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Construction and Calibration of a Rainfall Simulator

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A portable rainfall simulator featuring a rotating disc and nozzle, has been developed for use in field studies of erosion, infiltration, and runoff processes. Variable intensities of simulated rainfall ranging from 15 to 150 mm h^{-1} are produced by choice of appropriate nozzles and slot apertures in the rotating disc. The duration of the simulation can be precisely controlled by a shutter mechanism. The measured uniformity coefficients ranged from 91·2 to 94·3%. The kinetic energy of the simulated rainfall at intensities above 30 mm h^{-1} was close to that of natural rainfall.

1. Introduction

The processes of soil erosion, infiltration, and runoff can be studied under both natural and simulated rainfall conditions. Whereas it is desirable to study these processes under natural rainfall conditions, the spatial and temporal distribution of natural rainfall characteristics cannot be controlled, and hence data acquisition is very slow, if not difficult. Rainfall simulators have the ability to create controlled and reproducible artificial rainfall, which in turn expedites data collection. The construction and calibration of a portable nozzle type rainfall simulator (*Fig. 1*), developed at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is described here.

The ICRISAT simulator was based on the model of Marston[1] but included modifications which improve the evenness of rain distribution over the plot and which increase work efficiency and ease of operation.

2. Review of literature

Rainfall simulators can be broadly divided into drop-former and nozzle types. In the drop-former type the desired size of drop is formed at the tips of hanging yarns and threads, glass capillary tubes, hypodermic needles, polyethylene tubing, and brass or stainless steel tubes.[2] The drops fall when their weight overcomes the surface tension. The zero initial velocity, intensity control, size of the unit, unimodal drop sizes, difficulty in producing very small drops, and its transport (disassembling the unit, for transport from plot to plot in the field) have limitations in field use.

The nozzle type of simulators employ different kinds of nozzles and pressurised water to achieve rainfall simulation, with controlled initial velocity. The intensity of simulated rainfall can be controlled by pointing the nozzles upward,[3] moving the nozzle back and forth over the plot,[4] or by rotating a disc under the nozzle.[5] The size of the unit could be made to suit the field plot size and efficient transport can be achieved by mounting the unit on a trailer.

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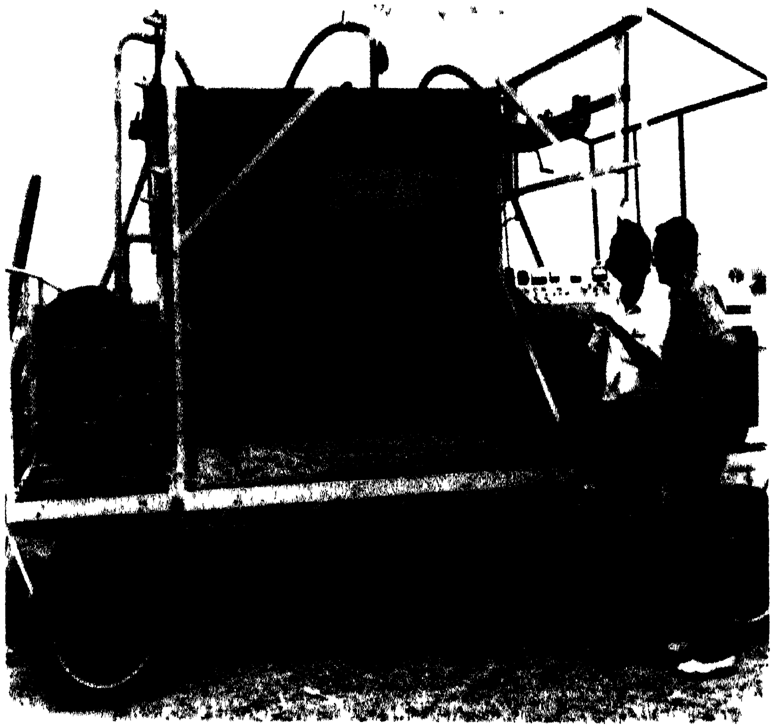

Fig. 1. Rainfall simulator developed at ICRISAT

Morin *et al.*[5] developed a simulator with a rotating disc using Spraying Systems' 1HH 12 and 1·5 H 30 nozzles; the range of intensities produced were 8–74 mm h^{-1} and 15–143 mm h^{-1} respectively. Another model developed by Grierson and Oades[6] was mounted on a two-wheeled trailer, and operated by swinging the spray unit over the plot area.

Among the different kinds of nozzles used in simulators, Spray Engineering Company's 7LA, Spraying Systems' 80100 Veejet, Rainjet 78C, and 1·5 H 30 Fulljet are more common.[2] The kinetic energy and application patterns of these nozzles are discussed in detail by Meyer and Harmon[7] and by Bubenzer.[8]

3. Construction

The simulator developed at ICRISAT consisted of a four-wheeled trailer fabricat.. from mild steel channels and angles, with a wheel track of 3 m (*Fig. 2*). On the 4·1 m × 2·5 m platform (A) of the trailer, a 2·4 m × 2·4 m opening is left for the simulated rain to fall through. The front and rear sides of the platform were used for supporting a pump (B), water tank (C), generator (D), and a control panel (E). The steering mechanism for the front wheels is based on Ackerman's principle of car steering. The trailer-mounted unit can be towed by car, tractor, or a pair of bullocks. A trough (F) houses the nozzle, rotating disc and disc drive mechanism of the simulator. The trough is fitted on a crab frame (G) which can be moved forward and backward over a saddle frame (H). The saddle frame along with the crab frame and the water trough can be adjusted laterally. Height and level adjustments are also possible with the help of four corner screws (I).

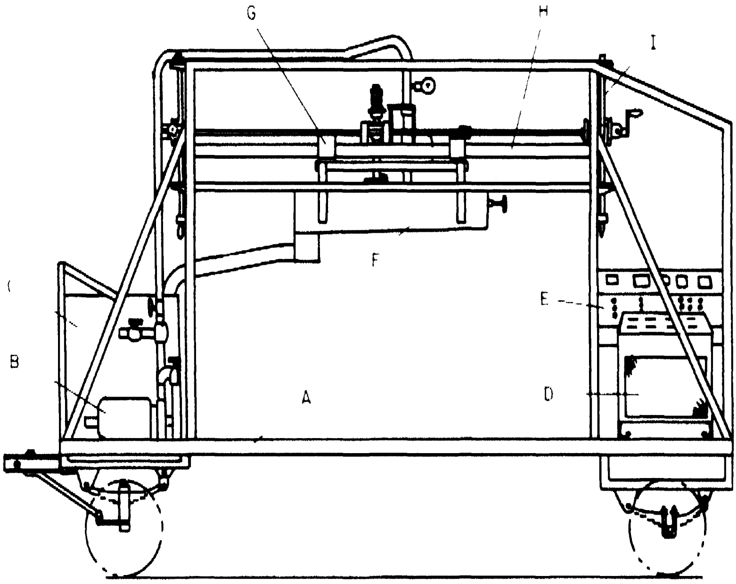

Fig. 2. Main assembly of rainfall simulator. A, Trailer platform; B, Pump; C, Water tank; D, Generator; E, Control panel; F, Trough; G, Crab frame; H, Saddle frame; I, Corner screws

A self-priming centrifugal 0·746 kW electric pump (B) was used to pump water from a tank of 6000 l capacity. Galvanized iron pipes of 38 mm i.d. were used to connect the pump with a nozzle (L) (*Fig. 3*). A bypass line with a bypass valve (M) from the nozzle to the tank (C) for pressure control, and a 100 mm i.d. flexible pipe (N) for recycling from the collection trough to the tank was provided.

Fig. 4 shows the details of the rotating disc assembly. The disc (O) is of 12 s.w.g. mild-steel sheet with seven radial stiffeners (P) for strength and to deflect water away from the centre of the disc.

Intensity is controlled in the model developed by Marston[1] by changing the position of

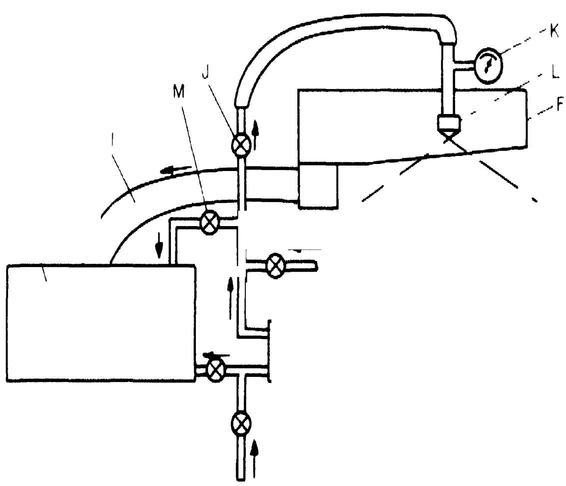

Fig. 3. Schematic diagram of pipeline. J, Valve for nozzle supply; K, Pressure gauge; L, Nozzle; M, Bypass valve; N, Flexible pipe

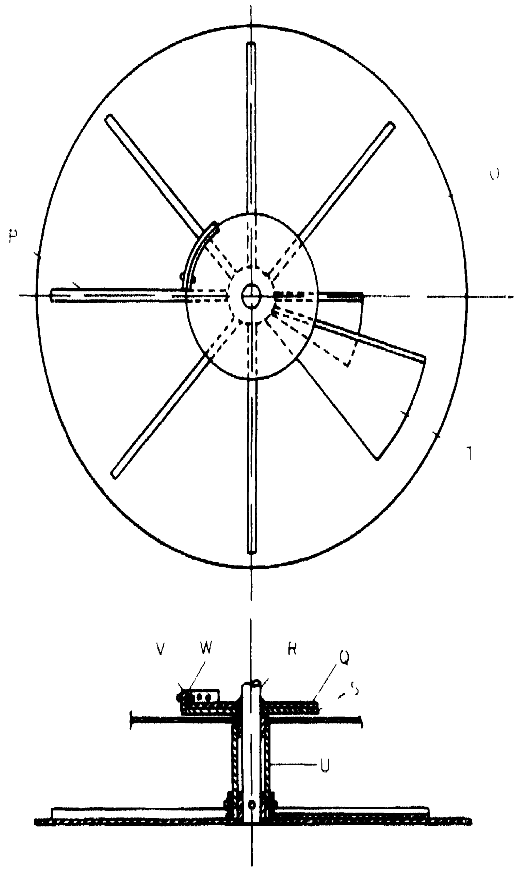

Fig. 4 Rotating disc assembly. O, Disc; P, Radial stiffeners; Q, Top disc; R, Shaft; S, Bottom disc; T, Flap; U, Pipe; V, Locking plate (bottom disc); W, Locking plate (top disc)

the flap over the opening of the rotating disc with the help of a bolt and nut. This can be inconvenient and difficult. In the present model the adjustment of the opening in the rotating disc is achieved by a mechanism of two discs placed above the top cover of the water trough (*Fig. 4*). The top disc (Q) is attached to the shaft (R) and to the main disc (O), the bottom disc (S) and the flap (T) are attached to the pipe (U). The shaft (R) passes through the pipe (U) allowing the flap (T) to move over the opening when the bottom disc (S) is moved from the outside of the water trough. The locking plate (V) fixed onto the bottom disc (S) with a single 6 mm hole, and locking plate (W) to the t disc (Q) with 8 holes such that the bottom disc (S) can be moved against the top disc and can be locked in to any one of the 8 holes provided, with a bolt and nut. The maximum and minimum opening of 60° and 7·5° can be achieved respectively in 8 steps of 7·5° each.

Different nozzles can be used to produce various intensities and rainfall patterns; Spraying Systems' 1 HH 12, and 1·5 H 30 nozzles were used for calibration. The characteristics of Spraying Systems' 1·5 H 30 nozzle such as drop size, drop size distribution, and kinetic energy were reported in detail by Marston.[1]

Another improvement made in our design enables effective control in starting and stopping the simulation (*Fig. 5*). In earlier designs it was necessary to cover the plot with a plastic sheet until the simulation stabilized and also to put it back when the simulation was to be stopped. In the present model this is achieved by a shutter-control, as shown in

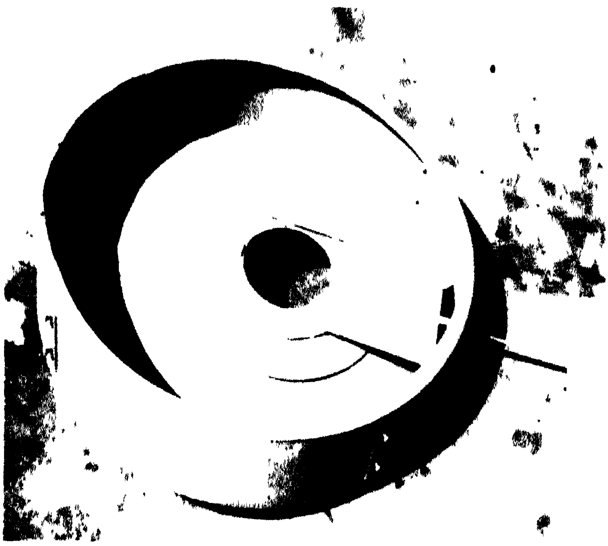

Fig. 5. Shutter control assembly

Fig. 6. The shutter (Y) is made of a square mild-steel sheet, which moves in two close fit "U" shaped channels fixed inside the water trough above the opening. A hole is made in the side wall of the water trough with a water tight rubber "O" ring, and a 12 mm dia. shaft (X) is passed through the hole and attached to the shutter (Y) inside the trough. A shutter handle (Z) is fixed to the shaft (X) so that the shutter can be moved forward and backward from outside the trough. The shutter handle, when pushed-in, closes the opening of the trough under the nozzle without any leaks and the water from the nozzle is completely recycled to the tank, and when pulled-out, the opening instantly exposes the plot to the simulated rain.

The drive for the rotating disc consists of a 0·373 kW motor directly coupled to a reduction-gear unit. This unit drives a variable-diameter pulley on the rotating disc axle. In order to achieve uniform distribution over the plot area the nozzle was rotated at

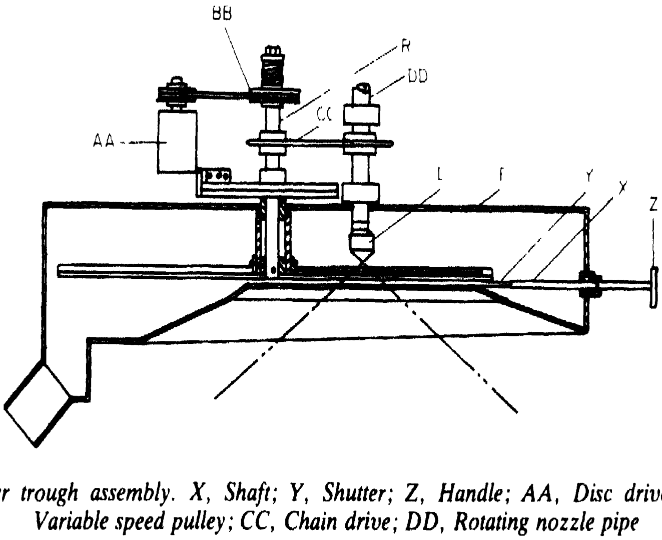

Fig. 6. Water trough assembly. X, Shaft; Y, Shutter; Z, Handle; AA, Disc drive motor; BB, Variable speed pulley; CC, Chain drive; DD, Rotating nozzle pipe

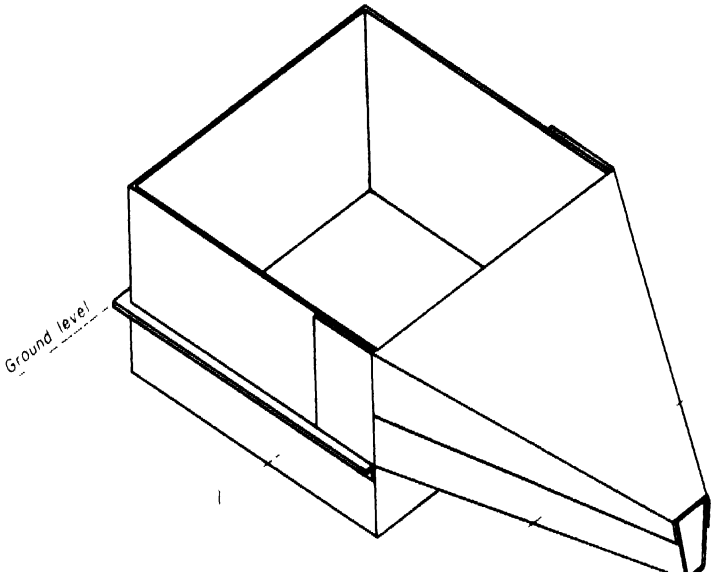

Fig 7. Schematic diagram of plot equipment. 1, Main body; 2, Triangular tray cover; 3, Traingular tray

6 rev/min to superimpose the pattern of the rain continuously over the plot area. The nozzle was mounted on two watertight bearings and driven by chain and sprocket from the disc axle.

The power for the electric motors is supplied by a 5.5 kVA generator through a control panel, which monitors the voltage and amperage of the current. An electronic water-level indicator, and an elapsed hour meter have also been fitted on the panel to indicate the total working hours of the simulator.

The simulator is completely covered with a tarpaulin sheet to provide efficient working conditions in the field under moderate winds. The control panel and all other controls are placed conveniently near the rear platform, to improve the ease of operation.

To collect the runoff water from the plot, a 1·5 × 1·5 m collection unit (*Fig.* 7) was fabricated. When the unit was installed on the plot area, the three sides of the plot will have a 100 mm high wall and the fourth side is open at the plot surface level. A triangular tray is made to fit in to the open side of the collection unit and inclines down to a narrow outlet, where the runoff is collected. Directly under the outlet a suitable hole can be dug to hold a sample bottle. The triangular tray has a cover to prevent water from the simulated rain from mixing with the runoff water. A channel 40 mm deep, 40 mm wide and 1·5 m long is attached to the side of the collection tray to collect samples for determining intensities.

4. Calibration and evaluation

The calibration tests were conducted to determine the evenness of raindrop distribution over the plot area. The uniformity coefficient (CU) percent was calculated by using the formula of Christiansen.[9]

$$CU = 100\left(1{\cdot}0 - \frac{\sum X}{mn}\right)$$

Table 1

Effect of nozzle inserts on intensity and uniformity coefficient. Spraying System' 1·5 H 30 nozzle: aperture, 37·5 deg; pressure, 70 kPa

Nozzle insert	*Intensity, mm h⁻¹*	*Standard error mean*	*Uniformity coefficient, %*
Unmodified*	102·7	1·0	77·2
8 dia 5 mm long	50·7	0·3	84·2
7 dia 7 mm long	68·3	0·4	87·6
7 dia 6 mm long	64·6*	0·3	89·4
7 dia 5 mm long	60·9	0 3	87·3
7 dia 6 mm taper	89·1	0·4	94 8

* Without fitting the inserts into the swirl unit's rectangle area

Table 2

Effect of disc aperture angle on uniformity coefficient, Modified Spraying Systems' 1·5 H 30 nozzle: pressure, 70 kPa. (Kinetic energy = 32 J m^{-2} mm^{-1})

Aperture angle, deg	15	22 5*	30	37·5	45	52 5	60
Intensity, mm h^{-1}	32·5	46·8	67·5	86·9	112·7	128·1	151·4
Standard error, mean	0·47	0·44	0·62	0·50	0·84	0·84	1·03
Uniformity coefficient, %	86·4	91·2	91·9	94 3	91·9	93·0	92·6

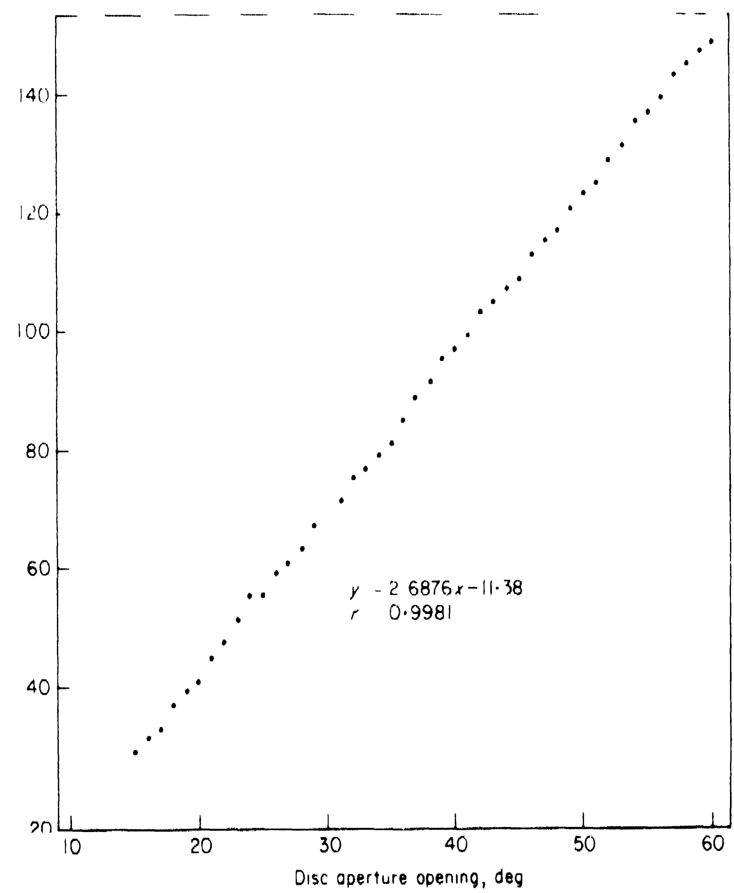

Fig. 8. Relationship between intensity and disc aperture opening

where CU = uniformity coefficient (%), m = mean value (mm h^{-1}), n = number of observations, and X = deviation of individual observations from the mean

Various intensities were applied, using eight apertures of the rotating disc. A plot of 1.5 m × 1.5 m was filled with 169 bottles of 106 mm i.d. and several 30 min runs of simulated rainfall were applied to the plot. The CU of <85% was attained for the 1.5 H 30 nozzle, with the disc aperture setting of 7.5° (pressure = 70 kPa). To improve uniformity the nozzle was modified with the help of the results of Pederson and Du Bois.[10] The rectangular opening in the nozzle swirl-unit was modified with small tapered cylinders to reduce the amount of water reaching the centre of the plot which in turn affects the uniformity of drop distribution. After trying different sizes of inserts it was found that a frustum of a cone of 7 mm base dia., 6 mm top dia. and 6 mm height gave a CU of 95%. The CU of various sizes of inserts placed in the swirl-unit is shown in Table 1.

The calibration of different apertures of the rotating disc with the 1.5 H 30 nozzle (with inserts) was done as described for the nozzle calibration. The aperture of the disc can be adjusted in eight uniform steps of 7.5°, which correspond to eight holes on the intensity adjustment discs. The number of the opening increases as the aperture enlarges. The calibration process was carried out from an aperture of 15–60°. The intensities and CU are shown in Table 2. A linear relationship between intensity and angle of ope- (aperture) is observed (*Fig. 8*) for angles from 15 to 60° ($Y = 2.6876\ X - 11$ $r^2 = 0.9981$). The kinetic energy, calculated with the help of the oil method used by Eigel and Moore,[11] was 32 J M^{-2} mm^{-1}

5. Conclusions

The trailer-mounted rainfall simulator is capable of reproducing various rainfall intensities and durations, and when combined with the runoff collection unit described, and provides a quick method for assessing soil erosion, infiltration and runoff data.

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