DESIGN, FABRICATION AND TESTING OF A RAINFALL SIMULATOR

BY

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THESIS

Submitted in partial fulfilment of the
requirement for the degree

Maſter of Technology in Agricultural Engineering

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

Department of Land and Water Resources & Conservation Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur, Malappuram

1993

DECLARATION

I hereby declare that this thesis entitled "**Design, Fabrication and Testing of a Rainfall Simulator** " is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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ACKNOWLEDGEMENT

I express my deep sense of gratitude and indebtedness to **Prof. T.P.George**, Dean in-charge, KCAET, Tavanur, Chairman of the advisory committee for his professional guidance, valuable advices, constructive criticism and constant encouragement during the course of this thesis work and in the preparation of manuscript.

I wish to express my heartfelt gratitude to **Prof. K.John Thomas**, Professor and Head, Department of Irrigation and Drainage Engineering, for his constructive suggestions and valuable advices during this study.

I express my indebtedness and deep felt gratitude to **Dr. K.I. Koshy**, Professor and Head (S.A.C), KCAET, Tavanur for his keen interest and constant encouragement throughout the course of this investigation.

The sincere and patient help extended by **Sri. M.R Sankaranarayanan**, Assistant Professor (Agrl. Engg.), College of Horticulture, Vellanikkara, is acknowledged with gratitude here.

I take this opportunity to express my heartful thanks to Dr. M. Sivaswami, Dr. P.Habeebur Rahman, Sri. Rathnakumar. V.K, Sri. V.R.Ramachandran, Sri. George Mathew. and Sri. Ajith Kumar.K Asistant professors, KCAET, Tavanur.

I sincerely acknowledge Sri. Samkunju.M.G. Jr. Programmer for his valuable help during the preparation of thesis.

I express my gratitude to the staff and students of KCAET, Tavanur, for the sincere help and co-operation extended towards me for the completion of this work.

Thanks are also due to the Kerala Agricultural University for granting me a Junior Fellowship to undergo the Post Graduate Programme.

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SYMBOLS AND ABBREVIATIONS

Agric	Agricultural
ASAE	American Society of Agricultural Engineers
cm	centimetre(s)
Dept	Department
et al.	and others
ft	feet
Fig.	figure
GI	galvanised iron
g	gram(s)
gpm	gallons per minute
ha	hectare(s)
hr	hour
ICRISAT	International Crop Research Institute for Semi Arid Tropics
J	Journal
kg/ha/hr	kilogram per hectare per hour
kpa	kilo pascal
l	litre(s)
Mg	metric tonne(s)
m	metre
mm	millimetre
m^3/ha/hr	cubic metre per hectare per hour

MS	–	mild steel
No.	–	number
Proc.	–	Proceedings
psi	–	pounds per square inch
PVC	–	Poly vinyl chloride
rpm	–	revolutions per minute
Tr.	–	Transaction
%	–	per cent

INTRODUCTION

INTRODUCTION

Land and water are the basic resources of a nation. Productive land is the source of human sustenance and security. The future of a country and its teeming millions depend to a large extent on the conservation of land and water through the proper use and treatment of land.

In India, there is very little area free from the hazards of soil erosion. It is estimated that out of 305.9 million hectares of reported area for land utilisation, 145 million hectares are in need of conservation measures. Severe erosion occurs in the sub-humid and humid areas due to high rainfall and improper management of land and water.

Soil erosion is the wearing away of land surface, by the action of such natural agencies as water and wind. One of the principal reasons for low productivity in agriculture is the deterioration of soil due to erosion. Excessive loss of soil and nutrients during heavy rains, deteriorate the productivity of agricultural land. Soil detached from the catchments gets deposited in the reservoirs, stream channels etc, thereby reducing their capacity and useful life.

Rainfall is the chief detaching agent in water erosion. Raindrop impact on soil surface has a pronounced effect on erosion. Rain drops cause soil splash, detach soil particles and make them available for transport. The amount of soil detached by rain depends on the rainfall characteristics, soil characteristics and on the influence of vegetation. Rain drop splash is of major importance as a contributor to erosion. Runoff is that portion of the precipitation that makes its way towards stream channels, lakes or oceans as surface or sub-surface flow. Runoff and soil loss can be measured from runoff plots as well as from watersheds.The watershed studies furnish a means of obtaining runoff and soil loss under field conditions. The errors which may occur due to variations in soil type, slope and rainfall during watershed studies can be minimised by adopting runoff plot studies. Knowledge of runoff and soil loss values under varying field conditions are a pre-requisite in the design of soil conservation structures.

Simulated rainfall is the application of water in a form similar to natural rainfall .This is an effective aid in soil erosion research. Simulators make it possible to produce storms at any desired time and location. They make the replication of research easier and facilitate the study of storm sequences. However, the characteristics of natural rain fall must be accurately simulated and limitations must be clearly recognised for proper interpretation of results.

Several parameters have been suggested for the design of rainfall simulators, but modelling criteria have not been accurately delineated. Most of the criteria suggested are based on rainfall energy or momentum. Both energy and momentum contain the two basic parameters - rainfall mass and impact velocity. The accurate simulation of drop size distribution and impact velocity of natural rainfall is difficult.

Artificial simualtion of rainfall has been achieved by employing drop formers of hanging yarn (Elison and Pomerene, 1944),tubing tip (Lane, 1947) and nozzle types(Meyer and McCunne, 1958). In the case of hanging yarn and tubing tip type drop formers, raindrops of the same size fall repeatedly on the same spot and a greater fall height is required to attain terminal velocity. Nozzle type drop formers are efficient but are costly. Therefore a simple and cheap rainfall simulator has to be developed.

A research programme involving the use of a rainfall simulator has the potential for developing more data at a low cost than most existing methods. Simulation of rainfall permits comparison of a variety of soil samples under identical conditions.

An attempt is made here to design and fabricate a rainfall simulator suitable for erosion studies from micro plots and conduct laboratory studies on erosion of laterite soil. The objectives of the research work are :

1. To design and fabricate a rainfall simulator.
2. To study the effect of land slope on soil loss and runoff at various simulated rainfall intensities for laterite soil.
3. To establish relationships between land slope, runoff , soil loss and rainfall.

REVIEW
OF
LITERATURE

REVIEW OF LITERATURE

A brief review of the literature relevant to the topics of soil erosion and the rainfall simulators are given in this chapter.

2.1 SOIL EROSION

Soil erosion is the detachment and transportation of soil material from one place to another through the action of wind, water in motion or by the beating action of the rain drops. (Michael and Ojha, 1966)

Hudson (1971) reported that water is the most important single agent of erosion. The fundamental cause of soil erosion is the rain acting on the soil. The amount of erosion depends upon the power of the rain to cause erosion and the ability of the soil to withstand the rain. Thus erosoin is a function of the erosivity of the rain and erodibility of the soil.

2.1.1. Factors affecting soil erosion

The major factors affecting soil erosion are climate, soil, vegetation and topography. Climatic factors affecting erosion are rainfall, temperature, and wind. Wind changes the velocity and angle of impact of raindrops. (Schwab *et al.* 1981)

2.1.1.1 Rainfall characteristics

The rainfall characteristics influencing erosoin are the intensity, drop size distribution and the energy of the storm.

2.1.1.1.1 Intensity

Intensity is particularly important as a potential parameter of erosivity. The force causing detachment of soil particle is associated with the impact of the individual water drop. The kinetic energy of rain is the causative factor in initiating the detachment of the soil.According to Wischmeier and Smith (1958) the intensity is related to total kinetic energy as

$$E = 12.1 + 8.9 \log I$$

where,

E - kinetic energy in m-Mg/ha-mm

I - intensity in mm/hr

2.1.1.1.2 Drop size distribution

The size, distribution and shape of rain drops influence the energy, momentum and erosivity of a rain storm. Laws and Parsons (1944) reported an increase in the median drop size with increase in the rainfall intensity. The relation between median drop size (D_{50} in mm) and rainfall intensity in inches per hour is found as

$$D_{50} = 2.23 \quad I^{0.182}$$

Hudson (1963) reported that the medium drop diameter increases upto intensity of 80 mm per hour but then decreases at high intensities.

2.1.1.1.3 Terminal velocity

Ellison (1947) developed a relationship between soil detached, terminal velocity, drop diameter and rainfall intensity as

$$E = K \, V^{4.33} \, d^{1.07} \, I^{0.65}$$

where,

E - the amount of soil detached

K - a constant of the soil

V - velocity of the raindrops in ft/sec

I - rainfall intensity in inches per hour.

d - diameter of the raindrops in mm

The kinetic energy of rainfall is related to velocity of raindrops at the time of impact with the soil. The terminal velocity of raindrop increases as the size increases (Hudson, 1971).

2.1.1.2 Soil characteristics

Physical properties of the soil affect the infiltration capacity and the extent to which it can be dispersed and trasnsported. The properties of the soil that influence erosion are soil structure, texture, organic matter content, moisture content and compactness of the soil (Schwab *et al.*1981).

2.1.1.3 Topography

Topographic features that influence erosion are degree of slope, length of slope size, and shape of the watershed (Schwab *et al.* 1981).

2.2 SOIL LOSSES

The average annual soil loss can be estimated by the equation suggested by Wischmeier(1976) as

$$A = 2.24\ R\ K\ L\ S\ C\ P$$

where,

A - average annual soil loss in metric tonnes/hectare
R - rainfall and runoff erosivity index
K - soil erodibility factor
LS - topographic factor
C - crop management factor
P - conservation practice factor

Rai and Singh (1986) studied the runoff and soil loss on steep hill slopes varying from 0 to 100 per cent in Meghalaya. The surface runoff varied between 68 mm on 10 per cent slope to 268 mm on 21 per cent slope. The runoff values showed increasing trend upto 21 per cent, beyond which the runoff amount decreased with the increase in slope. The soil loss was found to vary between 7 tonnes/hectare at 0 per cent slope to 891 tonnes/hectare at 21 per cent slope and beyond this the soil loss decreased steadily with increase in the steepness of the slope.

Narayana _et al._(1986) studied soil erosion under different agroclimatic condidions in India. In the southern hilly regions of Nilgiri hills, the runoff and soil loss from cropped area of potato was 4 per cent of rainfall and 39 tonnes per hectare respectively. In the laterite soils of Nilgiri hills untreated watersheds produced a runoff of 30 per cent of rainfall.

2.3 RAINFALL SIMULATORS

Rainfall simulators have been used to accelerate research in soil erosion and runoff from agricultural lands, high ways etc. Meyer (1965) defined simulated rainfall as water applied in a form similar to natural rainfall. Simulated rainfall provides means for creating a given rainstorm at a desired time and location. It enables investigators to obtain runoff and erosion data in a relatively short period of time (Bubenzer and Meyer, 1965).

The advantages of simulated rainfall and the desirable characteristics of rainfall simulators were stated by Meyer (1965).

2.3.1 Advantages of simulated rainfall

1. More rapid results can be obtained by applying selected simulated storms at selected treatment conditions. In contrast, erosion studies which rely on natural rainfall may require many years to obtain conclusive results.
2. Results from a few simulated storms at selected conditions often provide desired information.

3. Various measurements and observations which are difficult during natural rainstorms may be readily obtained during simulated storms.

4. Simulated rainfall is readily adaptable to highly controlled laboratory research.

2.3.2 Limitations of simulated rainfall

The limitations of simulated rainfall as a research tool was pointed out by Mech (1965). These are grouped into modelling limitations and operating limitations.

1. Modelling limitations

Soil and water research problems are usually associated with natural conditions of weather and soil. Factors like wind, light, temperature, humidity, vegetative influences etc are difficult to simulate. Measurements of soil loss, water loss and infiltration are difficult to extrapolate to field conditions and natural rain.

2. Operating limitations

The nature of most rainfall simulators limit the study to small plots, even if the erosion problem is generally associated with large areas and relatively long slopes. The need for an adequate supply of water in the vicinity of the experimental plots limits the location of the work.

2.3.3 Desirable characteristics of rainfall simulator

1. The drop size distribution and fall velocities of the produced rainfall must be near to those of natural rainfall.
2. The intensities of the produced rain should be within the range of storms producing medium to high rates of runoff and erosion.
3. The rainfall application area must be of sufficient size for satisfactory representation of treatments and erosion conditions.
4. The produced rainfall must be uniform over the study area.
5. Rainfall application must be continuous throughout the study area.

2.3.4 Types of rainfall simulators

Mutchler and Hermsmeier (1965) reported that the rainfall simulators for erosion study use one of the following drop forming methods,

1. Hanging yarns
2. Nozzles
3. Tubing tips

2.3.4.1 Hanging yarn type rainfall simulators

The construction details of a simulator using hanging yarns as drop formers was given by Ellison and Pomerene (1944). The drop formers were evenly spaced to give a uniform intensity distribution over the test area. The applicator unit or the test plot was moved to prevent the drops from repeatedly falling over the same spot.

Mutchler and Hersmeier (1965) reported the working of hanging yarn type simulators. For hanging yarn simulators a muslin cloth was laid loosely on a chicken wire screen so that depressions were formed in the cloth at each screen opening. A piece of yarn was attached to the cloth at each depression. Water applied as a spray to the cloth collected at the depressions and travelled down the hanging yarns to form drops.

2.3.4.2 Nozzle type rainfall simulators

Two basic parts of a nozzle type rainfall simulator are the nozzle or the drop former and the mechanism to apply the spray in the desired manner. Nozzle shape characteristics and the discharge rate govern the range of drop sizes formed. A nozzle with a uniform spray pattern and desirable dropsize distribution is not available. However, a near uniform intensity distribution may be achieved by overlapping the spray patterns of same nozzles (Mutchler and Hermsmeier, 1965).

Swanson (1965) developed a trailer mounted simulator. The simulator produced rainfall with characteristics of near natural rainfall drop size and velocity. The simulator could produce storms of medium and high intensities with minimum wind distortion.

Rotating booms are utilized to carry continuously spraying nozzles. Ten booms support thirty nozzles positioned on radii of 5, 10, 15, 20 and 25 ft. with 2, 4, 6, 8 and 10 nozzles on each respective radius. Intensities of 2.5 and 5 inch/hour are obtained by operating 15 or 30 nozzles. Each nozzle is mounted on a manually operated globe valve. Water is supplied through the stem to which the booms are attached. A small air cooled engine and a drive train were used to rotate the stem and booms. The Spraying Systems Company 80100 Veejet nozzle was used for the rotating boom simulator. The nozzles spray downward and are 9 ft. above the ground level. The booms are operated at 3.5 to 4 rpm. The simulator can be used on a pair of rectangular plots spaced 9 ft or more apart with an overall width of 40 ft or less. Close control of the rainfall intensity is obtained through a valve in the water supply line to the simulator. A delivery pressure of 15 to 20 psi is adequate.

Flows of 65 and 130 gpm are required for intensities of 2.5 and 5 inch/hour.

A rainfall simulator was developed by Meyer and Harmon (1979) for obtaining data on erosion, runoff and sediment sizes from row crop side slopes. The spray nozzle oscillates in an arc of about 90 degrees. Two Veejet nozzles 80100 and 80150 are mounted side by side so that either can be used for rainfall application. This simulator can apply a wide range of intensities at impact energy very similar to natural rainfall.

Floyd (1981) developed a rainfall simulator for use in small plot field experiments. The design was based on an oscillating boom housing a series of Veejet nozzles to which the water supply was periodically interrupted. The simulator covered an area of 7m x 4m The intensity of rain was 27mm per hour with a coefficient of variation of 11.3 percent. The drop size distribution approximated to that of natural rainfall of the same intensity but was deficient in drops of diameter greater than 3.5 mm. Impact velocity was 60 per cent of the terminal velocity. Veejet nozzles 80100 (Spraying Systems Company Limited, Illinois, USA) working at pressures in the range of 7 - 14 psi produced a drop size distribution approximate to that of natural rainfall having an intensity of 25.4 mm/hour.

A rainfall simulator with drop characteristics and intensities matching natural rainfall of the Palouse Region of the Pacific North-West (Bubenzer et al.,1985). It was a modular type simulator with units that would cover an area 2 m x 2 m. The simulator can cover plots 2 m wide with variable length determined by the number of units assembled. The 1/4th HH14WSQ Fulljet nozzle produced by Spraying Systems Inc. operated at a pressure of 100 kPa was used as the drop former. A drop size distribution similar to that of storms with rainfall intensities of 6 to 46 mm/hr were obtained by use of slotted rotating disc. The rotating discs had no significiant effect on the drop size distribution.

A portable boom mounted, continuous application rainfall simulator was constructed by Shelton et al. (1985).

Thomas and Samir (1989) reported the details of a portable simulator featuring a rotating disc and nozzle for use in field studies of erosion, infiltration and runoff process at ICRISAT Hyderabad. Variable intensities of simulated rainfall ranging from 15 to 150 mm/hr are produced by choice of appropriate nozzles and slot apertures in the rotating disc. The duration of simulation can be precisely controlled by a shutter mechanism. The measured uniformity coefficients ranged from 91.2 to 94.3 per cent.

A rainfall simulator was constructed with improved portability, water storage and ease in changing nozzles. The rainfall simulator comprised of water tanks and a rotating turret and boom attached at the rear of a flat-bed trailer. The boom is rotated to one side of the trailer for applying water to plots and positioned over the trailer and tanks for road transport. Interchangeable frames that hold nozzles are suspended from the end of the boom. Typical set up time is 5 min. The simulator can apply water at rates up to 100 mm/hr on an area of 40 sq.m for at least 90 min before refilling is needed. (Hinkle, 1990).

2.3.3. Tubing tip type rainfall simulators

Mutchler and Hermsmeier (1965) reported that the use of tubing tips is a precise method of forming water drops.

The simplest type of simulator is a single tip drop former used in single drop studies. Stainless steel tubing and hypodermic needle tips have been used in a forty feet high drop tower to produce 3 to 6mm diameter water drops. The simulator was used in splash erosion investigations. Drops as small as 0.1mm can be produced from the tubing tips by the air flowing down around the drop (Lane, 1947).

Mutchler and Mouldenhauer (1963) reported the construction details of a laboratory rainfall simulator using drop formers made by telescoping pieces of tubes. The simulator could produce intensity, drop size near to those of natural rain.

Mutchler (1965) conducted studies on water drop formation from capillary tubes and showed that diameter of the tube, surface tension and kinematic viscocity of water could be used as power functions in predicting the weight of drop formed. The diameter of the drop former can be found out from the following equation suggested by Mutchler .

$$W = 4.924 \frac{\sigma^{0.943} \, d^{0.832} \, q^{0.057} \, r^{0.093}}{g^{1.018}}$$

where,

W - the drop weight in g

σ - the surface tension of water in g/sec^2

d - tube diameter in cm

q - flow rate in g/sec

r - kinematic viscocity in cm^2/sec

g - gravitational constant

A simple and cheap rainfall simulator employing hypodermic needles as drop formers was developed by Choudhary et al. (1978). Hypodermic needles with tips pointed upward were fixed in holes drilled 7.5 cm apart in a GI pipe of 1.27 cm diameter and 1 m long. Each bank accomodated 13 needles. A spray unit was formed of two banks of identical gauge, mounted 1 m apart on a supporting frame located at a height of 3 m from ground surface. These banks were freely adjustable and kept inclined towards each other to ensure uniform rainfall distribution during simulation test. Water was supplied to each bank from a constant head water tank through 2.5 cm dia polyethylene pipe. The water supply was regulated with the help of a pressure regulator fitted to the polyethylene pipe line. The spray units were operated at pressures ranging from 0.09 to 0.3 kg/cm^2. Rainfall of varying intensity and drop size was produced by a combination of different needle sizes and water pressure. Rainfall characteristics in relation to needle size and water pressure are as following

Needle size (gauge)	Pressure Kg/cm^2	Rainfall Intensity (cm/hr)	Median drop dia. (mm)
24	0.30	3.4	1.1
	0.24	4.6	1.3
20	0.28	10.4	1.7
	0.18	11.9	2.3
	0.09	14.9	2.4
18	0.26	15.3	2.3
	0.18	17.7	2.4
	0.09	23.6	2.9

A tubing tip type rain fall simulator was designed and fabricated by Bosu and Sivanappan (1989) to study the runoff and soil loss characteristics of different soil series of Coimbatore District of Tamilnadu State. Hypodermic needles of 20 gauge are used as drop formers. A probable centrifugal pump with a diesel engine was used for pumping water to the simulator. The pressure of water supplied to the rainfall simulator was varied to vary the intensity of rainfall.The rainfall intensity is related to pressure as

$$I = - 606.67 P2 + 366.51 P - 10.44$$

where,

I - intensity in cm/hr

P - pressure in kg/cm^2

The drop size decreases with increase in intensity. The intensity and drop size are having a linear relationship

$$D = 2.387 - 0.033 I \quad (r = -0.99)$$

where,

D - drop size in mm

I - intensity in cm/hr.

2.4 MEASUREMENT OF RAINFALL CHARACTERISTICS

2.4.1 Intensity of rainfall

2.4.1.1 Non-recording type rain guages

The commonly used non recording rain guage is the Symon's rain guage. The rain guage is placed in the rain for a known period of time and the depth of water collected is noted. The depth for unit time gives the intensity.

2.4.1.2 Recording type of rain gauges

The commonly used rain gauges are the weighing bucket type and the float type.

2.4.1.2.1 Weighing bucket type

The weighing bucket type rain gauge essentially consists of a receiver bucket supported by a spring or lever balance or any other weighing mechanism. The movement of the bucket due to increasing weight is transmitted to a pen which traces the record on a clock driven chart. From the mass curve the intensity for any time can be obtained by determining the slope of the curve.

2.4.1.2.2 Float type rain gauge

The working of a float type rain gauge is similar to the weighing bucket type gauge. A funnel receives the rain water which is collected in a rectangular container. A float is provided at the bottom of the container. The float is raised as the water level rises in the container, its movement being recorded by a pen moving on a recording drum actuated by a clock-work. When the water level in the container rises so that the float touches the top the syphon comes into operation and releases water. Thus all the water in the box is drained. From the mass curve intensity can be determined by knowing the slope of the curve.

2.4.2 Droplet size

The various methods for droplet size determination are explained below.

The droplet size can be determined using a stain technique. Rhodamine dusted filter paper is used in this method.(Fyall and King, 1963). Droplets are collected on a suitable surface on which a mark,crater or stain is left by their impact. A standard surface is of magnesium oxide, obtained by burning magnesium ribbon,below a glass slide so that the central area is coated uniformly.On impact with Magnesium oxide, a droplet forms a crater which is 1.15 times larger than the true droplet size. The difference in size between the crater and true size is the spread factor. The reciprocal of the spread factor is used to convert the measurement of the crater to the true size. For magnesium oxide the spread factor is 0.86. The Magnesium oxide surface is less satisfactory for smaller droplets and those above 200 micrometre may shatter on impact(May, 1950).

Water droplets can also be collected on a grease matrix. The droplets can be collected on a microscope cavity-slide or some other suitable receptacle. A matrix of petroleum jelly and a light oil can be used (Cunningham _et al_. 1962)

Bosu and Sivanappan (1989) used glass plates smeared in silica gel as the collector for water droplets for their studies on droplet size distribution of the rain fall simulator fabricated by them.

The photographic method prevents environmental modification of the drops, as they can be measured after formation at or very near the point of formation. Also the droplet coalescence and evaporation pose no problem in obtaining photographs. The sampling apparatus consists of a high magnification camera,a light source and a spray chamber. The camera and the light source are arranged on opposite sides of the spray chamber. The spray droplets appear as white spots in a dark field on a developed film. A black dye is added to colourless liquids to make the droplets opaque and produce sharp boundaries of the images of the droplets on the negatives(Roth and Porterfield, 1965).

2.4.3 Determination of uniformity.

Uniformity coefficient is a measure of the degree of uniformity of rain fall . The coefficient is computed from field observations of the depth of water caught in open cans placed at regular intervals within the area. It is expresed by the equation developed by Christiansen(1942).

$$Cu = 100 \left[1.0 - \frac{\Sigma X}{mn} \right]$$

where,

m - average value of all observations in mm

n - total number of observation points

x - numerical deviation of individual observations from the average application rate in mm

MATERIALS AND METHODS

MATERIALS AND METHODS

This chapter describes the design procedure adopted for the fabrication of the rainfall simulator, tests conducted and the methodology for finding out the runoff and soil loss from the laterite soil.

3.1 Objectives

The objective in general of this research work was to design and fabricate a rainfall simulator suitable for soil erosion studies.

The specific objectives are as follows

1. Design and fabrication of a rainfall simulator.
2. Study the effect of land slope on soil loss and runoff at various simulated intensities of rainfall.
3. Establish relationships between land slope, runoff, soil loss and rainfall.

3.2 Design consideration for the fabrication of rainfall simulator

An oscillating, tubing tip type rainfall simulator was designed and fabricated.

According to Mutchler and Hermsmeier (1965) tubing tips is a precise method of making water drops. The hypodermic needles could produce drop sizes upto 5.8 mm. The drop size can be varied by changing the pressure of the water supplied to the needles. Therefore hypodermic needles were chosen as the drop former.

A drawback of the stationary tubing tip type drop former is that the rain drops of the same size fall repeatedly on the same spot. In order to prevent the drops from repeatedly falling on the same spot an oscillating type of tubing tip type rain fall simulator was fabricated.

3.2.1 Selection of intensity of rainfall

Langsholt(1992) conducted studies on the water balance in the lateritic terrain of Kerala. She reported that the maximum intensity of 10-minute rainfall recorded was 78.6 mm/hr. The simulator was designed to produce rainfall intensities upto 88 mm/hr.

3.2.2 Design of diameter of drop former.

3.2.2.1 Determination of rainfall drop diameter.

Mc Gregor and Mutchler (1976) recommended the following equations for the median drop(D_{50})of the rainfall.

$$D_{50} = 2.76 + 11.4 \exp(-1.04\ I) - 13.16 \exp(-1.171)$$

Where,

D_{50} - median drop size, mm

I - intensity of rainfall, inches per hour.

The above equation was used for calculating the median drop size of the design rainfall.

3.2.2.2 Determination of hypodermic needle diameter.

Mutchler (1964) showed that the diameter of a tube, surface tension of water and its kinematic viscosity could be used as power functions in predicting the waterdrop weight.

Knowing the median drop diameter (D_{50}), the weight of a single drop can be calculated assuming spherical shape for the waterdrop.

The following equations derived by Mutchler was made use of to determine the diameter of the hypodermic needle drop former.

$$W = 4.924 \frac{\sigma^{0.943} \; d^{0.832} \; q^{0.057} \; r^{0.093}}{g^{1.018}}$$

where,

W - water drop weight in g.

σ - surface tension of water in g/sec^2.

d - diameter of tube in cm.

q - flow rate in g/sec.

r - kinematic viscosity, cm^2 /sec.

g - gravitational constant.

The following intensities were selected for the study.

Intensity selected (I)					
	cm/hr.	4.80	5.60	7.00	8.80
	inch/hr.	1.89	2.20	2.76	3.46

Diameter of the hypodermic needles designed are presented in Table 1.

Table 1. Diameter of the Hypodermic needles for different intensities of rainfall

Intensity of rainfall inch/hr.	D_{50} mm	Volume of drop mm^3	Weight of drop g	Flow/ tube g/sec	Dia of needle cm	Dia of needle gauge
1.89	2.914	12.952	0.01295	0.681	0.04889	25
2.20	2.913	12.940	0.01294	0.790	0.04800	25
2.76	2.885	12.573	0.01257	0.993	0.04560	26
3.46	2.843	12.030	0.01203	1.248	0.04290	27

Inorder to account for different losses and based on previous research, larger diameter hypodermic needles of 20 and 18 gauge were selected.

3.2.3 Design of the drop former unit

Hypodermic needles of 20 gauge size and 18 gauge size were chosen as the drop formers. Two drop former units, one with 20 gauge needles and other with 18 gauge hypodermic needles were fabricated.

A pipe network with 1.8 cm diameter GI pipe was fabricated. The plan of the network is given in Fig.1(a). The network had an inlet for water at one end and a valve was fitted at the other end for releasing the entrapped air. The transverse pipes of the network were drilled at 7.5 cm interval to accommodate the heads of the 20 gauge hypodermic needles. The needles were fitted in these holes by soldering. Each transverse pipe was thus fitted with 28 needles. The drop former unit thus had 112 needles, 28 needles each on four transverse pipes. For the oscillatory movement of the drop former unit, four cast iron wheels of 5cm diameter were provided on both longitudinal sides of the drop former unit.

Another drop former unit similar in all respects but with 18 gauge hypodermic needles was also fabricated.

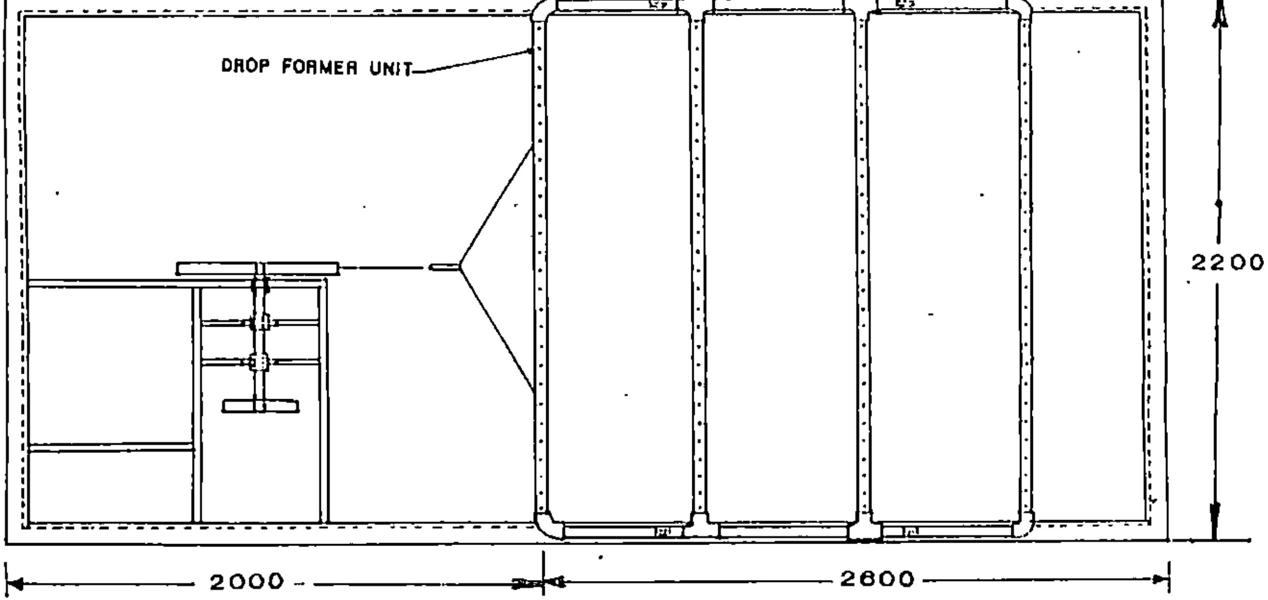
3.2.4 Design of the supporting frame work

In order to support the entire drop former unit, a frame was fabricated. Two angle iron pieces of length 4.6 m each having size 50mm x 50mm x 6mm were selected. Two other angle iron pieces of length 2.2 m with the same size were chosen. These four pieces were welded together to form a rectangular frame work of 4.6 m x 2.2 m. MS flats of 25 mm x 2 mm welded on both sides of the flat surface of the angle iron pieces on the longitudinal sides of the frame work. Thus both the longitudinal sides of the frame work formed channels for the movement of the wheels fitted on the drop former unit.

The pulleys and the cranking mechanism of the drive unit were fitted on a frame work of size 1.15 m x 1 m fitted on the main frame work.

The plan and elevation of the supporting frame work are shown in Fig.1 (a) and Fig.1 (b) respectively.

The frame work was supported by seven legs, one leg each on four corners and one leg each in between the two legs on the longitudinal side and one leg on the corner of the inner frame work. The legs were of 25 mm MS pipe and were 3 m long. The legs were joined to the frame by electric arc welding. The foot of each leg was fitted with horizontal MS flats 30 cm length to provide stability to the structure.



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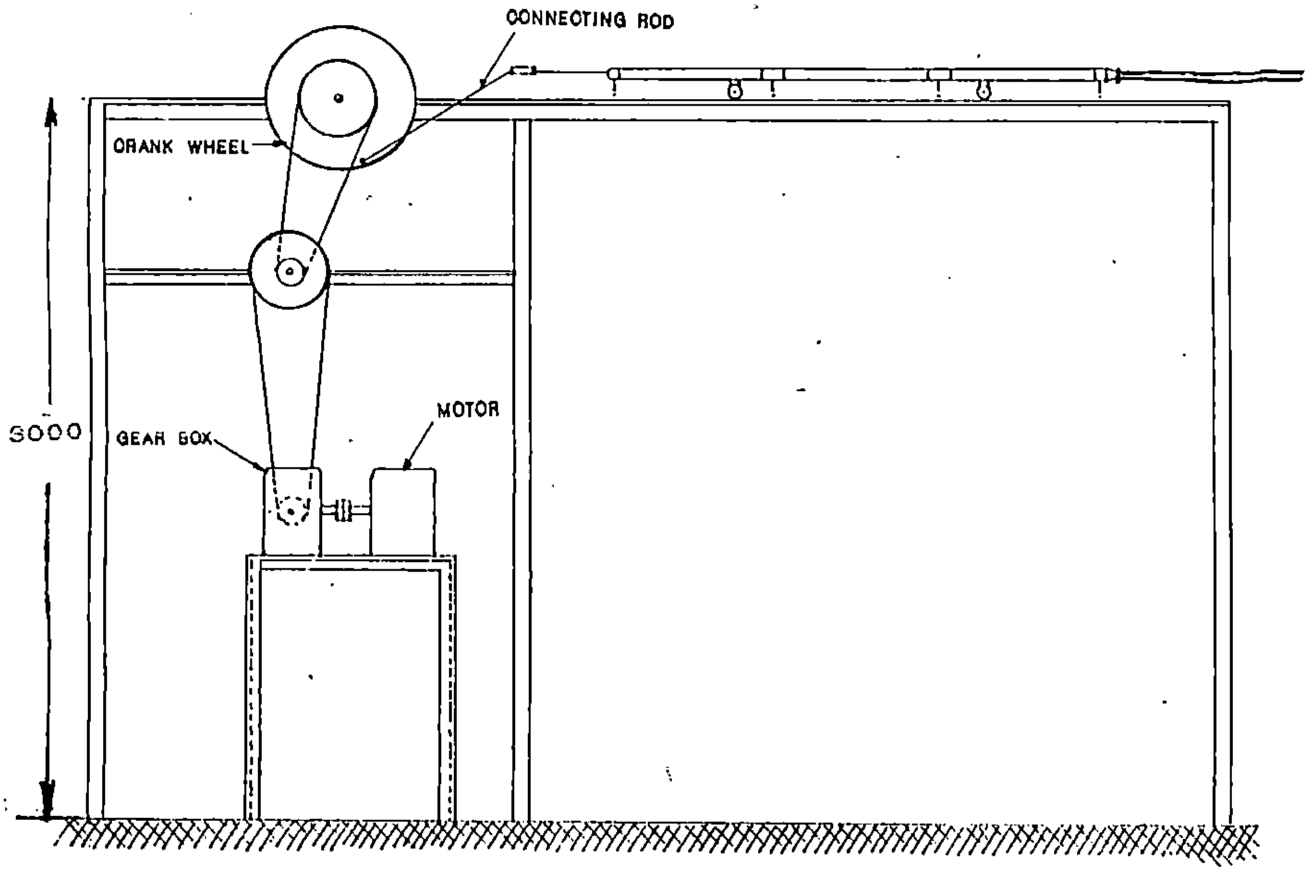


ELEVATION

FIG-1SCHEMATIC DIAGRAM OF THE RAINFALL SIMULATOR

A height of 3 m was chosen for the supporting frame work so that the droplets produced by the simulator attain their terminal velocity before reaching the ground surface as per Shelton _et al._ (1985).

3.2.5 Power transmission system

The power required to oscillate the drop former unit was taken from a single phase, 0.5 hp induction motor. The specifications of the motor are given below.

Speed - 1425 rpm.
Cycles - 50 Hz
Voltage - 230 V
Current - 3.7 A

The motor was coupled to a gear box of reduction ratio 10:1 . Thus the speed was reduced to 140 rpm. The output shaft of the gear box was fitted with a 76 mm V pulley (A) which drove a 305mm V pulley (B) reducing the speed to 35 rpm. The speed was further reduced to 8 rpm by using a combination of 76 mm and 305 mm V pulleys C and D respectively. A crank wheel of 660 mm diameter was fixed on the shaft of the pulley D. The connecting rod between the crank wheel and the drop former unit converted the rotory motion of the crank wheel to a reciproctaing motion of the drop former unit, thus forcing it to oscillate at

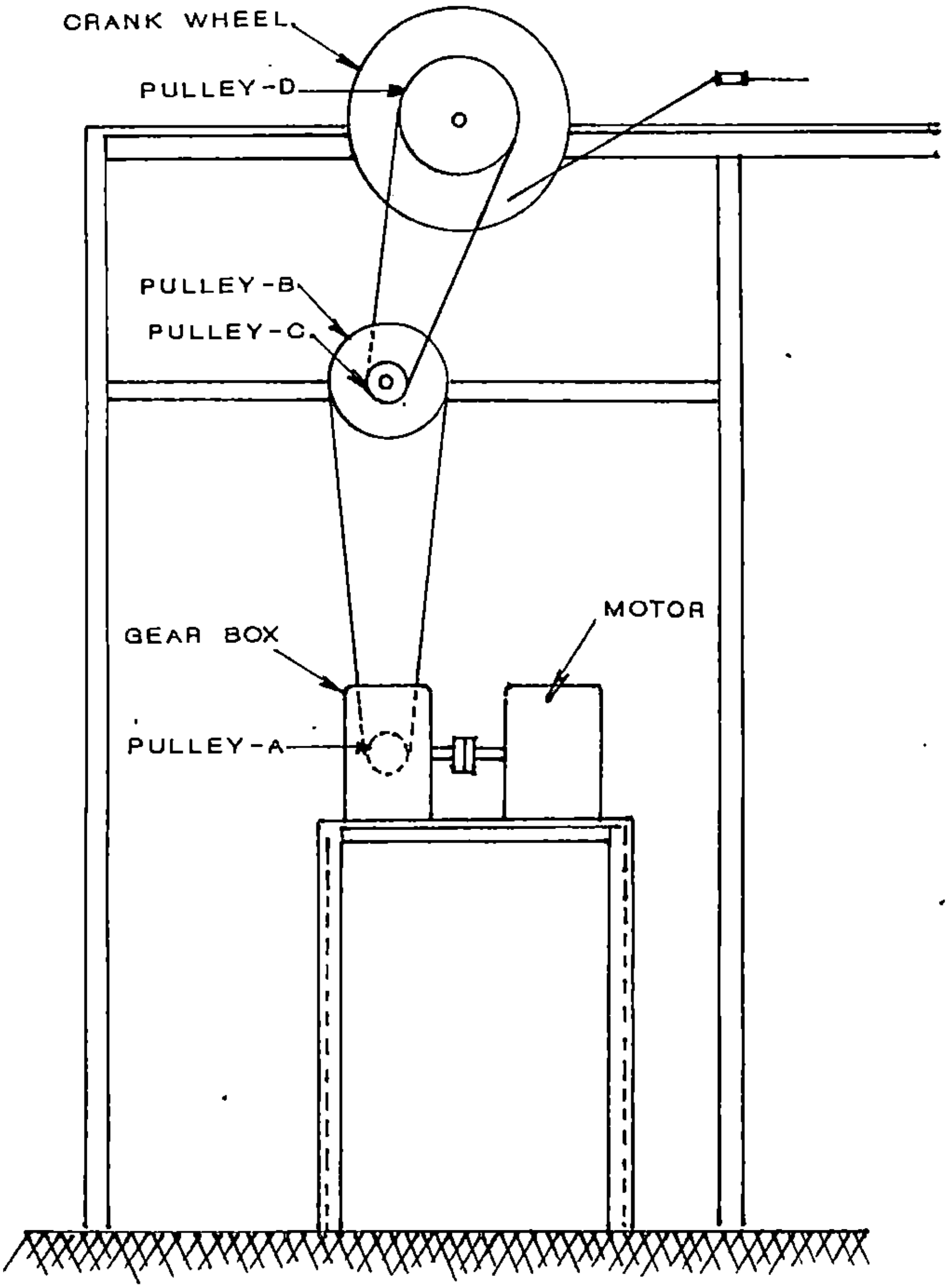
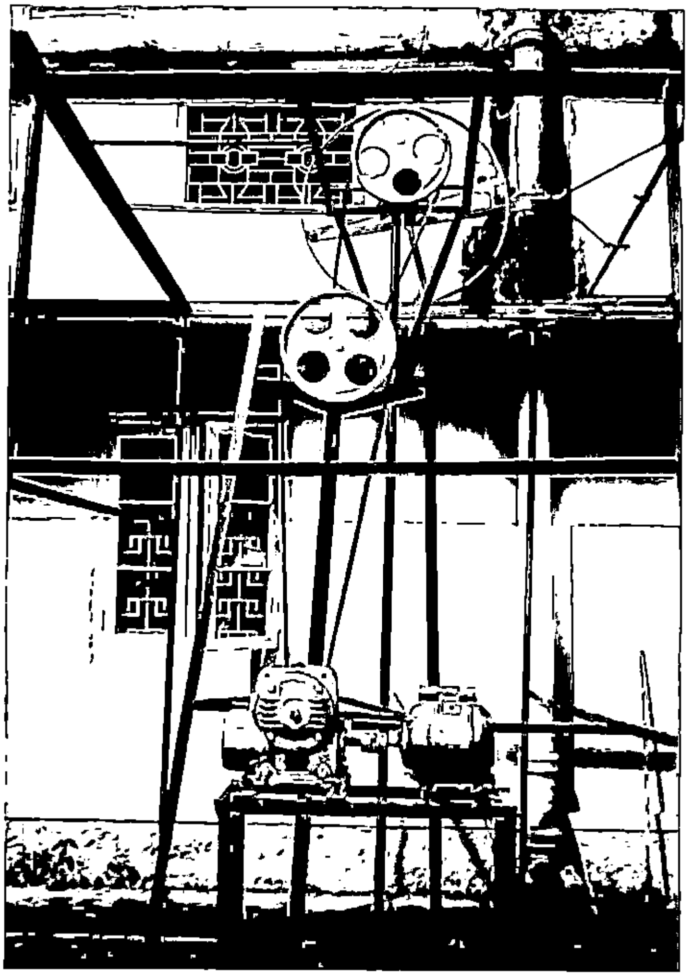


FIG-2 POWER TRANSMISSION SYSTEM



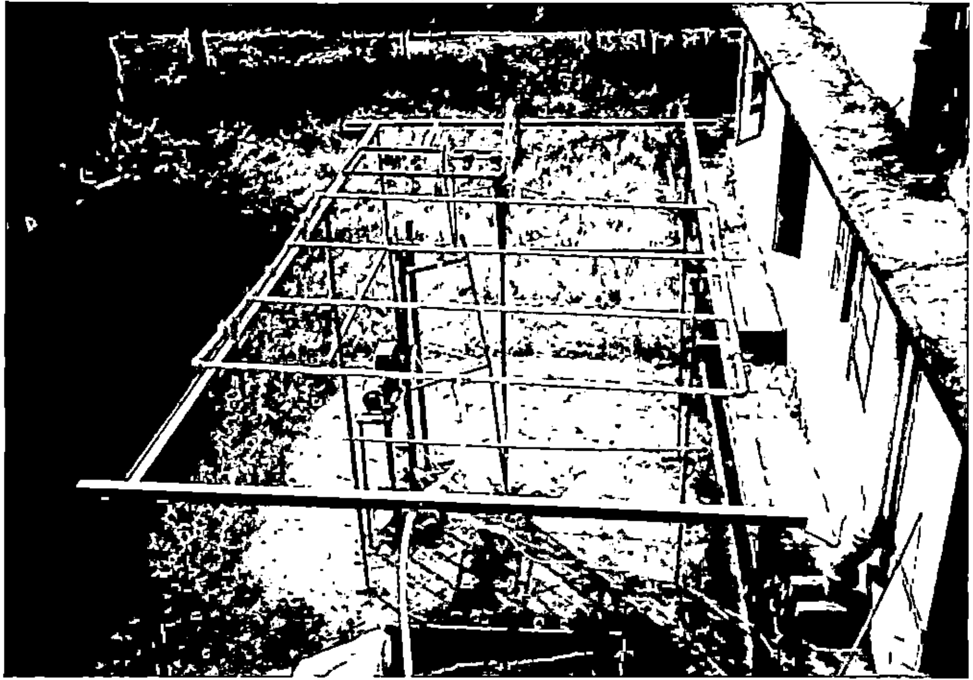
the rate of 8 oscillations per minute. The details of the power transmission system is as shown in Fig. 2. The photographic view of the power transmission system is shown in plate I.

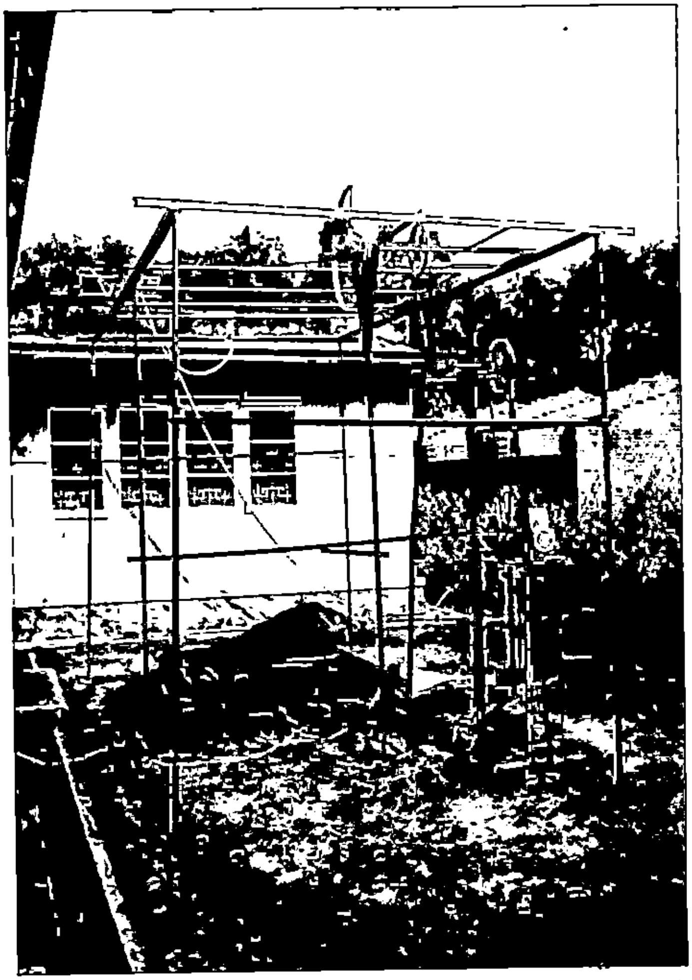
3.2.6 Water supply to the rainfall simulator.

Water supply to the rainfall simulator was taken from an overhead tank of size 60 cm x 90 cm x 50 cm made of MS sheet of 20 gauge. The height of the tank could be varied for changing the pressure of the supply water to the rainfall simulator. The tank got the supply of water from the main pipe line in the campus. The water was filtered through fine cloth filters before admitted to the adjustable overhead tank. This was done to prevent the blocking of the needles due to fine particles. A gate valve was provided at the delivery line of the tank. Water was supplied to the simulator through 1.8 cm diameter flexible hose.

3.3 Installation of the rainfall simulator

For installing the rainfall simulator the open area in between the laboratories and the smithy shop of KCAET. Tavanur was selected. The open area was cleared and the equipment was installed. That area was chosen in order to minimise distortions by wind. The height of the tank was varied by keeping the tank on





tables of suitable height. The photographic view of the rainfall simulator is shown in plates II(a) and II(b).

3.4 TESTING OF THE RAINFALL SIMULATOR

The rainfall stimulator was tested for intensity of rainfall, drop size and uniformity of application. With the drop former unit consisting of 20 gauge needles, instead of drops of water, a jet was produced and the jets got shattered while striking the ground. So the drop former consisting of 20 gauge needles was discarded. But in the case of the 18 gauge needle drop former unit, water drops were produced and hence it was used in further studies.

3.4.1 Intensity

The pressure of supply of water was kept as 0.128 kg/cm^2. The entrapped air was removed and the simulator was operated freely for 15 minutes. Twenty five catch cans of 10 cm diameter were placed at a grid spacing of 50 cm x 50 cm, simultaneously while raining . The unit was operated for 30 minutes. The volume of water collected in each can was recorded. The volume of water collectecd was converted in to its equivalent depth. The test was repeated for supply pressures of 0.158, 0.198, 0.212 and 0.242 kg/cm^2 respectively . The intensity was calculated for each supply pressure of water.

$$Cu = 100 \left[1.0 - \frac{\Sigma X}{mn} \right]$$

where,

Cu - uniformity coefficient, %

m - average value of all observations, mm.

n - number of observations

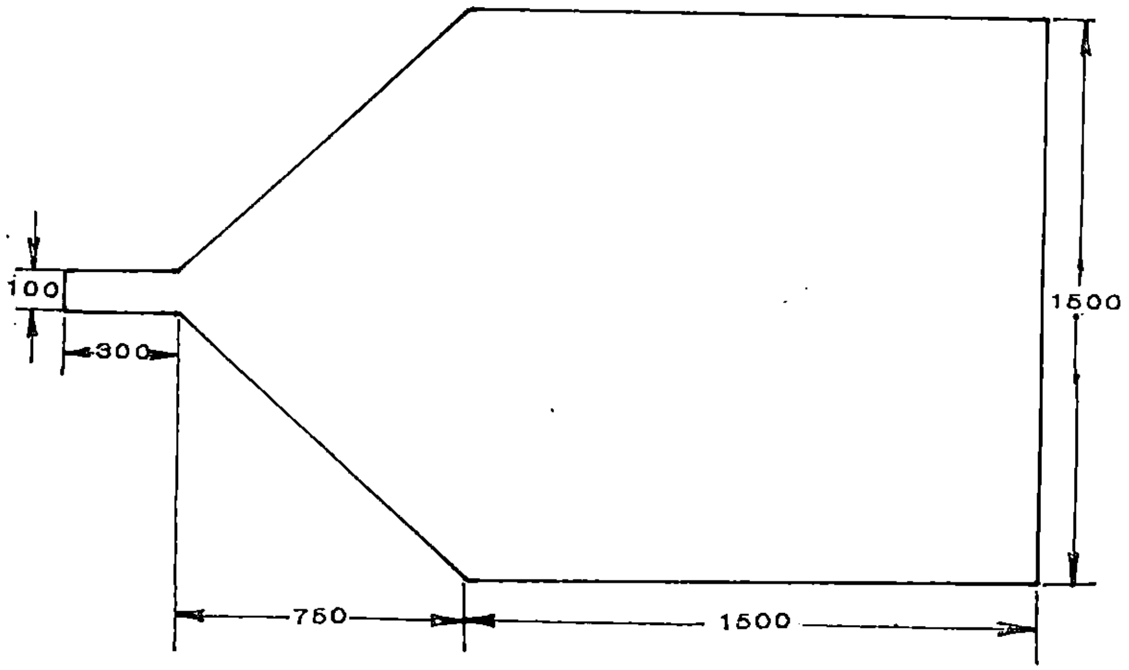
X - numerical deviation of individual observations from the average application rate.

The uniformity coefficient was calculated for the inner area of size 1.5 m x 1.5 m. The experiment was repeated for various intensities of rainfall.

3.5 EROSION STUDY

3.5.1 Design of the plot equipment

An equipment was necessary to hold the soil at the required slope on the test area and to convey the runoff and the eroded soil to the collectors. For this a plot equipment was fabricated. It consisted of a soil collection unit for holding the soil and a conduit for conveying the runoff. Schematic diagram of the plot equipment is given in Fig. 3.The soil collection unit was of size 1.5 m x 1.5 m with 40 cm height . It was fabricated using 20 gauge MS sheet. When the equipment was installed in the plot, the three sides of the plot had 30 cm high wall and the fourth side was open at the plot surface level. The



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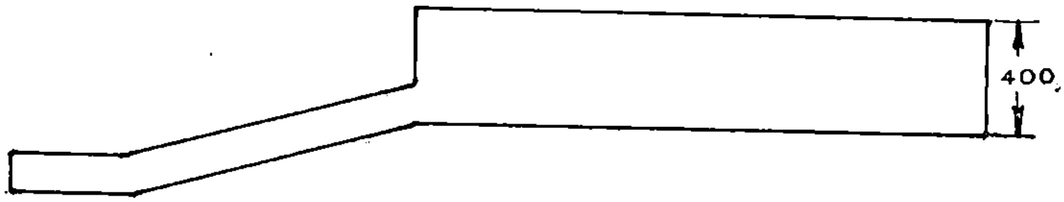
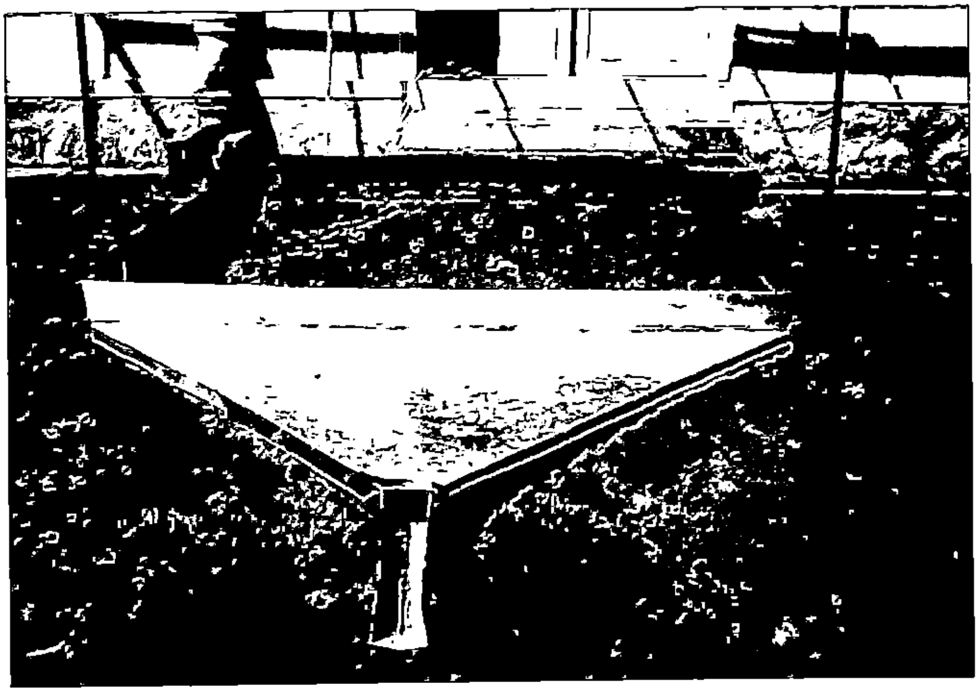


ELEVATION

FIG-3 DIAGRAM OF THE PLOT EQUIPMENT



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conduit for conveying the runoff was a triangular tray of 22 gauge GI sheet, made to fit into the open side of the soil collection unit. The conduit inclined down to a narrow outlet from where the runoff was collected. The triangular tray had a cover made of the same material to prevent the simulated rain falling outside the test plot from mixing with the runoff. The outlet of the tray was directed to a pit of size 1m x 1m x 1m. The runoff was collected in suitable containers placed in the pit. The photographic view of the plot equipment developed is shown in plate III.

3.5.2 Formation of soil plot for erosion study

Laterite soil was collected from the coconut garden of the Instructional farm, KCAET. Boulders were removed from the soil. A detailed mechanical analysis was done on a representative sample to obtain the grain size distribution. The soil was filled in the collection unit, at the required slope, with an initial slope of 20 per cent. The soil was allowed for natural compaction by exposing to rain for a few hours in three days.

3.5.3 Study of soil loss and runoff

The experimental plot was exposed to simulated rainfall of intensity 4.77 cm/hr by adjusting the pressure of water supply. A wet run was given for a period of 30 minutes. The runoff with the eroded soil was collected in a vessel placed below the narrow channel of the triangular tray in the pit, for a period of 10 minutes. The amount of runoff was recorded.

3.5.3.1 Computation of sediment load

The runoff sample was allowed to settle for a period of one week. Then the clear water was removed and the sediment was seperated by evaporation technique. The weight of the sediment was recorded. The sediment was analysed for particle size distribution. The test was repeated thrice.

The whole procedure was repeated for intensities of rainfall 5.6, 6.73 and 8.8 cm/hr.

The slope of soil in the collection unit was changed to 15 per cent. The soil was allowed for natural compaction by exposing to rain for few hours in three days. Erosion study was conducted for different intensities of rainfall as in the above case. The procedure was repeated for slopes of 10 per cent and 5 per cent.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

An oscillating tubing tip type rainfall simulator was designed and fabricated at K.C.A.E.T.Tavanur. The simulator was tested to determine the intensity, droplet size and uniformity of application of the rainfall produced. After the performance evaluation of the simulator, this simulator was used for erosion studies on laterite soil.The results of testing of the simulator and the erosion study conducted using it are presented in this chapter.

4.1 TESTING OF THE RAINFALL SIMULATOR

4.1.1 Intensity of rainfall

The simulator was supplied with water from an overhead tank whose height could be varied. The pressure of water supplied to the simulator was varied by changing the height of the water tank. The intensity of rainfall produced at each supply pressure was measured. The results are presented in Table 2. It was observed that for a supply of water at 0.128 kg/cm^2 pressure the intensity obtained was 4.77 cm/hr. From the table it was observed that the intensity of rainfall increased with the increase in the supply pressure.The pressure was increased up to 0.242 kg/cm^2 and the intensity obtained at that pressure was 8.80

cm/hr. The increase in intensity with pressure was due to the increase in the aplication rate of water.

A graph is plotted with the supply pressure of water on X-axis and intensity of rainfall obtained on Y-axis and is shown in Fig.4.

The data presented in Table 2 was analysed using the computer application software named " GRAPHER ". The resuts obtained is presented below.

Best fit curve	Equation	Percentage of residuals about the mean explained
Linear	$I = 33.272\ P + 0.336042$	96
Second Degree Polynomial	$I = 6.0386 - 31.9152\ P + 177.30\ P^2$	99

Where, I - Intensity of rainfall in cm/hr

P - Pressure in kg/ cm^2

The second degree equation,

$$I = 6.0386 - 31.9152\ P + 177.30\ P^2$$

was chosen as the relationship between the applied pressure and the intensity of rainfall because of its high validity which is seen from the above table.

Table 2. Effect of pressure of supply water on intensity of simulated rainfall

Supply press. Kg/cm^2	0.128	0.158	0.198	0.212	0.242
Intensity cm/hr	4.77	5.60	6.73	6.99	8.80

Table 3. Effect of intensity of rainfall on droplet size

Sl.No.	Supply pressure kg/cm^2	Intensity cm/hr	Mean droplet size mm
1	0.128	4.77	2.31
2	0.158	5.60	2.20
3	0.198	6.73	2.18
4	0.212	6.99	1.05
5	0.242	8.80	0.80

Table 4. Effect of Intensity of rainfall on uniformity

Sl.No.	Supply pressure kg/cm^2	Intensity cm/hr	Uniformity coeff. %
1	0.128	4.77	82.04
2	0.158	5.60	85.80
3	0 .198	6.73	87.45
4	0.212	6.99	87.56
5	0.242	8.80	88.10

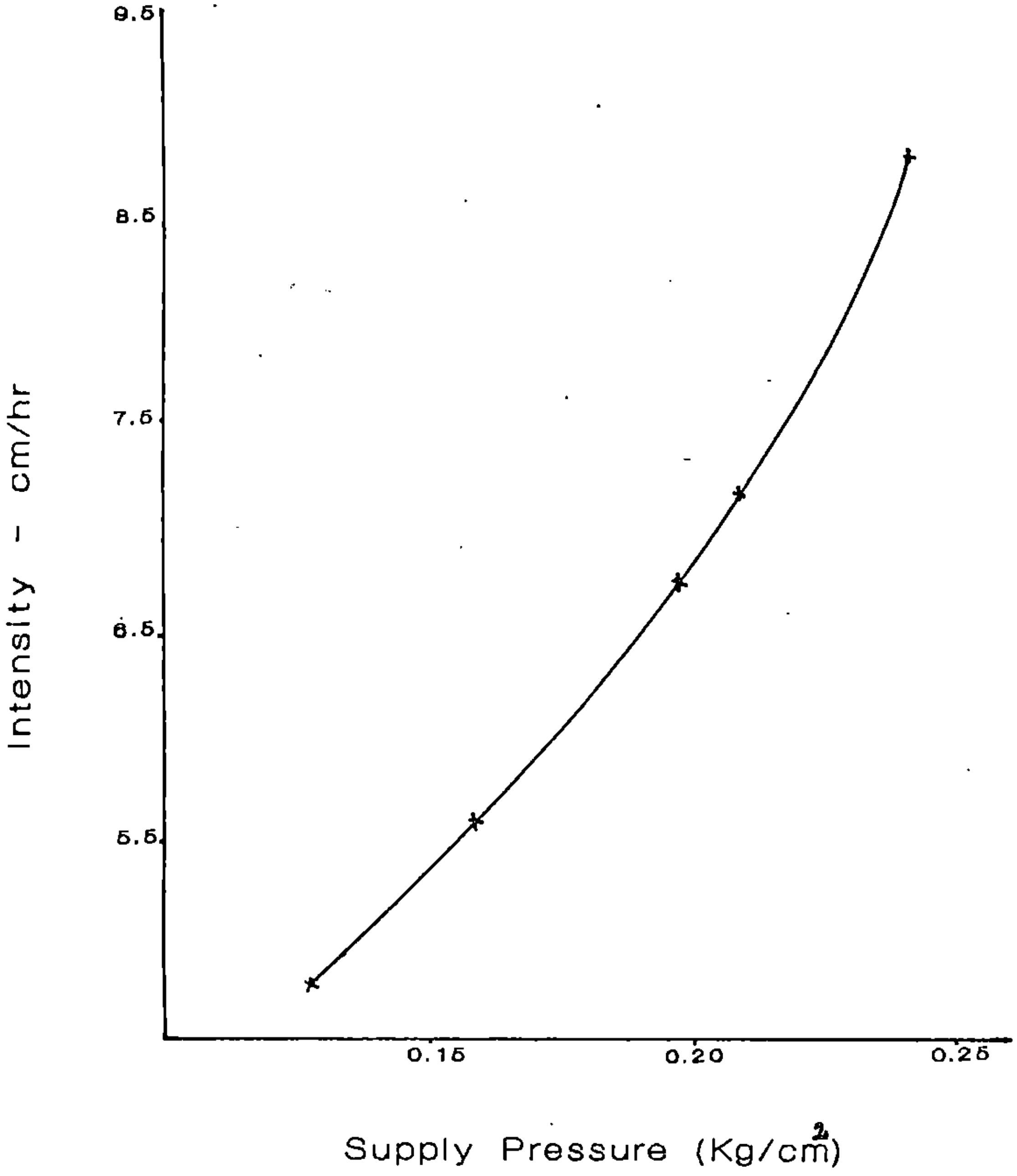

FIG-4 EFFECT OF SUPPLY PRESSURE ON INTENSITY

4.1.2 Droplet size

The intensity of rainfall produced by the simulator could be varied by changing the pressure of the supply of water to the simulator. The size of the droplets produced for different intensities of rainfall were measured and presented in Table 3. It was observed that for an intensity of 4.77 cm/hr the mean size of droplets produced was 2.31 mm. On increasing the intensity to 5.6 cm/hr the droplet size decreased to 2.20 mm. At a higher intensity of 8.8 cm/hr the droplet size was only 0.8 mm. The decreasing trend of droplet size with increase in intensity of simulated rainfall was in agreement with the results of earlier researches conducted. But in the case of natural rainfall the droplet size increases for intensities up to 8 cm/hr and thereafter decreases.

4.1.3 Uniformity of application

Experiments were conducted to determine the uniformity of the rainfall produced by the simulator at various intensities. The intensity of rainfall could be varied by suitably adjusting the height of the supply tank. The uniformity coefficients were determined for different intensities of rainfall. The results are presented in Table 4.

At 4.77 cm/hr intensity of rainfall the uniformity coefficient was 82.04, while at 8.8 cm/hr the uniformity coefficient was 88.1. Thus it was seen that the uniformity of application increased with the increase in the intensity of rainfall.

4.2 EROSION STUDY

The developed simulator was used in the laboratory study of erosion from a plot of size 1.5m X 1.5m. Laterite soil collected from the Instructional Farm of K.C.A.E.T.was filled in the plot equipment. Detailed mechanical analysis of the soil was conducted to study the grain size distribution. The results of the analysis are given in Table 5. The particle size distribution curve is shown in Fig. 5.

4.2.1 Effect of intensity of rainfall on soil erosion

Experiments were conducted to study the effect of intensity of rainfall on soil erosion. Intensities of rainfall selected were 4.77, 5.60, 6.73, and 8.80 cm/hr. Tests were conducted at the selected intensities on slopes varying from 5 to 20 per cent. The results obtained are presented in Tables 6, 7, 8 and 9. Graphs plotted between soil loss and intensity of rainfall for each slope are shown in Fig 6.

Table 5. Results of mechanical analyses of the field soil

Weight of dry soil sample 500 gm

Particle size mm	Weight retained g	Percentage retained	Cumulative Percentage retained	Cumulative Percentage finer
4.75	84.48	16.896	16.896	83.104
2.00	91.09	18.218	35.114	64.886
1.00	124.42	24.684	59.798	40.202
0.60	86.80	17.36	77.158	22.842
0.30	28.50	5.70	82.852	17.142
0.212	33.15	6.63	89.488	10.521
0.15	11.76	2.352	91.840	8.160
0.075	27.29	5.558	97.398	2.602
0.02	3.00	0.60	98.000	2.000
0.002	4.10	0.82	98.820	1.180
< 0.002	5.90	1.18	100.000	0.000

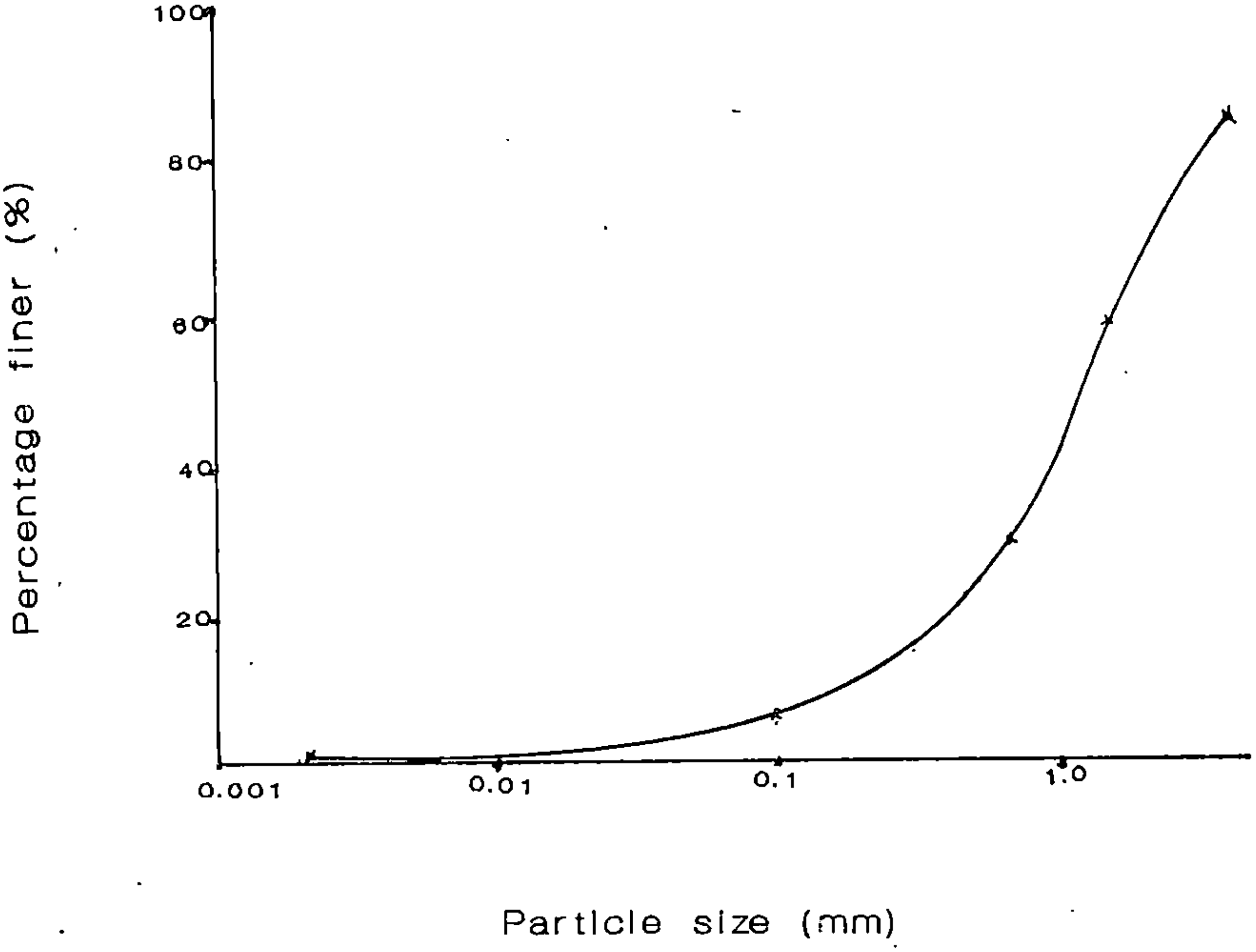

FIG-5 PARTICLE SIZE DISTRIBUTION CURVE OF FIELD SOIL

Table 6. Effect of intensity of rainfall on soil loss at 20 per cent slope

Sl.No.	Intensity cm/hr	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	4.77	19.15	510.66
2	5.60	27.74	739.74
3	6.73	50.36	1342.92
4	8.80	54.90	1464.00

Table 7. Effect of intensity of rainfall on soil loss at 15 per cent slope

Sl.No.	Intensity cm/hr	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	4.77	16.95	451.98
2	5.60	25.40	677.40
3	6.73	45.45	1212.00
4	8.80	52.10	1389.36

Table 8. Effect of intensity of rainfall on soil loss at 10 per cent slope

Sl.No.	Intensity cm/hr	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	4.77	10.50	280.00
2	5.60	22.50	600.00
3	6.73	39.00	1039.98
4	8.80	45.37	1209.84

Table 9. Effect of intensity of rainfall on soil loss at 5 per cent slope

Sl.No.	Intensity cm/hr	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	4.77	5.27	140.52
2	5.60	17.15	457.32
3	6.73	31.12	829.86
4	8.80	35.25	940.20

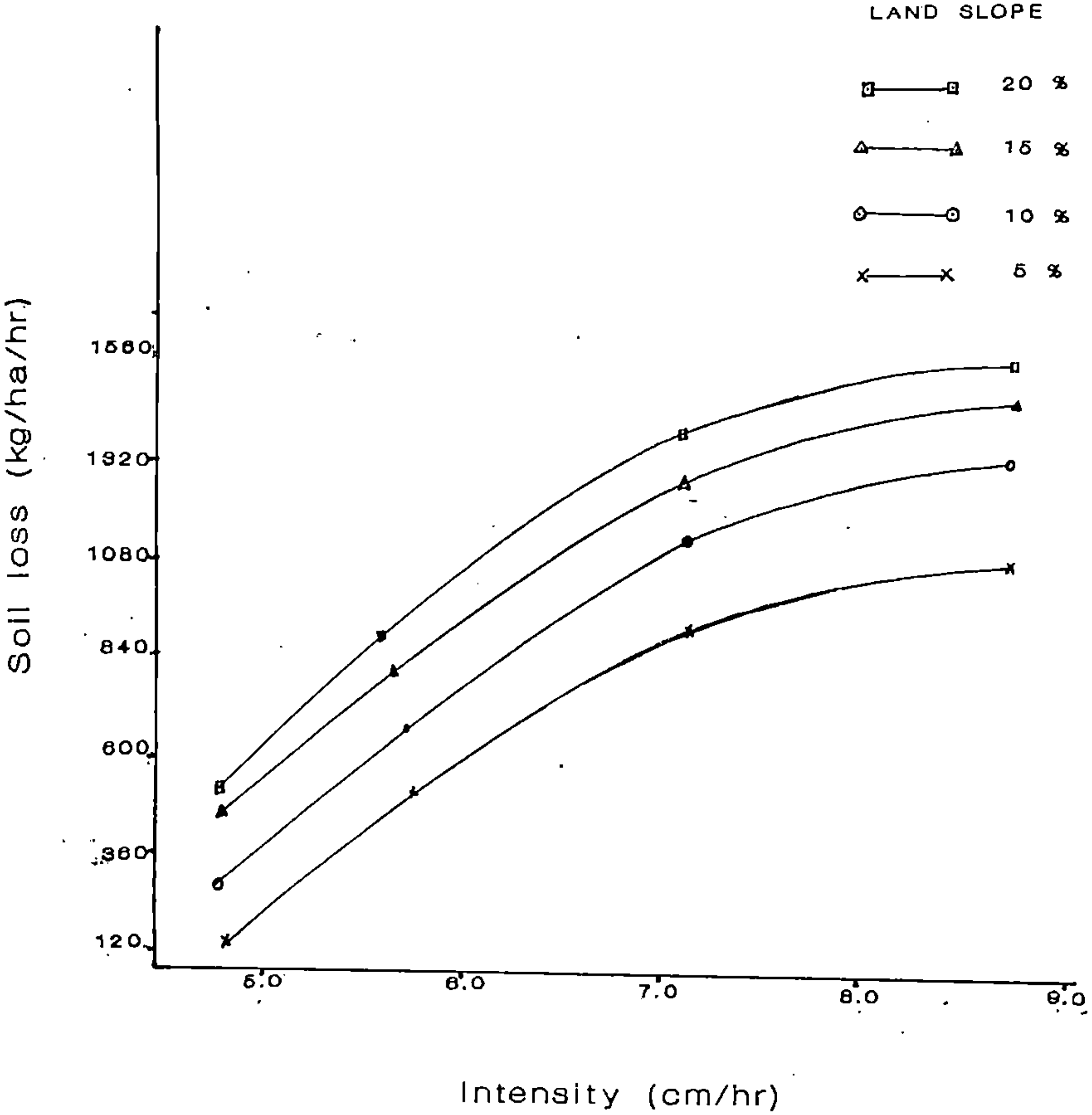

FIG-6 EFFECT OF INTENSITY ON SOIL EROSION

It was observed that the soil loss increased with the intensity of rainfall for all the slopes studied. At a rainfall intensity of 4.77 cm/hr, the soil loss from a plot of 5 per cent slope was 140.52 kg/ha/hr,while the soil loss was 940.2 kg/ha/hr when the intensity was raised to 8.8 cm/hr.Thus there was an increase in soil loss of 799.68 kg/ha/hr on increaing the intensity to 8.8 cm/hr from 4.77 cm/hr.The soil loss from the plot at 10 per cent slope and at 4.77 cm/hr intensity was 280 kg/ha/hr and on increasing the intrnsity to 5.6 cm/hr , the soil loss increased to 600 kg/ha/hr. At the higher intensity of 8.8 cm/hr the soil loss at 10 per cent slope was 1209.84 kg/ha/hr. Maximum soil loss of during this study was 1464 kg/ha/hr and it was from a slope of 20 per cent at an intensity of 8.8 cm/hr. The nature of the curves obtained for all the slopes studied were also similar.

4.2.2 Effect of land slope on soil erosion.

To study the effect of land slope on soil erosion experiments were conducted at 5,10,15 and 20 percentage slopes. Experiments were conducted at intensities of 4.77, 5.60,6.73 and 8.8 cm/hr. The results of the experiment are presented in Tables 10, 11, 12 and 13. At 4.77 cm/hr intensity of rainfall the soil loss from the land of slope 5 per cent was 140.52 kg/ha/hr, whereas the value increased to 280 kg/ha/hr for 10 per cent slope and the soil loss reached a higher value of 510.66 kg/ha/hr for

Table 10. Effect of land slope on soil loss at an intensity of 4.77 cm/hr

Sl.No.	Land slope %	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	5	5.27	140.52
2	10	10.50	280.00
3	15	16.95	451.98
4	20	19.15	510.66

Table 11. Effect of land slope on soil loss at an intensity of 5.60 cm/hr.

Sl.No.	Land slope %	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	5	17.15	457.32
2	10	22.50	600.00
3	15	25.40	677.40
4	20	27.74	739.74

Table 12. Effect of land slope on soil loss at an intensity of 6.73 cm/hr.

Sl.No.	Land slope %	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	5	31.12	829.86
2	10	39.00	1039.98
3	15	45.45	1212.00
4	20	50.36	1342.92

Table 13. Effect of land slope on soil loss at an intensity of 8.80 cm/hr.

Sl.No.	Land slope %	Soil loss for 10 min. g	Soil loss kg/ha/hr
1	5	35.25	940.20
2	10	45.37	1209.84
3	15	52.10	1389.36
4	20	54.90	1464.00

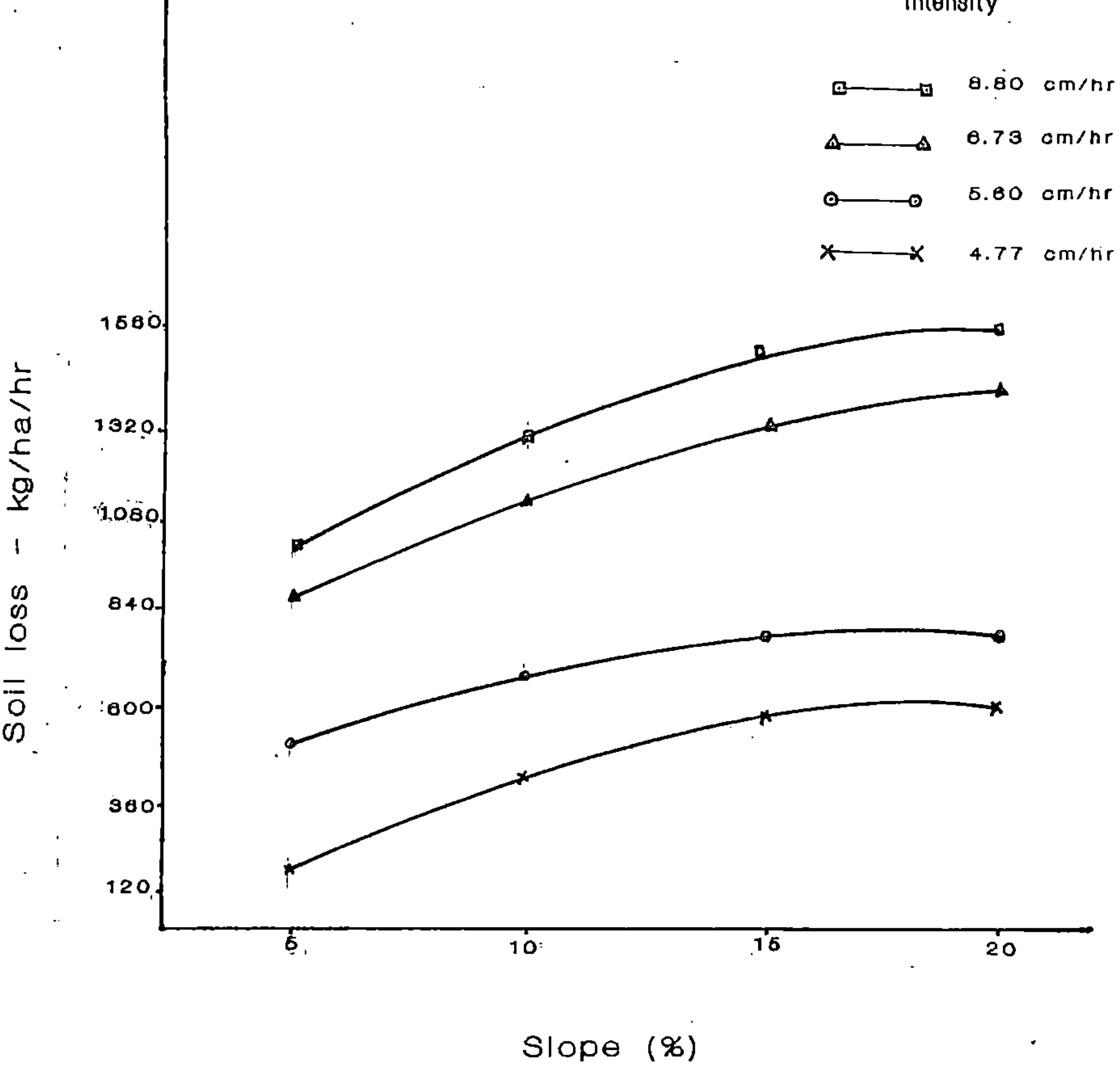

FIG-7 EFFECT OF LAND SLOPE ON SOIL EROSION

20 per cent slope. At a higher intensity of 8.8 cm/hr the soil loss from a plot of 5 per cent slope was 940.2 kg/ha/hr, while the soil loss was 1464 kg/ha/hr when the slope of the land was increased to 20 per cent.

A graph plotted with slope on X-axis and soil loss on Y-axis for different values of intensity of rainfall is shown in Fig 7. A general trend of increase in the soil loss with the slope was seen in all the graphs.

4.2.3 Empirical equation for soil erosion

A multiple regression equation relating soil erosion, intensity of rainfall and land slope was developed. The developed equation is as follows

$$E = -982.384 + 2834.63\ S + 225.239\ I \qquad (R = 0.94)$$

where,

E - quantity of soil eroded in kg/ha/hr

S - land slope in decimal

I - intensity of rainfall in cm/hr

R - coefficient of multiple linear regression

4.2.4 Effect of intensity of rainfall on runoff

Tests were conducted to study the effect of intensity of rainfall on runoff, on slopes of 5, 10, 15, and 20 percentages. Simulated rainfall of intensities 4.77, 5.6, 6.73 and 8.8 cm/hr were applied on each slope. The runoff collected was measured. The data obtained from slopes above 15 per cent was highly erratic. The results obtained are presented in Tables 14, 15 and 16. Graphs plotted between intensity of rainfall and runoff obtained from each slope are shown in Fig. 8.

At 5 per cent slope the runoff obtained for an intensity of 4.77 cm/hr was 144.8 m^3/ha/hr. On increasing the intensity to 5.6 cm/hr the runoff increased to 325.33 m^3/ha/hr and the value increased further to 432.0 m^3/ha/hr at 6.73 cm/hr intensity. The runoff volume reached a value of 526.67 m^3/ha/hr at 8.8 cm/hr intensity. The graphs obtained for various slopes studied were similar in nature. The runoff volume from 15 pre cent slope at 8.8 cm/hr intensity was 572.53m^3/ha/hr, whereas for slope of 5 per cents it was 526.67m^3/ha/hr respectively. It was observed that as the intensity increases the runoff also increases.

Table 14. Effect of intensity of rainfall on runoff at 15 per cent slope

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	4.77	11.40	366.67
2	5.60	16.13	430.13
3	6.73	18.80	501.33
4	8.80	21.47	572.53

Table 15. Effect of intensity of rainfall on runoff at 10 per cent slope

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	4.77	5.98	159.47
2	5.60	13.50	360.00
3	6.73	18.25	486.67
4	8.80	22.25	593.33

Table 16. Effect of intensity of rainfall on runoff at 5 per cent slope

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	4.77	5.43	144.80
2	5.60	12.20	325.33
3	6.73	16.20	432.00
4	8.80	19.75	526.67

Table 17. Effect of land slope on runoff at an intensity of 4.77 cm/hr

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	5	5.43	144.80
2	10	5.98	159.47
3	15	13.75	366.67

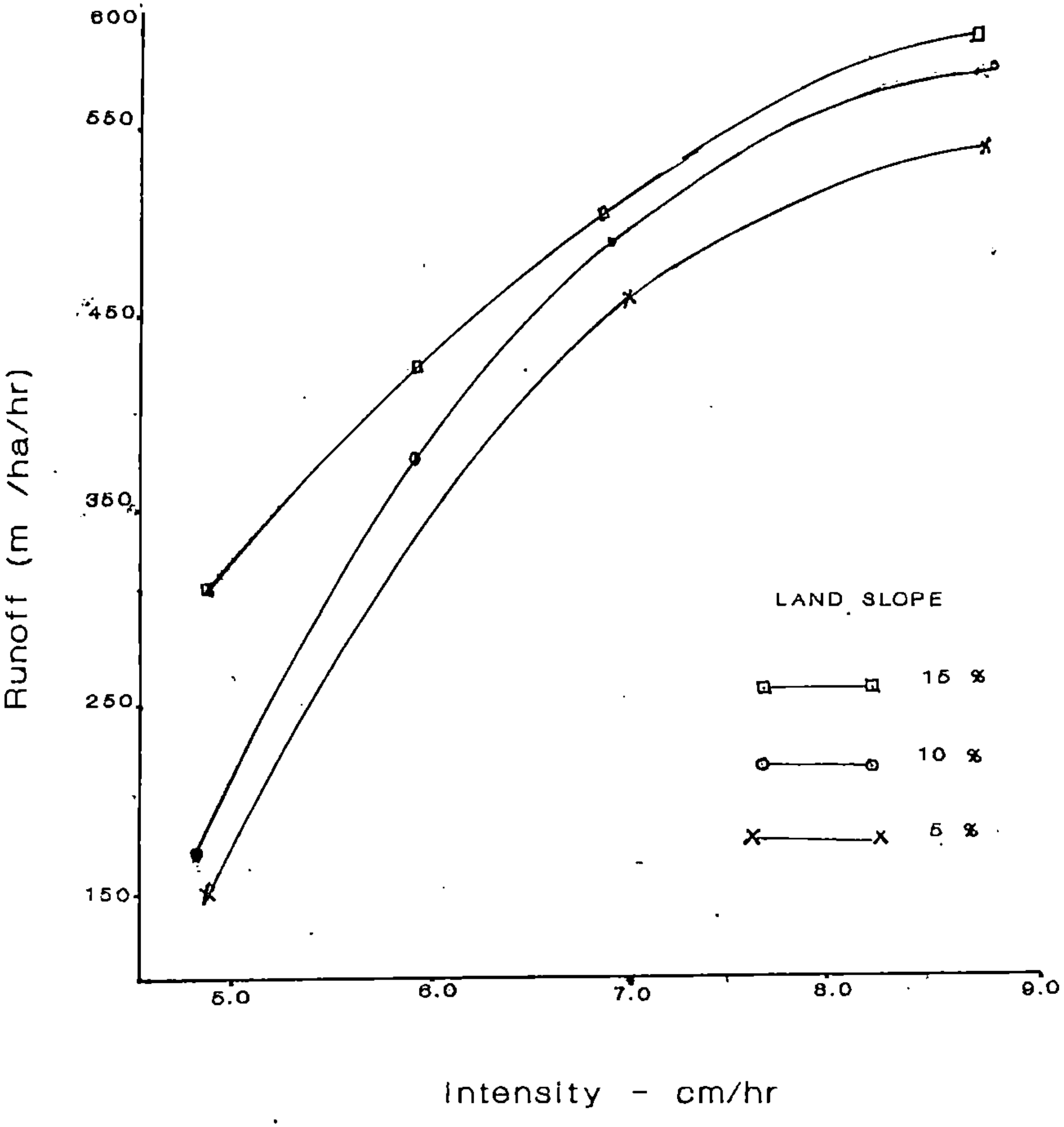

FIG-8 EFFECT OF INTENSITY OF RAINFALL ON RUNOFF

4.2.5 Effect of land slope on runoff

Tests were conducted at slopes of 5, 10, 15 and 20 percentage to study the effect of land slope on runoff. Experiments were conducted at simulated intensities of 4.77, 5.6, 6.73 and 8.8 cm/hr. The corresponding runoff were measered. The results of the experiment are presented in Tables 17, 18, 19 and 20. Graphs plotted between land slope and runoff for selected intensities of rainfall are shown in Fig. 9.

From the graph it was seen that the runoff increased with the slope. On slopes above 15 per cent, the data obtained were erratic. This may be due to the small size of the plot and pre saturation conditions of the soil under study. From the figures it also revealed that the runoff increases with increase in the intensity of rainfall for a particular value of slope.

4.2.6 Empirical equation for runoff

A multiple regression equation relating runoff, intensity of rainfall and land slope was developed. The developed equation is as follows,

$$Q = -216.174 + 1104.65\ S + 79.375\ I$$

$$(R = 0.92)$$

Table 18. Effect of land slope on runoff at an intensity of 5.60 cm/hr

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	5	12.20	325.33
2	10	13.50	360.00
3	15	16.13	430.13

Table 19. Effect of land slope on runoff at an intensity of 6.73 cm/hr

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	5	16.20	432.00
2	10	18.25	486.67
3	15	18.80	501.33

Table 20. Effect of land slope on runoff at an intensity of 8.80 cm/hr

Sl.No.	Intensity cm/hr	Runoff for 10 min. l	Runoff m^3/ha/hr
1	5	19.75	526.67
2	10	22.25	593.33
3	15	21.47	572.53

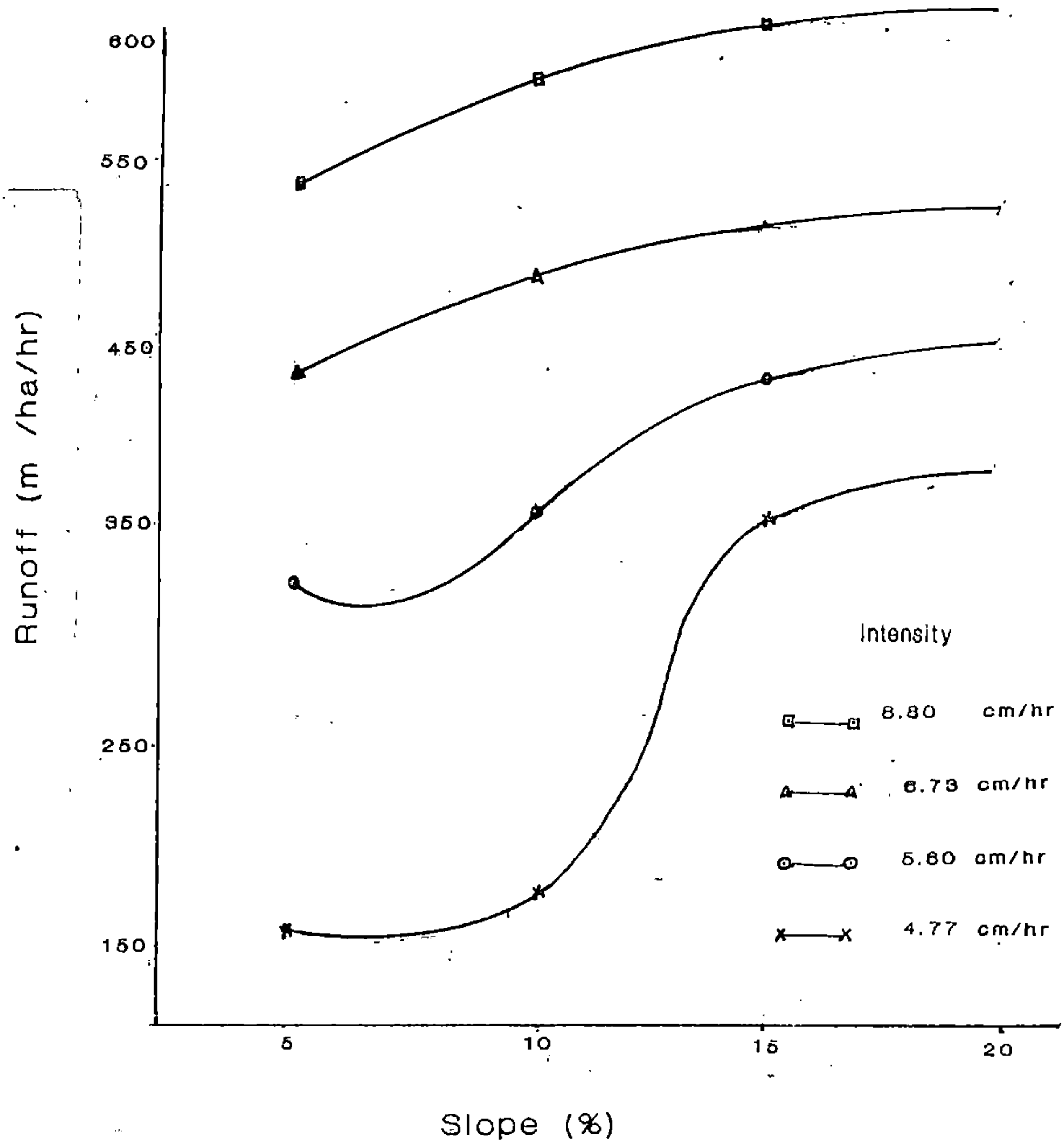

FIG-9 EFFECT OF LAND SLOPE ON RUNOFF

Where,

Q - runoff in m^3/ha/hr

S - land slope in decimal

I - intensity of rainfall in cm/hr

R - coefficient of multiple linear regression

4.2.7 Grain size of eroded soil

The grain size of the eroded soil from all slopes of 5, 10, 15 and 20 percentages at 8.8 cm/hr intensity was studied. The eroded soils were collected and a combined sieve and pipette method of particle size analysis of the eroded samples were conducted. The results are tabulated in Table 21.

A semi-logarithmic plot of grain size and percentage finer for different slopes are shown in Fig.10.

From the results obtained it was seen that the particles of size more than 2 mm were not present in the eroded sample collected from all the four slopes. This may be due to the less time of exposure to the rain, the particles detached might not have got the opportunity time to travel to sediment collectors. From the graphs obtained it was seen that for a particle size of 0.2 mm the percentage finer was 74.3 at 5 per cent slope and the corresponding percentage finer at 10, 15

Table 21. Results of mechanical analysis of the eroded soil

Slope %	Particle size mm	percentage retained	Cumulative Percentage retained	Percentage finer
5	2.00	0.00	0.00	100.00
	0.20	25.70	25.70	74.30
	0.02	23.00	48.70	51.30
	0.002	22.10	70.80	29.20
	< 0.002	29.20	100.00	0.00
10	2.00	0.00	0.00	100.00
	0.20	25.20	25.20	74.80
	0.02	22.80	48.00	52.00
	0.002	22.60	70.60	29.40
	< 0.002	29.40	100.00	0.00
15	2.00	0.00	0.00	100.00
	0.20	24.80	24.80	75.20
	0.02	22.60	47.40	52.60
	0.002	22.20	69.60	30.40
	< 0.002	30.40	100.00	0.00
20	2.00	0.00	0.00	100.00
	0.20	24.60	24.60	75.40
	0.02	23.20	47.80	52.20
	0.002	22.40	70.20	29.80
	< 0.002	29.80	100.00	0.00

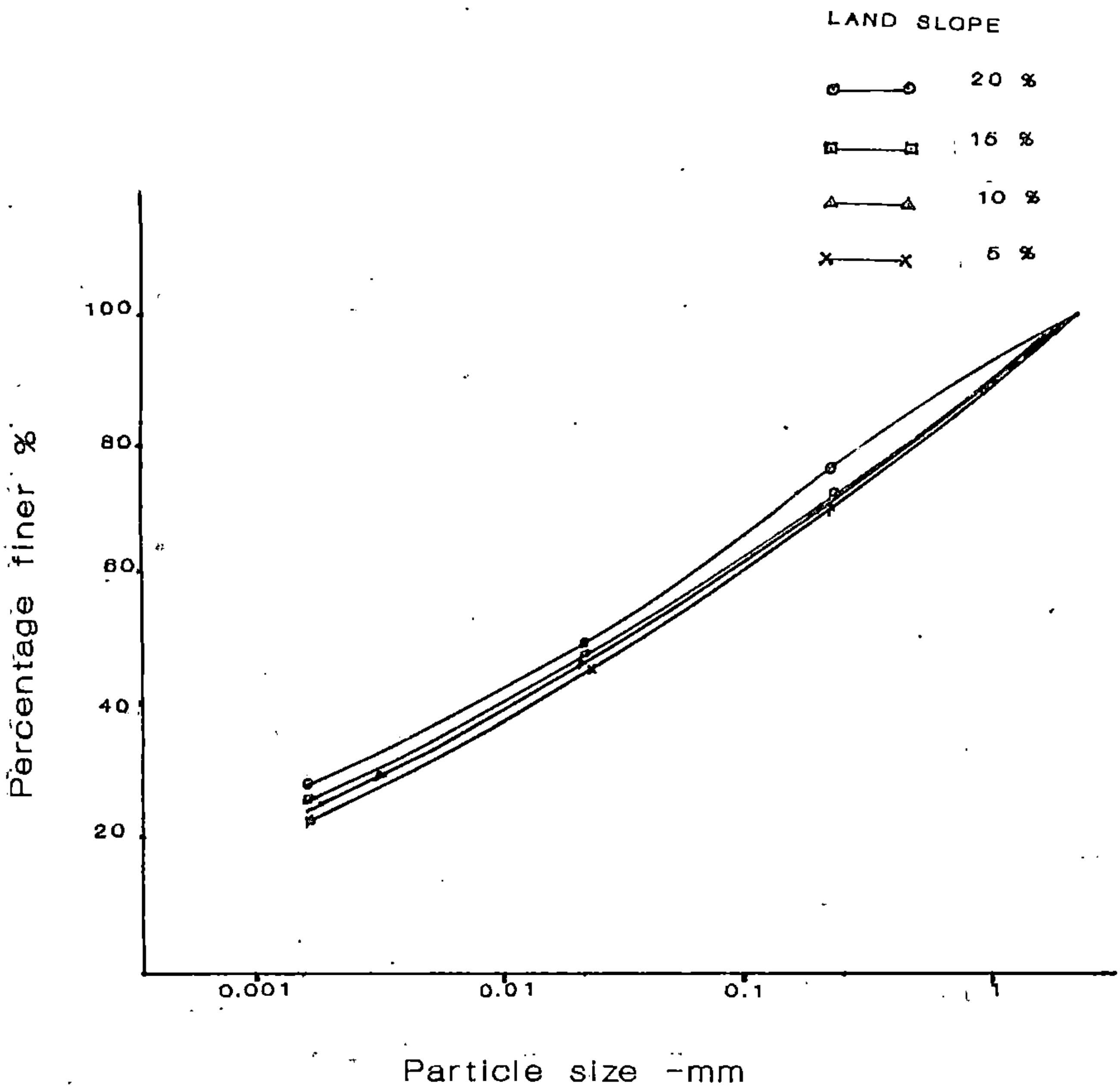

FIG-10 PARTICLE SIZE DISTRIBUTION CURVE OF ERODED SOIL and 20 per cent slopes were 74.8, 75.2 and 75.4 respectively. Similarly for a particle size of 0.02 mm, the percentage fine was 51.3 at 5 per cent slope and the corresponding percentages of fines at 10, 15, and 20 per cent slopes were 52, 52.6 and 52.2 respectively. The same trend was observed for other sizes also.

SUGGESTIONS FOR FURTHER WORK

As a result of the present study conducted, the following areas are considered important for further investigations

1. In the present study it was observed that the droplet size decreased with increase in intensity of rainfall whereas in the case of natural rainfall the droplet size increases with intensity. Further studies can be attempted to develop a drop former unit producing droplets similar to natural rainfall.

2. Experiments on erosion were conducted on bare soil during this study. A detailed investigation is suggested to ascertain the influence of vegetative cover on erosion.

SUMMARY

Deterioration of soil due to erosion is considered as a principal reason for low agricultural production. Severe erosion occurs due to high rainfall and improper management of land and water. Excessive loss of nutrients also takeplace together with soil erosion. Rainfall is considered as the most important agency responsible for erosion.Rain drops cause the soil to be splashed and the flowing water carries the detached particles.

Rainfall simulators are considered as effective aids in soil erosion research.Simulators make it possible to produce predetermined storms at any desired time and location. Results of the erosion studies can be obtained with rainfall simulators in a short period of time compared to studies involving natural rainfall.A rainfall simulator suitable for erosion studies was designed and fabricated at KCAET,Tavanur. The rainfall simulator designed and fabricated in this study was of an oscillating, tubing tip type. The design intensity of rainfall was based on the maximum intensity of 10 - minute rainfall recorded in Kerala. Hypodermic needles were used as the drop formers. Inorder to prevent the drops from repeatedly falling on the same spot,the drop former unit was designed as an oscillating one.

The rainfall simulator consisted of a drop former unit, a supporting frame work,power transmission system and provision for water supply. The drop former unit consisted of hypodermic needles fitted on a 1.8cm diameter GI pipe network. The network had four transverse pipes and each transverse pipe was fitted with 28 needles. Two drop former units,one fitted with 20 gauge needles and the other with 18 gauge needles were fabricated. The drop former unit with 18 gauge needles was used in further studies. In order to support the drop former unit, an angle iron frame work was fabricated. The frame work was supported by legs of 3 m height. The drop former unit was made to oscillate at 8 oscillations per minute.The water supply to the simulator was taken from an overhead tank.The pressure of water supply was varied adjusting the height of the tank.

The simulator was tested for intensity, drop size and uniformity of application. The simulator could produce various intensities by changing the pressure of water supply.From the test results a relationship was established between intensity and the supply pressure of water as,

$$I = 6.0386 - 31.9152\,P + 177.30\,P^2$$

where,

I - Intensity, cm/hr

P - Pressure, kg/cm^2

The dropletsize decreased with the intensity of rainfall. The mean droplet size obtained was 2.31 mm at 4.77 cm/hr intensity and it decreased to 0.8 mm when the intensity was increased to 8.80 cm/hr. Christiansen's uniformity coefficients were determined for differeent intensities of rainfall. Higher values of uniformity coefficients were obtained at higher intensities.The uniformity coefficients varied from 82 to 88 per cent corresponding to intensity variations ranging from 4.77 to 8.80 cm/hr.

A plot equipment was fabricated to hold the soil at the required slope for erosion studies. It consisted of a soil collection unit for holding the soil over an area of 1.5 m x 1.5 m and a conduit for conveying the runoff.

Experiments were conducted to study soil loss and runoff from laterite soil. The studies were conducted for 4.77, 5.60, 6.73 and 8.80 cm/hr intensities of rainfall at 5, 10, 15 and 20 per cent slopes.

The soil loss increased with the intensity of rainfall for all the slopes studied. At a rainfall intensity of 4.77 cm/hr the soil loss from a slope of 5 per cent was 140.52 kg/ha/hr, while the soil loss was 940.20 kg/ha/hr when the intensity was raised to 8.80 cm/hr. Maximum soil loss during this study occured from a slope of 20 per cent at 8.80 cm/hr intensity of rainfall. The soil loss from 20 per cent slope at 8.80 cm/hr intensity was 1464 kg/ha/hr.

A general trend of increase in the soil loss with the slope was observed for all the simulated intensities of rainfall. At 4.77 cm/hr intensity the soil loss from a slope of 5 per cent was 140.52 kg/ha/hr whereas the soil loss increased to 280 kg/ha/hr for 10 per cent slope.The soil loss from a slope of 20 per cent at the same intensity of 4.77 cm/hr was 510.66 kg/ha/hr. At a higher intensity of 8.80 cm/hr the soil loss from 5 per cent slope was 940.20 kg/ha/hr while the soil loss from 20 per cent slope was 1464 kg/ha/hr for the same intensity.

The runoff obtained for a rainfall intensity of 4.77 cm/hr from a slope of 5 per cent was 144.8 m^3/ha/hr. The runoff from the same slope of 5 per cent at 5.6 cm/hr intensity was 325.33 m^3/ha/hr and the runoff increased further to 432 m^3/ha/hr at 6.73 cm/hr intensity. The graphs plotted between runoff and intensity for various slopes studied were similar in nature. In general the runoff increased with slope.

Empirical equations were developed for estimating soil erosion and runoff for various intensities of rainfall and land slopes. The equations are :

1. $E = -982.384 + 2834.63\,S + 225.239\,I$

$(R = 0.94)$

2. $Q = -216.174 + 1104.65\,S + 79.375\,I$

$(R = 0.92)$

where,

E - quantity of soil eroded in kg/ha/hr

Q - runoff in m^3/ha/hr

S - land slope in decimal

I - intensity of rainfall in cm/hr

Particle size analysis of the eroded soil samples obtained from the 5,10,15 and 20 per cent slopes at 8.80 cm/hr intensity was done. It was seen that particles of size more than 2 mm were not present in the eroded samples.

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APPENDICES

APPENDIX - I

Determination of hypodermic needle diameter

The intensity of rainfall selected are

$I_1 = 4.80$ cm/hr $\quad I_2 = 5.6$ cm/hr

$I_3 = 7.0$cm/hr $\quad I_4 = 8.80$ cm/hr

Taking $I_1 = 4.8$ cm/hr

$= 1.89$ inch/hr

As per Mc Gregor and Mutchler (1976)

$$D_{50} = 2.76+11.40\ e^{(-1.04I)}-13.16\ e^{(-1.17\ I)} \text{ --------(1)}$$

where,

I - intensity of rainfall, inch/hr

$$D_{50} = 2.76 +11.40\ e^{(-1.04x1.89)}-13.16e^{(-1.17x1.89)}$$

$$= 2.9137 \text{ mm}$$

Volume of drop' $V_1 = \dfrac{\pi\ (D_{50})^3}{6}$

$= 12.9518$ mm^3

Weight of the drop $w_1 = 0.01295$ g

Substituting in the equation suggested by Mutchler(1965)

$$w = 4.924 \frac{\sigma^{0.943}\ d^{0.832}\ Q^{0.057}\ r^{0.093}}{g^{1.018}}$$

where,

w - water drop weight, g

σ - 73.575 g/sec^2

r - 0.00804 cm^2/sec

g - 981 cm/sec^2

To calculate, Q the flow rate per tube,

Area covered by the simulator = 2.6x2.2

$\doteq$ 5.72 m^2

Intensity I_1 = 4.8 cm/hr

Total volume of rainfall = 0.27456 m^3/hr

Total number of needles = 112

Flow per tube Q_1 = 0.681g/sec

substituting for $Q = Q_1$ in equation (2)

$$0.01295 = 4.924 \frac{73.575^{0.943} \, d^{\,0.832} \; 0.681^{0.057} \; 0.00804^{\,0.093}}{981^{1.018}}$$

on simplification

$d = 0.04889$ cm

ie

diameter of the needle = 0.04889 cm 25 gauge

similarly

Taking I_2 = 5.6 cm/hr

Diameter of the needle d_2 = 0.0429 cm 25 gauge

Taking I_3 = 7 cm/hr

Diameter of the needle = 0.0456 cm 26 gauge

Taking I_4 = 8.80cm/hr

The diameter of the needle = 0.0429 cm 27 gauge

APPENDIX-II

Intensity and uniformity of simulated rainfall at different pressures

Diameter of the catch can = 10cm

Sl. No.	Pressure kg/cm^2	Volume of water collected at different stations for 30 minutes (cm^3)									Intensity cm/hr	Uniformity coefficient
		s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9		
1	0.128	192	221	175	240	195	152	220	154	137	4.77	82.04
2	0.158	244	222	213	334	157	210	219	220	190	5.60	85.8
3	0.198	305	284	213	272	301	285	198	289	233	6.73	87.45
4	0.212	260	256	247	298	328	351	237	238	258	7.00	87.56
5	0.242	398	339	289	389	390	384	272	298	353	8.80	88.10

APPENDIX - III

Soil loss and runoff from the test plot.

Area of the test plot = 2.25 m^2

Duration = 10 min

(a)

Pressure kg/cm^2	Intensity cm/hr	Slope %	Runoff l	Mean runoff l	Runoff m^3/ha/hr	Soil Loss g	Mean soil loss g	Soil loss kg/ha/hr
0.128	4.77	5	4.9 5.5 5.9	5.43	144.8	4.65 5.43 5.72	5.27	140.52
0.158	5.6	5	12.35 11.75 12.2	12.2	325.33	17.7 16.45 17.29	17.15	457.32
0.198	6.73	5	14.75 17.35 16.5	16.2	432.0	29.33 32.82 33.19	31.12	829.86
0.242	8.8	5	19.25 17.85 22.15	19.75	526.67	34.35 30.36 41.03	35.25	940.20

(b)

Pressure kg/cm2	Inte-nsity cm/hr	Slope %	Runoff l	Mean runoff l	Runoff m^3/ha/hr	Soil Loss g	Mean soil loss g	Soil loss kg/ha/hr
0.128	4.77	10	5.43 5.5 7.1	5.98	159.47	9.69 9.75 12.05	10.5	280.00
0.158	5.6	10	13.19 14.44 12.81	13.5	360.00	20.02 24.10 23.38	22.50	600.00
0.198	6.73	10	18.83 17.58 18.33	18.25	486.67	35.08 41.24 40.67	39.00	1039.98
0.242	8.8	10	22.75 22.25 21.75	22.25	593.33	48.49 44.27 43.35	45.37	1209.84

(c)

l. o.	Pressure kg/cm2	Intensity cm/hr	Slope %	Runoff l	Mean runoff l	Runoff m^3/ha/hr	Soil loss g	Mean soil loss g	Soil loss kg/ha/hr
1	0.128	4.77	15	13.0 14.0 14.25	13.75	366.67	15.53 16.26 19.06	16.95	451.98
2	0.158	5.6	15	16.00 16.40 16.00	16.13	430.13	24.10 26.90 25.69	25.40	677.40
3	0.198	6.73	15	18.83 18.57 19.00	18.80	501.33	45.52 44.89 45.93	45.45	1212.00
	0.242	8.8	15	21.60 21.40 21.40	21.47	572.53	52.72 51.24 52.34	52.10	1389.36

II (d)

Sl. No.	Pressure kg/cm2	Intensity cm/hr	Slope %	Runoff l	Mean runoff l	Runoff m^3/ha/hr	Soil Loss g	Mean soil loss g	Soil loss kg/ha/hr
1	0.128	4.77	20	11.78 11.28 11.14	11.40	304.00	18.69 20.63 18.14	19.15	510.60
2	0.158	5.6	20	14.00 16.33 15.19	15.17	404.53	26.10 28.85 28.27	27.74	739.74
3	0.198	6.73	20	18.83 17.58 18.33	18.25	486.67	51.97 48.52 50.59	50.36	1342.92
4	0.242	8.8	20	22.75 22.24 21.75	22.24	593.07	55.10 54.78 54.83	54.90	1464.00

DESIGN, FABRICATION AND TESTING OF A RAINFALL SIMULATOR

BY

KURIEN. E. K.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering & Technology
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1993

ABSTRACT

Rainfall simulators are considered as effective aids in soil conservation research. Simulators make it possible to produce predetermined storms at any desired time and location. A rainfall simulator suitable for soil erosion studies was designed and fabricated at KCAET Tavanur.The developed simulator was tested for its performance. Erosion studies on laterite soil was conducted using the developed simulator.

The rainfall simulator designed and fabricated was of an oscillating, tubing tip type. The drop former unit consisted of 112 numbers of 18 gauge hypodermic needles fitted on a 1.8 cm GI pipe network. The speed of oscillation was 8 oscillations per minute. The drop former unit was supported at a height of 3 m above ground level.Intensity of rainfall was varied by changing the pressure of water supply to the simulator.

The simulator was tested for intensity, droplet size and uniforimity of application of the rainfall produced. The intensity of rainfall was related to the pressure of water supply as

$$I = 6.0386 - 31.9152 P + 177.30 P^2$$

The drop size obtained was 2.31 mm for an intensity of 4.77 cm/hr and the corresponding drop sizes for intensities of 5.60, 6.73, 6.99 and 8.80 cm/hr were 2.20, 2.18, 1.05 and 0.80 mm respectively. Christiansen's uniformity coefficients calculated for intensities ranging from 4.77 to 8.80 cm/hr varied from 82 to 88 per cent.

Experiments were also conduced to study soil loss and runoff from laterite soil.The soil loss increased with the intensity of rainfall for all the slopes studied. Maximum soil loss of 1464 kg/ha/hr occured from a slope 20 per cent at a rainfall intensity of 8.80 cm/hr. A general trend of increase in soil loss with slope was observed. At an intensity of 8.80 cm/hr the soil loss from 5 per cent slope was 940.2 kg/ha/hr whereas the soil loss from 20 per cent slope was 1464 kg/ha/hr for the same intensity. At 5.60 cm/hr intensity of rainfall the runoff from a slope of 5 per cent was 325.33 m^3/ha/hr whereas the runoff was 432m^3/ha/hr at 6.73 cm/hr intensity for the same slope.

Empirical equations were developed for estimating soil erosion and runoff for various intensities of rainfall and land slopes. The equations are :

1. $E = -982.384 + 2834.63\ S + 225.239\ I$

   $(R = 0.94)$

2. $Q = -216.174 + 1104.65\ S + 79.375\ I$

   $(R = 0.92)$