# Prediction of Runoff and Erosion from Natural Rainfall Using a Rainfall Simulator[1]

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## ABSTRACT

Field rainfall simulators have been used extensively for runoff and erosion studies. To more accurately interpret and apply the results of studies using simulated rainfall, it is necessary to know the relative effects of natural vs. simulated rainfall.

A comparison was made of the soil and water losses from three natural storms and three simulated storms on cultivated fallow plots under similar rainfall and soil conditions. A rainulator was used to apply the simulated storms. Soil losses from the three simulated storms averaged 77% of those from the natural rainstorms. This compares closely, considering that the average EI value for the simulated storms was 78% of that for natural rainstorms. The runoff from the simulated storms compared quite closely to runoff from the natural storms.

The study showed that, in general, the rainulator can be used to simulate rainfall for runoff and erosion research with confidence that the results will reflect the runoff and soil loss that would occur under similar conditions of natural rainfall.


*Additional Index Words:* rainulator, soil loss.

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Runoff plots have long been used in soil erosion research to evaluate various cropping and management systems on different soils under natural rainfall. Ten to 20 years of measurements have been required to obtain representative sampling of natural rainstorms to fully evaluate treatment effects. Natural-rainfall runoff plots have been costly to establish and maintain over such long periods.

In recent years, rainfall simulators have been used extensively to hasten the accumulation of information from runoff-erosion studies. These simulators give controlled application of rainfall closely resembling the drop characteristics and kinetic energy of natural rain. Preselected rainstorm intensities and durations are applied to plots on which new or untested cropping and management practices have been established. Most rainfall simulators are portable, which permits relatively rapid testing of many variables.

One rainfall simulator, the rainulator (1), has been used for more than 10 years in several areas of the country in a wide variety of runoff and erosion studies. This simulator can apply rainfall over an area up to 594 m$^2$. The water drops are very similar to natural raindrops in size distribution and terminal velocity. For example, at an intensity of 5.08 cm/hour, the median drop diameter of simulated raindrops is 2⅛ mm compared with the 2.5-mm diameter of natural raindrops (2). The nozzles used on the rainulator require intermittent operation because of their high flow rate. For the three rainfall intensities that the rainulator is capable of applying—3.18, 6.35, and 12.70 cm/hour—the kinetic energy discharged by the nozzles 2.44 m above the ground is 84%, 76%, and 70%, respectively, of that of similar intensity natural rainfall (1, 3). Nozzles have not

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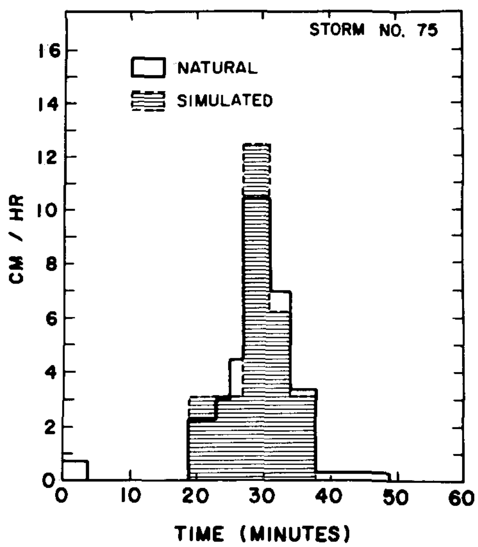


**Fig. 1—Intensity patterns for natural and simulated rainfall—Storm no. 75.**

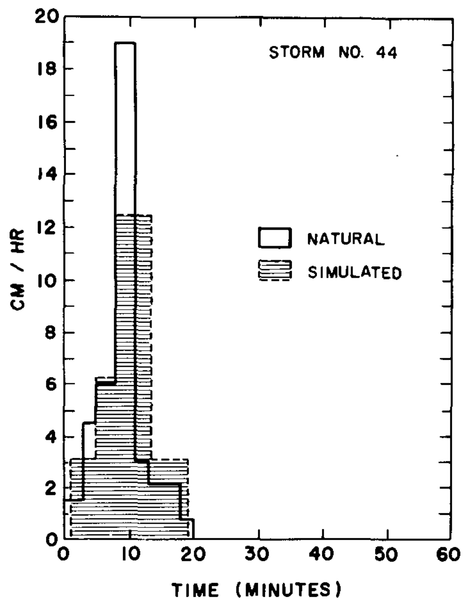


**Fig. 2—Intensity patterns for natural and simulated rainfall—Storm no. 44.**

been developed to discharge kinetic energy equal to that of natural rainfall of similar intensities.

To more accurately interpret and apply the results of studies using a rainulator, it is necessary to know the relative effects of natural vs. simulated rainfall. This knowledge can then be directly related to most erosion and runoff studies for quantitatively evaluating soil erodibility. Consequently, this study was undertaken to relate the effects of simulated rainstorms to those of natural rainstorms on erosion and runoff from cultivated fallow plots under similar antecedent soil moisture and rainfall conditions.

## PROCEDURE

A set of natural-rain runoff plots has been maintained since 1961 at the Barnes-Aastad Soil and Water Conservation Research farm, near Morris, Minnesota (4). Three of these plots have been maintained continuously in cultivated fallow. All soil and water losses from the natural runoff plots have been measured continuously since establishment.

An area adjacent to the natural runoff plots has also been maintained in cultivated continuous fallow since 1961. Although runoff and soil losses were not measured on this area, tillage operations on it were the same as those on the continuous fallow natural-rainfall plots. In 1967, this area was divided into four plots, each the size of the natural runoff plots—22.13 m long by 4.06 m wide.

Rainfall records from the natural-runoff plots were studied closely to select storms whose intensity patterns and durations were such that they could be closely approximated by the rainulator. Three storms were selected: one was simulated on two of the four rainulator plots, and the other two were simulated on both of the remaining rainulator plots on 2 successive days. Figures 1–3 show the rainfall patterns for the three selected storms. The two plots subjected to each selected rainstorm served as replications. Since the rainulator is designed to apply simulated rainfall at only three intensities (3.18, 6.35, and 12.70 cm/hour), the natural rainfall intensities could not be duplicated exactly.

To equalize antecedent soil moisture conditions on the rainulator plots and the natural-rainfall plots for the time lapse between tillage and the test storms, water was applied to the rainulator plots with irrigation sprinklers. The time intervals for irrigation coincided with the time intervals of the natural rainfall. The rainulator plots were covered with plastic sheets during the preconditioning period to avoid wetting by natural rainfall. Table 3 shows the pretreatment schedule of the plots from the time of last tillage to the time of application of the test storms.

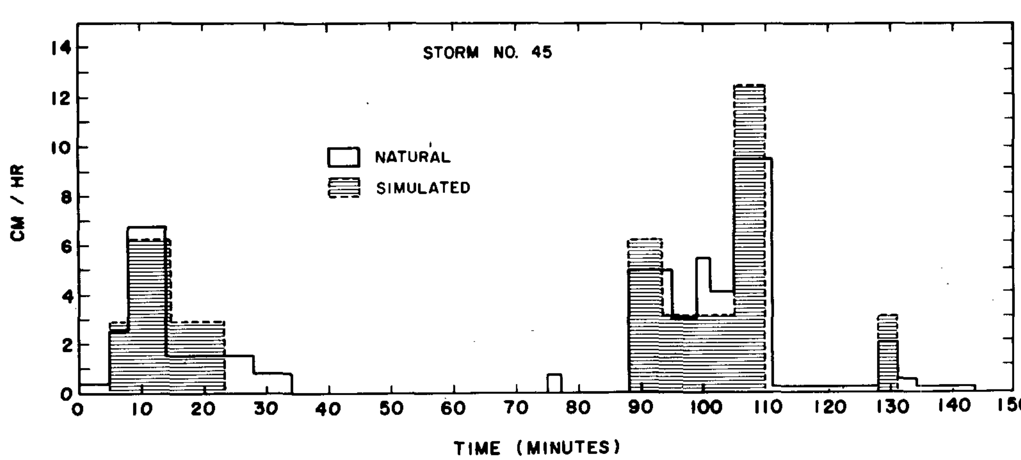


**Fig. 3—Intensity patterns for natural and simulated rainfall—Storm no. 45.**

**Table 1—Particle size distribution**

| | Particle class | Surface soil | Washoff Storm no.75 | Washoff Storm no.44 | Washoff Storm no.45 |
|---|---|---|---|---|---|
| | | | % | | |
| Natural-rain plots | Sand | 40.0 | 14.76 | 24.73 | 31.96 |
| | Silt | 39.2 | 58.56 | 48.88 | 43.21 |
| | Clay | 20.8 | 26.68 | 26.39 | 24.83 |
| Rainulator plots | Sand | 46.51 | 21.62 | 27.87 | 32.12 |
| | Silt | 33.59 | 53.92 | 47.46 | 42.39 |
| | Clay | 19.90 | 24.46 | 24.67 | 25.49 |

**Table 2—Soil properties of the top 15 cm of soil**

| | Bulk density | % organic matter | Soil pH | Suspension percentage | Moisture retention 1/3 atm | Moisture retention 15 atm |
|---|---|---|---|---|---|---|
| | $g/cm^3$ | | | | % | |
| Natural-rain plots | 1.13 | 4.38 | 6.36 | 5.85 | 24.08 | 11.64 |
| Rainular plots | 1.24 | 4.94 | 5.75 | 4.18 | 23.02 | 11.54 |

During the selected test storms, all runoff and soil loss were measured using standard rainulator procedures (5). Soil samples were taken to determine antecedent soil water content just before the rainulator tests. The surface soil of the rainulator plots was also sampled for soil physical analysis to determine if there were any basic differences between those plots and the natural runoff plots (Table 2).

Surface soil texture was quite similar on the two plot areas, both falling in the loam classification, although the rainulator plots had a slightly higher sand content (Table 1) and bulk density (Table 2). As is normally the case, the eroded soil particles contained a much higher percentage of the finer particles, silt and clay, than did the original surface soil. Generally, the physical characteristics of the soils in the two sites were similar.

Storm no. 75 was preceded by a total of 2.06 cm of rainfall in the 18 days between the last cultivation and the actual storm, while storm no. 44 was preceded by 5.33 cm in 9 days. Two of the rainulator plots were prewetted in a pattern similar to that preceding storm no. 75 and the other two were prewetted in a pattern similar to that preceding storm no. 44. Storm no. 45 followed storm no. 44 by 20 hours; consequently, this storm was simulated on the same plots as storm no. 44 and the pretreatment included storm no. 44. These two storms compare somewhat with the "dry" and "wet" runs which are standard in most rainulator experiments.

The characteristics of the three simulated rainstorms in general closely matched the intensity-duration patterns of the natural rainstorms. Storm EI values were lower for the simulated storms because of the known lower energy of the simulated rain. A greatly disproportionate amount of water would have been required to make the storms equivalent on an EI basis (6).

## RESULTS

Table 4 shows the average soil and water losses and EI values for the rainulator and natural rainfall plots. The EI for the simulated storms was computed using applied intensity and duration, and the fact that the energy of the simulated rainfall was 2151.80 kg $m/m^3$ regardless of application intensity (1).

The soil losses for the three rainulator storms ranged from 76% to 79% of the soil losses from the comparable natural rains. The EI value for the rainulator storms was 78% of the natural-rain EI. When EI values are made equal by an approximate straight line adjustment and soil losses are adjusted accordingly, further justification for judging the soil loss equivalence is seen from the overlapping of the total soil loss ranges, 41.56 to 48.20 metric tons/ha for rainfall plots and 41.10 to 47.81 metric tons/ha for simulator plots. Runoff was little affected by the deviation of rainfall simulation—9% more total water was applied with the rainulator and 11% more water ran off.

**Table 3—Pretreatment wetting of rainulator plots***

| Storm event | Number of days before run | Amount of water applied |
|---|---|---|
| | | cm |
| Storm no. 75 | 18 | 1.09 |
| | 8 | 0.10 |
| | 8 | 0.08 |
| | 6 | 0.20 |
| | 0-2 hours | 0.58 |
| | Total | 2.06 |
| Storm no. 44 | 9 | 2.67 |
| | 9 | 0.10 |
| | 8 | 0.79 |
| | 4 | 0.61 |
| | 3 | 1.17 |
| | Total | 5.33 |

* From date of last cultivation to date of test.

**Table 4—Average soil and water losses from natural and simulated rainfall**

| | Water received | Applied EI | Soil loss Average | Soil loss Range | Runoff Average | Runoff Range |
|---|---|---|---|---|---|---|
| | cm | | metric tons/ha | | cm | |
| Storm no. 75 | | | | | | |
| Rainfall plots* | 1.80 | 10.0 | 2.24 | (1.79- 2.71) | 0.38 | (0.33-0.46) |
| Rainulator plots† | 1.73 | 8.0 | 1.75 | (1.50- 2.02) | 0.41 | (0.41-0.51) |
| Storm no. 44 | | | | | | |
| Rainfall plots* | 1.78 | 10.7 | 12.35 | (11.21-13.32) | 0.74 | (0.71-0.76) |
| Rainulator plots† | 2.21 | 9.9 | 9.80 | (8.16-11.43) | 1.04 | (0.94-1.17) |
| Storm no. 45 | | | | | | |
| Rainfall plots* | 3.68 | 26.6 | 30.49 | (28.56-32.17) | 2.31 | (2.24-2.41) |
| Rainulator plots† | 3.96 | 19.2 | 23.31 | (22.60-24.05) | 2.36 | (1.98-2.72) |
| Total | | | | | | |
| Rainfall plots* | 7.26 | 47.3 | 45.08 | (41.56-48.20) | 3.43 | (3.28-3.63) |
| Rainulator plots† | 7.90 | 37.1 | 34.86 | (32.24-37.50) | 3.81 | (3.33-4.40) |

* Three replications. † Two replications.

Rainfall amounts were similar for the natural and simulated storms no. 75 and no. 44, but soil loss was more than five times greater and runoff was about two times greater for storm no. 44 than for storm no. 75. The soil loss and runoff relationships were similar for the natural and simulated rainfall. The large difference in soil and water losses for the two storms of near equal amounts of rainfall was apparently due to differences in antecedent soil moisture and rainfall intensity patterns. The fact that the large differences in erosion and runoff between storms no. 75 and no. 44 were nearly the same for the simulated rains as for the natural rains attests to the validity of simulated rainfall experimental procedures.

The 2.06 cm of rainfall in the 19 days between the time of tillage and the occurrence of storm no. 75 came in five rather small increments, only one of which exceeded 0.64 cm. Consequently, the soil surface had not been subjected to a great amount of rainfall energy and was still fairly loose, capable of receiving and retaining a large amount of water. Storm no. 44, on the other hand, was preceded by 5.33 cm of rainfall over a period of 9 days. This rainfall occurred in five increments, four of which exceeded 0.64 cm. The soil, therefore, had been subjected to a considerable amount of rainfall energy and was in a wet condition before the simulated storm.

Storm no. 45, of course, was preceded by the same antecedent rainfall as storm no. 44, plus storm no. 44 itself.

Quantities of water applied during simulated storms no. 75 and no. 45 were 102% of those from the natural storms, and the simulated-rain runoff was 101% of that from natural storms. Simulated storm no. 44, however, produced almost 50% more runoff than did its natural counterpart. For this storm, the amount of water applied with the rainulator was 0.43 cm, or 24%, more than that received during the natural storm. Most of this excess, about 0.31 cm, ran off.

## SUMMARY

A comparison was made of the soil and water losses from three natural storms and three simulated storms on cultivated fallow plots under similar rainfall and soil conditions. A rainulator was used to apply the simulated storms. Soil losses from the three simulated storms averaged 77% of those from the natural rainstorms. This compares closely, considering that the average EI value for the simulated storms was 78% of that for natural rainstorms. The runoff from the simulated storms compared quite closely to runoff from the natural storms.

The study showed that, in general, the rainulator can be used to simulate rainfall for runoff and erosion research with confidence that the results will reflect the runoff and soil loss that would occur under similar conditions of natural rainfall. Runoff from rainulator plots should be about the same as from natural-rainfall plots if the intensity-duration pattern is similar. However, EI values and soil losses from rainulator storms will be about 25% less than from natural rainfall of similar intensity-duration patterns.

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