
Simple, Portable Equipment for Erosion Experiments
Under Artificial Rainfall

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Portable and inexpensive equipment was designed to investigate soil erosion and run-off and to be simple to construct, maintain and operate on plots with areas of 4 to 10 m$^2$. It includes components for simulating rainfall, for providing a water supply, and for collecting sediment from a bounded plot. The rainfall simulator consists of a wooden frame supporting a metal track in which a wheeled trolley with a vertically mounted spray nozzle is rapidly pulled back and forth along the plot. Commercially available crop-spraying nozzles yield median drop-size and kinetic-energy characteristics which are about 80% and 60–70% respectively of those in natural rainfall with the same intensity. Christiansen's coefficient of uniformity of water application ranges from 80 to 90% when wind problems are controlled. Run-off and eroded soil are collected in a folded sheet-metal trough with a 10% slope in its floor and a narrow outlet for convenient sampling. The design is easily modified to fit the needs of the research and all materials and equipment are widely and cheaply available.

1. Erosion experiments with rainfall simulators

Many scientists concerned with soil erosion and land management have stressed the value of controlled experiments under simulated rainfall for studying infiltration and erodibility. Most of the experiments have been carried out in technologically advanced agricultural areas where capital, skilled labour and water are abundant. Fewer experiments have been conducted in rangelands and remote areas without these amenities. The increasing concern about land management in remote grazing lands of Africa and in developing nations generally has stimulated interest in extending quantitative, experimental studies of hydrology and soil erosion to such areas. In these regions, decisions will have to be made about the influence of various cultivation practices and animal stocking rates without the benefit of decades of plot studies on run-off and erosion under natural rainstorms. Controlled experiments under artificial rainstorms are particularly useful for supplying data for such purposes.

All simulator designs attempt to reproduce both the intensity and the drop-size distribution of natural rainstorms, because both run-off rate and the kinetic energy of raindrops affect soil loss. Unfortunately, when a nozzle with an orifice large enough to produce natural drop diameters (0.25 to 6 mm) is used, the resulting rainfall intensity is much higher than that of natural storms. The rainfall intensity can be reduced by interrupting the water application, and Hudson has reviewed the methods of interruption used in previous rainfall simulators. At one end of the spectrum of available simulators are large "rainulators" that interrupt the spray by switching the flow on and off and moving the nozzles back and forth across the plot. These machines require heavy investment of capital and skilled labour and are difficult to move and maintain, but they simulate the kinetic energy of natural rainfall over large plots reasonably well. At the other end of the scale are portable or laboratory sprinklers that spray plots of a square metre or less. Some of these supply kinetic energy at unrealistically low rates. The Morin simulator interrupts the spray with a rapidly rotating disc from which a segment has been cut, and the simulator generates realistic, though highly variable, rainstorm energy. However, the
small size of the measurement area of all these systems is a significant limitation when one wishes to study run-off hydraulics or the effects of cultivation methods or large soil features such as cracks on infiltration and soil erosion.

Here we describe a cheap and mechanically simple apparatus for conducting experiments under artificial rainstorms on plots up to 5 m long and 2 m wide. We also describe a simple method for plot installation with reusable materials. The equipment yields reproducible measurements of infiltration capacity and soil erodibility and is large enough to sample the effects of shrubs and other clumped vegetation and of various cultivation techniques such as ploughing or hoeing. It is also large enough for meaningful geomorphic studies of rainsplash and sheetwash erosion.

The rainfall simulator can be transported easily over rough country on a 4-wheel drive vehicle, and even when assembled has been carried for distances of 1 km by 6 people. It can be assembled around a truck within 1 hour and repaired in the field. The plot boundaries and collection trough can be installed in 1 hour. All materials and equipment for construction are generally available in developing countries.

The apparatus has been used to quantify the effects of soil type, hill-slope gradient, vegetation cover, and cattle trampling on run-off and soil loss from Kajiado District in Kenya, and to investigate the controls of sediment loss from logging roads in the Olympic Mountains of Washington.

2. The rainfall simulator

The rainfall simulator consists of a bolted wooden frame 3 m high, 2 m wide and 5.3 m in length from which a steel or aluminium track is suspended along the centre line of the structure (Fig. 1). In order to diminish the rainfall intensity a single nozzle is attached to a wheeled trolley (Fig. 2) which can be pulled along the track using ropes attached to the ends. The track and trolley are the kind used for supporting sliding doors and thus can be obtained in most countries.

Fig. 1. The rainfall simulator. The hose leads to the nozzle mounted on a trolley which is pulled rapidly back and forth along the track in the centre of the wooden frame. The man is holding the pressure gauge attached to the hose.
The speed of movement along the track is limited only by the robustness of the trolley which is subject to shocks as it collides with the ends of the overhead track. The ends of the track can be protected with foam rubber. If the ropes from both ends of the trolley are connected to an anchored bicycle wheel, the trolley can be made to traverse a 5.3 m-long track in less than 2 s. On windy days we shielded the plot by attaching a heavy canvas sheet to the upwind side of the wooden frame, and anchoring the frame to a truck parked alongside.

Water is supplied to the nozzle on the trolley from a water source such as a stream or tank-truck by a small pump driven by a petrol engine. A wheeled water tank of the kind used by military authorities holds 1 or 2 m$^3$ of water, which suffices for one experiment. In order to control the pressure at which the nozzle operates, the outlet from the pump can be connected to a junction which leads a part of the water back to the tank, as shown diagrammatically in Fig. 3. A valve on this return hose can be tightened or released to increase or decrease the pressure and flow rate in the line connected to the nozzle. After an initial adjustment the pressure generally remains constant during the entire experiment.

Locally available agricultural nozzles can be used in the simulator once they are tested for spray characteristics using a standard procedure, such as the flour-pellet method. The nozzles most frequently used in simulators are the Veejet and the Fulljet produced by Spraying Systems Company of Bellwood, Illinois, U.S.A. Because such nozzles were not available to us at the time of our experiments, we used a set of nozzles manufactured by the Delavan Company of West Des Moines, Iowa, U.S.A., and because they functioned well, we describe them here. Drop-size and kinetic-energy characteristics of these models were determined using the procedure described by Meyer.

![Diagram of the suspension system](image)

**Fig. 2.** End and side diagrams of the suspension of a spray nozzle from a trolley which moves on wheels in an overhead track running the length of the rainfall simulator.

![Diagram of the system used for supplying water to the rainfall simulator](image)

**Fig. 3.** Schematic diagram of the system used for supplying water to the rainfall simulator. The inclusion of a recirculating loop allows fine adjustment of the pressure in the line feeding the spray nozzle even if a fixed-capacity pump is used.
The most suitable Delavan nozzles for plot experiments are the type SQ series which produce a square spray at moderate pressure and a circular spray at low pressure. We have calibrated 3 such nozzles, which can provide a range of rainfall intensity, drop size and kinetic energy (Table I) depending on fluid pressure and plot size. The rainfall intensity from the nozzle at a given pressure is dependent on the size of the experimental plot which is limited by the acceptable length of the plot and the effective width of the spray (the width beyond which the application rate declines dramatically). For 5 m long plots the three nozzles produce rainfall intensities ranging from 56 to 114 mm/h (Table I). In Figs 4 and 5 we have compared the kinetic-energy and median drop-size of spray from the Delavan nozzles with those from Spraying Systems nozzles and with natural rainfall characteristics. The Delavan nozzles emit drops with a median diameter about 80% of those in natural rainstorms and produce about 60 to 70% of the kinetic energy in natural rain of the same intensity.

A potential limitation of the equipment concerns the uniformity of the simulated rainstorm because the technique of pulling the nozzle back and forth over the plot creates intermittent rainfall on any section of the plot. We have computed the Christiansen coefficient of rainfall uniformity for 1-hour experiments and found that it exceeded 80% in two-thirds of the 70 field experiments that we have conducted, and exceeded 75% in the rest, except in 2 experiments when strong winds complicated the distribution. Although the Christiansen coefficient is now the standard measure of the uniformity of simulated rainfall, it does not indicate whether there is a systematic variation of rainfall within the plot. For example, in Fig. 6 we show 2 typical rainfall maps on 1·2 m and 2·0 m wide plots. Both these maps show a rainfall maximum toward the centre of the plot and a distinct decrease in rainfall towards the direction of constant wind. The former effect can be minimized by shortening the plot or lengthening the overhead rail. The second effect can be reduced by using a narrow plot and by avoiding times of strong winds which have a diurnal pattern in many areas. We have found the most useful plot dimensions to be 4 m long and 1·0 to 1·2 m wide. Measurements of mean velocity and depth on the resulting run-off indicate hydraulic roughness characteristics comparable with experiments conducted under laboratory conditions by other investigators.

3. The plot

Proper installation of the plot is almost as important as the design of a rainfall simulator. Flaws can severely affect measurements of infiltration capacity, the timing of run-off and thus
Fig. 4. Kinetic energy of natural rainfall and artificial sprinklers. The shaded area indicates the range of data from natural rainstorms in Japan, India, Trinidad, Southern Rhodesia, and Washington, D.C., U.S.A. (compiled from various sources), and Louisiana and Mississippi, U.S.A. Delavan sprinkler used in the apparatus described herein; O, Fulljet nozzle in the Morin system; △, Veejet SCC 80100 nozzle used in the "rainulator".

Fig. 5. The median drop diameter of natural rainfall and artificial sprinklers. Symbols, locations and authors same as in Fig. 4.
the results of hydraulic calculations, and the amount of sediment eroded during an experiment. At the lower end of each plot a sheet metal trough received the run-off and sediment and conveyed them to a measuring point. Contact with the soil must be watertight, stable against erosion, and smooth so that eroded sediment does not become lodged at the lip. Particular care must be taken in brittle, cracked soils, especially those with a rough microtopography.

Installation began with the digging of a 2 m-long, 25 cm-deep trench, the upslope face of which was carefully smoothed. Immediately upslope of the trench, a 2 cm-thick, 10 cm-wide layer of topsoil was removed. A cross-sectional diagram of the excavation is shown in Fig. 7(a).

Fig. 6. Rainfall distribution (mm) during 1-hour field experiments on plots 2 m and 1.2 m wide. The uniformity of rainfall along the plot can be improved by altering the plot length, as shown by the solid and heavily dashed boundaries. Wind direction is indicated by the arrows.

Fig. 7. Stages in the installation of the run-off collector.
A preformed, sheet-metal trough (Fig. 8) was then placed in the trench, and held firmly against the upslope face by backfilling the trench behind the trough, as shown in Fig. 7(b). The trough was designed so that when its roof lay horizontal, its floor had a gradient of 10%, which proved to be sufficient to convey all eroded soil rapidly to the outlet.

When the trough was firmly in place, a preformed sheet metal lip was installed as shown in Fig. 7(c). The lip was first bent so that it had a short limb, about 2 or 3 cm side, and a broader limb about 20 cm wide. The short limb was driven firmly into the soil at the upper boundary of the strip from which the topsoil had been removed. Wetting the strip of soil before driving in the lip minimized the disturbance. In order to ensure a watertight seal between the lip and the topsoil and to prevent erosion of the contact, a strip of plaster of Paris was used to stabilize the lip, as shown in Fig. 7(c).

The soil along the boundaries of the plot was then softened by wetting, and 15 cm-wide metal strips were driven firmly into the topsoil. The lower ends of the boundary extended onto the lip of the trough and were fixed to it with plaster of Paris. During the experiments, we observed no concentrations of run-off or erosion along the plot boundaries.

4. Measurement of run-off and soil loss

Samples of the run-off water and sediment were collected from the narrow mouth of the trough in litre plastic bottles, the time for filling being recorded. Because the moving spray nozzle produced fluctuations in the hydrographs of run-off and soil loss, it was necessary to collect 20 to 30 samples during experiments of 1-hour duration. Between the collection of these sediment samples, the run-off rate was measured as often as possible over 2-min periods by sampling and discarding the collected run-off. Typically the 2-min sampling procedure yielded 10–20 samples and the mean run-off rate for the period usually had a standard error of only 2–3%. Temporal variability of run-off can be kept to a minimum by moving the spray nozzle back and forth across the plot as rapidly as possible. We found the hydrograph to be quite smooth when the nozzle moved at a speed of 2 m/s or greater.

A minimum of 2 people are required to operate this equipment. A third person can measure local flow depth and velocity, should such information be required.

Fig. 8. Run-off collector cut from a piece of sheet metal bent to form a trough with a slope of 10%
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REFERENCES