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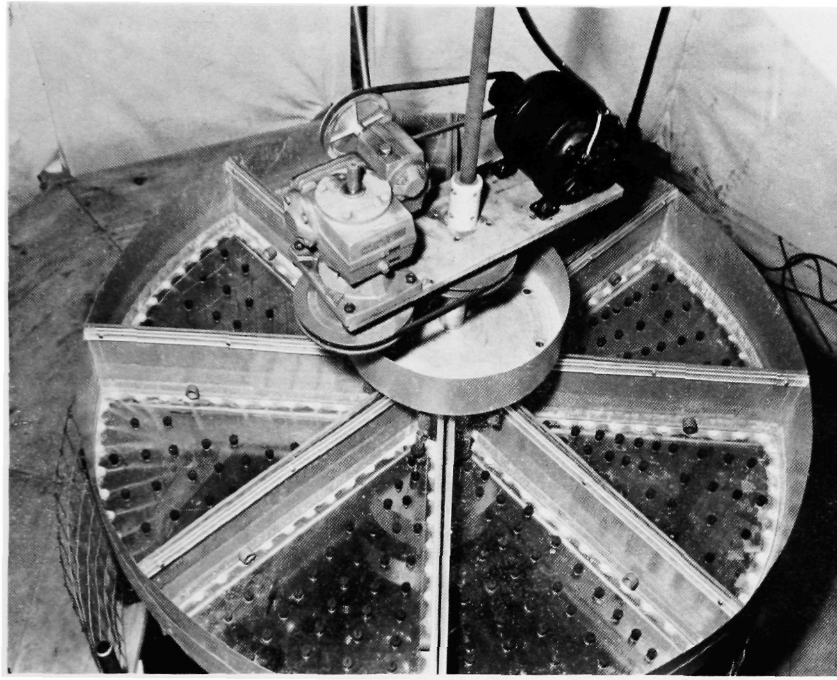

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DESIGN, CONSTRUCTION, AND CALIBRATION OF A LABORATORY RAINFALL SIMULATOR[1]

Eliot Epstein and Walter J. Grant[2]

The use of field plots under natural rainfall conditions to evaluate factors that cause or contribute to erosion requires a long period of study in order to cover a range of climatic variations. To shorten the time required for erosion studies, field plot and laboratory rainfall simulators have been developed. The rainfall simulator at the University of Maine was designed for the study of soil characteristics as related to soil erodibility, and for the determination of soil erodibility factor (K) as used in the universal soil loss prediction equation.

Many of the early rainfall simulators failed to produce natural rainfall-type storms because the characteristics of natural rainfall, especially kinetic energy, drop size distribution, and velocity of fall, were not well known. In 1941 Laws (4)[3] studied the rainfall drop velocity as influenced by drop size and distance of fall. In 1943 Laws and Parsons (5) related the raindrop size distribution to rainfall intensity. Following these studies Ellison (2), Ellison and Pomerene (3), and Adams, et al. (1) employed drop towers which took into account some of the characteristics of natural rainfall. The primary disadvantage of these studies were:

1. High rainfall intensities ranging from 5 to 14 inches per hour.
2. Low height of fall. Consequently, the terminal velocity of natural rainfall was not attained.

To overcome some of the shortcomings of early rainfall simulators, the characteristics for the design of a new simulator were formulated at

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[1]Contribution of The Soil and Water Conservation Research Division, Agricultural Research Service, USDA, and The Department of Plant and Soil Sciences, Maine Agricutural Experiment Station, University of Maine

[2]Research Soil Scientist and Soil Scientist, USDA

[3]Literature cited on page 9.

a workshop meeting at Purdue University in 1958. The characteristics recommended were:

1. Maximum height of fall from the applicator head to the soil pan to be such that the resulting energy per unit of water is as near as possible to that of natural rainfall. The relationship between drop size, height of fall, and resulting kinetic energy is shown in table 1.
2. Storm characteristics to be based on EI values, rather than intensity alone, varying between a maximum limit of 10,000 and minimum limit of 1,000, where E is the kinetic energy in ft.-tons/acre-inch, and I the maximum 30-minute intensity in inches per hour (11).
3. Drop sizes to be in the range of 2 - 6 mm.
4. Intensity to be in ranges of 0.5, 1.0, 2.0, and 3.0 inches per hour.

More detailed review of rainfall simulator research can be found in other publications (6, 7, 8, 9).

Table 1.—Kinetic energy for various drop size and height of fall[a]

Drop size	KE at terminal velocity	Height of fall 6 ft.	10 ft.	20 ft.	30 ft.
mm.	Ft-tons/acre-inch	Ft-tons/acre-inch			
2	815	430	585	750	800
3	1230	510	720	1030	1175
4	1485	565	815	1220	1369
5	1605	595	880	1330	1500

[a]Calculated from the data of J. Otis Laws (4).

Design and Construction of Simulator

In 1961 a laboratory rainfall simulator was constructed at Orono, Maine, for small soil pan studies. The applicator, constructed from design plans developed at the Purdue University workshop in 1958, is located at the top of a 30-foot conventional silo. This arrangement provides a 25-foot height of fall and convenient working space.

The applicator (fig. 1) is 54 inches in diameter and consists of eight wedge-shaped segments. This unit rotates at 1 rpm. The applicator head is supported from the floor, as its weight with water is in excess of 300 pounds. Further stabilization is provided by cross bars attached to the truss of the silo.

Two different drop formers are used. To produce a 5.1 mm. drop, a drop former was made of short lengths of stainless steel tubing in a graded series. Water enters the small diameter tubing and the large diameter tubing provides the desired drop size (10).

Natural raindrops range up to 6 mm. in size for all intensities. The volume of rain in 5.0 mm. or larger drops in high intensity natural rainfall is about 5% (5) which results in a medium drop size of about 3.0 mm. To produce drops of 3.2 mm. diameter a 24 guage stainless steel tubing is being used.

To minimize a drop furrow effect on the surface of the soil sample, each wedge-shaped section of the applicator has a different drop former arrangement. The position radius of each drop former was calculated from the applicator area and the selected number of drop formers (10).

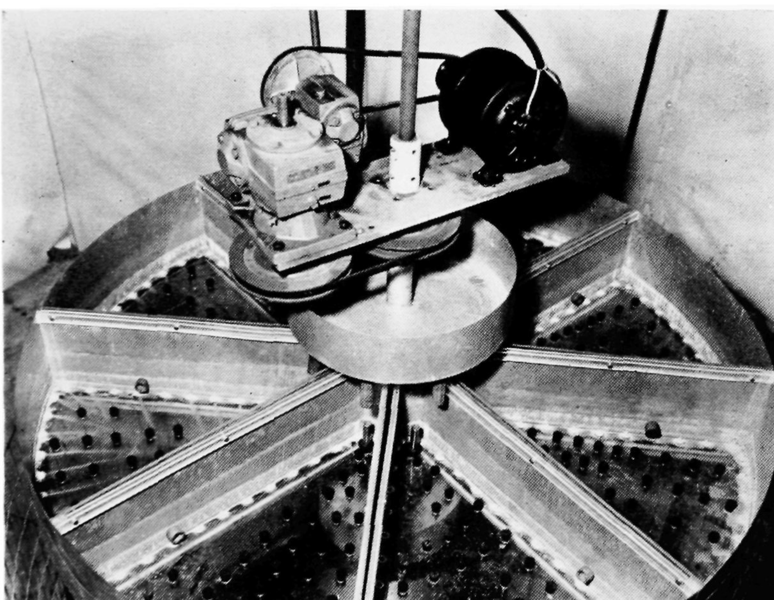


Figure 1. Rainfall simulator

The soil pans presently being used are 12x12 inches and hold a soil sample 6 inches in depth (fig. 2). One of the problems with small pans is the evaluation of soil loss as result of splash. In field erosion splash soil returns to the surface. This loose material is more easily erodible. In most small pan studies no attempt was made to return the splash. Some of the present studies are being designed to evaluate splash and provide a means of returning it to the pans.

Calibration and Application

The relationships of rates of discharge and drop formation to height of head for the 5.1-mm. drop former are shown in figures 3 and 4. With increase in height of head the discharge rate and the number of drops per minute increased.

Table 2 shows the effect of height of head on drop size and the resulting kinetic energy. An increase from 2 to 10 cm. in head increased the average drop diameter by 0.06 mm. Therefore, any fluctuations in head during a run or between the various runs will result in a negligible change in the drop diameter and resulting kinetic energy.

The amount of water reaching the soil pans under the applicator varies with the position of the pans (fig. 5). Little variation occurred in the 14- and 17-inch radius bands. As the pans were moved to the outer periphery of the applicator edge, a decrease in rainfall intensity was noted. This was especially true with the lower heads.

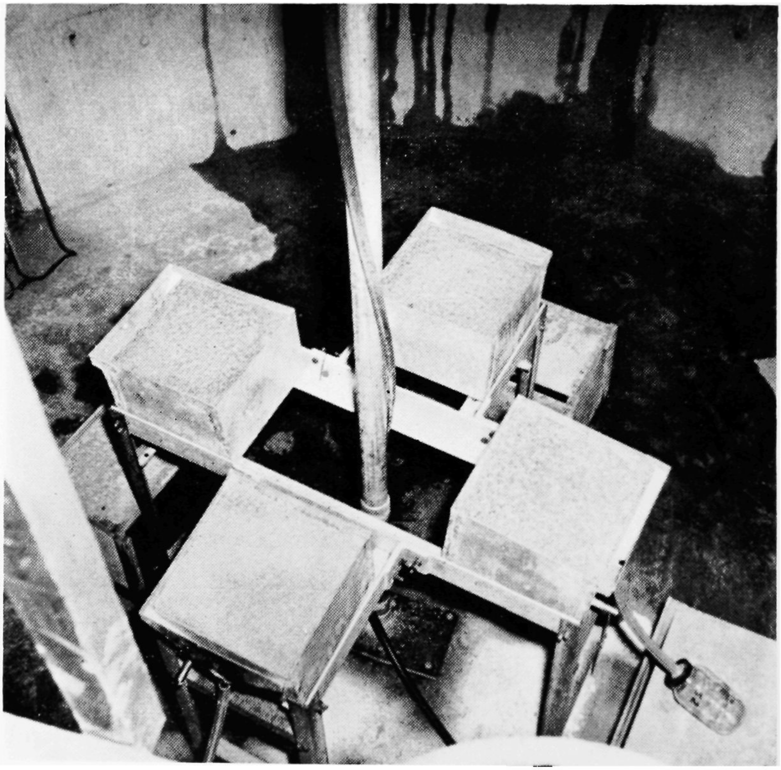


Figure 2. Four soil pans

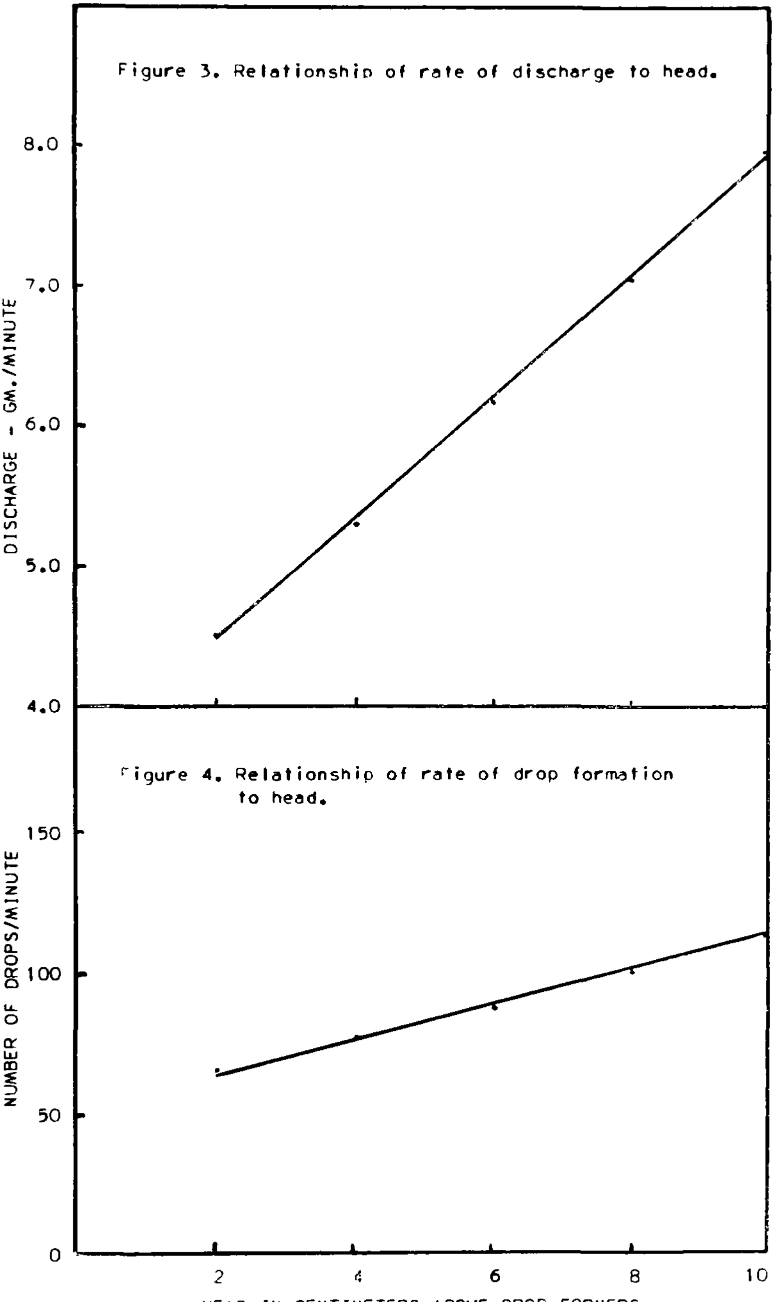


Figure 3. Relationship of rate of discharge to head.

Figure 4. Relationship of rate of drop formation to head.

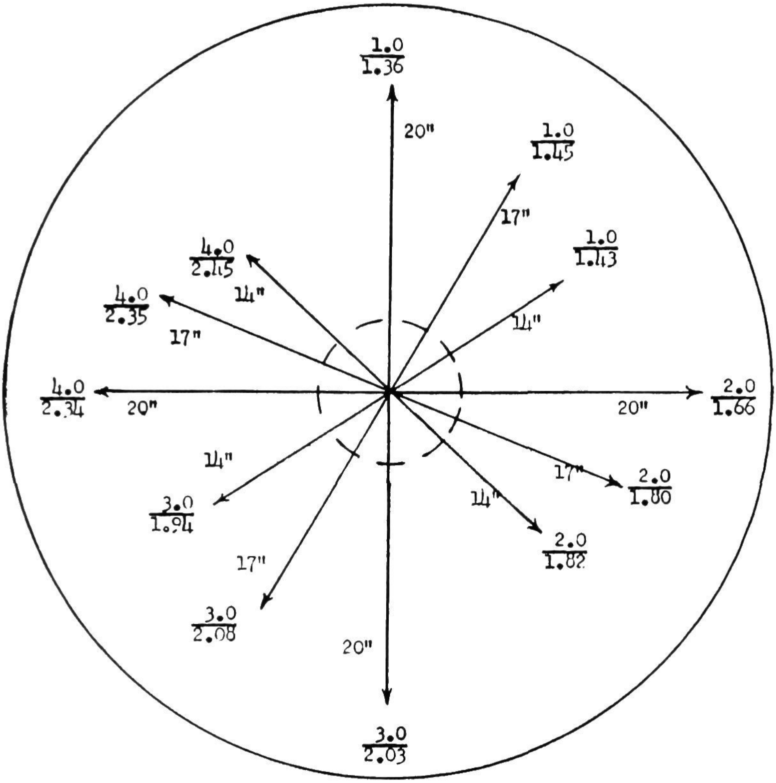
Table 2.—The effect of height of head on drop diameter and resultant kinetic energy

Needle No.	Height of head in centimeters				
	2	4	6	8	10
	Drop diameter—mm.				
1	5.089[a]	5.085	5.083	5.141	5.136
2	5.080	5.084	5.136	5.162	5.132
3	5.064	5.049	5.136	5.176	5.162
4	5.074	5.094	5.080	5.074	5.112
5	5.085	5.136	5.126	5.166	5.162
6	5.094	5.127	5.157	5.146	5.118
7	5.084	5.090	5.103	5.131	5.167
8	5.089	5.108	5.099	5.089	5.136
Average diameter	5.082	5.097	5.115	5.136	5.141
	Kinetic energy—Ft. lbs./acre-inch x 10^5 [b]				
	30.13	30.14	30.15	30.15	30.16

[a]Each figure represents the average of 1000 drops.

[b]At Terminal velocity.

Figure 5. Rainfall intensity in relation to position of soil pans.



note: Upper figure - head
Lower figure - intensity

One of the factors affecting soil loss is the moisture content of the soil at the time of rain. Table 3 shows the variability in soil loss for soils of different moisture contents. The soil used in these studies was a Caribou loam screened through a 6.4 mm. screen (.25 inch). The least variation occurred when the soil had 15-19% moisture content. This represents a moisture tension range of 2 bars.

The size of soil particle will also affect the rate of soil loss (table 4). The greatest variation in soil loss within a given sieve size was with the 2.0 mm. particles. The least variation in soil loss occurred when soil was passed through the larger sieve sizes.

Table 3. —Effect of antecedent soil moisture on the variability of soil loss[1]

Trial	Air Dry	15-19%	21-24%	Saturated
		Grams/Sq. Ft.		
1	91.4	90.1	95.4	80.4
2	79.4	73.4	78.8	98.7
3	91.4	89.0	79.0	131.3
4	80.2	95.1	70.5	145.8
5	77.7	84.0	89.8	142.4
6	53.7	87.7	88.6	120.8
7	111.0	94.8	89.0	75.4
8	75.7	80.5	104.6	90.4
9	64.2	90.3	102.1	78.0
Average	80.5	87.2	88.6	107.0
No samples at 95% confidence with tolerance of ± 10 gm.	10	2	5	28

[1]Caribou soil passed through ¼-inch sieve.

Table 4.—The relation of soil losses to sizes of particles and aggregates

Trial	Particle size[a]			
	2 mm	6.4 mm	9.5 mm	12.7 mm
1	80.0	100.9	91.6	97.7
2	88.9	104.5	100.4	—
3	88.1	86.7	91.0	88.0
4	108.3	74.5	93.5	80.8
5	72.3	97.7	79.8	75.1
Average	87.5	92.9	91.3	85.4

[a]Upper limit

Summary

A rainfall simulator was constructed which had the necessary characteristics to reproduce the erosion-index (EI) values of natural rainfall. This rainfall simulator is being used to evaluate soil erodibility factors for various soil types to be used for prediction of soil losses in the field. The simulator can also be used for basic studies in erosion, infiltration and water movement, and movement of chemicals and pesticides through the soil.

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