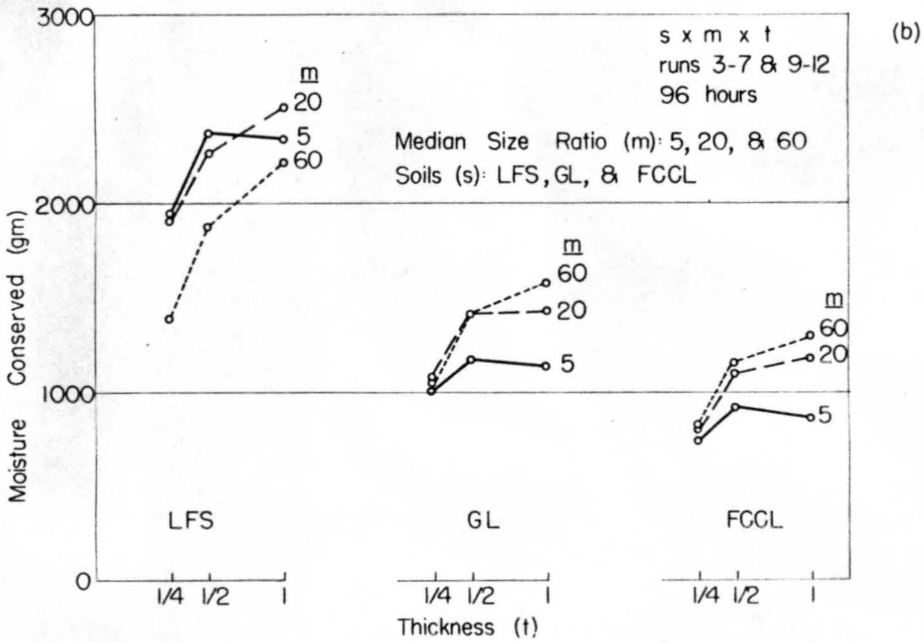


Fig. 5 Some results of the study of gravel mulches

size ratio of twenty. For the loam and clay loam, however, the most effective layer had a thickness of one inch and a median size ratio of sixty.

DISCUSSION OF RESULTS

The ineffectiveness of a gravel mulch with a median size ratio fo five and a uniformity coefficient of six can be explained as follows: Figure 2 shows that this layer had a considerable amount of particles smaller than a significant amount of the base soil. It is probable that this fraction of the mulch retained its ability to conduct water to the surface until a substantial amount of water had been lost from the soil below.

The relative ineffectiveness of the layer with a median size ratio of sixty and a uniformity coefficient of 1.5 on the fine sand was probably due to the fact that the pores of this mulch were very large. When wind blows across the surface, turbulence and convection can occur within the large pores of this mulch. Thus, water can be removed from this mulch faster than by the diffusion process occurring in mulches with smaller pores. The median grain-size of this layer was 9 mm or approximately 1/3 inch. The effect of high wind velocity on the mulch with a median size ratio of sixty on Loveland fine sand is also shown by Figures 3(b) and 3(c).

The increasing effectiveness of the gravel mulches or the fine sand with increasing radiation may at first seem to be an error. However, it may be that the increase in radiation had little effect on the amount of water evaporated through the mulches, but increased the water loss from the bare soil. Thus the difference in loss of moisture may increase with increasing radiation.

The use of a 96-hour period as a standard for measuring the effectiveness of gravel mulches may at first seem unreasonable. It must be remembered, however, that most of the loss of water from bare soils will occur shortly after rains when the soil surface is moist. In climates where most of the water is applied by infrequent irrigations or heavy rains, gravel mulches cannot be expected to conserve much water. A similar reasoning applies in regard to the adoption of short soil columns for this study; i.e., most of the water lost by evaporation from bare soils is lost from the soil near the surface.

CONCLUSIONS FROM THE RESULTS

From the observations and analyses described in the foregoing, we may conclude the following concerning the characteristics of a suitable gravel mulch for general atmospheric conditions:

1. The thickness should exceed ½ inch; but except where the mulch necessarily must consist of grains larger than about ¼ inch, the thickness need not exceed about one inch.
2. The mulch should not contain a substantial fraction of grain-sizes that are smaller than the larger grains of the underlying soil--at least than the larger grains that make up a substantial fraction

of the underlying soil. In other words nearly all of the pores of the mulch should be substantially larger than the largest pores of the soil below. A median-size ratio of approximately twenty will usually meet this requirement.

3. If in order to meet requirement No. 2, a layer of gravel containing grains larger than about ¼ inch diameter is necessary the thickness of the layer should probably be greater than one inch.

PLANS FOR FUTURE STUDIES

The experiments described in the foregoing seem to give a clear picture of what is necessary to create a satisfactory gravel mulch. Further studies on this subject do not seem to the authors to be necessary.

Future studies will attempt to provide information that will indicate how gravel mulches might be used and managed. One possible use; for example, might be to conserve moisture around sugar beet seeds to increase germination. In order to evaluate this possiblity, one ought to know, among other things, what surface area surrounding a point on a soil surface needs to be covered by a mulch in order to conserve a substantial amount of water at that point. It is planned to study this problem theoretically and experimentally during the coming year.

Another possible use might be as an aid in getting water into aquifers from light frequent rains falling on large non-agricultural areas in the West. In order to evaluate the latter possiblity, one ought to know roughly how extensive are the areas in the West where such a project would be feasible and also whether or not one could devise equipment that could economically create a mulch from the fraction of larger grains occuring near the soil surface.

TABLE 1. Variables studied during runs 3-7 and 9-12 of experiments on the effect of gravel mulches on evaporation from soils.

Variables Studied	Increments of Each Variable
Soils (s)	(1) Loveland fine sand (LFS) (2) Greeley loam (GL) (3) Fort Collins clay loam (FCCL)
Gravel Mulches*	
Thickness (t)	(1) ¼ inch (2) ½ inch (3) 1 inch
Median Size (m) - - $\frac{(D_{50})\text{ gravel}}{(D_{50})\text{ soil}}$	(1) 5 (2) 20 (3) 60
Uniformity (u)	All layers uniform; i. e., passed one sieve but retained on next size smaller.
Atmospheric Conditions	
Incident Radiation (r) (No. of 250-w lamps)	(1) 0 lamps (2) 2 lamps (3) 4 lamps
Wind Velocity (w) (Gusty Conditions--no velocity 80% of the time)	(1) 0 fps (2) 8 fps (3) 25 fps
Temperature (Constant)	90° F
Relative Humidity (Constant)	30%

* See Figure 1

TABLE 2. Variables studied during runs 14-22 of experiments on the effect of gravel mulches on evaporation from soils.

Variables Studied	Increments of Each Variable
Soils (s)	(1) Loveland fine sand (LFS) (2) Greeley loam (GL) (3) Fort Collins clay loam (FCCL)
Gravel Mulches* Thickness (t)	All layers--1 inch thick
Mediam Size (m) -- $\frac{(D_{50})\text{ gravel}}{(D_{50})\text{ soil}}$	(1) 5 (2) 20 (3) 60
Uniformity (u) -- $\frac{D_{60}}{D_{10}}$ (Hazen's Uniformity Coefficient)	(1) 1.5 (2) 3 (3) 6
Atmospheric Conditions Incident Radiation (r) (No. of 250-w lamps)	(1) 0 lamps (2) 2 lamps (3) 4 lamps
Wind Velocity (w) (Gusty Conditions--no velocity 80% of the time)	(1) 0 fps (2) 10 fps (3) 25 fps
Temperature (Constant)	90^{o} F
Relative Humidity (Constant)	30%

* See Figure 2

TABLE 3 Analysis of variance for runs 3-7 and 9-12 of experiments on the effect of gravel mulches on evaporation from soils.

Source of Variation	df	Sum of Squares	Mean Square
Main effects:			
Soils (s)	2	661,975	330,988**
Median Size (m)	2	9,754	4,877**
Thickness (t)	2	98,986	49,493**
Radiation (r)	2	11,228	5,614**
Wind Velocity (w)	2	2,675	1,338**
First order interactions:			
s x m	4	48,401	12,100**
s x t	4	8,209	2,052**
s x r	4	34,162	8,540**
s x w	4	35,172	8,793**
m x t	4	13,618	3,404**
m x r	4	628	157
m x w	4	13,793	3,888**
t x r	4	3,305	826**
t x w	4	2,249	562**
r x w	4	4,625	1,156**
Second order interactions:			
s x m x t	8	1,427	178
s x m x r	8	751	94
s x m x w	8	14,920	1,865**
s x t x r	8	269	34
s x t x w	8	1,776	222*
s x r x w	8	8,770	1,096**
m x t x r	8	818	102

TABLE 3 (Con't.) Analysis of Variance

Source of Variation	df	Sum of Squares	Mean Square
Second order interactions (con't.):			
m x t x w	8	2,025	253**
m x r x w	8	1,120	140
t x r x w	8	1,149	144
Third order interactions:			
s x m x t x r	16	838	52
s x m x t x w	16	1,891	118
s x m x r x w	16	1,423	89
s x t x r x w	16	506	32
m x t x r x w	16	2,399	150
Fourth order interaction (or error):			
s x m x t x r x w	32	2,592	81
TOTAL	242	991,454	

TABLE 4 Analysis of variance for runs 14-22 of experiments on the effect of gravel mulches on evaporation from soils.

Source of Variation:	df	Sum of Squares	Mean Square
Main effects:			
Soils (s)	2	1,993,249	996,624**
Median Size (m)	2	85,663	42,832**
Uniformity Coefficient (u)	2	33,627	16,814**
Radiation (r)	2	39,275	19,638**
Wind Velocity (w)	2	3,339	1,670**
First order interactions:			
s x m	4	12,015	3,004**
s x u	4	10,500	2,625**
s x r	4	43,870	10,968**
s x w	4	33,003	8,251**
m x u	4	93,710	23,428**
m x r	4	1,610	402**
m x w	4	5,878	1,470**
u x r	4	80	20
u x w	4	1,144	286*
r x w	4	25,689	6,422**
Second order interactions:			
s x m x u	8	26,212	3,276**
s x m x r	8	3,445	431**
s x m x w	8	3,446	431**
s x u x r	8	2,405	301**
s x u x w	8	543	68
s x r x w	8	25,453	3,182**

TABLE 4 (Con't) Analysis of Variance

Source of Variation:	df	Sum of Squares	Mean Square
Second order interactions (con't):			
m x u x r	8	667	83
m x u x w	8	1,303	163
m x r x w	8	2,218	277**
u x r x w	8	487	61
Third order interactions:			
s x m x u x r	16	7,475	467**
s x m x u x w	16	3,724	233**
s x m x r x w	16	4,558	285**
s x u x r x w	16	1,899	119
m x u x r x w	16	598	37
Fourth order interaction (or error):			
s x m x u x r x w	32	2,709	85
TOTAL	242	2,469,794	

REFERENCES

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

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

3. Progress Report No. 6, Colorado contributing project to W-32. "Study of evaporation from soil surface." November 1960.