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Development of a programmable rainfall simulator for soil hydrological studies

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ABSTRACT :The fabrication and operating characteristics of a programmable rainfall simulator have been discussed. In the simulator eight veejet nozzles at 3 m spacing were mounted at a height of 3 m above the ground on supporting 'A' frames with distributor and oscillating mechanisms. The system can satisfactorily simulate rainfall at higher intensities (75 to 150 mm hr^{-1}) with uniformity coefficient ranging from 0.25 to 0.81 in a macro runoff plot of 24 m x 3 m size. Five rain gauges were used to control the desired rainfall intensity through the computer control systems by feed back mechanism. A tipping bucket type runoff gauge was fixed at the outlet of the runoff plot to automatically record the runoff volume through data logger fitted in the system. The link software provides the initial experimental output. This simulator can be used for overland flow, erosion and in-*situ* moisture conservation studies with different land management practices.

Key words: Rainfall Simulator, Design, Prototype testing

The erosion, runoff and infiltration process studies are conducted under both natural and artificial rainfall conditions. The intensity and duration of natural rainfall varies during the course of the storm making it difficult to generate useful information on erosion versus rainfall intensity relationships for particular duration. During one monsoon season, many storms of similar intensities and duration may not occur to arrive at valid relationships and therefore replication of erosion measuring experiments over years may be required. A rainfall simulator is an important research tool, as simulated rainfall can be controlled to obtain the desired rainfall characteristics and can to some extent replace natural rainfall for many such studies and is essential for quick laboratory research.

Laboratory and field plot studies provide valuable information needed for developing techniques used in soil conservation. Small/mini rainfall simulators can normally be used to characterise the site-specific soil physical properties that initiate erosion and allow infiltration. But, the erosion phenomenon on various land slopes as influenced by rainfall intensity and duration can only be studied using bigger size rainfall simulator capable of generating rainfall at varied intensities. Further, to assess erosion hazards it is necessary to examine the land surface between rills and the initiation of transport of detached soil particles to the rills by rain drop impact. This can be achieved by using a simulator that effectively simulates natural rainfall events over a considerably large area/plot. The erosion plots (Lal, 1988) are classified into 3 categories: (1) small plots (2) USLE plots and (3) large plots. By, using mini/small rainfall simulators over smaller plots rill erosion is difficult to study. The initiation of rill and inter rill processes can be studied in USLE plot (22 m x 2m). The deposition and small channel processes in rills and inter rills can be studied with large plots of size 2 to 4 hectares. Practically it is difficult to cover large area with rainfall simulator and also it is difficult to control the spatial landscape and soil variabilities. Therefore, fairly bigger plots with rainfall simulator may be a practicable proposition for erosion and hydrological studies. In the present case macro plots almost equivalent to the dimensions of USLE plots are developed for hydrologic studies with a rainfall simulator of size 24 m x 3 m.

A programmable rainfall simulator for longer plots was tested and compared with a rainulator (Neibling et. al 1981). The nozzles of the programmable simulator were the same as those of the rainulator, but cycle times of nozzle were reduced from about 2.0 to 0.5 seconds for a rainfall intensity of 64 mm/hr. Repeatable intensities are easier to obtain with the programmable simulator than with the rainulator, but intensity is slightly more uniform with the rainulator.

Foster et. al., 1982 designed a programmable rainfall simulator for field studies on plots of 4 m x 11 m size and longer. The simulator was fitted with oscillating nozzles and excess water was recirculated within individual trough unit. Variable intensities in time and space could be programmed. Although spray from the nozzles was intermittent, the 0.5 second delay between spray applications at a 60 mm/hr intensity was sufficiently short to have minimal effects on infiltration, runoff and erosion. The simulator was reliable and easy to use, but was more expensive than other similar simulators.

A new Kentucky rainfall simulator (portable nozzle type) was developed to study infiltration and runoff processes (Moore et. al., 1983). At intensities greater than 25 mm/hr the simulator closely approximates the kinetic energy of natural rainfall. Rainfall intensities upto 185 mm/hr^{-1} could be produced and uniformity coefficients ranged from 80.2 to 83.7%.

A portable rainfall simulator was extensively used at the Institute of Hydraulic Structures and Agricultural Engineering, University of Karlsruhe, Germany (1989-90) for developing simulation model for transport of soil particles in a small rural catchment.

Considering the limitation of small plot studies for runoff qualification a rainfall simulator for a fairly large runoff plot (24 m x 3 m) was developed at CRIDA. The operating system has been fully computerised for obtaining different intensities for desired duration. The runoff measuring system (tipping bucket with electronic sensor) has been linked to computer for recording runoff during experimentation.

Description of the Simulator

The width of the simulator is 3.0 m and the length is 24.0 m to cover a standard size runoff plot. It is a framed metal structure with oscillating nozzle mechanism mounted on the top of 'A' frame. The structure has 8 nozzles spaced equally at 3 m interval and at a height of 3 m above the ground (Fig.1). Standard spraying 80100 veejet nozzles are used (Foster et al., 1982) as they produce acceptable results for erosion studies (Barnett and Dooley , 1972, Young and Burwell, 1972). The nozzles are mounted on a metal pipe and is connected to the oscillating mechanism operated by 0.5 hp d.c. motor with cam arrangement such that the nozzles can cover whole width of the plot. The nozzle height is maintained at 3 m from the ground surface to attain a terminal velocity similar to that of natural raindrops. Each nozzle is connected to a reinforced pipe that can withstand pressure of flowing water and is fitted with pressure gauge and a gate valve. These gate valves can be used to close the nozzles depending on the requirements of the experiment for adjusting the water flow and restricting the experimental area of the plot. All such pipes which are connected to nozzles are in turn connected to a water source. Water is supplied to all eight nozzles by a single centrifugal pump drawing water from a masonry water storage sump of 10 m^3 capacity through a non-return value. Provision has been made to cover the entire structure with PVC sheet to avoid wind drift. The simulator can be dismantled and put in neighbouring plots by changing the length of the water supply pipe.

The simulator generates artificial rainfall at desired intensities with rainfall characteristics matching to those of natural rainfall. In case of single nozzle, the oscillating angle of the nozzle was kept at 60° to obtain uniformity in application in an area of 3 m x 3 m. The specifications of the 80100 nozzle are presented in Table-1. In the distributor there are eight PVC tubings each connected to the nozzle.

For structural stability, the frame of the simulator is made of hollow mild steel pipe and 32 mm rolled steel as shown in Figs.2 and 3. The simulator assembly stands on rolling rubber wheels fitted to the frame. Around the runoff plot boundary, a cement wall of 45 cm (30 cm below ground and 15 cm above the ground) is provided to demarcate the boundary of the runoff area and restrict the lateral seepage flow.

A brick masonry control room is constructed nearby to house the control mechanism including a computer (Fig 2). In the control room, provisions have been made through various control units to change the oscillation speed of the nozzles and the rotational speed of the pump through computer control systems for obtaining desired rainfall intensity. The oscillating time cycle of the nozzle is maintained at 1 sec for covering the width of plot (3 m). For controlling the rainfall intensity tipping bucket rain gauges are kept in the runoff plot to sense the rainfall intensity and give a feed back to the control system so that the pump speed is automatically adjusted to obtain desired intensity through the nozzles. These operations can be regulated sitting before the computer terminal in the control room.

A double ring infiltrometer was installed in the middle of the plot to assess the variations between the static and dynamic infiltration rates.

Operating Characteristics

Rain drop size and velocity

Drop size is one of the most important criteria to match simulated rain with natural rain. Rain drop size may be specifically categorised and the mean value may be calculated over the intensity ranges. The size of rain drops were determined by Flour Pellet method (Hudson, 1937). The mean diameter of rain drops for different rainfall intensities were calculated and analysis was done to find out the mean rain drop diameter over intensity ranges tested. Mean drop sizes thus obtained with different nozzle pressures are presented in Table-2. Within the pressure ranges of 0.44 to 1.85 kg cm^{-2} the

Table-1 : Performance data of proprietary 81000 Veejet Spray Nozzle supplied by Manufacturer used in the design and prototype development of the rainfall simulator

Spray angle at 3 bar	Specification	equivalent orifice diameter (mm)	Spray angle		Nozzle discharge (lt/min)			
			1.5 bar	3.0 bar	0.3 bar	1 bar	2 bar	3 bar
80°	8100	6.4	75°	80°	12.5	23	32	39

Table-2 : Performance parameters of a 80100 nozzle for use in rainfall simulator

Nozzle pressure (kg/sq.cm.)	Mean drop diameter (mm)	Spray angle	Intensity (mm/hr)	Velocity (m/Sec)
0.44	3.4	45°	989.10	5.18
0.70	2.9	54°	1069.5	5.18
0.85	3.0	56°	1155.0	7.77
1.05	2.9	58 °	1135.5	7.77
1.21	2.6	59 °	1010.0	7.56
1.24	2.7	60 °	1275.0	10.36
1.50	2.6	61 °	1472.0	10.36
1.68	2.5	62 °	114.0	10.36
1.85	2.2	65 °	1578.0	10.36

mean rain drop size varied between 2.2 mm to 32.4 mm. The variations in average drop size are in conformity with the findings of Meyer and Mc Cune. 1958.

Spray angle and intensity

A single 80100 nozzle was tested for the spray pattern, angle of spray and the point rainfall intensity along the centre line. The spray pattern was a flat spray type and conformed to the pattern obtained by the manufacturer. The spray angle varied between 45° to 65° in the nozzle pressure range of 0.44 kgcm^{-2} to 1.85 kgcm^{-2} (Table-2). It was found that to get a spray coverage of 3.0 m along the nozzle centre line (as required to be covered by a single nozzle in the present simulator) the nozzle pressure should be more than 0.7 kg cm^{-2}.

The 80100 nozzle produced point intensities along the centre line at the rate of 1000 mm/hr and more depending on the nozzle pressure (Table-2). To reduce these intensities to be consistent with natural rain, the nozzles were provided with an oscillating mechanism for to and fro movement across the runoff plot. Thus the working intensity with the intermittent rain would be close to the desired actual rainfall intensities. The oscillating angle was then adjusted to 60° to get the coverage of a plot of 3 m x 3 m by individual nozzle. Thus, eight nozzles were provided to cover the experimental plot of 24 m x 3 m with the spray trajectory of adjacent nozzles overlapping each other.

The analysis of exit velocity of water drops through the nozzle showed the variation in velocity in the range of 5.18 m/sec to 10.36 m/sec (Table-2). These values are in close agreement with the terminal velocities of rain drops (Gunn *et. al,* 1949). Hence, the simulated rain thus obtained can satisfactorily represent the natural rainfall to a great extent.

Rainfall uniformity

Glass beakers of 500 cc were placed at 1 m apart over the entire runoff plot for measuring the uniformity of application of the artificial rainfall and the uniformity can be measured by the uniformity coefficient (Christiansen, 1942). The uniformity coefficient of 100% indicates an absolutely uniform application:

The uniformity coefficient (Cu) is calculated from

Cu = 100 (1 - x/mn) .... (1) where

m = average value of all observations

n = total number of observation points

x = Sum of the absolute numerical deviation of individual observations from the average application rate.

In the present case the uniformity coefficient varied between 75 to 81% with the test rainfall intensities of 75 to150 mm/hr.

Runoff and Sediment Measurement

Tipping bucket runoff gauge assembly

Accurate measurement of runoff rate can be made for catchments of less than 100 m^2 by tipping bucket runoff gauge (Edwards et al. 1974). Considering maximum rainfall intensity of 150 mm/hr over the runoff plot, the tipping bucket of 3 liters per tip was designed and fitted at the outlet of runoff plot (Fig.4). The tipping bucket is made of 16 gauge mild steel sheet. Other items in tipping bucket assembly are activated magnet to sense the tips, reed switch, vertical chute assembly to direct the runoff water into the chamber of tipping bucket, data logger for recording the number of tips per minute, and telephone cable from the reed switch to data logger fitted in the computer unit.

For calibration of the tipping bucket, known flow rate is allowed into the runoff trough and the number of tips per minute is counted for each flow rate. The test was conducted with flow rates ranging from 0.148 l s^{-1} to 1.596 l s^{-1}. Calibrated equation then developed is

$$Q = 0.03617\ N^{1.103}\ (R^2 = 0.995) \quad \ldots\ldots (2)$$

where Q = rate of flow, l s^{-1}

N = number of tips per minute

When the runoff event occurs, the number of tips per minute is recorded in the computer and actual runoff volume is computed using the above equation. Then the total runoff, peak runoff rate and rainfall-runoff relationships etc. can be obtained.

Sediment sampling

A part of runoff water is collected from the tipping bucket assembly into a container through a 5 mm PVC pipe for finding out the quantity of silt load in runoff water. The runoff sample is collected every minute after the start of runoff. Sediment content is found out in the laboratory after measuring the sample volume and oven drying the sample at 105°C.

Simulator Operation

The rainfall simulator can be operated interactively using the computer fitted to the simulator control system. The input data consists of experimental code, set rainfall intensity, rainfall duration, rain gauges in operation, time interval for recording and display of date, time for which runoff may continue after the cessation of rainfall. At the end of the experiment, for each time interval the rain intensities at different rain gauges and the runoff volume are recorded over the experimental period and stored in a file. The average and actual intensity of rainfall is computed from the use of total water used over the experiment period.

Link Software:

A link computer software has been developed to obtain the initial hydrologic information from the simulator run. The actual runoff for each time interval is calculated by using eqn.2. The computer output provides various related hydrologic information like time to runoff, average soil loss, saturated infiltration etc., as shown in the sample output (Table-3).

Summary

A programmable rainfall simulator of 24 m x 3 m size was designed and built for hydrological studies which can produce rainfall intensities ranging from 75 to 150 mm/hr with 75 to 81% uniformity with standard Veejet spray nozzle of type 80100. Tipping bucket type runoff gauge is used for measuring runoff rate and volume from runoff plot Tests using simulator can generate useful hydrological information viz., runoff, infiltration, sediment yield etc. from runoff plots under different land management practices. Thus, the effectiveness of different conservation practices can be studied and compared in controlled environments.

References

Barnett A.P. and Dooley, A.E. 1972. Erosion potential of natural and simulated rainfall compared. TRANSACTIONS of the ASAE. 15(6). 1112-1114.

Christiansen, J.P. 1942. Irrigation by sprinkling University of California Agril. Experimental Station, Bulletin No.670. 124 p.

Edwards I.J., Jackson, W.D. and Fleming P.M. 1974. Tipping bucket gauges for measuring runoff from experimental plots. Agril. Meteorology 13: 189-201.

Foster G.R., W.H. Neiblling and R.A. Nattermann. 1982. A programmable rainfall simulator. Paper No.82-2570: American Society of Agricultural Engineers, St. Joseph, Michigan. USA.

Gunn, Ross and Kinger, G.D. 1949. Terminal Velocity of Water Droplets in stagnant air. Journal of Meteorology 6: 243-248.

Hudson. N. 1937. Soil Conservation, London, Batsford p. 320.

Institute of Hydraulic Structures and Agril. Engg. (Institute fuer Wasserbau and Kulturtechnik), 2989-90. Annual Report (Jahresbericht), University of Karisruhe, Germany, pp. 48-50.

Lal R. 1988. Soil Erosion research methods. Soil and Water Conservation Society, Iowa, pp. 9-36. USA.

Moore, I.D., M.C. Hirschi, and B.J. Barfield. 1983. Kentucky rainfall simulator. Transactions, American Society of Agricultural Engineers 26: 1085-1089.

Neibling, W.H. Poster, G.R., Nattermann, R.A. Nowlin J.D. and Holbert P.V. 1981. Laboratory and field testing of a programmable plot-sized rainfall simulator. Erosion and Sediment Transport Measurement (Proceedings of the Florence Symposium) IAHS Pub. No.133 : 405-414.

Young R.A. and Burwell R.A. 1972. Prediction of runoff and erosion from natural rainfall using a rainfall simulator. Soil Sci. Soc. Amer. Proc. 36 (5): 827-830.