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# REALISTIC RAINFALL SIMULATION FOR FIELD INVESTIGATION*

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## Introduction

In this day of scientific advancement it would seem that the simulation of a process as common as rainfall would be quite simple. However, those scientists that have tried it have encountered many problems. The main difficulty in rainfall simulation is to achieve the combination of relatively low intensity with realistic drop sizes and high impact velocity.

Rainfall simulators used in the past can be divided into two basic types, drip simulators and nozzle simulators. Drip simulators include those that use hanging yarn, glass tubing, hyperdermic needles, etc. to form small tips from which drops fall by gravity. The main advantage of drip simulators is in their ability to produce a combination of relatively large drops at a low rate of application. However, impact velocities approaching those of natural rain cannot be achieved unless the dripper is placed more than 10 meters above the soil (1)(2). Because of this height requirement the drip simulators are not practical for field investigations.

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Nozzle simulators produce a drop distribution that includes a large number of drop sizes. If the nozzle is directed downward the pressure can be regulated to give an impact velocity similar to the terminal velocity of raindrops. Increased pressure, however, reduces the size of drops. Thus in order to obtain realistic sized drops of high velocities, large orifice openings in the nozzles are required. This causes excessive application rates. This then is the paradox of the nozzle type simulator. An attempt to use large nozzles and reduce the intensity has been made in three basic ways: (A) To spray the nozzle over a large area by turning it upward such as the Type F simulator; (B) To physically move the nozzle back and forth across a plot of suitable size such as the rainulator developed by Meyers and McCune (6); or (C) To physically remove a portion of the water from the high capacity nozzle to obtain realistic intensities as with the rotating disk rainfall simulator first developed as a laboratory model by Morin, Goldberg, and Seginer (4).

The Type F simulator produces a drop size distribution larger than intense natural rainfall, since the nozzles are turned upward the drops fall from zero velocity for a distance of approximately 3 meters. As will be shown later, this distance is not sufficient to give the large drops sufficient energy to duplicate natural rainfall.

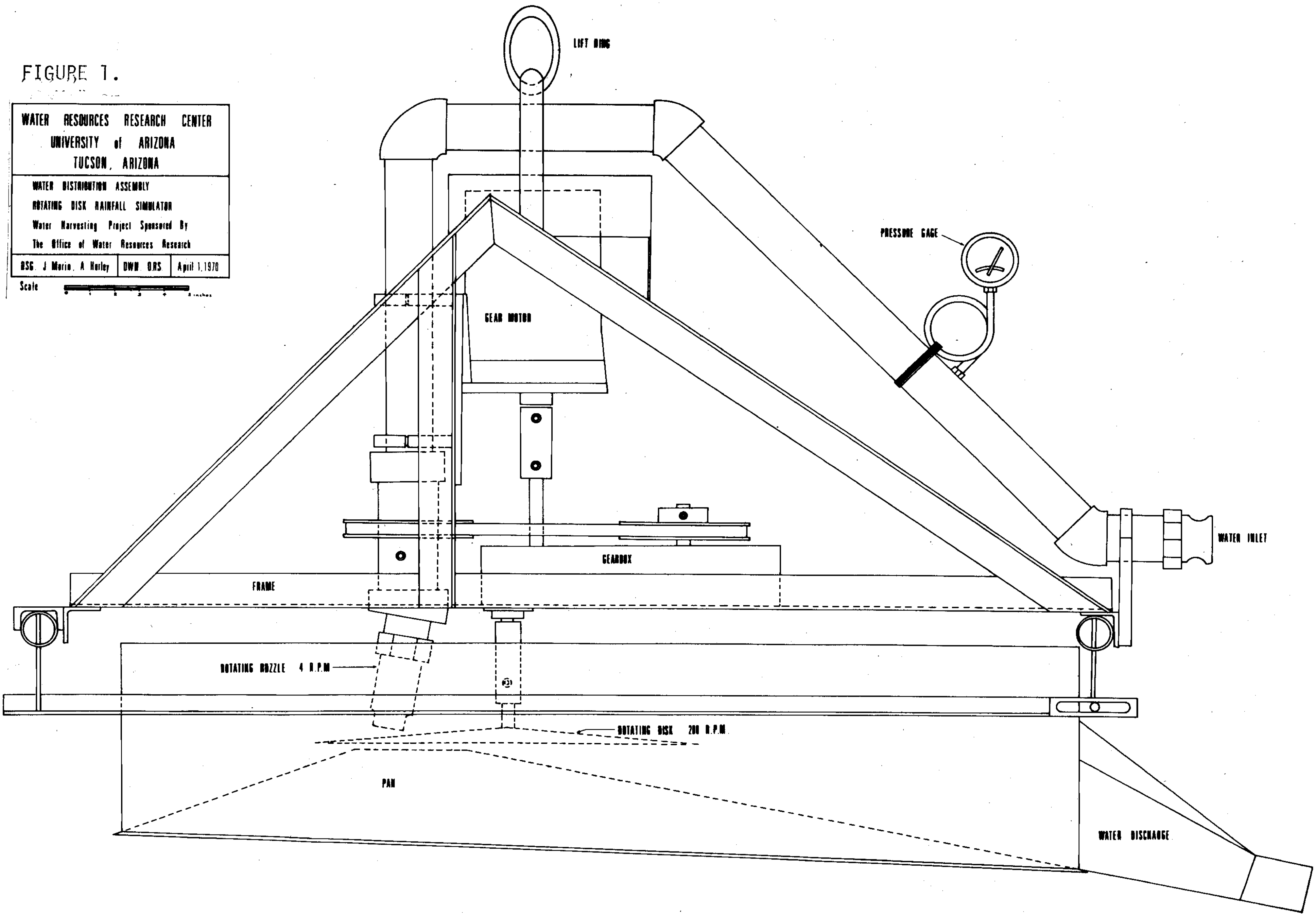
The Rainulator developed at Purdue University utilizes an 80100 Veejet nozzle for rain simulation. As will be shown later, this high capacity nozzle for rain gave kinetic energies that were much closer to natural rainfall than nozzles that had been used on other simulators. However, in order to reduce the intensity to a reasonable rate the nozzle sprays intermittently. This is accomplished both by moving a series of spray bars back and forth over the plot and by adjusting the number of spraying nozzles to vary the intensity. An advantage of the Rainulator is that relatively large areas can be covered with simulated rain. The disadvantages of the Rainulator are: (A) The intermittent operation of the nozzles; (B) the limitation in selection of intensities; and (C) Although coming much closer than nozzles previously used, the 80100 Veejet does not provide as much kinetic energy as natural rainfall (5).

The purpose of this paper is to describe the construction of a field simulator using the principle of the rotating disk that would be suitable for determination of infiltration rate in the field and compare this simulator's characteristics with other well known models. The need for the development of a more realistic type simulator was markedly illustrated during a study of the effect of a gravel mulch on runoff (6). During this study, a sprinkling infiltrometer patterned after the model of Bertrand and Parr (7) was used to determine infiltration rates on natural and gravel covered surfaces. Using this simulator there was no significant difference in infiltration rate of a plot whose surface was covered with a layer of 25 mm of gravel and an essentially bare natural soil on a desert watershed located near Tucson, Arizona. An obvious reason for this anomaly was that the 5B nozzle only produces approximately 37 percent of the kinetic energy of natural rainfall at 50 mm/hr (7)(8).

## Rotating Disk Rainfall Simulator

The rotating disk rainfall simulator utilizes a full-cone-spray type nozzle similar in principle to those used by Bertrand and Parr (7) but much larger in capacity. The best nozzle was found to be the Spraying Systems Co. Fulljet 1-1/2H30. This nozzle, when elevated 2 meters and operated at pressure of 0.6 atmosphere, will produce an intensity of 1540 mm/hr. In order to reduce this intensity to something more reasonable, a slotted metal disk was rotated on a vertical axis beneath the nozzle. See Figure 1.

FIGURE 1.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WATER DISTRIBUTION ASSEMBLY
ROTATING DISK RAINFALL SIMULATOR
Water Harvesting Project Sponsored By
The Office of Water Resources Research
DSG. J Morin, A Hurley
DWN. ORS
April 1, 1970
Scale
LIFT RING
PRESSURE GAGE
GEAR MOTOR
WATER INLET
GEARBOX
FRAME
ROTATING NOZZLE 4 R.P.M
ROTATING DISK 200 R.P.M.
PAN
WATER DISCHARGE

Drops from the nozzle reach the experimental plot only when the aperture is under the nozzle. In any other position the water is thrown towards the circumference of a revolving disk where it is drained away by means of a collector pan. The excess water is returned from the pan through a storage tank to the supply pump for repeated use. The complete field assembly constructed at the University of Arizona is shown in Figure 2.

The nozzle on the field model also rotates at 4 rpm which is an improvement over the original laboratory model where the pan containing the soil was rotated.

The unique feature of the rotating disk simulator is implied in its name. It is the rotation of disks with various size openings that makes it possible to produce intensities from close to zero up to the full nozzle capacity. Disks can be changed in the field in less than one minute, making it possible to study the effect on infiltration rates of a series of intensities such as occur in natural storms.

The disks are shaped to a shallow cone with 5 degree side slopes. The disks are 40 cm in diameter and constructed of 1 mm brass sheets. Disks with 5, 10, 15, 30, and 40 degree aperture angles were prepared. This corresponds with intensities ranging from 17 mm/hr to 152 mm/hr, when the height is set at 2 meters and the nozzle is rotating at a 10 degree angle from the vertical. The cocking of the nozzle to one side is also an improvement over the original laboratory model, in that better uniformity can be obtained over a larger area. The 10 degrees was arrived at by experimentation to produce the most uniform rainfall distribution. With these improvements the coefficient of variation for the 50 mm intensity is 9.1 percent.

The rotation of the disk on the field model is fixed at 200 rpm. This selection in rotation speed was based on previous studies on a laboratory model in Israel (4). This speed produces a rain that is visually continuous.

FIGURE 2.

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FIELD MODEL —
ROTATING DISK RAINFALL SIMULATOR
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| DSG J Morin, A Rorley | DWN DRS | April 1, 1970 |
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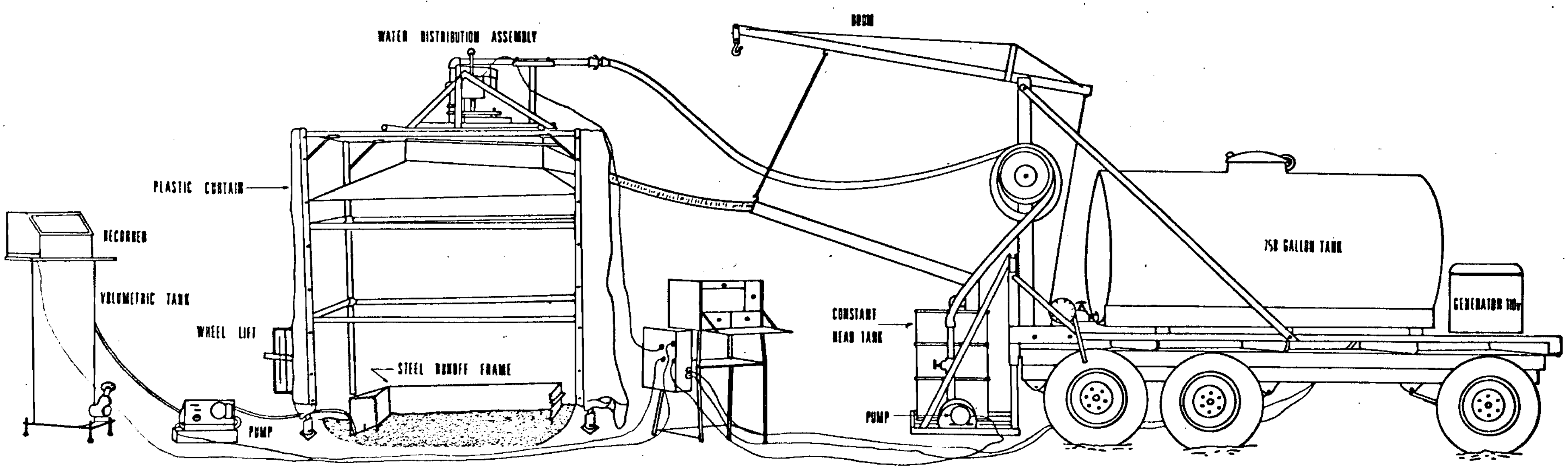

There is some pulsation but it is not much more than would be experienced during an intense natural rainstorm.

In the field model when the nozzle is 2 meters above the surface, a circular area with a diameter of 2.1 meters is wetted. A runoff plot 1.3 meters on a side is established in the wetted area through the use of a steel frame. The plot position relative to the nozzle was carefully established so as to produce the best uniformity in rainfall distribution. The steel plot frame is placed 2.5 cm into the soil on three sides. A separate steel plate, 20 cm deep, is placed on the lower end of the plot to serve as a retainer for the slight amount of excavation required to insert the tapered water collector at the end of the plot.

The water is collected in a tapering pan at the end of the plot and pumped, using a squeegee type pump up into a volumetric tank where the accumulated runoff is measured with a water level recorder. Through the proper selection of the size of volumetric tank and speeding up the movement of commercially available water level recorders, the accumulated runoff can be read to the nearest 0.10 mm and the time to the nearest 5 seconds. For most runs a rectilinear chart giving an accumulated runoff to the nearest 0.15 mm and the time to the nearest 15 seconds is used. Terminal infiltration rates can quickly be determined in the field by measuring the slope of the runoff accumulation.

Rainfall intensity is checked periodically by covering the surface of the soil in the runoff plot with plastic. If care is taken to keep the height of the nozzle at a constant height of 2 meters and if the plot is correctly positioned, the variation in rainfall intensity is very small. The coefficient of variation for a given rainfall intensity over 9 months of intensive use was found to be approximately 0.8 percent. The reason the uniformity is so good is due primarily to the large opening in the nozzle that prevents any variation due to plugging.

The field model is powered with a 7500 watt electric generator. A 1/4 h.p. electric gear motor drives both the rotating disk and the rotating nozzle. A 3/4 h.p. electric motor drives a 78 gpm centrifugal pump for pressurizing the nozzle. The recorder is also powered with an electric clock which is started at the time rainfall begins.

The frame supporting the water distribution assembly is constructed out of 1-1/4 inch aluminum pipe. A wind shield of reinforced clear plastic is used which allows sufficient light for photography work. The water distribution assembly, frame, and curtain is light enough that two men can carry it. However, bicycle wheels were mounted to the frame in order that one man can move it and operate the simulator. For moving longer distances in the field the entire assembly is elevated with the boom and transported with the trailer. Over 250 1-hour or longer infiltrating tests have been made with the field model. One man can make an average of four 1-hour runs in an 8-hour day. This includes plot preparation, moving and setting up the simulator.

Comparison of Rainfall Characteristics with Other Simulators

Rainfall simulator data in the past characteristically have been used primarily for qualitative determinations (5). Some investigators have tried unsuccessfully to find a good correlation between infiltration rates determined using a simulator, with those determined from hydrograph analysis (9). This is caused in part by the failure by most simulators to adequately duplicate the characteristics of natural rainfall.

Before raindrop characteristics were known, a rainfall simulator that applied both the amount and intensity of a design storm was considered adequate. With increased knowledge of raindrop characteristics came an appreciation of the fact that simulated rainfall should also have a drop size distribution very similar to natural rainfall, with all drops falling at their terminal velocities. This has proven to be absolutely necessary if there is any exposed surface in the plot area covered by the simulator. In both erosion studies and infiltration studies the failure to adequately duplicate drop size distribution and the terminal velocity of natural rainfall can result in gross errors. If there are no exposed surfaces, such as in a dense grass cover, drop size distribution and kinetic energy of the simulator are not important. Under this condition the important factors are the intensity and uniformity of application over the plot. According to a literature survey by Meyer (5), the rainfall parameters which are important in both the erosion of soil and the infiltration rate on exposed surfaces include (A) kinetic energy ($1/2MV^2$), (B) momentum (MV), (C) kinetic energy per unit of drop-impact area ($1/2MV^2/A_d$), (D) interactions of these variables with rainfall intensity. A comparison of some of the most used simulators was also made by Meyer. This comparison expressed as a percent of natural rainfall as determined by Laws (10) is given in Table 1, together with the same data for the rotating disk simulator. A drop size distribution comparison between the Purdue Rainulator and the Purdue Sprinkling Infiltrometer, compared to the Rotating Disk Rainfall Simulator, is given in Figure 3. The terminal velocities versus water drop diameter for drops coming from the 1-1/2H30 nozzle as compared to the terminal velocities of freely falling drops, are given in Figure 4. It should be emphasized that the energy characteristics of natural rainfall are dependent on many factors other than intensity. This is verified by a comparative plotting of the observations of several investigators, given in Figure 5. Their data show that the kinetic energy per unit of mass increases with increasing intensity.

TABLE 1. COMPARISON BETWEEN VARIOUS RAINFALL SIMULATORS AND NATURAL RAINFALL OF 50 MILLIMETERS PER HOUR

(The performance of the simulators relative to that of natural rainfall as based on various parameters is presented in percents. After Meyer (5) except for the rotating disk simulator.)

| Parameter | Rainfall Simulator Type C | Type F | Rainulator | Rotating Disk |
|---|---|---|---|---|
| Kinetic energy per unit of rainfall ($\alpha\Sigma(pV^2)$) | 44 | 56 | 77 | 100 |
| Momentum per unit of rainfall ($\alpha\Sigma(pV)$) | 68 | 76 | 87 | 99 |
| Total kinetic energy per unit of total drop impact area ($\alpha\Sigma(pV^2)/\Sigma(p/D)$) | 82 | 72 | 62 | 86 |
| Total momentum per unit of total drop impact area ($\alpha\Sigma(pV)/\Sigma(p/D)$) | 126 | 98 | 70 | 85 |
| Kinetic energy per unit of drop impact area (by increments) ($\alpha\Sigma(pDV^2)$) | 65 | 70 | 63 | 110 |
| Momentum per unit of drop impact area (by increments) ($\alpha\Sigma(pDV)$) | 105 | 97 | 72 | 107 |

$\alpha$, proportionality factor.
p, portion by weight in a given drop size group
V, terminal velocity
D, drop diameter
Type C, produces a nearly uniform drop size which is much larger than most raindrops. The drops fall from zero velocity for a distance of only 1.4 meters.
Type F, produces a drop-size distribution larger than intense natural rainfall. The drops fall from zero velocity for a distance of only 3 meters.
Rainulator, produces a drop-size distribution slightly smaller than intense natural rainfall. Drop velocities are near terminal velocities except for large drop sizes.
Rotating disk simulator. Nozzle 1½H30; pressure 0.6 atm; angular velocity 30 rpm; aperture angle 10 deg. To obtain 50 mm per hr with these characteristics an aperture angle of 14 deg is required.

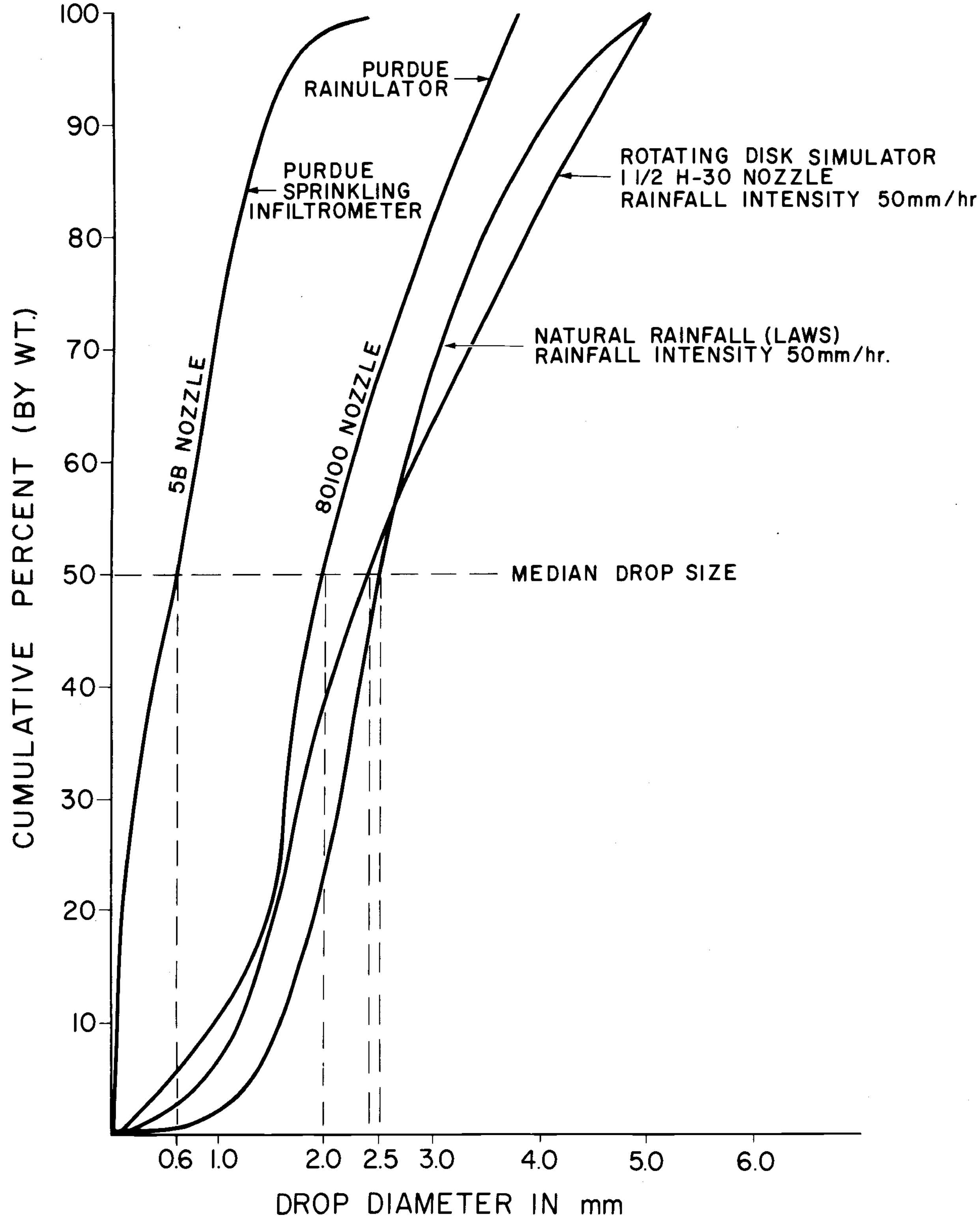


FIGURE 3. DROP SIZE DISTRIBUTION OF SIMULATOR NOZZLES COMPARED WITH NATURAL RAINFALL.

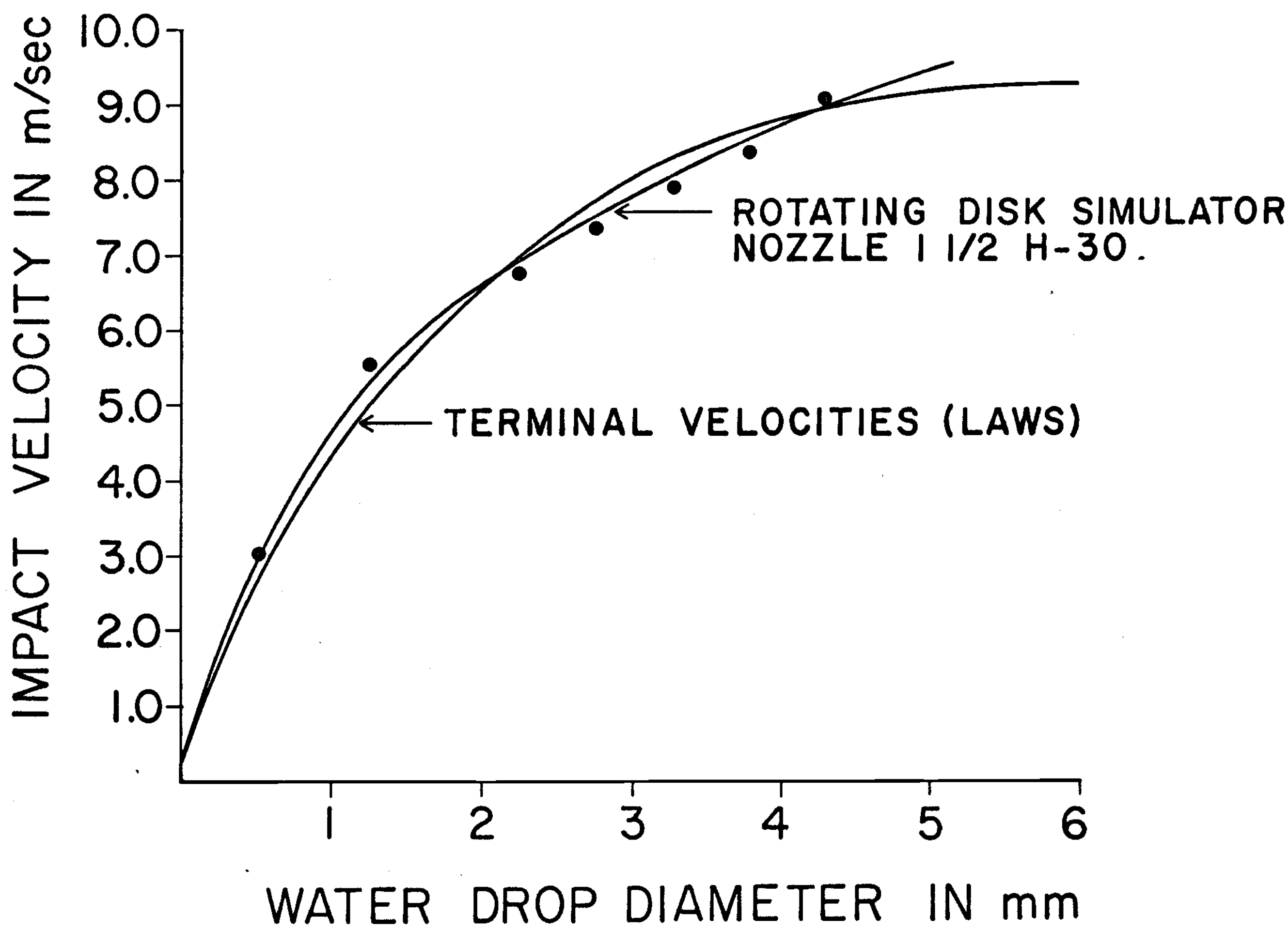


FIGURE 4. IMPACT VELOCITY OF RAIN DROPS FROM ROTATING DISK SIMULATOR COMPARED WITH TERMINAL VELOCITIES OF FREELY FALLING DROPS.

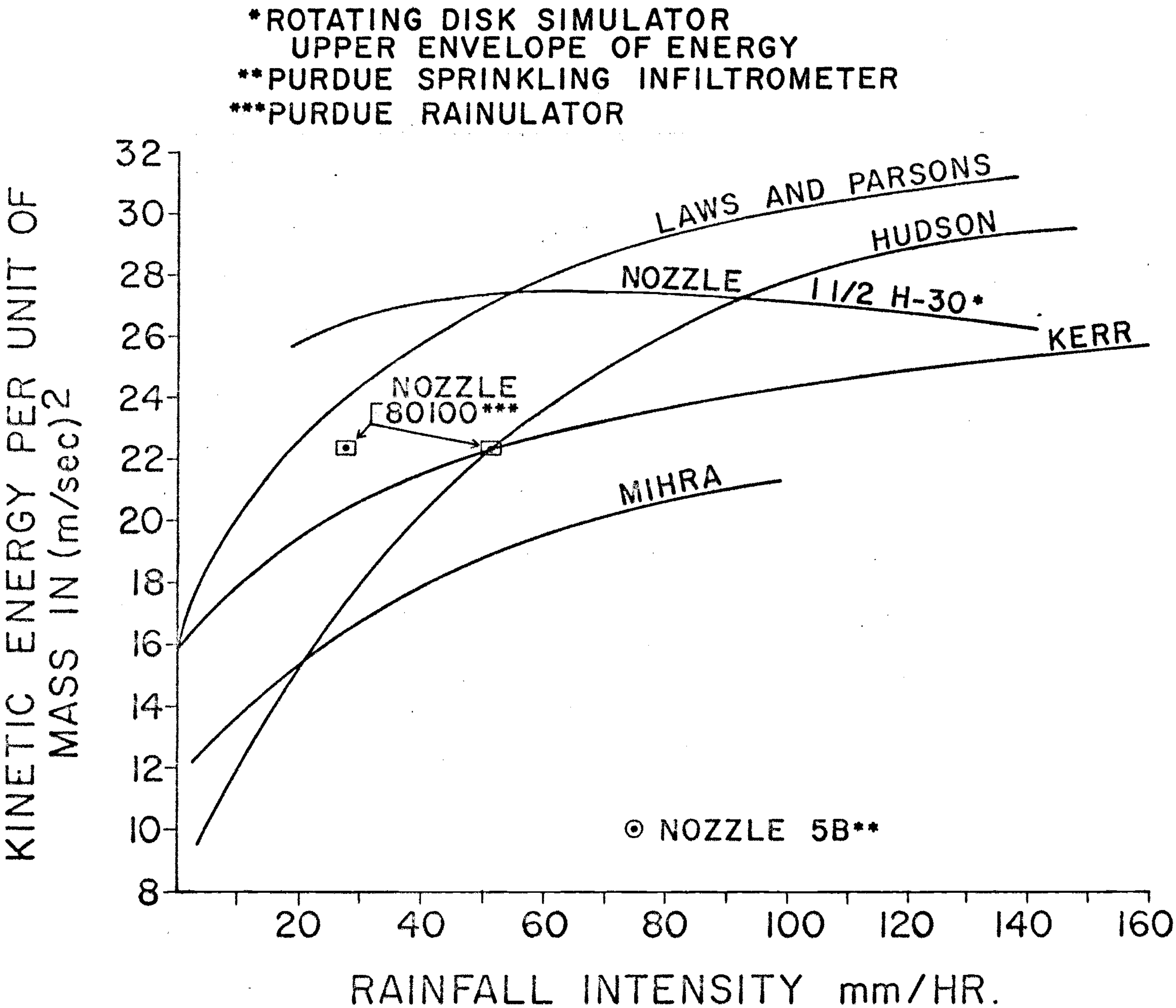


FIGURE 5. RELATION OF RAINFALL SIMULATORS KINETIC ENERGY TO THE KINETIC ENERGY OF NATURAL RAIN AS REPORTED BY SEVERAL INVESTIGATORS.

Nozzle 5B, as used in the Sprinkling Infiltrometer, produces only one intensity. In the Rainulator, spray from the 80100 nozzles was overlapped to produce two different intensities. The kinetic energy per unit of mass would be the same for both intensities as indicated in Figure 5. Due to the ability to select any desired intensity from the rotating simulator by varying the aperture in the rotating disk, the kinetic energy-rainfall intensity relation can be plotted as a continuous line.

Comparison of Infiltration Data Obtained for Two Simulators

The characteristics of the rainfall produced by nozzle 1-1/2H30 seem to be closer to natural rainfall than other simulators used in the past. The importance of this improvement has been verified in actual field runs made at Atterbury Experimental Watershed on sandy loam soil and at Page Experimental Ranch on sandy clay loam. Table 2 shows terminal infiltration rates obtained on the same plots, using first nozzle 5B in the Sprinkling Infiltrometer and then approximately 1 year later making the same determination on the same plots with the rotating disk simulator. Two types of surfaces are considered in the table. The control or natural surface in which there is considerable exposed surface and a treatment of 15 mm depth of gravel cover in which there is no exposed surface. As mentioned earlier, the infiltration rate on the natural soil is essentially the same as on the soil with a 25 mm layer of gravel, when using the Sprinkling Infiltrometer. However, with the rotating disk simulator on the natural soil, the terminal infiltration rate was reduced to one-third of that determined previously. This was due to the higher kinetic energy causing inwash and creation of a surface skin, by reorganization and compaction of the soil structure at the surface of the soil (11)(12). In fact,

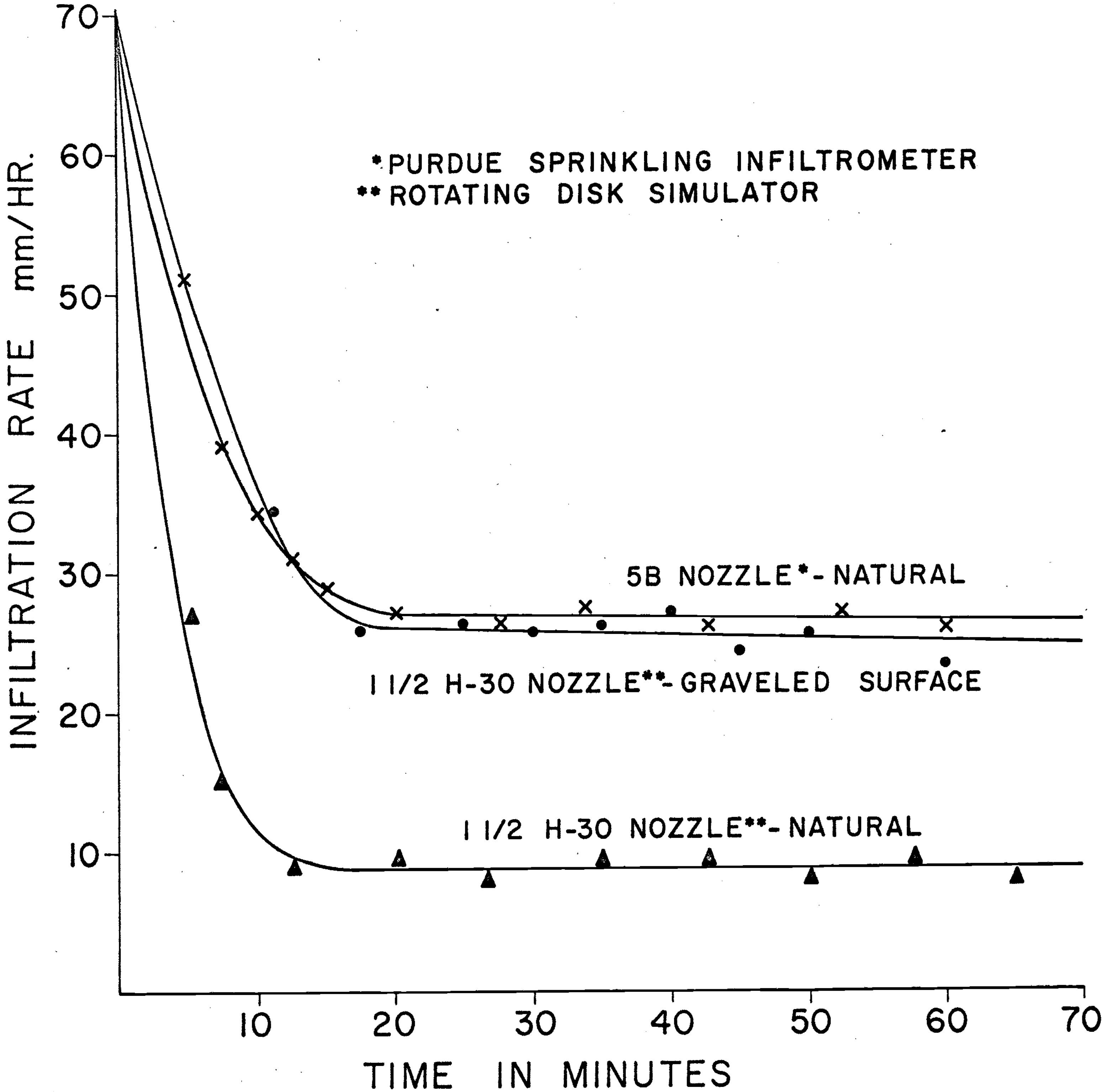


FIGURE 6. ATTERBURY WATERSHED INFILTRATION RATE COMPARISON.

TABLE 2.

ATTERBURY EXPERIMENTAL WATERSHED
INFILTRATION RATE COMPARISON USING TWO TYPES OF SIMULATORS

(Infiltration Rate mm/hr.)

| Plot No. | Treatment | Rotating Disk Rainfall Simulator* | Purdue Sprinkling Infiltrometer** |
|---|---|---|---|
| 5<br>8<br>9 | Control | 8.6<br>9.4<br>9.1 | 31.5<br>20.3<br>25.6 |
| Average<br>Standard Deviation | | 9.1<br>0.3 | 25.9<br>3.3 |
| 3<br>6<br>12 | 25mm Layer of Gravel | 25.6<br>21.3<br>27.7 | 19.3<br>25.1<br>22.6 |
| Average<br>Standard Deviation | | 24.8<br>1.8 | 22.3<br>1.7 |

*Nozzle 1½H-30, avg. rainfall intensity of 42.4 mm/hr.

**Nozzle 5B, avg. rainfall intensity of 56.4 mm/hr.

this surface crusting seemed to be the controlling factor in the infiltration rate (11). The variance in terminal infiltration rate between the control plots using the rotating disk simulator was much less than that found when the Sprinkling Infiltrometer was used. This was not the case when the surface was covered with gravel. The gravel cover adsorbed the kinetic energy from the raindrops. With the surface protected,subsurface conditions became the controlling factor in determining the infiltration rate. Figure 6 gives the average infiltration curves for the runs reported in Table 2. The average curve for 5B nozzle-graveled surface was not included, since it is essentially a duplication of the 5B nozzle-natural.

Figure 7 gives results at Page Ranch located in a heavily grassed area north of Tucson. These runs were all made in the same day. This figure demonstrates the tremendous difference between infiltration rates as determined by the two types of simulators on bared soil. The soil was bared by carefully removing the tops of the grass in such a way as to not disturb the subsurface. There was not much difference between the infiltration rate determined by the Sprinkling Infiltrometer on the bared soil, as compared to the infiltration rate determined by the rotating disk simulator on the natural or grass-covered surface. The above results from the rotating disk simulator are consistent with the physics of the infiltration process. The rotating disk simulator is proving to be a valuable tool in treatment evaluation in the Water Harvesting Project presently under way at the University of Arizona. Preliminary work has been done in comparing the infiltration rate, as determined using the rotating disk simulator, with that determined by hydrograph analysis on small watersheds. On an acre semiarid plot at Atterbury Experimental Watershed, the average terminal infiltration rate determined making eight runs with the rotating disk

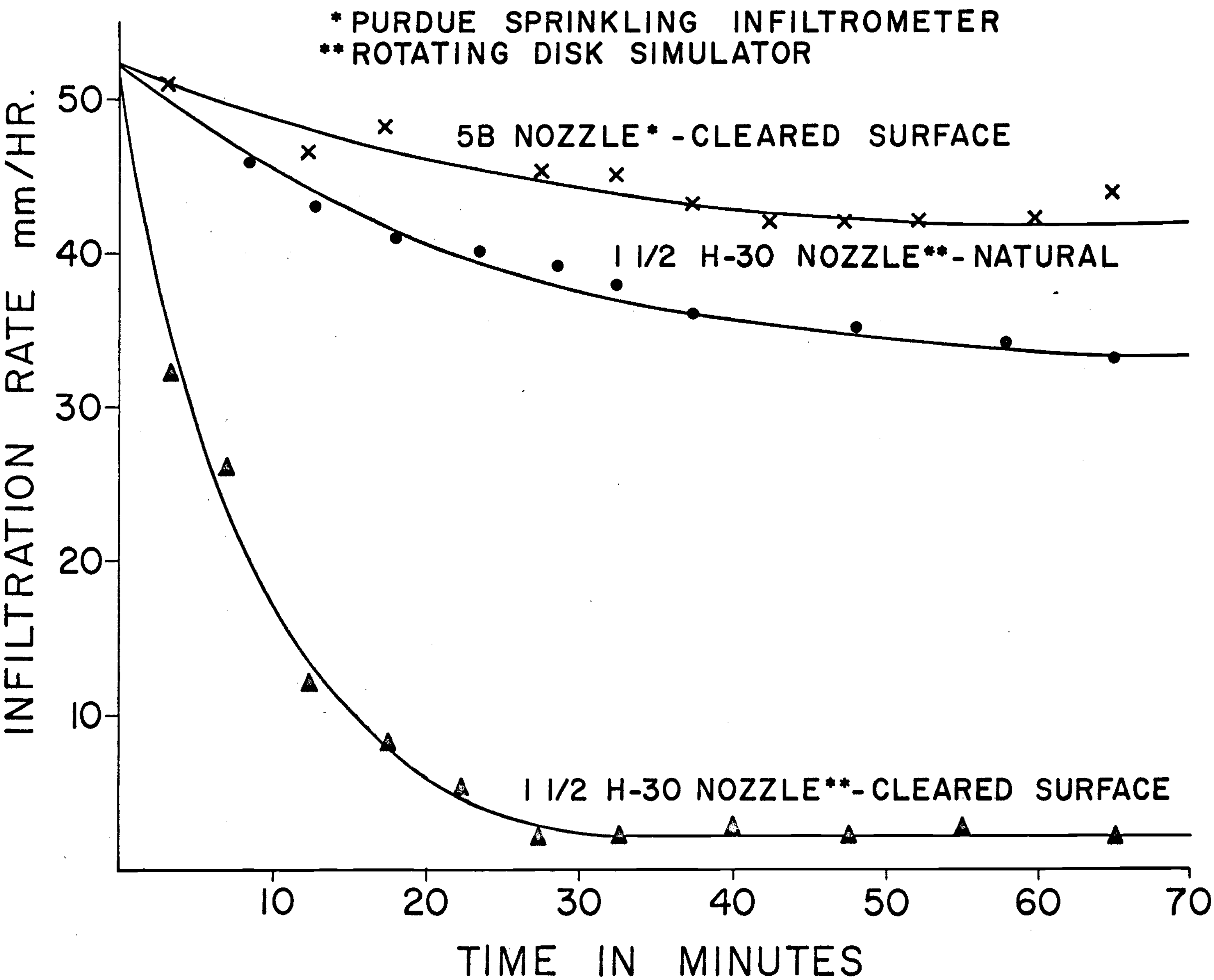


FIGURE 7. PAGE RANCH INFILTRATION RATE COMPARISON

simulator was found to be 6.8 mm/hr. A hydrograph analysis of a storm that occurred just after the infiltration runs were made indicated that the average terminal infiltration rate on the acre was 8.4 mm/hr, a difference of 19 percent. During the runs with the simulator differences were noted in the infiltration rates when the simulator was placed over Creosote bushes, Cholla cactus, etc., as compared to open areas. Because of this it is believed that a weighting of infiltration runs based on the percentage vegetation type represented by the particular run on the watershed will cause the infiltration rate as determined by the simulator to be even closer to that determined by hydrograph analysis. This weighting will be done in the future. If this is successful, additional runs will be made on larger watersheds to obtain realistic infiltration rates for rainfall-runoff models for prediction purposes.

## Summary

The rotating disk simulator field model developed at the University of Arizona has proven to give realistic infiltration data in over 250 runs made to date. The rainfall characteristics of the rotating disk come closer to duplicating natural rainfall than previously used field simulators. The ability to vary intensity without significantly changing drop size distribution or uniformity should prove invaluable in future studies. This aspect of the simulator has not as yet been fully explored. The simulator has proven to be a valuable tool in quickly determining the effect of various treatments on the infiltration rate. Finally, preliminary studies have indicated a high correlation between terminal infiltration rate as determined by the rotating disk rainfall simulator, as compared to those determined by hydrograph analysis.

## Acknowledgment

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