ERODIBILITY AND RUNOFF POTENTIAL OF LATERITE SOILS UNDER SIMULATED RAINFALL CONDITIONS

By
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THESIS
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DECLARATION

I hereby declare that this thesis entitled "**ERODIBILITY AND RUNOFF POTENTIAL OF LATERITE SOILS UNDER SIMULATED RAINFALL CONDITIONS**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Tavanur,

23.10.1999.

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CERTIFICATE

Certified that this thesis entitled **"ERODIBILITY AND RUNOFF POTENTIAL OF LATERITE SOILS UNDER SIMULATED RAINFALL CONDITIONS"** is a record of research work done independently by **Smt. Sajeena, S.**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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SAJEENA, S.

Dedicated to
My Husband and Daughter

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SYMBOLS AND ABBREVIATIONS

Agric.	-	Agricultural
Am.	-	America
ASAE	-	American Society of Agricultural Engineers
Bull.	-	Bulletin
°C	-	Degree centigrade
cm	-	centimetre(s)
cm/h	-	centimetre per hour
chap.	-	chapter
Cir	-	Circular
Cons.	-	conservation
contd.	-	continued
Dept.	-	Department
Engg.	-	Engineering
et al.	-	and other people
etc.	-	etcetra
Fig.	-	Figure
ft	-	feet
g	-	gram(s)
G	-	Gauge
G.I	-	Galvanized Iron
G.V.	-	Gate valve
h	-	hour

ha	-	hectare(s)
i.e	-	that is
J.	-	Journal
kg	-	kilogram
kg/cm^2	-	Kilogram per square centimetre
kg/ha/h	-	kilogram per hectare per hour
m	-	metre(s)
m^2	-	square metre(s)
m^3	-	cubic metre(s)
min.	-	minute
ml	-	millimetre(s)
mm	-	millimetre(s)
mm/h	-	millimetre per hour
m^3/ha/h	-	cubic metre per hectre per hour
manag.	-	management
No.	-	number
pp.	-	pages
proc.	-	proceedings
PVC	-	Poly Vinyl Chloride
Res.	-	Research
Resour	-	Resources
rpm	-	revolutions per minutes
s	-	second(s)

Sci.	-	Science
Soc.	-	Society
t	-	tonne(s)
t/ha	-	tonne per hectare
Tech.	-	Technical
Tr.	-	Transactions
Univ.	-	University
USDA	-	United States Department of Agriculture
Vol.	-	volume
&	-	and
°	-	degree(s)
>	-	greater than
<	-	less than
/	-	per
%	-	per cent

Introduction

INTRODUCTION

Soil constitutes the physical basis for our agriculture. One of the principal reasons for low productivity in agriculture is the progressive deterioration of soil due to erosion. Soil erosion is the detachment, transportation and deposition of material from one place to another through the action of wind or water.

Soil erosion by rain involves the transport of soil particles by a number of processes. Particle transport by drop splash and surface water flow may occur in series or in parallel or together depending on the size and topography of an eroding area. Erosion is a primary source of sediment that pollutes streams and fills reservoirs there by reducing their capacity and useful life. Erosion also adds to the removal of valuable plant nutrients with the runoff.

In India there is very little area free fiom the hazards of soil erosion. It is estimated that out of the 305.9 million hectares of reported area of land utilized, 145 million hectares are in need of conservation measures. In Kerala, it is estimated that out of 2.248 lakh hectares of cropped land 1.757 lakh hectares are in need of conservation measures (Gurmel Singh *et al.*, 1990). Severe erosion occurs in the sub-humid and humid areas due to high rainfall and improper management of land and water. The problem of soil erosion and consequent depletion of soil fertility in the State is due to high intensity rainfall and undulating topography of cultivated land.

Rainfall is the major detaching agent in water erosion. The capacity of rainfall to transport soil by splash is a function of degree of slope, rainfall characteristics, soil properties, micro-topography and wind velocity. Rain drop erosion or splash erosion results from soil splash caused by the impact of falling rain drops. The falling rain drops break down soil aggregates and detach soil particles from soil mass and cause them available for transport. Rain drop splash is of major importance as a contributor to erosion. 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. Knowledge of runoff and soil loss values under varying field conditions are a pre-requisite in the design of soil conservation structures.

In India, laterite soil occupy an area of 1,30,066 sq km and is well developed on the summits of Deccan hill, Karnataka, Kerala and Eastern Ghats, West Maharashtra and Central parts of Orissa and Assam. In the Indian Peninsula laterite and related residual deposits of bauxite, iron, manganese and nickel ore have widespread distribution at varied altitudes. Two forms of laterites have been recognised in India, high level and low level, the latter frequently supposed to be of detrital origin. The high level form was found to cap the summits of hills and plateau on the high lands of Central and Western India whereas, the low level laterite was associated with large tracts in the neighbourhood of both coasts of the Deccan Peninsula.

Laterite soils are by far the most important soil group in Kerala covering the largest area. The broad belt of land lying between the sea and the eastern hilly regions of the State, varying in width from 50-100 km, is a lateritic belt. The soil is porous, well drained and have poor capacity for retaining moisture. Kerala State forms the "type locality" of laterites. Almost every crop grown in the State is cultivated on laterite soils. The lateritic terrain of Kerala occupies the midland region of the State and this tract can be considered as the backbone of the State, as its economy depends upon this terrain which produce most of its cash crops.

Most of the soil erosion by water occurs during and immediately following a relatively few rainstorms, which may occur almost at any time. Erosion research under such conditions has numerous limitations. Simulated rainfall may be applied at selected intensities, for known durations and land treatment conditions. Such control is much greater than with natural rainfall. Research data regarding soil loss from laterite soils are few. This study will provide valuable information in estimating soil loss from laterite soils, which can be effectively used in planning land use and conservation methods.

Rainfall simulators have gained wide acceptance as a useful tool for infiltration and erosion research. Simulators produce rainfall events that may be replicated at any desired time or location, making it possible to collect data in a timely and cost effective manner. To be most effective, a simulator must reproduce the drop characteristics and intensities of the natural rainfall of the area in which they are to be used.

Researchers studying runoff and soil loss from rainfall have recognized the desirability of using rainfall simulators to supplement and expedite their investigations. The use of a rainfall simulator enables nearly immediate evaluation of carefully controlled plot conditions as well as observation of the erosion processes involved. Basic characters of a natural rain storm which are required to be simulated in a laboratory are rainfall intensity, uniformity of distribution of rain drops, drop size and rainfall velocity approaching the terminal velocity of the natural rainfall.

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 and 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 is difficult.

Rainfall simulators based on the type of accessories fitted on them could be grouped into (1) pipes and orifices, (2) tubing tip/hanging yarn/hypodermic needles, (3) rotating disc type, (4) nozzle type and (5) air and water mixture system. The oscillating tubing tip type rainfall simulator developed by Kurien and George (1998) at KCAET, Tavanur could produce rainfall intensities varying from 48 mm/h to 90 mm/h. The rainfall produced on an application area of 1.5 m x 1.5 m had uniformity varying from 82 per cent to 90 per cent depending on the intensity of the rainfall.

The present study was undertaken to estimate the erodibility and runoff potential of the three well defined series of laterite soils, viz. Mannamkulam series, Naduvattom series and Vellanikkara series under simulated rainfall conditions.

The objectives of the present study are, modification and improvement of the existing rainfall simulator developed by Kurien and George (1998) for better performance and to study the erodibility and runoff potential of the selected series of laterite soils under simulated rainfall conditions.

Review of Literature

REVIEW OF LITERATURE

Rainfall simulators have been used for many years by researchers to accelerate and extend their study of soil erosion. Conservationists and planners of erosion control and water management systems need simple methods for determining the basic erodibility and runoff potential of specific soil site complexes during the development of land use plans. The previous studies relevant to the topics of soil erosion, runoff and rainfall simulators are briefly reviewed in forgoing sections.

2.1 Laterite soils

Laterite is a near-surface or surficial material formed on any parent rock by weathering, precipitation and residual accumulation. This weathering, which comprises the products of the 'Laterite Profile', causes depletion in alkali and alkaline earth elements leaving a residue of secondary forms of iron and aluminium with or without silicon , quartz and other highly resistant minerals.

In Kerala at Angadippuram a ferraginous, vesicular, soft material occurring within the soil which hardens irreversibly on exposure and used as a building material was first recognized as "laterite" by Francis Buchanan (1807). He coined the term laterite from "later", the Latin word for brick. A number of theories were propounded to explain the genesis of laterite soils. D'Hoor (1954) grouped these theories into

1. Concentration of sesquioxides by removal of silica and bases i.e. relative accumulation.

2. Concentration of sesquioxides by accumulation either across the profile or between profiles i.e. absolute accumulation.

Typical laterite soils are characterised by a vesicular structure and the accumulation of hydrated oxides of iron and aluminium. Laterite soils may vary in depth from 1.8 to 3 m and may have a thick layer of Kaolin clay below. These soils do not manifest typical clay properties such as plasticity, cohesion, expansion and shrinkage to any greate extent. They are porous and well drained and have poor capacity for retaining moisture. The base exchange capacity is also low.

From the distribution of the laterite soils it can be seen that this vast region have a large portion of favourable topography for agriculture and adequate temperature for the plant growth. There are only very few physical constraints for crop production. These physical constraints include susceptibility to erosion , low water holding capacity and drought stress.

In Kerala, laterite soils are classified into different series according to their locality and profile features (Soil Survey Department, Kerala). Three series of laterite soils were selected for the erosion study. The characteristics of these soils are given below.

2.1.1 Mannamkulam series

Mannamkulam soils are moderately deep to very deep with a solum thickness varying from 40 to 120 cm. The surface layer is yellowish red to dark reddish brown, medium acidic. The subsoil is yellowish red to dark red, medium acidic. Subsoils have abundant gneissic cobbles and stones. Boulders are common on the surface. These soils are developed on gneissic parent material on moderately steep to very steep hill slopes. These soils are well drained with moderate permeability.

2.1.2 Naduvattom series

Naduvattom soils are moderately deep to very deep with a solum thickness of more than 40 cm. The surface layer is medium acidic yellowish red to dark red and 15 to 23 cm thick. The subsoil is medium acidic reddish brown to dark red and more than 20 cm thick. These soils are well to excessively drained. Permeability is high, runoff is medium and available water holding capacity is moderate. The organic carbon content and nutrient exchange capacity of the soil is medium. These soils are susceptible to moderate erosion and they possess good physical properties except the high content of gravel in the subsurface layer. They occur on gently sloping to moderately steep side slopes.

2.1.3 Vellanikkara series

Vellanikkara soils are deep to very deep with a solum thickness varying from 50 to 110 cm. Typically the surface layer is reddish brown, friable, strongly acidic and about 20 to 25 cm thick. Subsoil is yellowish red to dark reddish brown, friable, strongly acidic. Lower part of the subsoil is characterized by the presence of gneissic cobbles and stones. These soils occur on moderately sloping to steep hill slopes. These soils are well drained with moderate permeability and the moisture holding capacity is medium. The content of organic carbon is medium to high. These soils are susceptible to moderate erosion.

2.2 Soil erosion

Morgan (1986) defined soil erosion as a two phase process consisting of the detachment of individual particles from soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles, a third phase (deposition) occurs. Key factors influencing soil erosion are erosivity of the causing agent and the erodibility of the soil.

Owoputi and Stolte (1995) reported that one of the problems associated with soil erosion is the reduction of soil nutrient and thus decreased agricultural productivity. Another concern with erosion is an increase in turbidity of runoff which has an adverse effect on the quality of our surface water. In addition , the sedimentation lowers available reservoir storage.

2.2.1 Factors affecting soil erosion

The major variables affecting soil erosion are climate, soil properties, vegetation and topography (Schwab *et al.*, 1981). Of these the vegetation and to some extent the soil properties may be controlled. The climatic factors or the topographic factors, except slope length are beyond the power of man to control.

Climatic factors affecting erosion are precipitation, temperature, wind, humidity and solar radiation. Temperature and wind are most evident through their effects on evaporation and transpiration. Wind also changes raindrop velocities and angle of impact.

2.2.1.1 Rainfall characteristics

The amount of erosion from raindrops has been linked to the rainfall characteristics such as the rainfall intensity, drop diameter, impact velocity and rainfall kinetic energy.

The size, distribution and shape of raindrops influence the energy, momentum and erosivity of rainstorm. Laws and Parsons (1944) reported that median drop size increases with the increase in the rainfall intensity. The relation between median drop size (D_{50} in mm) and rainfall intensity ((I) in inches per hour is found as

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

Wischmeier and Smith (1958) reported that 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.

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/h.

Hudson (1963) reported that the medium drop diameter increases up to an intensity of 80 mm/h and then decreases.

Bubenzer and Jones (1971) reported that the mean splash rate of soils exposed to rainfall of a nearly constant kinetic energy level and impact velocity was influenced by drop size at the lower energy levels. The smaller drops produced significantly less splash than the larger ones, even though the kinetic energy, total rainfall mass and impact velocity were almost constant. As the energy level increased, the influence of drop size decreased.

Foster (1982) and Rose *et al.* (1983) developed an equation,

$$D_I = K_I C I^a$$

Where,

D_I - raindrop detachment,

K_I - measure of soil detachability by rainfall,

C - constant th. epresents the fraction of the surface that is not protected by cover,

I - rainfall intensity,

a - constant that ranges from 1.3 to 2.0.

This equation is used to estimate the detachment caused by raindrop action.

Meyer and Harmon (1984) simulated rainfall to evaluate the effect of rainfall intensity on inter rill erosion from 18 cropland soils encompassing a wide range of textures. They found that the inter rill erosion rate (E) in kg /m^2/s could be related to rainfall intensity I (m/s) by the power equation

$$E = a I^b$$

Where a and b are the coefficient and exponent of best fit respectively. Average value for the exponent 'b' is 1.98 for low clay content soils, suggesting the equation

$$E = C\,I^2$$

Where I^2 is the erosivity term and C is the inter rill erodibility coefficient (kg . s /m^4).

The equation for predicting soil detachment by raindrops was developed by Sharma and Gupta (1989). In the equation, soil detachment is related to the raindrop kinetic energy and a critical condition defined as the threshold kinetic energy.

This equation is generally written as

$$D_l = K_l\,(e - e_0)^b$$

Where,

D_l - soil detachment by raindrop,

K_l - soil detachability coefficient,

e - kinetic energy of the drop,

e_0 - threshold kinetic energy,

b - constant that is assumed equal to unity.

The main concept of this equation is that detachment by raindrops is a function of the raindrop energy and of the soil resistance.

2.2.1.2 Soil characteristics

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

Surface roughness and residue cover have been shown to be effective in reducing erosion (Griffith *et al.*, 1986).

Surface roughness increases the water storage capacity in the tilled layer of the soil which reduces the velocity of runoff and the rate of erosion. Small impoundnents may form behind residue and provide the same effect as surface roughness.

2.2.1.3 Topography

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

Kinnell and Cummings(1993) studied about the soil gradient interactions in erosion by rain impacted flow, with 0.9 m long inclined soil surfaces eroding under rain impacted flow. Three major forms of sediment discharge to slope gradient relationships were observed when the effect of flow discharge (q_w) on sediment discharge (q_{si}) was considered in terms of equation

$$q_{si} = q_w \, K_1 \, I \, f(s)$$

where,

K_1 - a factor which varies with the susceptability of the soil to erosion by rain – impacted flow,

I - rainfall intensity,

f(s) - effect of slope gradient.

2.3 Runoff and soil loss

The relationship of erosion to rainfall momentum and energy is determined by the factors such as raindrop mass, size, shape, size distribution , velocity and direction. The method used for predicting the soil loss should consider each of the factors involved and should be easily applied to field conditions. The most accurate soil loss equation that is now field operational is the Universal Soil Loss Equation (USLE) suggested by Wischmeier (1976).

The average annual soil loss can be estimated from the equation

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

where,

A - average annual soil loss in Metric tonnes/ha,

R - the rainfall and runoff erosivity index by geographic location

K - soil erodibility factor which is the average soil loss in Mg/ha per unit of erosion index for a particular soil in cultivated continuous fallow with an arbitrarily selected slope length of 22 m and slope steepness of 9 per cent,

L,S - topographic factors,

C - cropping management factor, which is the ratio of soil loss for given conditions to soil loss from cultivated continuous fallow,

P - the conservation practice factor, which is the ratio of soil loss for a given practice to that for up and down, the slope farming.

The USLE is a powerful tool that has been used by soil conservationists for almost three decades for on-farm planning of soil conservation practice, and assessing the regional and national impact of erosion and implementing public policy related to soil conservation.

A revised version of USLE has been developed by updating the USLE and is termed as Revised Universal Soil Loss Equation, RUSLE.

Some of the improvements being made to the USLE factors in the RUSLE (Kenneth *et al.*, 1991) are given below,

1. A greatly expanded erosivity map based on more than 1,200 gauge locations.
2. Some revisions and additions including corrections for high R-factor areas with flat slopes to adjust for splash erosion associated with raindrops falling on ponded water.
3. Development of a seasonally variable soil erodibility term (K). The seasonal variability is addressed by weighting the instantaneous estimate of K in proportion to the EI (the per cent of annual K) for 15- days intervals.
4. A slope length factor that varies with soil susceptibility to rill erosion.
5. Soil loss is much more sensitive to changes in slope steepness than to changes in slope length.
6. A more nearly linear slope steepness relationship that reduces computed soil loss values for very steep slopes and complex slopes can be represented readily to provide a better approximation of the topographic effect.

7. A subfact approach for calculating the cover-management term (C), with the subfactors representing consideration of prior land use, crop canopy, surface cover and surface roughness. The subfactor relationship is given by the equation

$$C = PLU.\ CC.\ SC.\ SR$$

$$SC = \exp(-bM)$$

Where, PLU - prior land use subfactor,

CC - canopy cover subfactor,

SC - surface cover subfactor,

SR - surface roughness subfactor,

M - percentage of ground cover,

b - coefficient assigning a value of either 0.025 for USLE, 0.035 or 0.05 for RUSLE.

8 Improved conservation practice values **(P)** for the effects of contouring, terracing, strip cropping and **management** practices for range land. The practices require estimates of surface roughness and runoff reduction.

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 t/ha at 0 per cent slope to 891 t/ha at 21 per cent slope and beyond this the soil loss decreased steadily with increase in steepness of the slope for the present study.

Blough *et al.* (1990) conducted a study to evaluate the effects of residue cover and surface configuration on runoff and erosion responses of the Letort silt loam reconstructed in the laboratory under simulated rainfall. Four field conditions were simulated by producing surface configuration and residue covers comparable to field situations. Infiltration and surface storage created as a result of slit tillage nearly eliminated surface runoff and therefore erosion , until the slit overflowed. After the slit overflowed, the erosion rates were approximately equal to the other conservation tillage treatment. Surface residue decreased surface runoff and erosion and increased the amount of water that infiltrated into the soil. The surface storage provided by the slit treatment further increased the opportunity for infiltration.

McIsaac and Mitchell (1992) studied the temporal variation in runoff and soil loss from simulated rainfall on corn and soybeans. Soil loss per ha from soybeans and soil loss per ha-mm of runoff from corn varied by as much as a factor of four from one year to another.

Much of the variations in soil loss appeared to be related to variations in runoff, slope steepness and antecedent rainfall.

Grosh and Jarret (1994) studied the interrill erosion and runoff from a 504 mm-square box filled with disturbed Hagerstown silty clay loam under a simulated 20 min., 92 mm/h rainfall at six slopes ranging from 5 to 85 per cent. Steady - state wash soil loss (soil suspended in runoff) increased linearly with slope, with measuring rates ranging from 3.34 g/m^2-min. at 5% slope to 22.47 g/m^2-min. at 85% slope. Total splash detachment (down slope + up slope) increased with slope. Ninetynine per cent of splash moved down slope at the 85% slope. There were no differences between steady- state runoff rates for slopes from 15 to 85%, with a mean runoff rate of 66.5 mm/h.

Myers and Wagger (1996) studied runoff and sediment loss from a Pacolet sand clay loam soil in a two year field experiment. Conventional tillage (CT), no tillage grain production with surface residue (NTG) and no tillage silage production without surface residue (NTS) were compared under simulated rainfall of 12.7 and 50.8 mm/h. Residue cover was greater than 90% in NTG plots, 41% in NTS and less than 10% in CT. Sediment loss (NTG < NTS < CT) was associated with residue cover. Average first event runoff in both years was 40% for NTG, 44% for NTS and 22% for CT. Runoff doubled with CT on the second event each year suggesting soil surface seal development.

The effect of dead roots on runoff, soil erodibility, splash detachment, and aggregate stability were studied in laboratory by Ghidey and Alberts (1997). Dead roots had no effect on runoff but significantly influenced (P<0.05) soil loss and sediment concentrations. Soil loss and sediment concentrations from annual row crops were significantly higher than those from perennial crops; however, the differences in soil loss among the crops were small relative to the differences in root mass and root length. The effect of dead roots were not observed on splash detachment as they were on soil strength, aggregate index and dispersion ratio. Splash detachment was highest during the initial 10 min. of simulation and then decreased approximately.

2.4 Rainfall simulators

Rainfall simulators are used to study hydrologic process such as infiltration, erosion, sediment transport and runoff. 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).

2.4.1 Advantages and limitations of simulated rainfall

Meyer (1965) presented the advantages of simulated rainfall,

1. More rapid results can be obtained by applying selected simulated storms at selected treatment conditions.

2. Results from a few simulated storms at selected conditions often provide desirable informations.

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.

2.4.1.1 Modelling limitations

Soil and water research problems are usually associated with natural conditions of weather and soil. It is difficult to simulate factors like wind, light, temperature, humidity, vegetative influences etc. Measurements of soil loss, water loss and infiltration are difficult to extrapolate to field conditions and natural rain (Mech, 1965).

2.4.1.2 Operating limitations

The nature of most rainfall simulators limit the study to small plots. The need for an adequate supply of water in the vicinity of experimental plots limits the location of work (Mech, 1965).

2.4.2 Types of rainfall simulators

Attempts have been made world over to design different types of rainfall simulators. These can be grouped into following five categories based on the types of accessories fitted on them (Shrivastava and Ghanshyamdas, 1998):

1. Pipes and orifices,
2. Tubing tip / Hanging yarn / Hypodermic needles,
3. Rotating disc type,
4. Nozzle type,
5. Air and water mixture system.

2.4.2.1 Pipes and orifices

Craddock and Pearse (1938) developed a portable rainfall applicator, in which two pipe lines with upward facing nozzles at regular intervals and placed on a survey tripod, run along the length of study plot. The jet of water from nozzles is raised upto a height of 7.62m, which falls over the study plot and has a zero initial velocity.

Neal (1938) designed a rainfall simulator with wooden soil tank of 0.001 acre area, 0.61m depth and a screw jack to adjust the bed slope from 0 to 16 per cent.

Pandey (1967) developed a simulator with 0.795mm diameter holes spaced at 20 to 32 cm apart and facing downwards. The drawback with these simulators was generation of high intensity rainfall, variation in raindrop in pipes and less height of the fall than the required 5-7 m.

2.4.2.2 Tubing tip/Hanging yarn/Hypodermic needles

Adams *et al.* (1957) designed a portable rainfall simulator for laboratory studies. They used glass capillary tubes protruding vertically downwards through the base of a water tank and fitted above a collection tray, from which water drops fall on the tray.

Mutchler and Moldenhauer (1963) developed a rainfall simulator by using drop formers, made of telescopic pieces of tubes, in which a small tube located at the top controls the flow and a larger tube produces the raindrop through the lower end. Tubing tips system produced raindrops with greater precision in a large range of sizes as compared to the hanging yarn system. The intensity of rainfall was controlled by the smallest tube and by the head of the water over the 'rop formers.

Bosu and Sivanappan (1989) designed a tubing tip type rainfall simulator with hypodermic needles of 20 gauge size and drop formers. Three intensities of 5, 12 and 30 cm/h were selected for simulation studies, based on the rainfall pattern of the region.

Bhardwaj and Singh (1992) developed a low cost portable rainfall simulator infiltrometer for infiltration, runoff and erosion studies. Raindrops were formed at the tip of wire loops inserted in capillary holes of diameter 0.9mm drilled through a 10mm thick circular perpes sheet. The characteristics of the simulated rainfall were evaluated with intensities of 100 mm/h and 200 mm/h.

Sandeep (1995) used hypodermic needles fitted vertically upwards, in a triangular pattern on LDPE lateral pipes, for laboratory studies.

Kurien and Goerge (1998) developed an oscillating tubing tip type rainfall simulator to study soil loss and runoff at KCAET, Tavanur. Hypodermic needles were used as the drop formers. The uniformity coefficients varied from 82 to 88 per cent corresponding to intensity variations ranging from 4.77 to 8.8cm/h. The soil loss increased with intensity of rainfall for all the slopes.

Roshni (1998) developed a rainfall simulator and a soil trough to conduct the soil hydraulic studies at KCAET, Tavanur, Kerala. The portable rainfall simulator comprised of a drop forming mechanism mounted on a supporting frame. The drop forming mechanism consisted of a tank with a perforated bottom. Copper wire loops of 20 gauge were suspended through these perforations. A float valve ensured a constant head of water in the tank to get the desired intensity of rainfall. The moisture content, tension, surface runoff and outflow were monitored at different rainfall intensities.

The limitations of these types of rainfall simulators are that continuous jets of rain hit the soil at particular points below the drop former, which may not happen in nature and the close spacing of drop formers adopted for getting a better uniformity resulted in high rainfall intensities than desired (Shrivastava and Ghanshyamdas, 1998).

2.4.2.3 Rotating disc type rainfall simulator

Morin and Seginar (1967) at the Soil Erosion Research Station, Emokhefear, Israel developed a rainfall simulator with a downward facing nozzle spraying continuously and a metal disc rotating in an horizontal plane shielding the soil intermittently. A radial slot was provided in the disc, and each time the slot passed under the nozzle, a short burst of rain passed through it on the plot below. The proportion of the spray passing through the slot is determined by the angle of the slot.

Singh (1988) at G. B Pant University, Pantnagar fabricated a rotating disc type rainfall simulator having a 60 cm diameter disc. Segments of 20^0, 30^0 and 45^0 angles were cut directly below the nozzle. A rotation of 45 rpm was obtained with the help of a regulator fitted to a 60 watt motor of a ceiling fan as the rotating device. The disc was slightly dished at 5 per cent slope to facilitate disposall of the excess water.

Thomas *et al.* (1989) made a portable rainfall simulator which produced intensities ranging from 15 to 150 mm/h by choosing appropriate nozzles and slot apertures in the rotating disc. The duration of simulation was controlled by a shutter mechanism.

In rotating disc type simulators, momentary burst of rainfall occurs intermittently, which is unnatural. Also such type of simulators can cover only very less area and small heights of fall which restricts water drops from reaching the terminal velocity (Shrivastava and Ghanshyamdas, 1998).

2.4.2.4 Nozzle type

Meyer and McCune (1958) designed a portable rainfall simulator, called rainulator, of 3 x 25 m size. It is probably the first simulator, which could produce a given kinetic energy . The rainfall intensity is controlled by the spray nozzle fitted on an overhead carriage which traverses backward and forward across the plot and by the process of switching on and off the flow of water to the nozzle with the help of a solenoid valve. Later Meyer (1960), modified this design by using 12 numbers of spraying units.

Bubenzer and Meyer (1965) designed a rainfall simulator with three vee jet nozzles, spraying downwards, from a height of 2.43 m on a plot of 3.04 x 0.61 m. The nozzle were rapidly oscillated across the plot to obtain a high energy at a reasonable intensity.

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

Hinkle (1989) used nozzles, which were spaced at 2 m distance and placed 2.9 m above the plot. From this equipment, he obtained uniformity coefficient ranging between 70 to 90 per cent. Hirschi *et al.* (1990) described a micro-computer controlled rainfall simulator utilizing oscillating nozzles. They developed softwares to generate uniform or variable intensity simulation events. Maximum rainfall intensity obtained was 11.6 cm/h and the coefficient of uniformity (CU) was 89.8 per cent.

Bruce *et al.* (1996) developed a portable rainfall simulator for use in field infiltration experiments. The rainfall simulator was constructed from standard 40 mm PVC pipe. The PVC frame was bolted together with wing nuts. Attached to the top of the frame were eight sprinkler heads mounted at an elevation of 1.83m. At this elevation, water droplets achieve a velocity of approximately 4.6m/s. One of the positive features of the rainfall simulator is that the intensity of the rainfall can be varied between 1.27 cm/h and 30.5 cm/h depending on the pump used, using a simple compression stop valve and pressure gauge.

Shrivastava (1996) developed a rainfall simulator for laboratory studies using micro sprinkler nozzles which sprayed water from the height of 4.5m. The rainfall intensities varied from less than 1 to 16 cm/h with drop sizes less than 4mm and CU of 70 per cent.

Summer *et al.* (1996) designed the rainfall simulator using laterals arranged at 14.6m spacing. The nozzles sprinkled water from 3m height with a rainfall intensity of 25 mm/h and CU of 91 per cent.

Cullum (1997) constructed two types of rainfall simulators using three types of electronic controls. The first simulator has oscillating nozzles and the second one had fixed nozzle on a travelling traverse or a moving carriage. Single and variable rainfall intensities were achieved with this solution. The digital interface board and micro stepping motor solutions provided programmable capability through software previously unavailable in field research. The software provides a user friendly interaction and the ability for controlled variations of rainfall intensity and duration.

The limitations of the above simulators are poor uniformity coefficient for achieving the terminal velocities. However, in these simulators, rainfall intensities and drop sizes can be controlled easily by suitable nozzles and optimum pressures. The simulated rainfall in these appear to natural rainfall (Shrivastava and Ghanshyamdas, 1998).

2.4.2.5 Air and water mixture system

Brakensick *et al.* (1979) designed a rainfall simulator, using self contained modules of 0.61 m x 0.92 m in size, and utilized two compartment systems of water and air.

Shelton *et al.* (1984) designed a non- intermittent rainfall simulator, which used compressed air, injected ahead of the stationary nozzles in a square pattern, to control the rainfall parameters.

Shelton *et al.* (1985) designed a continuous rainfall simulator by injecting air into a water conduit. The purpose of the injected air was to maintain higher discharge pressures for producing a better rainfall uniformity without increasing the rainfall intensity. Rainfall intensities, ranging from 76 to 168 mm/h, with a minimum distribution uniformity of 84 per cent, can be obtained by this simulator.

The limitations of such simulators are similar to that of nozzle type simulators, except that these can produce lesser amount of rainfall intensities without affecting the coefficient of uniformity (Shrivastava and Ghanshyamdas, 1998).

2.5 Measurement of rainfall characteristics

2.5.1 Intensity of rainfall

Rainfall Intensity Gauge is an experimental raingauge to measure the intensity of rainfall without the necessity of using a recording instrument with the inherent daily attendance for the changing of charts. An intensity raingauge without clockwork was developed in India by Neares in 1921 for monsoon conditions, using a horizontal jet under varying head and hence varying trajectory. A number of containers placed in line with the trajectory of jet caught the rainfall at varying rates of fall, so that both the rates of fall and the quantity of rain within various rates could be ascertained (Varshney, 1986).

Intensity is a measure of the quantity of rain falling in a given time. For measuring the intensity or quantity of rainfall, non-recording type and recording type raingauges are used. Recording gauges produce a continuous plot of rainfall against time and provide valuable data of intensity and duration of rainfall (Subramanya, 1994).

2.5.2 Droplet size

There are various methods for determining the droplet size viz. Stain method, Photographic method, Momentum method, Immersion method and Flour pellet method.

Rhodamine dusted filter paper is used in Stain method (Fyall and King, 1963). Droplets are collected on a suitable surface on which a mark, crater or stain is left by their impact. On a standard surface of 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 flour pellet method as described by Kohl (1974) consists of calibrating plain flour by dropping water drops of known diameter into trays containing about a 25 mm thick layer of sifted uncompacted flour. The flour pellets are oven dried at 110^0 C. The dried pellets are weighed and the mass ratio is determined. The flour trays are then exposed to natural or artificial rain and the drop sizes determined via the calibration curves. The flour pellet method does not require any special equipment to determine the drop size.

2.5.3 Uniformity of rainfall

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

$$CU = 100(1 - \Sigma x/mn)$$

Where m - average value of all observations,mm

n - total number of observation points,

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

2.6 Methods of predicting runoff

Methods described below are applicable to small agricultural watersheds of less than a few thousand acres in size. Both runoff rate and runoff volume are important parameters in the watershed management and therefore shall be described separately.

2.6.1 Estimation of runoff rate

Most important method for predicting a design peak runoff rate is the Rational method suggested by Ramser (1932) and is expressed by the equation

$$Q = 1/36\ CIA$$

Where,

Q - design peak runoff rate, m^3/s,

C - runoff coefficient,

I - maximum average rate of rainfall, cm/h over the entire area which may occur during the time of concentration,

A - watershed area, ha.

Time of concentration of a watershed is the time required for the runoff water to flow from the most remote (in time of flow) point of the area to the outlet. When the duration of a storm equals the time of concentration, it is assumed that all parts of the watershed are contributing simultaneously to the discharge at the outlet. The equation for time of concentration developed by Kirpich (1940) is,

$$T_c = 0.0195\ L^{0.77}\ S^{-0.385}$$

Where,

T_c - time of concentration in min,

L - maximum length of flow in m,

S - average slope of the area in m/m.

The main advantage of the rational formula is that it can always be used to give an estimate of maximum runoff rates no matter how little recorded information is available (Norman, 1981).

The rational method is applicable to watershed of less than 1300 hectares(Schwab *et al.*, 1981). This method is based on two assumptions.

1. Rainfall occurs at uniform intensity for a duration at least equal to the time of concentration of the watershed, and
2. Rainfall occurs at a uniform intensity over the entire area of the watershed.

2.6.2 Estimation of runoff volume.

Knowledge of the volume of runoff from a watershed is necessary to design the water storage system and surplussing arrangements. Different mathematical models that are developed to predict runoff deal mainly with prediction characteristics affecting runoff amount and peak rates. In an attempt to simplify and standardise runoff prediction, the soil conservation service (SCS) of the United States Department of Agriculture (USDA) has developed a runoff prediction model, based on many years of storm flow records from agriculture watershed and certain watershed characteristics such as indices of soil cover complex and antecedent moisture condition.

This SCS method is used to predict direct runoff by the relation

$$Q = (I - 0.2S)^2 / (I + 0.8S)$$

Where,

Q - direct surface runoff, mm

I - storm rainfall, mm

S - maximum potential difference between rainfall and runoff in mm starting at the storm beginning.

For convenience in evaluating antecedent moisture, soil conditions, land use and conservation practices, the US Conservation Service(1972) defines

$$S = 25400/N - 254$$

Where

N – an arbitarary curve number varying from 0 to 100.

2.7 Measurement of runoff

The various devices applicable to measure the runoff are current meter, weirs and flumes, float method etc.. Current meter is widely used in measuring the flow in large streams. Weirs and Parshall flumes are suitable to measure the runoff from small watersheds.

Runoff measuring stations are often equipped with water stage recorders which continuously record the water level in the stream. The stage recorder consists of a float which is connected to the main channel by a pipe or trench. As the water level rises or falls, the float actuates a pen which records on a clock-driven chart the water level in the stream. This makes possible the calculation of total runoff volume for a period of stream flow (Michael and Ojha, 1993).

For safe disposal of runoff water, channels or ditches are often constructed along the slope in the small or large watersheds. Open channel or open ditch refers to any conduit in which water flows with a free water surface (Tripathy and Singh, 1993).

Materials and Methods

MATERIALS AND METHODS

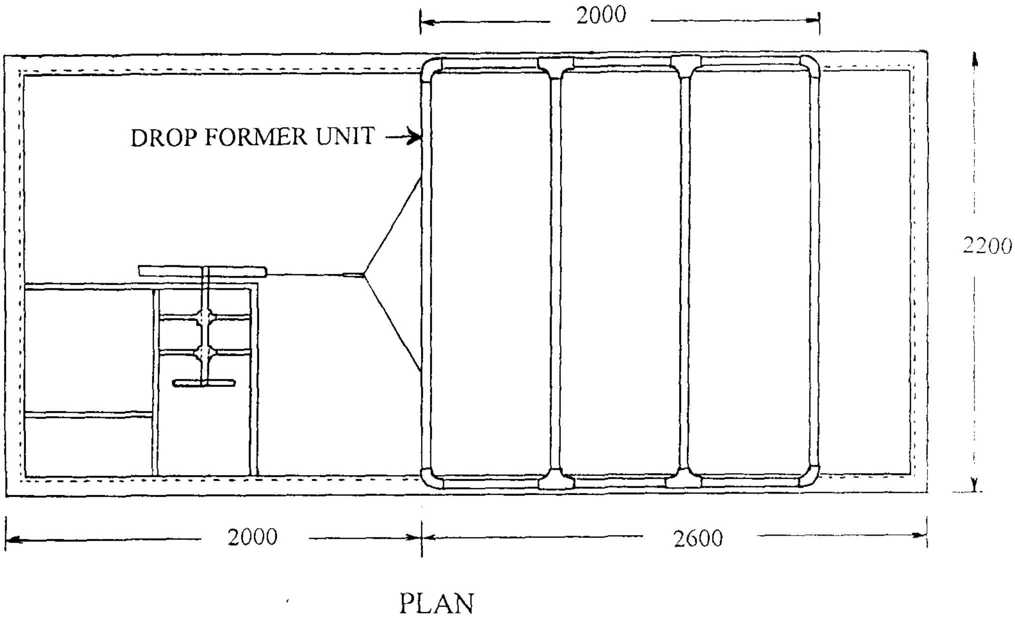
This chapter describes the design procedure, materials used and methodology adopted for finding out runoff and soil loss from the laterite soils.

3.1 Design and fabrication of a rainfall simulator

An oscillating, tubing tip type rainfall simulator was fabricated based on the design of Kurien and George (1998).

According to Mutchler and Hermsmeier (1965) tubing tip is a precise method of making water drops. The hypodermic needle could produce drop size up to 5.8mm. 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 formers.

A draw back 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 this, an oscillating type tubing tip type rainfall simulator was fabricated. Figure.1 shows the schematic diagram of the rainfall simulator. The overall view of the experimental setup is shown in Plate I.



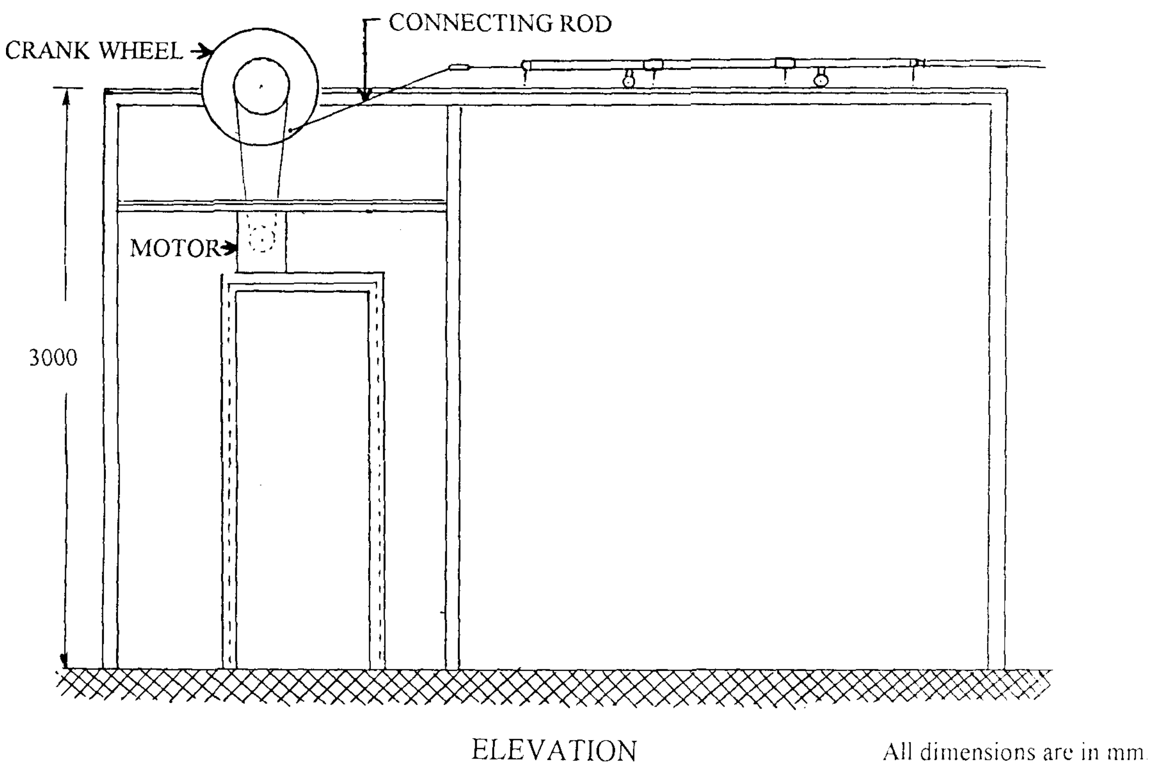


Fig.1 Schematic diagram of the rainfall simulator

Plate I. Overall view of the experimental set up

3.1.1 Design of the drop former unit

The drop former unit with 18 gauge hypodermic needles and a network of 1.8 cm diameter GI pipe was fabricated. The plan of the net work is given in Fig.1. The network had an inlet for water and two valves for releasing entrapped air. The transverse pipes of the net work were drilled at 5 cm interval to accommodate the heads of the 18 gauge hypodermic needles. The needles were fitted in these holes by soldering. Each transverse pipe was fitted with 44 needles. The drop former unit thus had 176 needles, 44 needles each on four transverse pipes. For the oscillatory movement of the drop former unit, four cast iron wheels of 5 cm diameter were provided on both longitudinal sides of the drop former unit. The close view of the drop forming unit is shown in Plate II.

3.1.2 Design of the supporting frame work

In order to support the entire drop former unit, a frame was fabricated. A rectangular frame work of 4.6m x 2.2m was fabricated with angle iron pieces having size 50 mm x 56 mm x 6 mm. MS flats of 25 mm x 2 mm were welded on both sides of the flat surface of the angle iron pieces on the longitudinal sides of the frame work to form channels for the movement of the wheels fitted on the drop former unit. The pulley and the cranking mechanism of the drive unit were fitted on a frame work of size 1.15 x 1 m fitted on the main frame work.

Plate II. Close view of drop forming unit

The frame work was supported by seven legs made of 3 m long 25 mm MS pipe. The legs were welded to the frame. The foot of each leg was fitted with 30 x 5 mm horizontal MS flats 30 cm in length, to provide stability to the structure.

The plan and elevation of the supporting frame work is shown in Fig.1.

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

3.1.3 Power transmission system

The power required to oscillate the drop former unit was taken from a three phase geared motor. The specifications of the motor are given below.

Speed - 45 rpm

HP - 3

Voltage - 415 V

Current - 3.4 A

The output shaft of the motor was fitted with a 75 mm V pulley (A), above which a 305 mm V pulley (B) which reduces the speed to 13 rpm. A crank wheel of 660 mm diameter was fixed on the shaft of the pulley B. The connecting rod between the crank wheel and the drop former unit converted the rotory motion of the crank wheel to a reciprocating motion of the drop former unit, thus forcing it to oscillate at the rate of 13 oscillations per minute. The details of the power transmission system is shown in Fig.2. A view of the power transmission system is shown in Plate III.

3.1.4 Water supply to the rainfall simulator

A centrifugal pump operated by an electric motor was used to lift the water from a storage tank of 2000 litres capacity and to develop the required pressure for working the rainfall simulator. The discharge line included two gate valves (GV-I & GV-II) and a ball valve (BV). A pressure gauge of 0-2 kg /cm^2 range was fixed in the discharge line just after the ball valve. GV-I was provided at the delivery line to control the discharge to the simulator. GV-II was connected to the by pass flow line and was used to control the by pass flow and set the operating pressure by controlling the bypass flow back to the storage tank. The discharge line was controlled easily by means of the ball valve.

Specifications of the pump

Head - 15 m

HP - 0.5

Speed - 2880 rpm

Operating conditions - 230 V, 2.8 A, 50 Hz.

The tank got the supply of water from the main pipe line in the campus. The water was filtered through fine cloth filters before collecting it in the tank. This was done to prevent the clogging of the needles by fine particles. Water was supplied to the similator through a 1.8 cm diameter flexible hose.

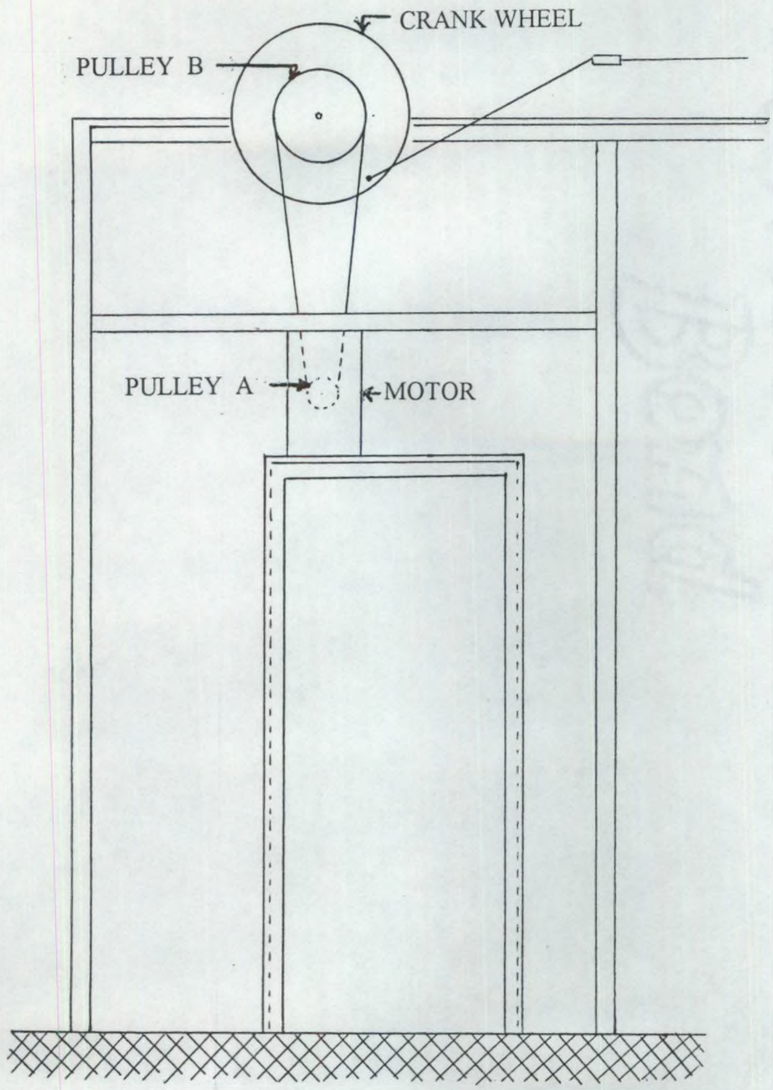
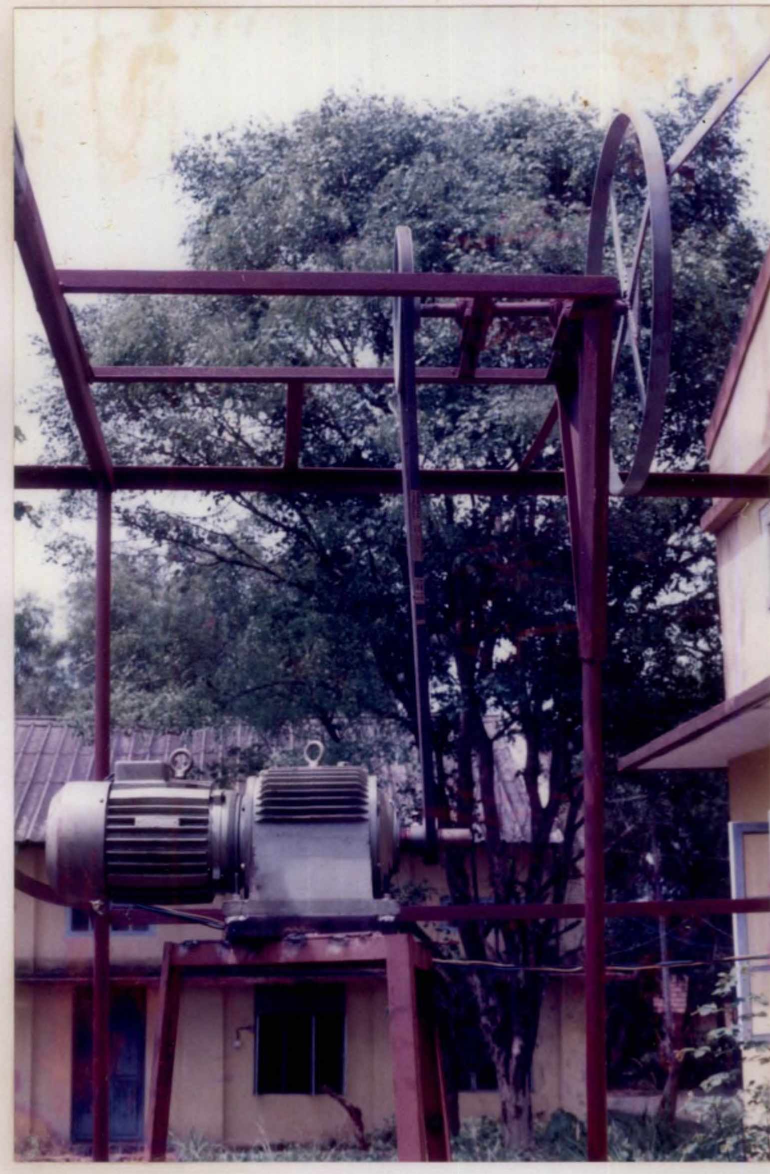


Fig.2 Power transmission system

Plate III. Power transmission system



3.2 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. That area was chosen in order to minimise distortion by wind.

3.3 Testing of rainfall simulator

The rainfall simulator was tested for different intensities by changing the operating pressure of the supply water by adjusting the by-pass control valve.

3.3.1 Determination of simulated rainfall intensity

The rainfall simulator was operated at a pressure of 0.2 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 x 50 cm simultaneously while simulator is operated. The unit was operated freely for 15 minutes. The volume of water collected in each can was recorded and this volume was converted into its equivalent depth. The test was repeated for supply pressures of 0.3, 0.4, 0.5 and 0.6 kg/cm^2 respectively. The intensity was calculated for each supply pressure of water.

3.3.2 Determination of drop size

The drop size was determined using the flour-pellet method. This method consists of calibrating plain flour pellets formed by dropping water drops of known diameter into trays containing about a 25 mm thick layer of sifted uncompacted flour. The flour pellets were dried, weighed and a mass ratio determined.

3.3.2.1 Calibration

A syringe and a set of hypodermic needles of sizes 16 G, 18 G, 21 G and 24 G were taken. A particular volume of water was filled in the syringe. The number of droplets produced by each needle for that volume was found. It was repeated six times for each needle. The diameter of droplets produced by each needle was found by using the following formula,

$$D = (6000 \times V/n)^{1/3}$$

Where,

D - drop diameter, mm

V - volume of water in a syringe, ml

n - number of droplets produced.

A plate was filled with dry sifted flour. Droplets were allowed to fall drop by drop by pressing the syringe slowly. The pellets formed were oven dried for 24 hours at 110°C. The dried pellets were separated from the flour by sieving and the mass of the pellets produced by each droplets size was determined. The same process was repeated thrice.

The relationship between the droplet diameter (d) droplet mass (M) was generated by regression analysis.

3.3.2.2 Determination of simulated raindrop size

Plates of 20 cm diameter and 3 cm depth were filled with sifted flour. The rainfall simulator was operated at a particular pressure. The plates was placed below the simulator so that the simulated droplets fell on the flour. The flour with the pellets was dried at 110°C for 24 hours. The pellets were sieved and weight of known number of pellets formed was taken. Using the calibrated relationship, the mean droplet diameter collected in the plate was determined. This procedure was repeated for different rainfall intensities.

3.3.3 Uniformity of rainfall

The pressure of supply of water was kept at 0.2 kg/cm^2. The entrapped air was removed. Catch can of 10 cm diameter was placed in the rain at 25 grid stations at an interval of 50 cm x 50 cm. The unit was operated for 15 minutes. The volume of water collected in each can was recorded and was converted into equivalent depth of rainfall. The uniformity coefficient (Cu) was calculated using the Christiansen's formula,

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

Where,

Cu - uniformity coefficient, %

m - average volume 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 m x 1 m. The experiment was repeated for various intensities of rainfall.

3.4 Determination of basic soil properties

Soils belonging to the series of Mannamkulam, Naduvattom and Vellanikkara were collected from their specific locations. These soils were analysed for the properties.

3.4.1 Texture analysis

Texture analysis of the soil was done by determining the particle size distribution. The analysis was performed at two stages:(1) sieve analysis and (2) sedimentation analysis.

3.4.1.1 Sieve analysis

A representative sample of the soil was dried in the oven at 104°C for 24 hours. From the dried soil, 1 kg was taken for the analysis. The analysis consisted of coarse and fine analysis. A set of 100 mm, 63 mm, 20 mm, 10 mm and 4.75 mm sieves were used for coarse analysis. The weight of the materials retained on each sieve were noted. For fine analysis 2 mm, 1 mm, 500, 425, 300, 212, 150 and 75 micron is sieve were used. The set of sieves were placed one above the other on a mechanical sieve shaker such that the 2 mm sieve containing the soil sample was on the top and the 75 micron sieve at the bottom, with a receiver below it. The sieve shaker was operated for 10 minutes and the portion retained on each sieve was weighed and noted.

The percentage of soil retained on each sieve is calculated on the basis of the total mass of the soil sample taken and from these results, percentage passing through each sieve is calculated. If the portion passing 75 micron size is substantial, wet analysis is done for further sub-division of particle size distribution.

3.4.1.2 Sedimentation analysis

The sedimentation analysis was done with the help of a hydrometer. The hydrometer analysis is based on Stoke's law, according to which the velocity at which grains settle out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grain. The hydrometer and the sedimentation jar are calibrated before the start of the analysis.

After calibration, a graph was plotted between effective depth (He) and the density readings (R_h) of the hydrometer. The necessary corrections to be made were also determined. Hundred grams of the soil was first treated with hydrogen peroxide solution to remove organic materials. Next, the soil was treated with 0.2 N hydrochloric acid to remove calcium compounds, if any. After washing the mixture with warm water till there was no acid reaction to titmus, the oven dried soil was weighed and 100 ml dispersing agent (Sodium hexa metaphosphate) was added. The soil suspension was washed through a 75 micron IS sieve; the mass of those passing through the sieve was transferred to a 1000 ml measuring cylinder making up the volume accurately to 1000 ml. The hydrometer was immersed in it and the readings were taken at different time intervals. The percentage finer (N) was determined and a particle size distribution curve was plotted.

3.4.2 Consistency

Consistency limits which are most useful for engineering purposes are liquid limit and plastic limit. These limits are expressed on a water content index.

3.4.2.1 Liquid limit

The liquid limit was determined with the help of the standard liquid limit apparatus designed by Cassagrande. About 120 g of the specimen passing through 425 micron sieve was mixed thoroughly with distilled water to form a uniform paste. A portion of the paste was placed in the cup of the Cassagrande apparatus and spread into position and a groove was cut in the soil pat using the Cassagrande BS tool. The number of blows required for the two parts of the soil sample to come into contact at the bottom of the groove was noted. The water content was determined by taking soil sample from near the closed groove and subjecting it to oven drying method. A graph was plotted between number of blows as abscissa on a logarithmic scale and the corresponding water content as ordinate. The water content corresponding to 25 blows was taken as the liquid limit.

3.4.2.2 Plastic limit

The soil specimen, passing through 425 micron sieve was mixed thoroughly with distilled water so that the soil mass could be easily moulded with fingers. A ball was formed of 10 g of the soil mass and rolled between the fingers and a glass plate into a thread of uniform diameter. When the diameter was 3 mm, the soil was remoulded again into a ball. The process of rolling and remoulding was repeated till the thread starts just crumbling at a diameter of 3 mm. The water content of the crumbled threads was determined. The test was repeated twice with fresh samples. The plastic limit was taken as the average of the three water contents.

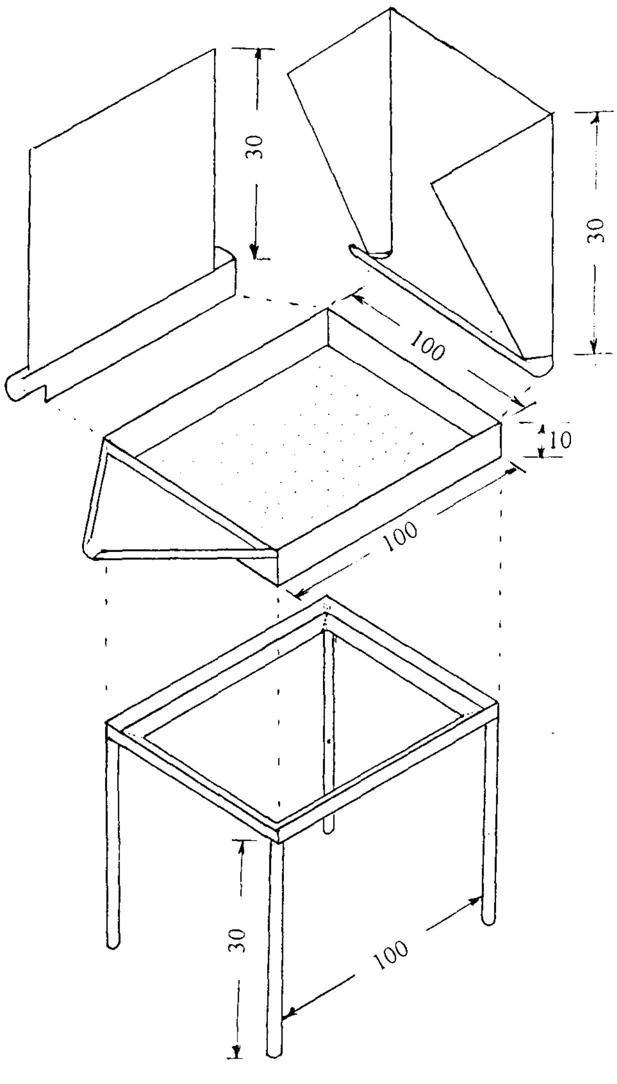
3.5 Erosion study

3.5.1 Design of the soil trough

The soil trough was designed based on the work of Ghosh and Jarrett (1994). Figure 3 shows the soil trough designed for this experiment. Twenty gauge G.I. sheet was used for making the soil trough of size 1 m x 1 m and 100 mm deep. The downslope side depth of the box was 95 mm instead of 100 mm so that runoff could pass over it without ponding. A spout for channel runoff to a collection point was rivetted to the lower side of the box and 3 mm holes were drilled at a spacing of 10 mm in the bottom of the box to allow water to drain during the test. All the sides of the box had 30 cm high wall and the lower side wall rested on the side of the front runoff spout, having a 5 mm wide gap between the wall and the top of the lower side for runoff water and soil to pass through. The test box was placed on a stand with adjustable legs to adjust the slope angle of the box for each test. A view of the soil trough with stand is shown in Plate IV. The soil was filled in the soil trough and was allowed for natural compaction by exposing to rain for several days.

3.5.2 Study of soil loss and runoff

The experimental plot was exposed to simulated rainfall of different intensities 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 runoff spout for a period of 5 minutes. The amount of runoff was measured using a measuring jar. This process was repeated for different



All dimensions are in mm

Fig.3 Soil trough with stand

Plate IV. Soil trough with stand

slopes and the test was repeated thrice for each series of laterite soil. The set up for erosion study is shown in Plate V.

3.5.2.1 Computation of sediment load

The runoff sample was allowed to settle for a week. Then the clear water was drained and the sediment was separated by evaporation technique. The weight of the sediment was recorded. The sediment was analysed for particle size distribution. The test was repeated thrice for each series of laterite soil at different slopes and rainfall intensities.

Plate V. Set up for erosion study

Results and Discussion

RESULTS AND DISCUSSION

An oscillating hypodermic needle type rainfall simulator was fabricated and installed at KCAET, Tavanur. A soil trough with adjustable legs was also fabricated for soil erosion and runoff studies. The simulator was tested for different intensities by varying supply pressure of water to the simulator. The droplet size and uniformity of application of the rainfall were determined for different intensities. After the performance evaluation of the simulator, it was used for erosion studies on three series of laterite soils i.e.Mannamkulam series, Naduvattom series and Vellanikkara series, the results of which are discussed in this chapter.

4.1 Testing of rainfall simulator

4.1.1 Intensity of rainfall

The simulator was tested for various intensities by changing the supply pressure of water to the simulator. The intensity of rainfall produced at each supply pressure was measured. The results are given in Table 1. It was found that the intensity increased with the increase in supply pressure. A maximum intensity of 23 cm/h was obtained for a pressure of 0.6 kg/cm^2. The increase in intensity with pressure was due to the increase in the application rate of water. A graph is plotted with the supply pressure as abscisa and intensity as ordinate and is shown

Table 1. Effect of pressure of supply water on intensity of simulated rainfall

Sl.No.	Pressure of supply water (kg/cm^2)	Intensity of simulated rainfall (cm/h)
1	0.2	7.41
2	0.3	14.05
3	0.4	18.63
4	0.5	21.71
5	0.6	23.00

Table 2. Effect of intensity on simulated rain drop

Sl. No.	Intensity (cm/h)	Mean droplet size (mm)
1	7.41	2.60
2	14.05	1.85
3	18.63	1.75
4	21.71	1.50
5	23.00	1.30

in Fig.4. A relationship between supply pressure and intensity of rainfall of the following form was obtained.

$$I = -87.205\ P^2 + 108.61\ P - 10.786\ (R = 0.99)$$

Where,

I - Intensity of rainfall, cm/h

P - Supply pressure, kg/cm^2

R - Coefficient of regression

4.1.2 Raindrop size

The size of droplets produced for different intensities of rainfall were determined by the flour-pellet method. This method consisted of calibration and determination of the drop size. After calibration, a relation between droplet diameter 'd' and mass of droplet 'm' was established and the calibration curve is shown in Fig.5. The relation is given by

$$d = 666.49\ M^{1.4169}$$

Where,

d = diameter of droplet, mm

M = mass of droplet, g

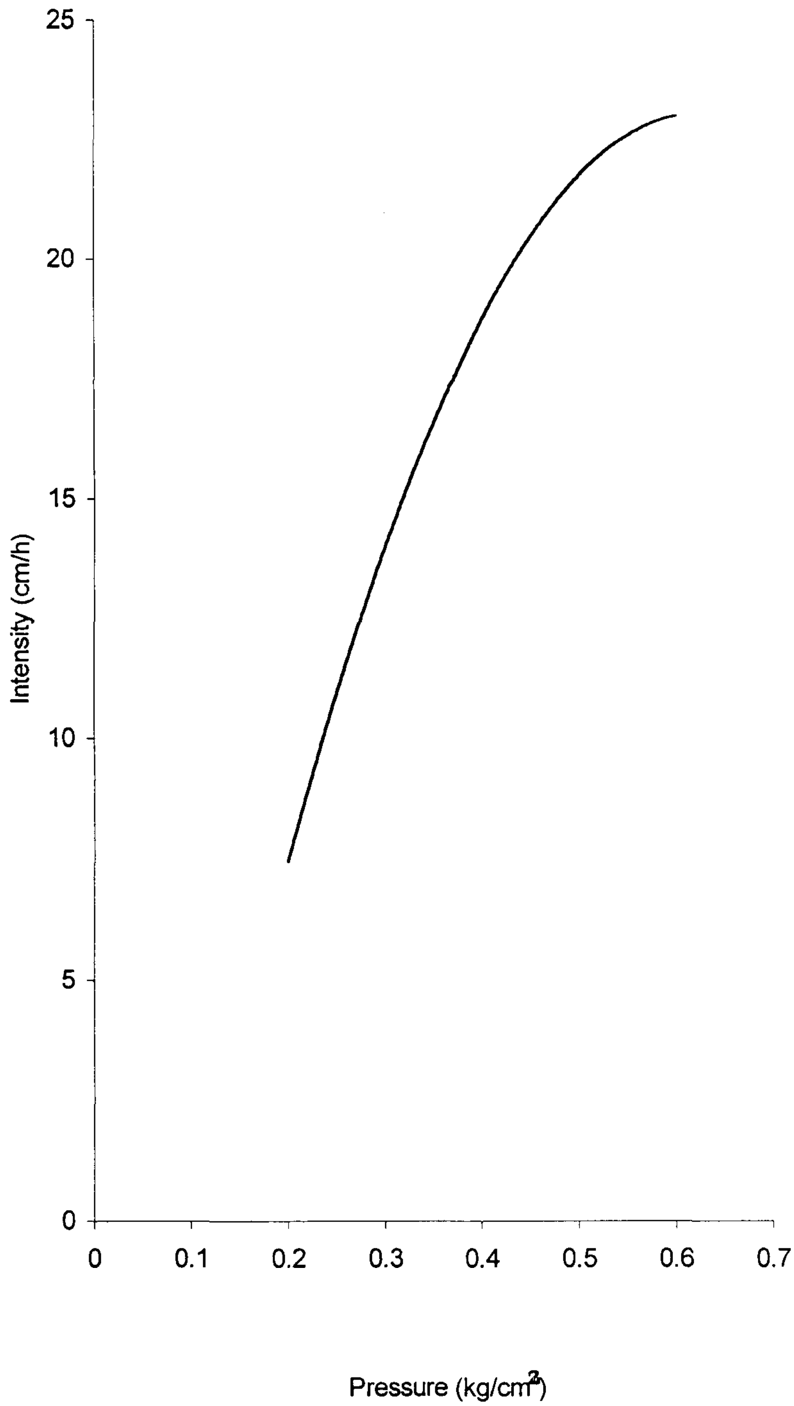


Fig.4 Supply Pressure - Intensity curve.

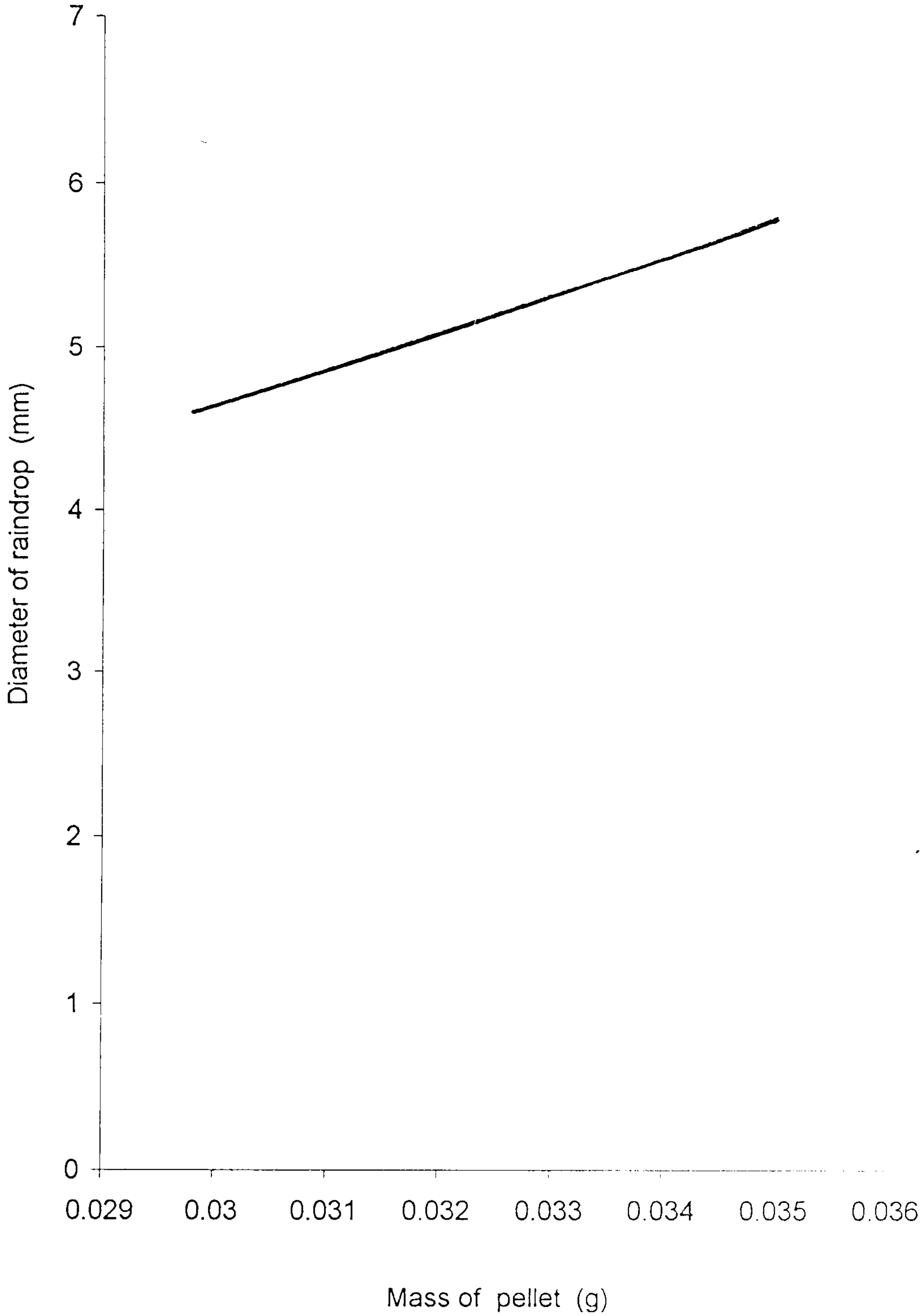


Fig.5 Calibration curve for raindrop size determination

Using this relation the drop size was determined. Table 2 gives the variation in drop size with intensities of rainfall. It was observed that for an intensity of 7.41 cm/h the mean droplet size was 2.6 mm. On increasing the intensity to 23 cm/h, the droplet size decreased to 1.3 mm. The decreasing trend of droplet size with increase in intensity of simulated rainfall was in agreement with the results of earlier researchers.

4.1.3 Uniformity of rainfall

The Christiansen's uniformity coefficient was worked out at different intensities of rainfall and the results are given in Table 3. A uniformity of 91.53 per cent was obtained for an intensity of 23 cm/h. The uniformity coefficient reduced to 88.10 per cent for an intensity of 7.41 cm/h. At higher pressures of application, the variation in the discharge of needles was less and this in turn gave higher values of uniformity.

4.2 Soil properties

4.2.1 Texture analysis

The relative proportions of the different grain sizes which make up the soil mass of each series of soils were determined. Both sieve analysis and sedimentation analysis were carried out. The particle size distribution curve for three series of soils are given in Figures 6, 7 and 8.

Table 3. Uniformity of rainfall at various intensities

Sl. No.	Intensity of rainfall (cm/h)	Uniformity (%)
1	7.41	88.10
2	14.05	89.81
3	18.63	90.43
4	21.71	91.10
5	23.00	91.53

Table 4. Consistency limits of different series of laterite soils

Sl.No.	Series of soils	Liquid limit (%)	Plastic limit (%)
1	Mannamkulam series	31.6	24.29
2	Naduvattom series	29.3	21.80
3	Vellanikkara series	41.0	29.92

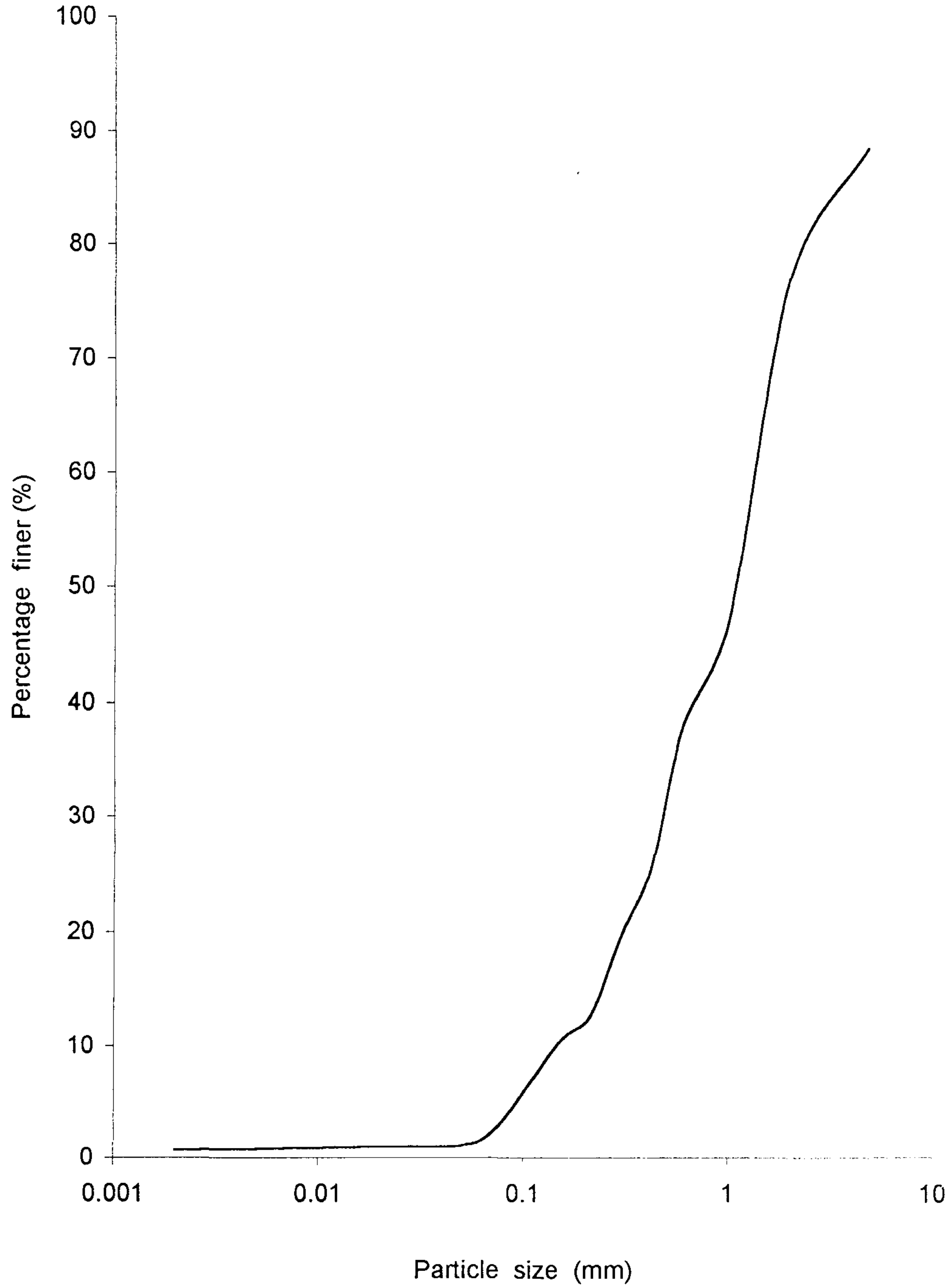


Fig.6 Particle size distribution curve of field soil
(Mannamkulam series)

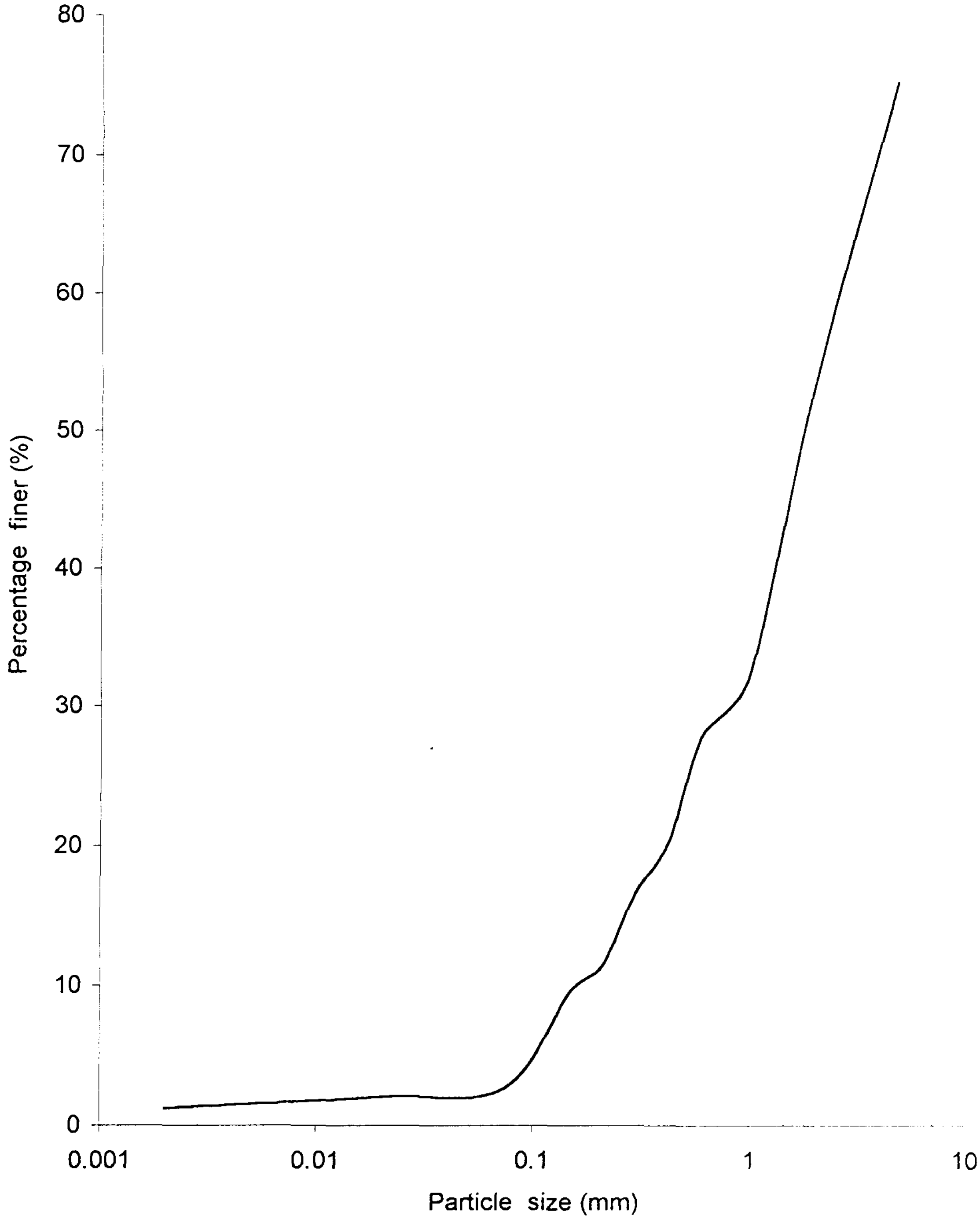


Fig.7 Particle size distribution curve of field soil
(Naduvattom series)

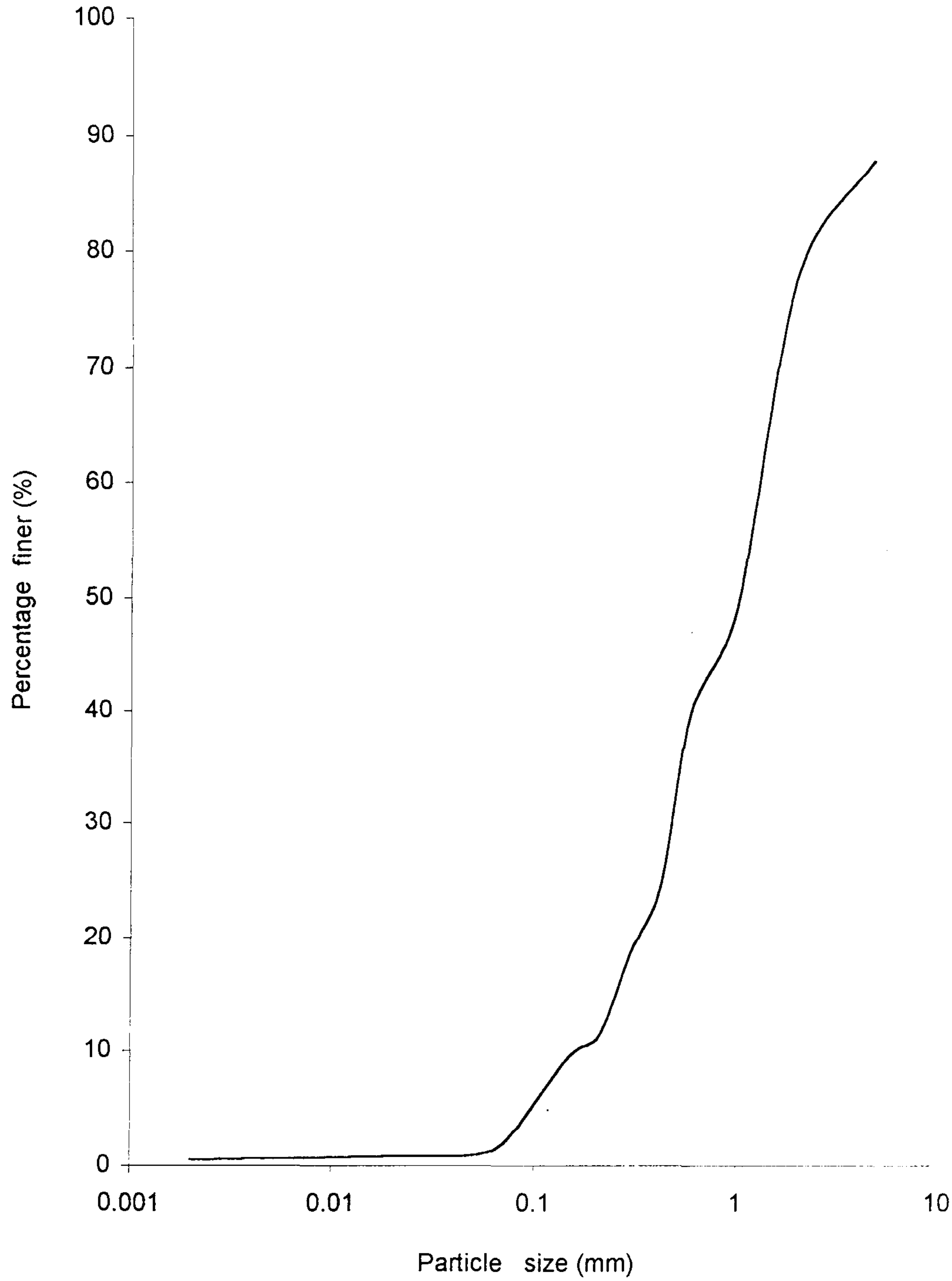


Fig.8 Particle size distribution curve of field soil (Vellanikkara series)

From the figures it was observed that the particle size distribution pattern of the three series of soil are similar and they are coarse grained.

4.2.2 Consistency of the soils

Consistency limits which are most useful for engineering purposes are liquid limit and plastic limit. Consistency denotes the degree of firmness of the soil which may be termed as soft, firm, stiff or hard. Experiments were conducted to evaluate the liquid and plastic limits of the three series of laterite soils and the results are given in Table 4. The flow curves for liquid limit determination for the three series of soils are shown in Figures 9, 10 and 11.

4.3 Erosion and Runoff study

Laterite soils of three different series namely Mannamkulam series, Naduvattom series and Vellanikkara series were collected from representative locations identified with the help of Soil Survey Unit of the Department Agriculture, Government of Kerala. Study of the texture and consistency were done. The soils were subjected to erosion and runoff studies using the rainfall simulator fabricated by placing the soil in the soil trough. The soil loss and runoff were measured at the selected intensities of rainfall on slopes varying from 5 to 25 per cent.

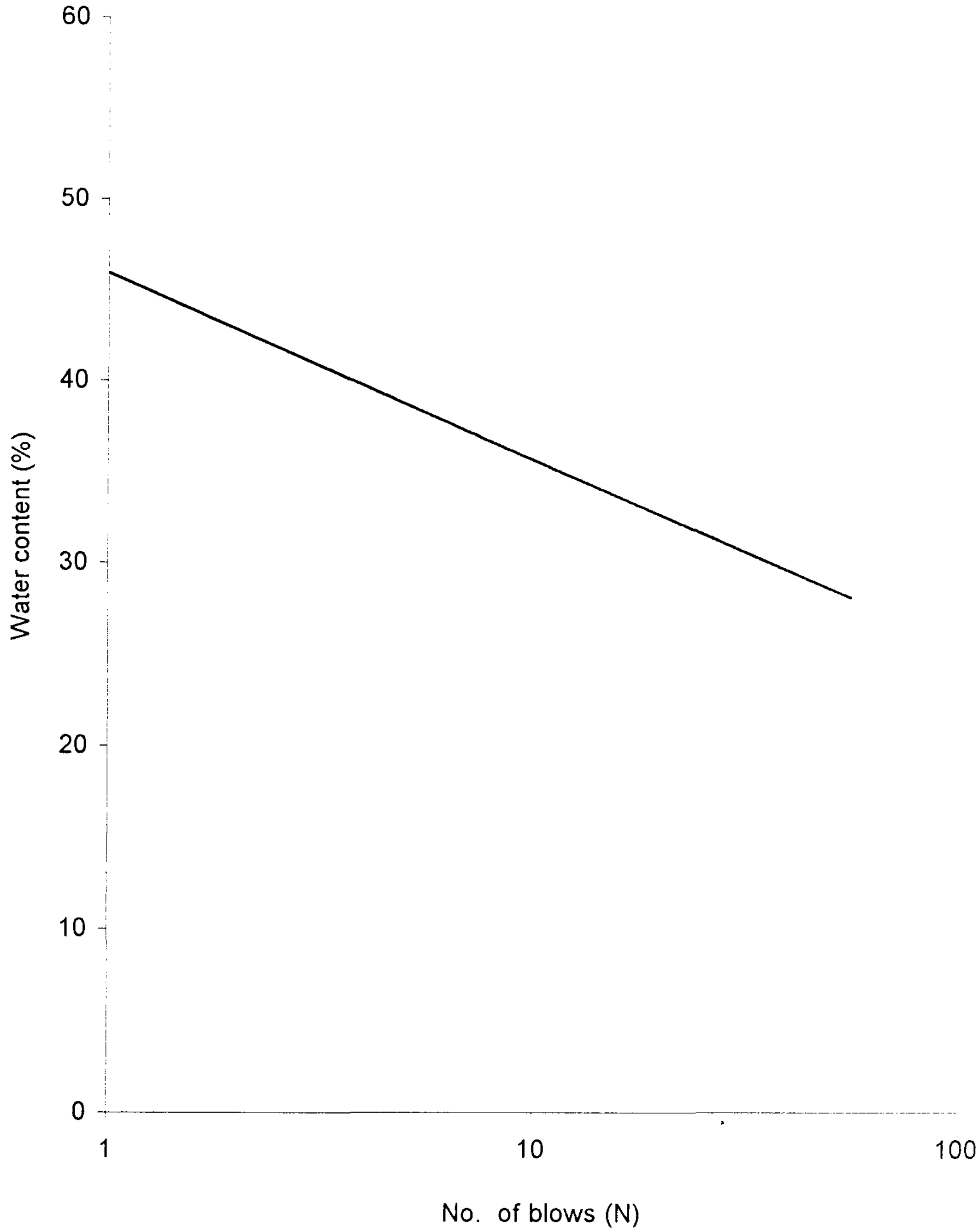


Fig.9 Flow curve for liquid limit determination
(Mannamkulam series)

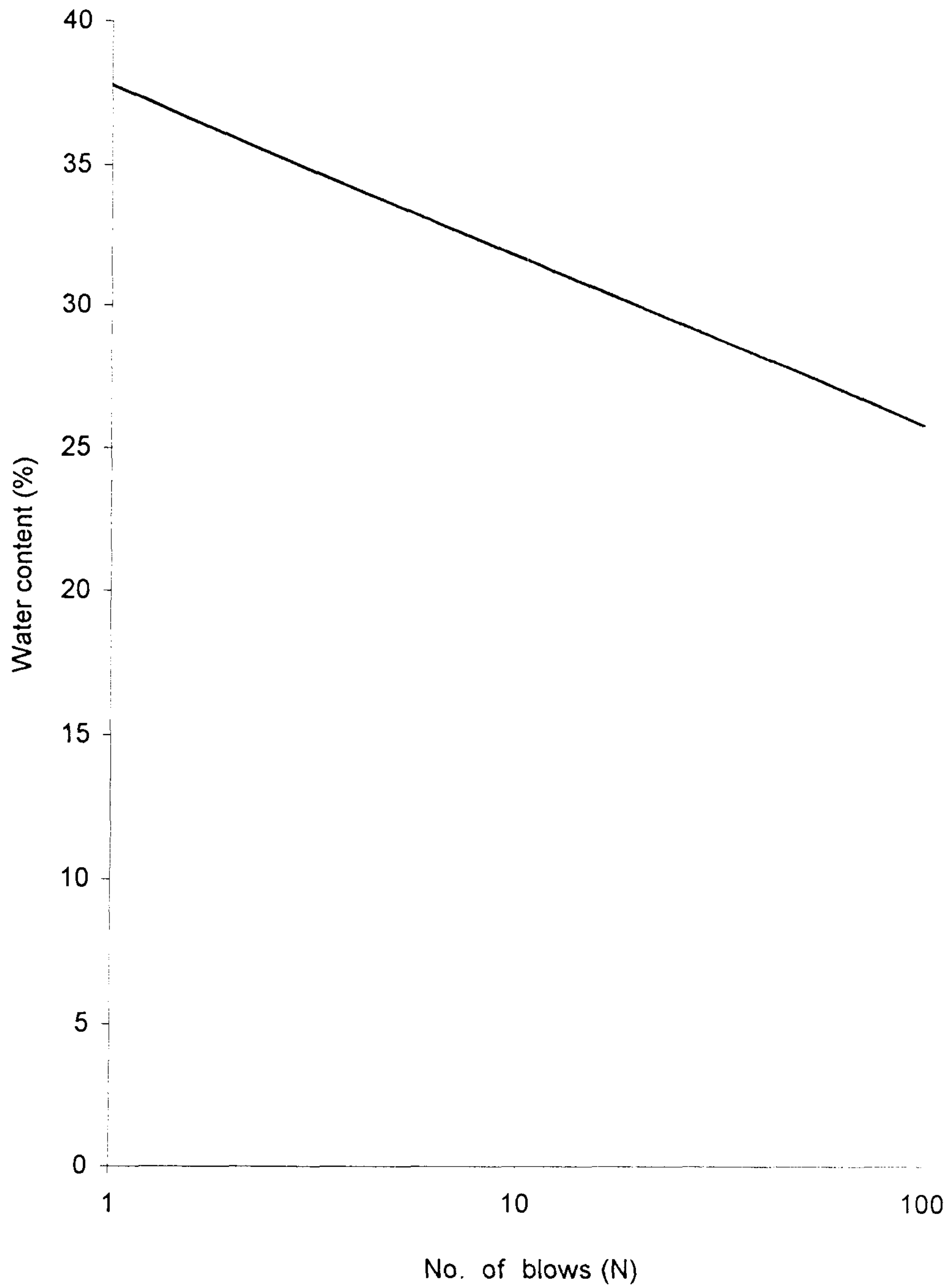


Fig.10 Flow curve for liquid limit determination
(Naduvattom series)

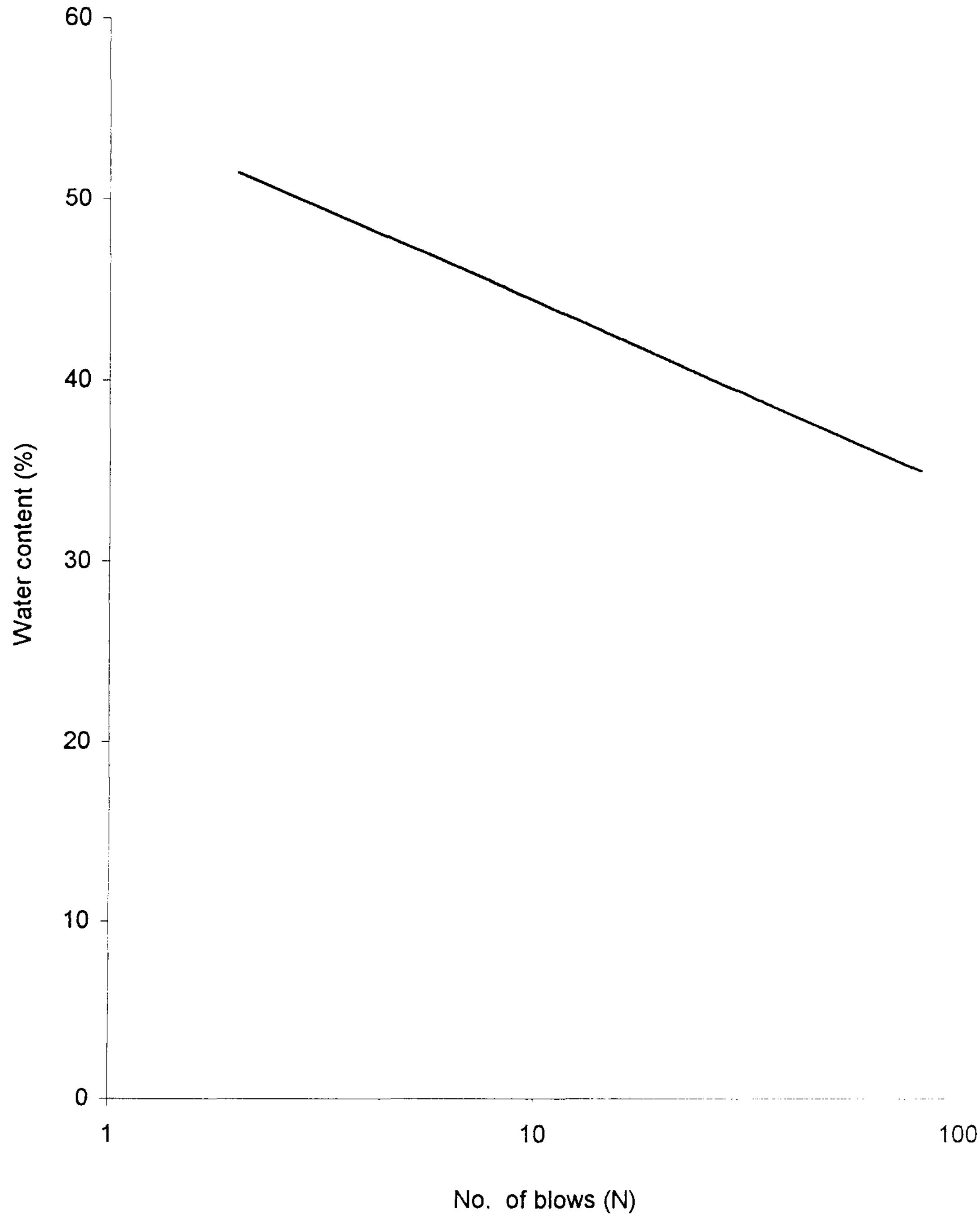


Fig.11 Flow curve for liquid limit determination
(Vellanikkara series)

4.3.1 Effect of intensity of rainfall on soil loss

Tests were conducted at the selected intensities of rainfall on slopes varying from 5 to 25 per cent to study the effect of intensity of rainfall on soil loss. The results obtained for Mannamkulam series, Naduvattom series and Vellanikkara series of soils are given in Appendix-II. The relationship between soil loss from Mannamkulam series of soil and intensity of rainfall for each slope is shown in Fig.12.

From the graph, we can see that soil loss increased with the intensity of rainfall for the slopes studies. At an intensity of 7.41 cm/h, the soil loss from the plot of 5 per cent slope was 684 kg/ha/h while the soil loss was 7710 kg/ha/h when intensity was raised to maximum i.e. 23 cm/h. Thus there was an increase in soil loss of 7026 kg/ha/h on increasing the intensity to 23 cm/h from 7.41 cm/h. The soil loss from the plot with 10 per cent slope and at an intensity 7.41 cm/hr was 714.0 kg/ha/h. As the intensity increased to 23 cm/h, the soil loss also increased to 8670.0 kg/ha/h. Thus it is observed that the soil loss increases with increasing slope and intensity. The maximum soil loss was obtained from the plot of maximum slope of 25 per cent at the maximum intensity i.e. 23 cm/h.

A similar pattern was observed in the case of soil loss from Naduvattom series and Vellanikkara series of soils and are shown in Figures 13 and 14 respectively. When compared to Vellanikkara series and Mannankulam series, the soil loss from Naduvattom series was low. The nature of the curves obtained from three series of soils for all the slopes are similar.

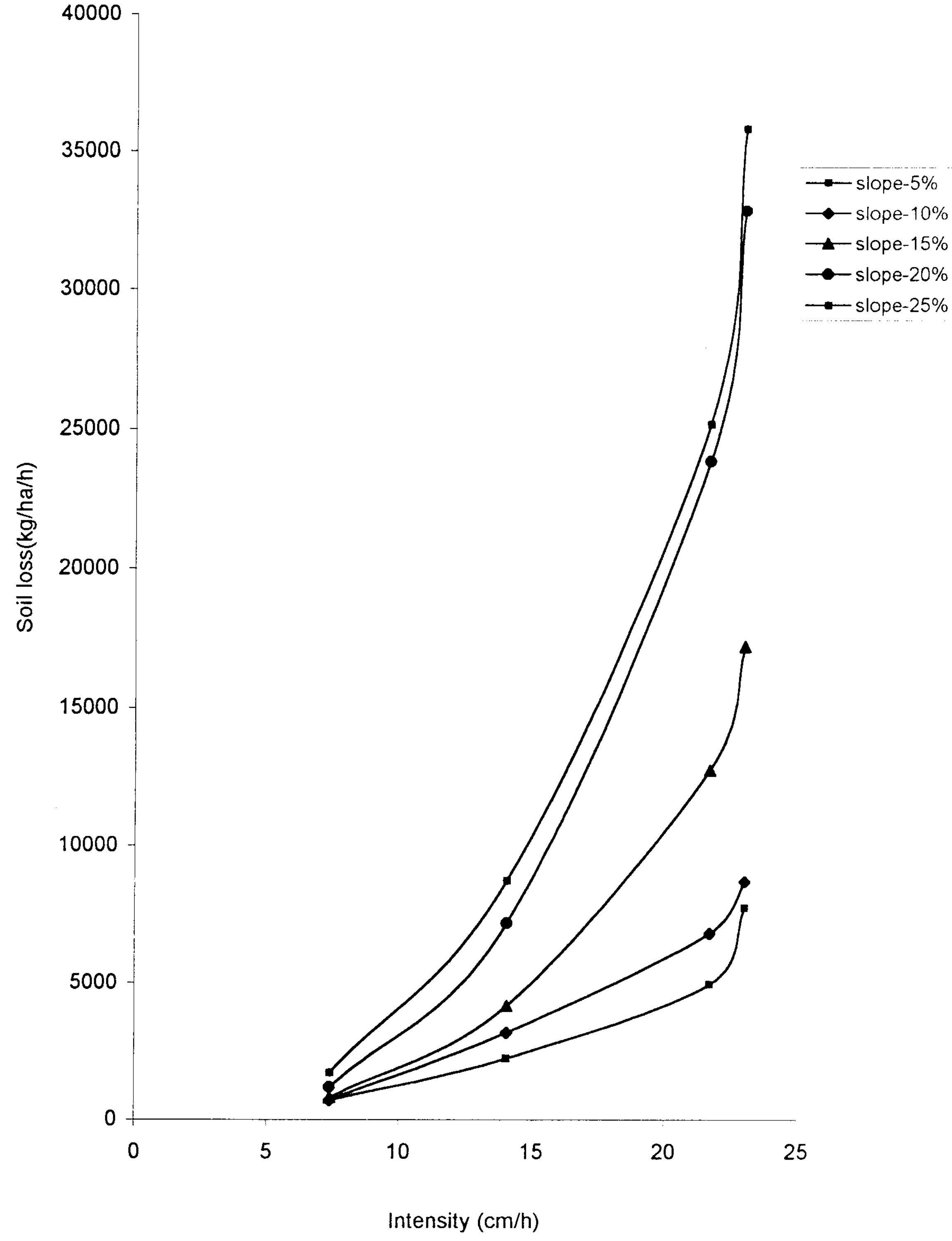


Fig.12 Effect of intensity on soil loss (Mannamkulam series)

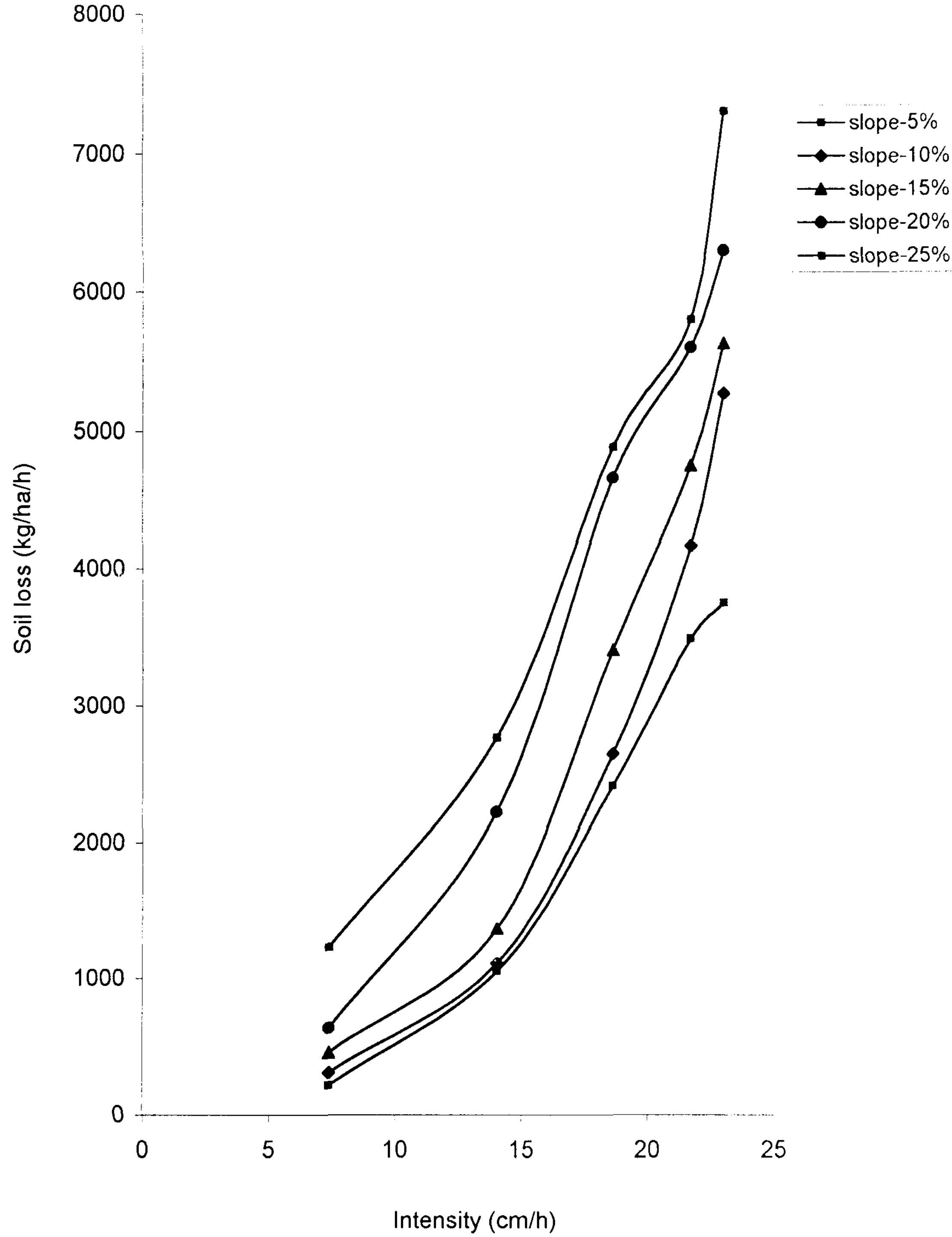


Fig.13 Effect of intensity on soil loss (Naduvattom series)

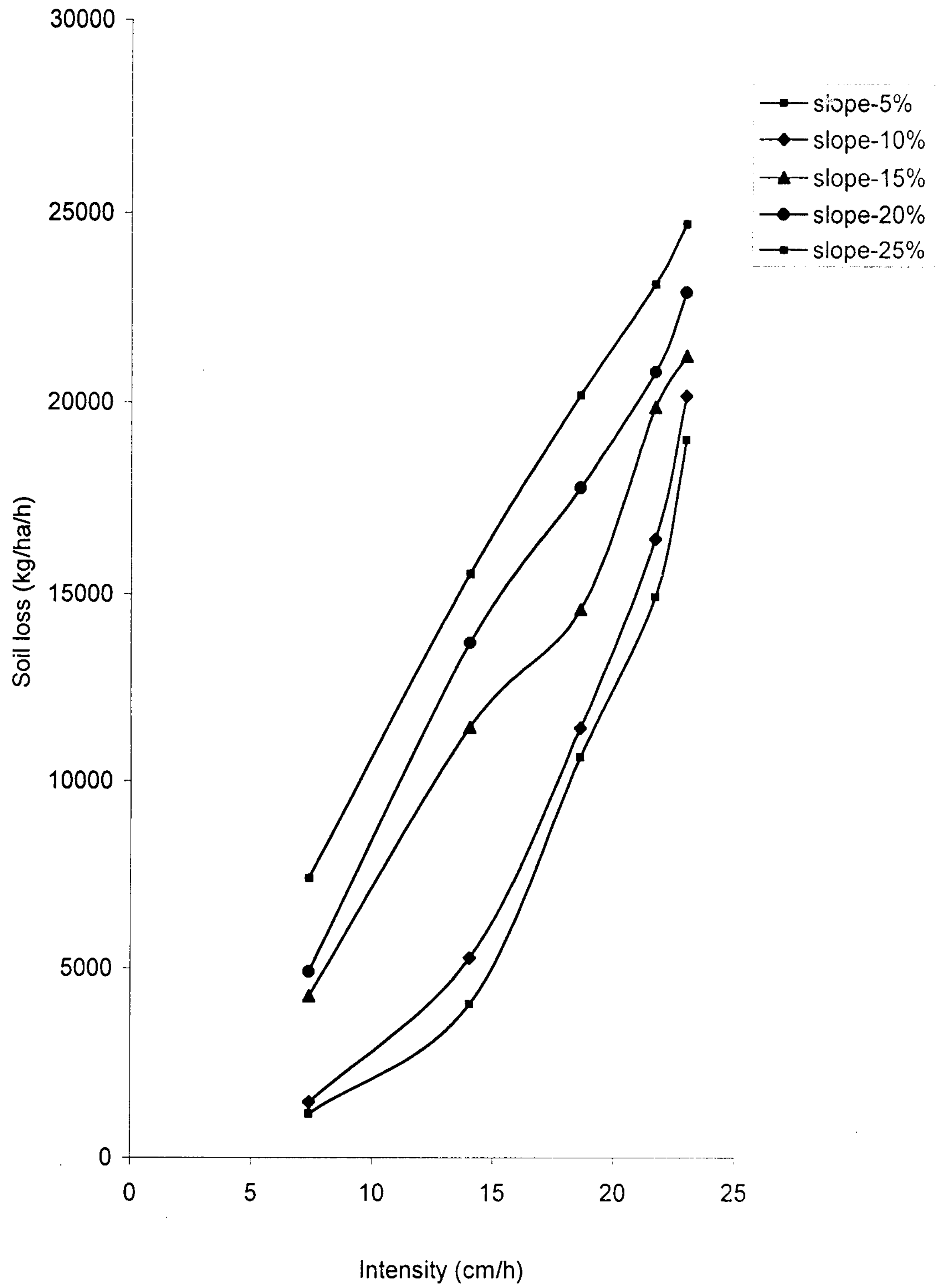


Fig.14 Effect of intensity on soil loss (Vellanikkara series)

4.3.2 Effect of land slope on soil loss.

Experiments were conducted to study the effect of land slope on soil loss at varying intensities and slopes. The results obtained are given in Appendix-III. Effect of land slope on soil loss for Mannumkulam series is shown in Fig.15. At an intensity of 7.41 cm/h the soil loss from 5 per cent slope was 684 kg/ha/h, whereas the the value increased to 714 kg/ha/h for 10 per cent slope. At a higher intensity of 23 cm/h, the soil loss from a plot of 5 per cent slope was 7710 kg/ha/h while it was 35762.8 kg/ha/h when slope was increased to 25 per cent. Similar trend was observed in the case of Naduvattom and Vellanikkara series of soils and are shown in Figures 16 and 17 respectively. A general trend of increase in the soil loss with the slope is seen in all the cases.

4.3.3 Empirical equation for soil loss

Multiple regression equations relating soil loss, intensity of rainfall and land slope were developed for each series of soil. The developed equations are given in Table 5.

4.3.4 Statistical analysis

Statistical analysis was carried out with the help of the computer package 'Systat 8.0' for checking any significant difference between the three series of soils studied. Tukey test for multiple comparison was used for comparison of means. From the analysis it was seen that there is no significant difference in soil loss between Mannamkulam series and Vellanikkara series. But there was a

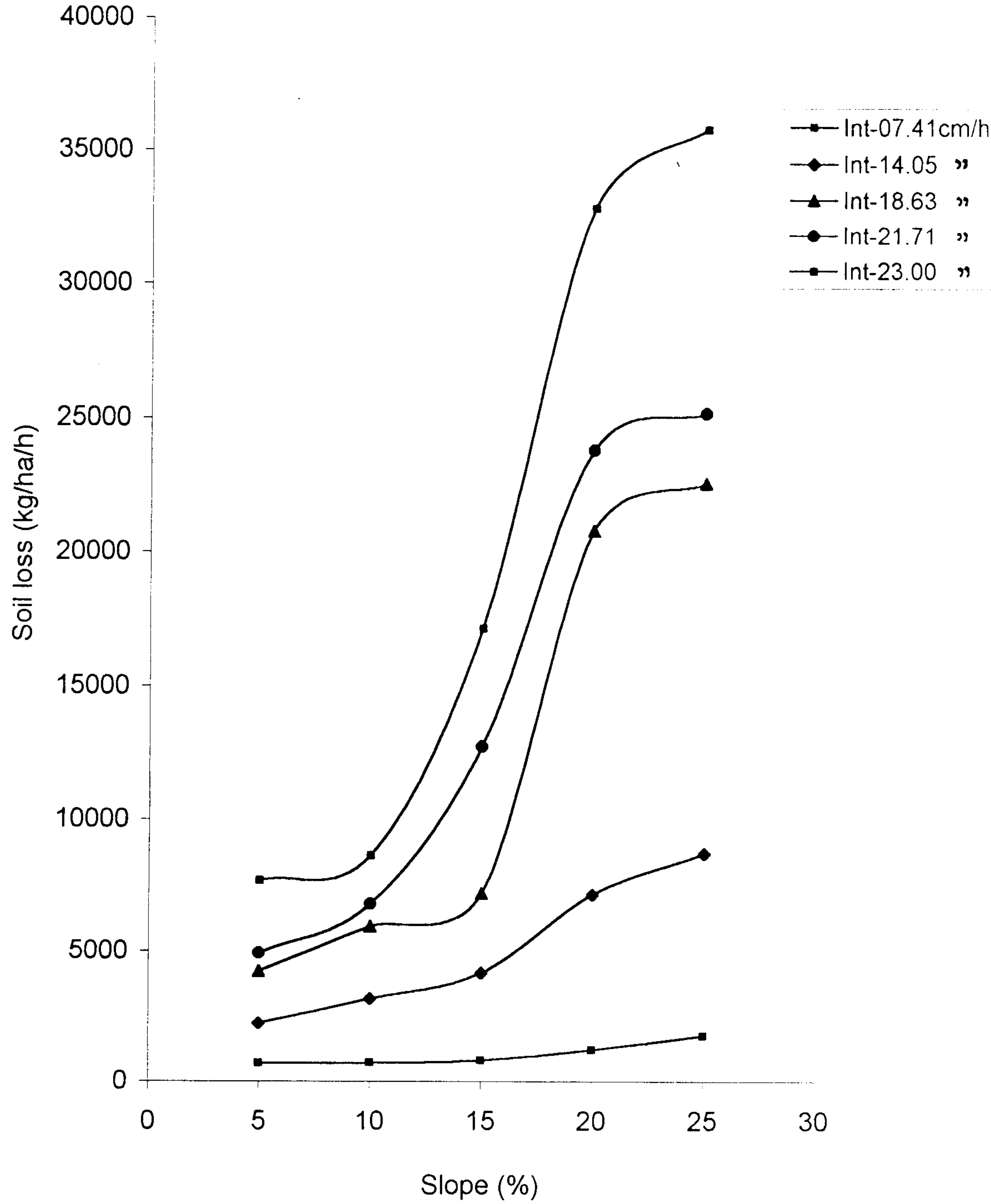


Fig.15 Effect of land slope on soil loss
(Mannamkulam series)

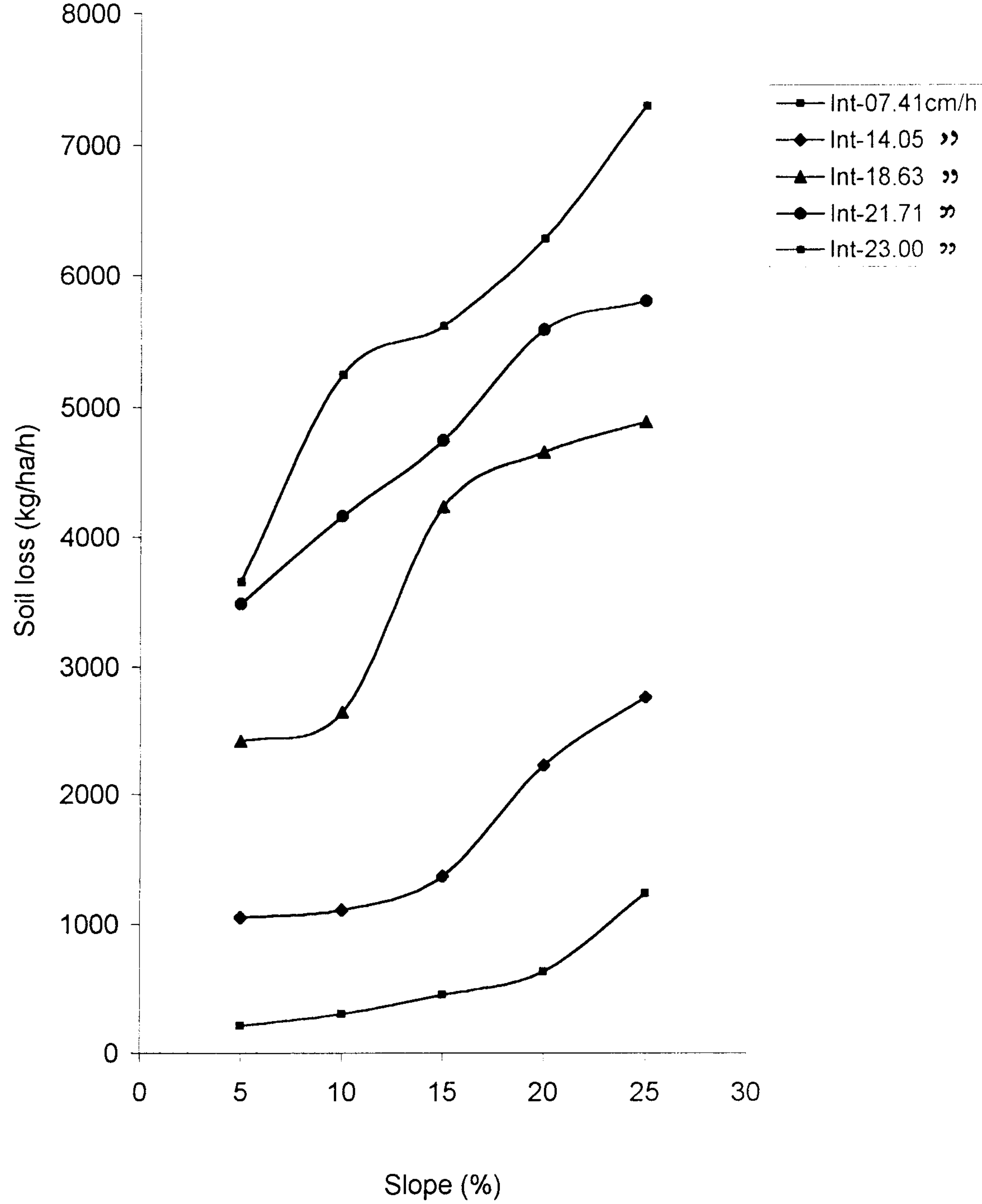


Fig.16 Effect of land slope on soil loss
(Naduvattom series)

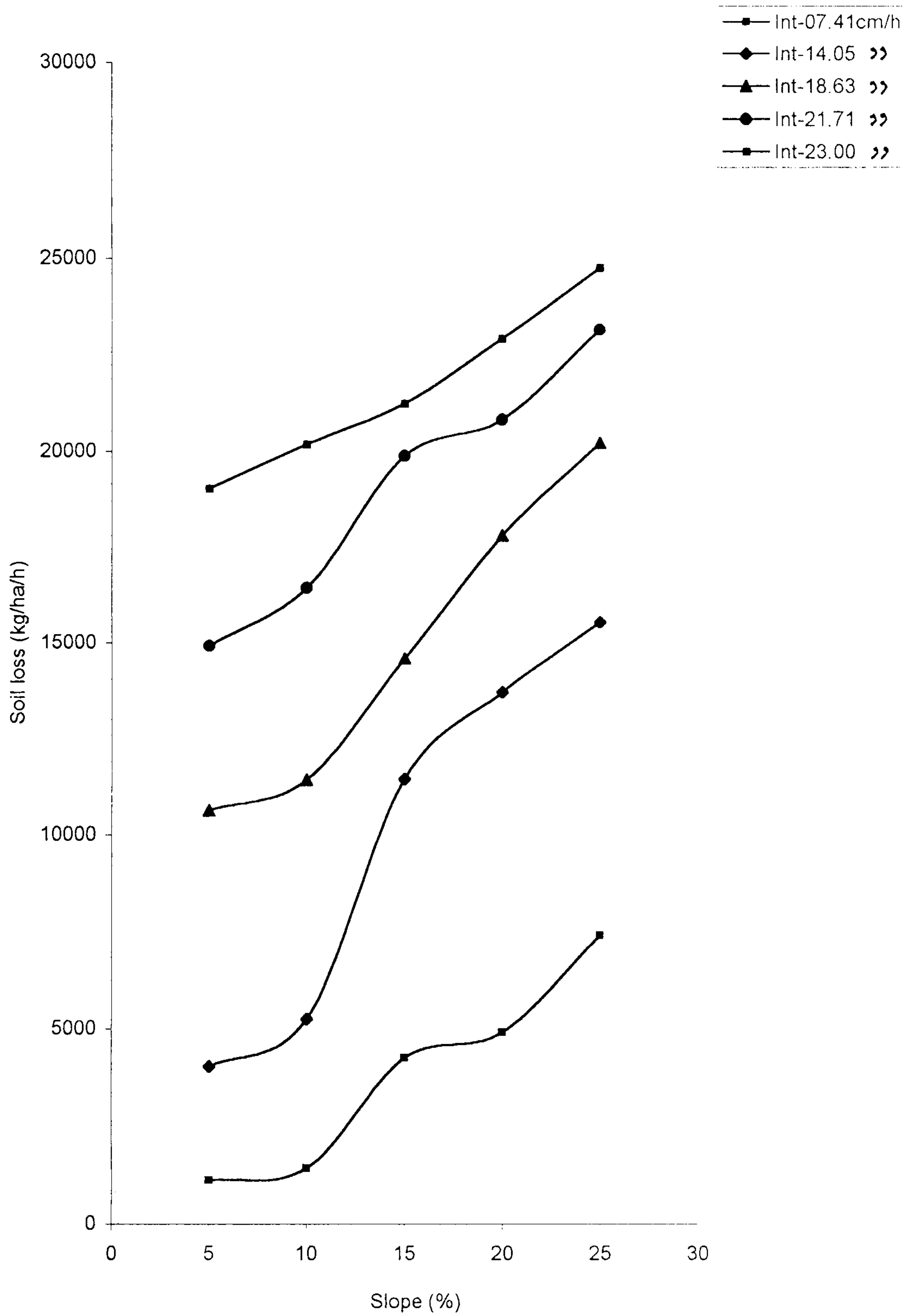


Fig.17 Effect of land slope on soil loss (Vellanikkara series)

Table 5. Empirical equations for soil loss of different soil series.

Soil series	Equation	R value
Mannamkulam series	E = 1167.797 I + 835. 109 S – 21686.07	0.90
Naduvattom series	E = 324.766 I + 112.799 S –3912.219	0.97
Vellanikkara series	E = 1115.662 I + 431.064 S – 11512.284	0.98

Where,

E = Soil loss in kg/ha/h,
I = intensity of rainfall in cm/h, ranging from 7.41 cm/h to 23 cm/h,
S = land slope in %, ranging from 5% to 25%,
R = Coefficient of Multiple regression.

significant difference in soil loss between Mannamkulam series and Naduvattom series and also a significant difference beween Naduvattom series and Vellanikkara series. The results obtained from computer analysis are given in Appendix-IV.

4.3.5 Effect of intensity of rainfall on runoff

Tests were conducted to study the effect of intensity of rainfall on runoff, on slopes ranging from 5 to 25 per cent for three series of soils. Simulated rainfall intensities of 7.41, 14.05, 18.63, 21.70 and 23.00 cm/h were applied on each slope. The results obtained from each series of soils are given in Appendix-V.

In the case of Mannamkulam series, at 5 per cent slope the runoff obtained for an intensity of 7.41 cm/h was 342.0 m^3/ha/h. On increasing the intensity to 14.05 cm/h, the runoff increased to 864.0 m^3/ha/h and the runoff reached a value of 1236.0 m^3/ha/h at 23 cm/h intensity. It was observed that as the intensity increases the runoff also increases. Similarly as the slope increases the runoff also increases. The graphs obtained for various slopes studied are similar in nature and are shown in Fig.18. The maximum runoff was obtained from the plot of 25 per cent at an intensity of 23 cm/h and was 1686.0 m^3/ha/h.

Similar trend was observed in the case of Naduvattom and Vellanikkara series of soils and are shown in Fig.19 and 20 respectively. The maximum runoff 1818 m^3/ha/h was obtained from the plot of Naduvattom series.

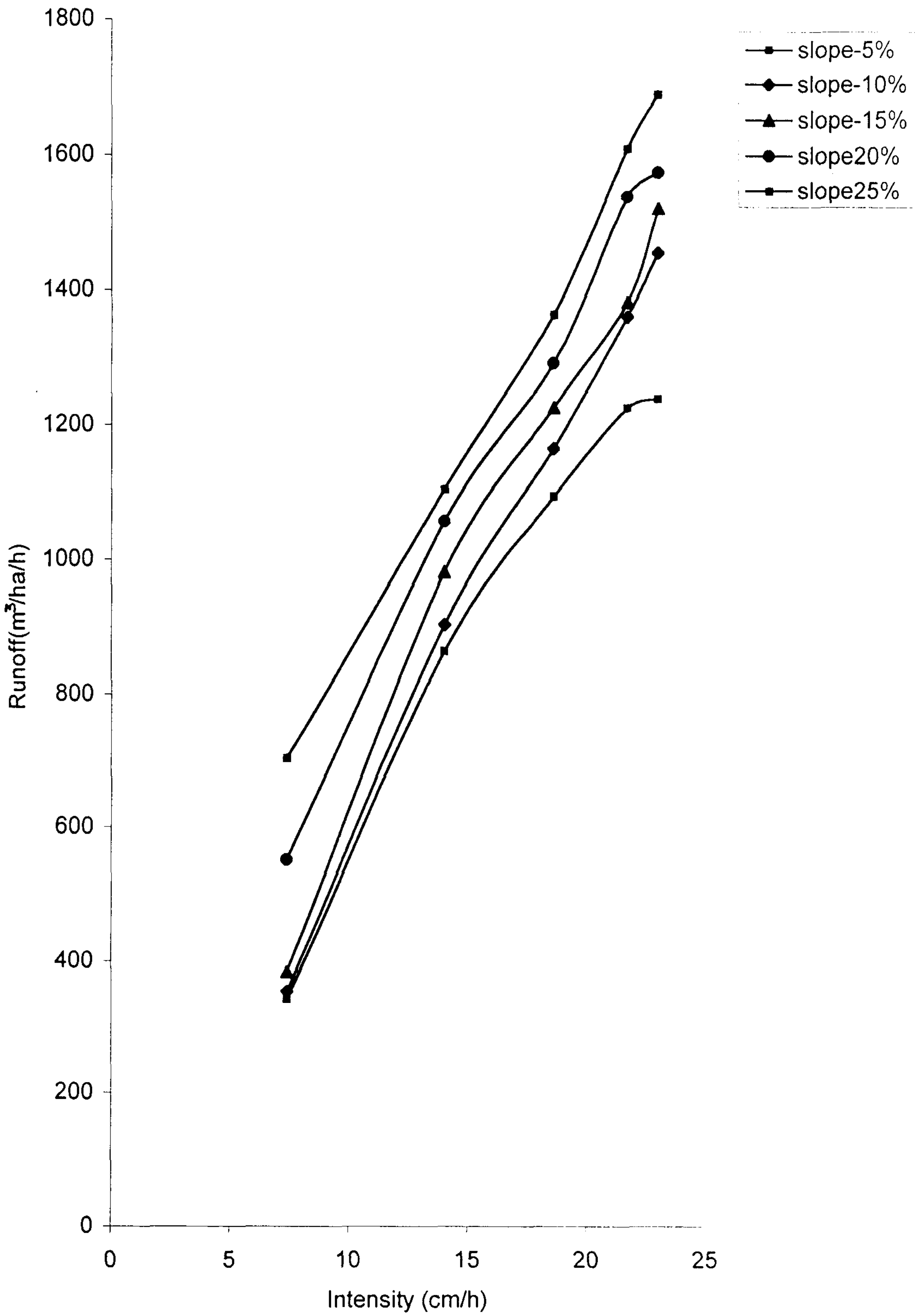


Fig.18 Effect of intensity on runoff (Mannamkulam series)

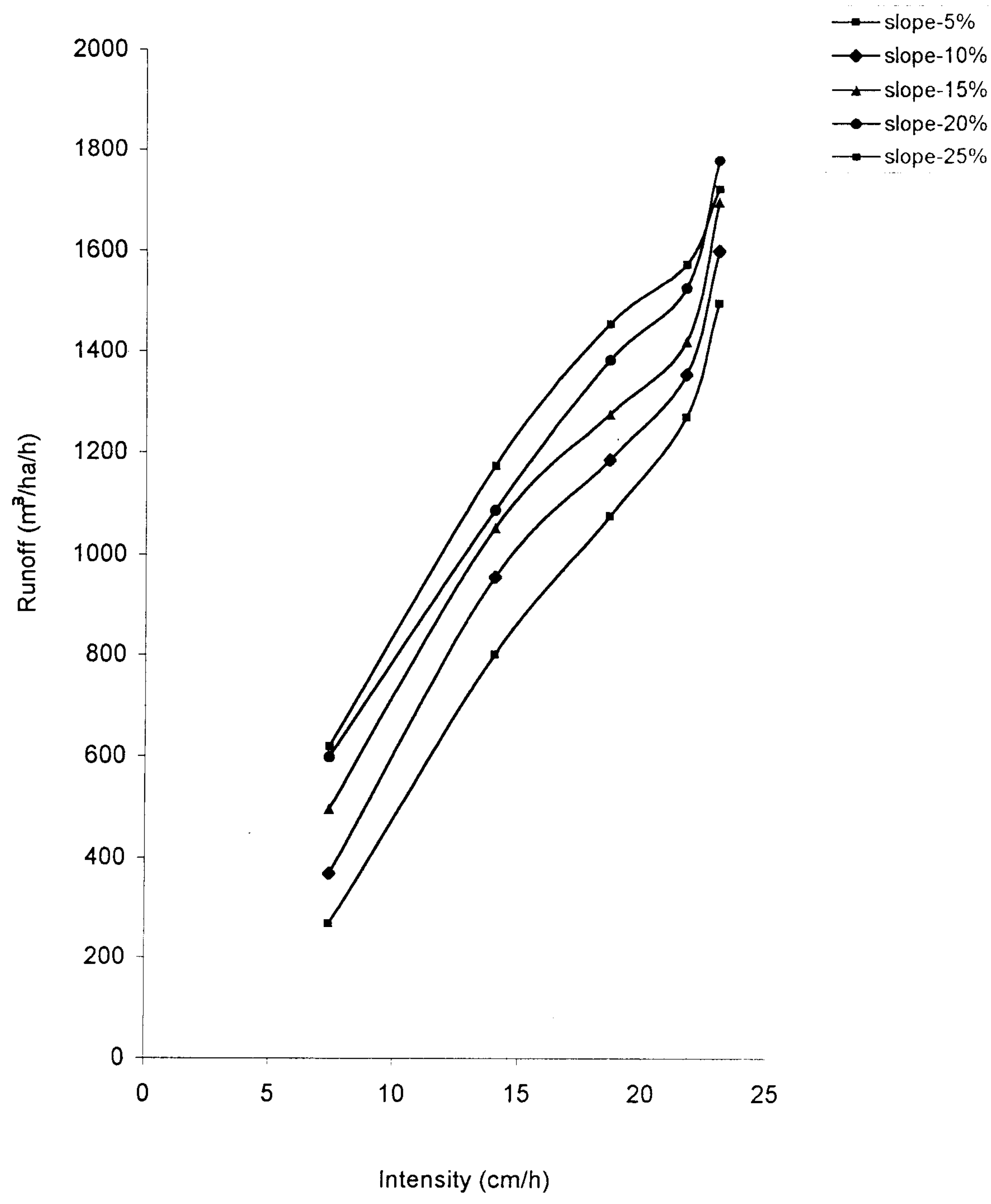


Fig.19 Effect of intensity on runoff (Naduvattom series)

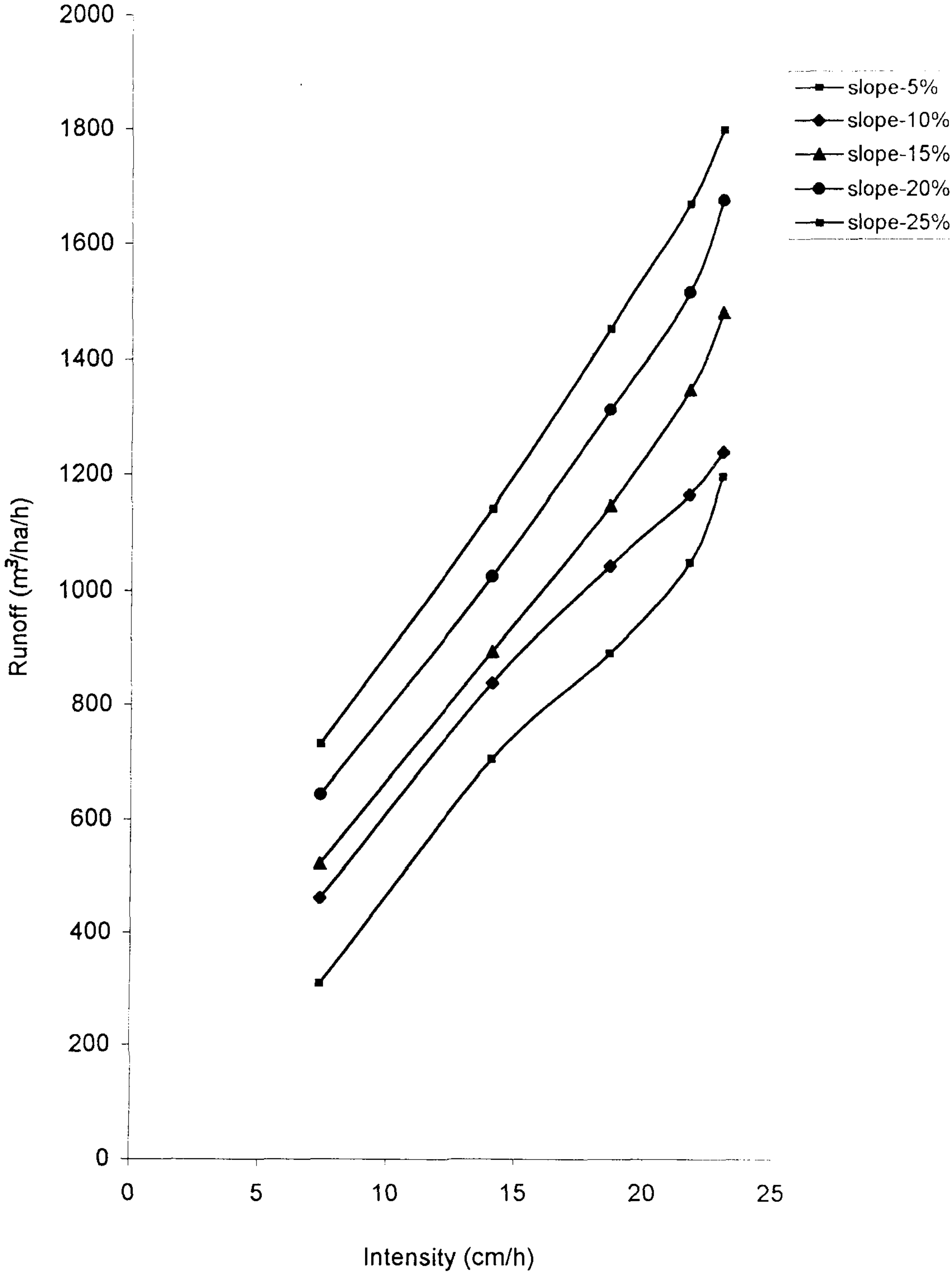


Fig.20 Effect of intensity on runoff (Vellanikkara series)

4.3.6 Effect of land slope on runoff

Test were conducted at slopes of 5, 10, 15, 20 and 25 percentage to study the effect of land slope on runoff for each series. Experiments were conducted at five simulated intensities on each slope and the corresponding runoff were measured. The results obtained from each series of soils are given in Appendix-VI.

Figures 21, 22 and 23 shows the effect of land slope on runoff for selected intensities of rainfall from the plots of Mannumkulam series, Naduvattom series and Vellanikkara series respectively. From the graphs it is seen that the runoff increases with the slope. It also reveales that the runoff increases with increase in the intensity of rainfall for a particular value of slope. Nature of the curves obtained from the series of soils are similar.

4.3.7 Empirical equation for runoff

Multiple regression equations relating runoff, intensity of rainfall and land slope were developed for each series of soils. The developed equations are given in Table 6.

4.3.8 Statistical analysis

Statistical analysis was carried out with the help of the computer package 'Systat 8.0' for checking any significant difference in runoff between three series of soils studied. Tukey test was used for comparing the means. From the analysis

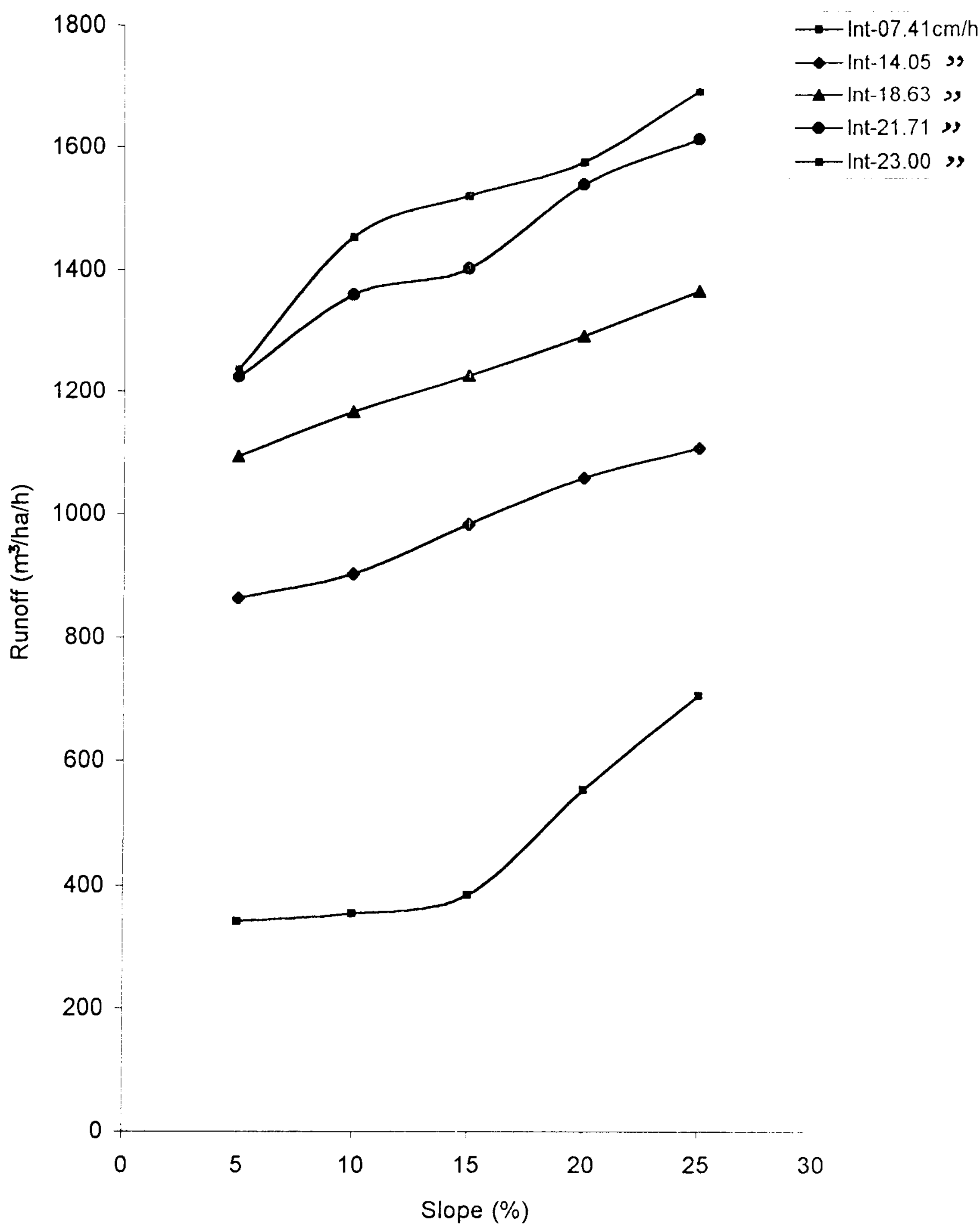


Fig.21 Effect of land slope on runoff (Mannamkulam series)

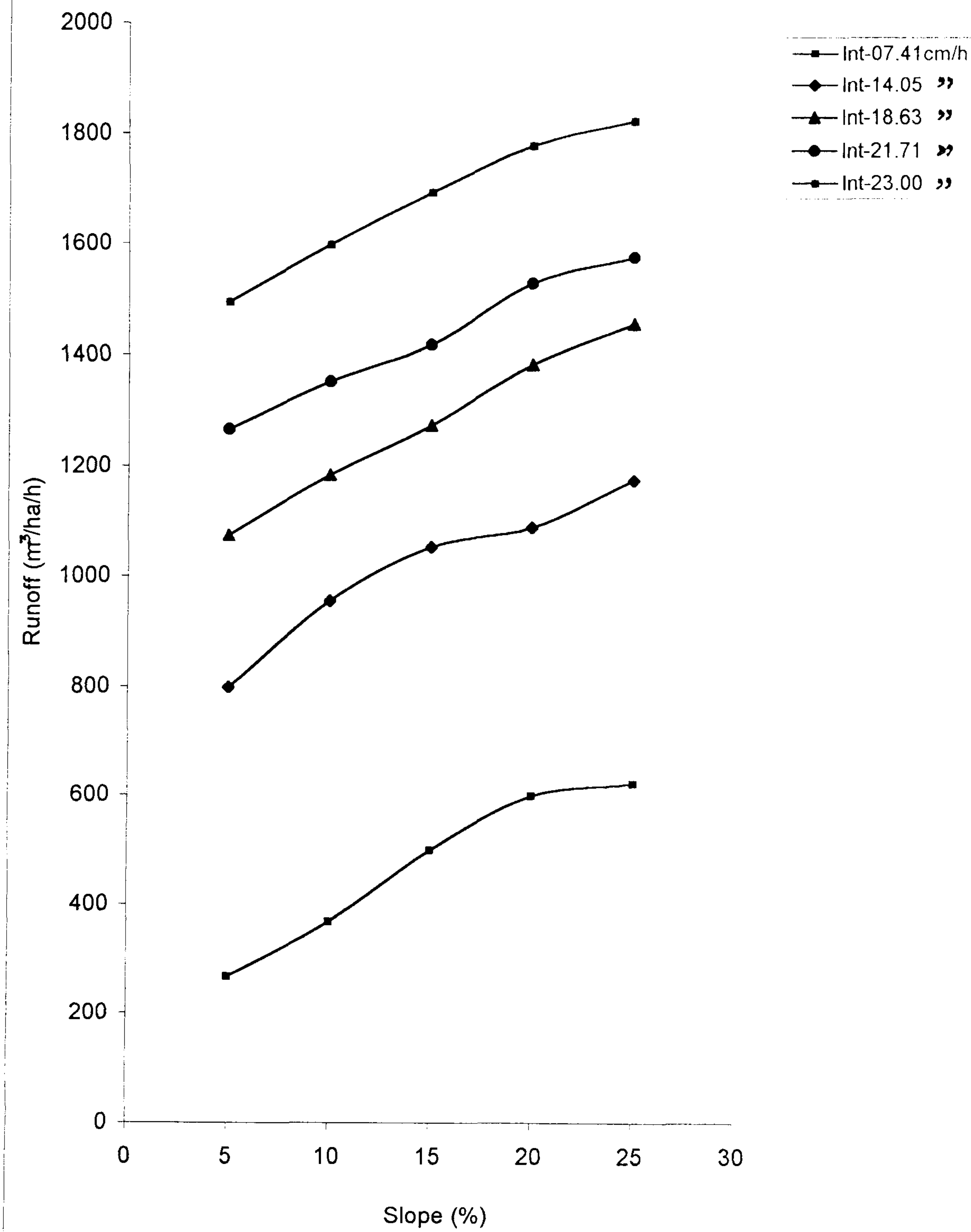


Fig.22 Effect of land slope on runoff (Naduvattom series)

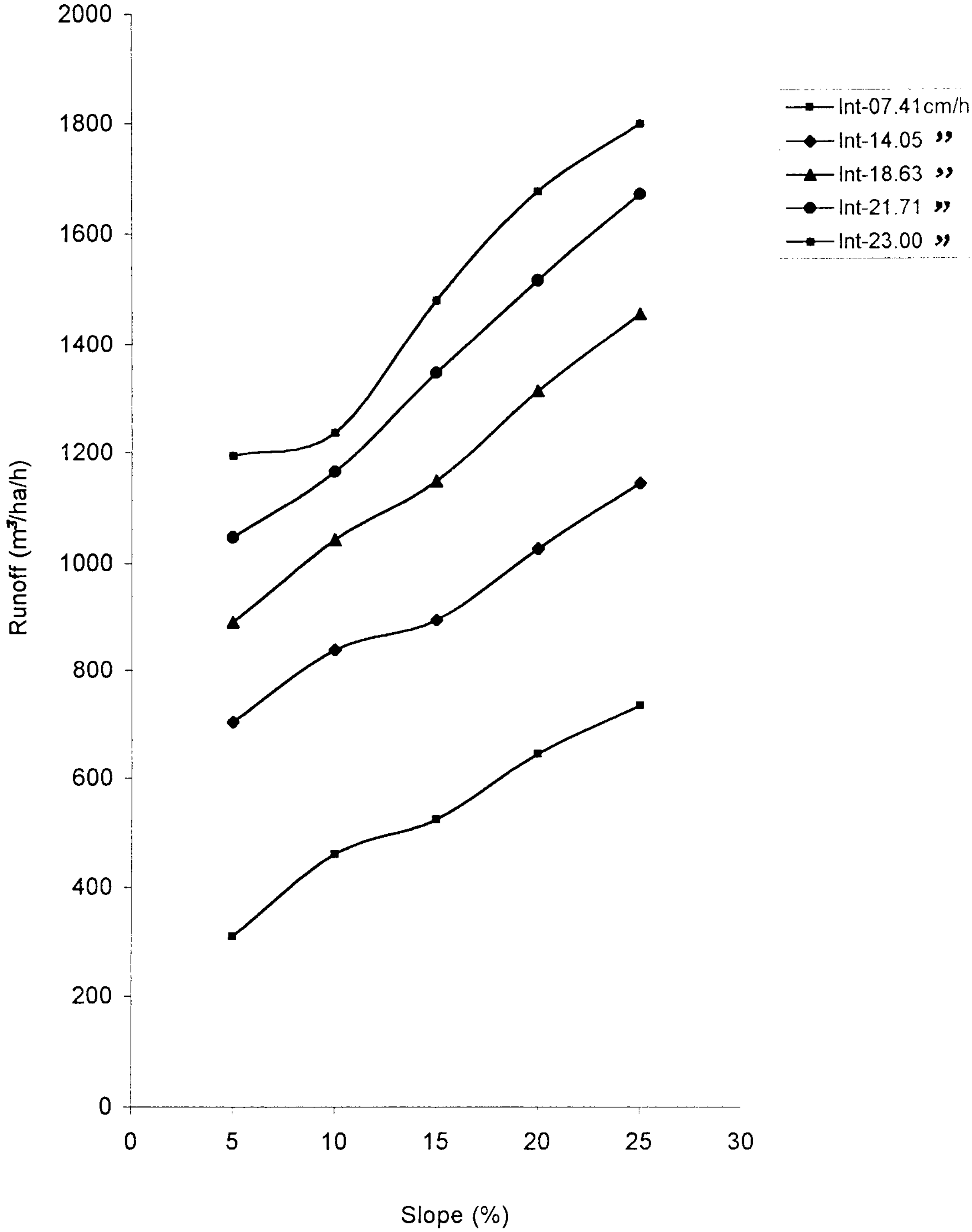


Fig.23 Effect of land slope on runoff (Vellanikkara series)

Table 6. Empirical equations for runoff of different soil series

Soil series	Equation	R value
Mannamkulam series	Q = 65.016 I + 16.747 S − 235.923	0.99
Naduvattom series	Q = 74.542 I +19.434 S − 394.323	0.99
Vellanikkara series	Q = 58.742 I + 26.837 S −310.019	0.99

Where,

Q = runoff in m^3/ha/h,
I = intensity of rainfall in cm/h, ranging from 7.41 cm/h to 23 cm/h,
S = land slope in %, ranging from 5% to 25%,
R = coefficient of multiple regression.

it was seen that there was no significant difference in runoff between three soil series studied. The results obtained from the computer analysis are given in Appendix-VII.

4.3.9 Grain size distribution of eroded soil

The particle size of the eroded soil from all slopes at 23 cm/h intensity for three series of soils were studied. The eroded soils were collected and a combined sieve and sedimentation analysis was carried out. The results are tabulated in Appendix-VIII.

A semi-logarithmic plot of grain size and percentage finer for different slopes of three series of soils are shown in Figures 24, 25 and 26.

From the results, it was observed that the particles of size more than 4.75 mm were not present in the eroded sample collected from lower slopes of 5 and 10 per cent for all three series of soils. For higher slopes, eroded particles of size more than 4.75 mm were found in small quantities. This may be due to the less time of exposure to the rain, as the particles detached might not have got the opportunity time to travel to sediment collectors. From the graph, it was observed that curves obtained from each series of soils are almost similar in nature. In the case of Naduvattom series of soil, particles finer than 75 micron was more.

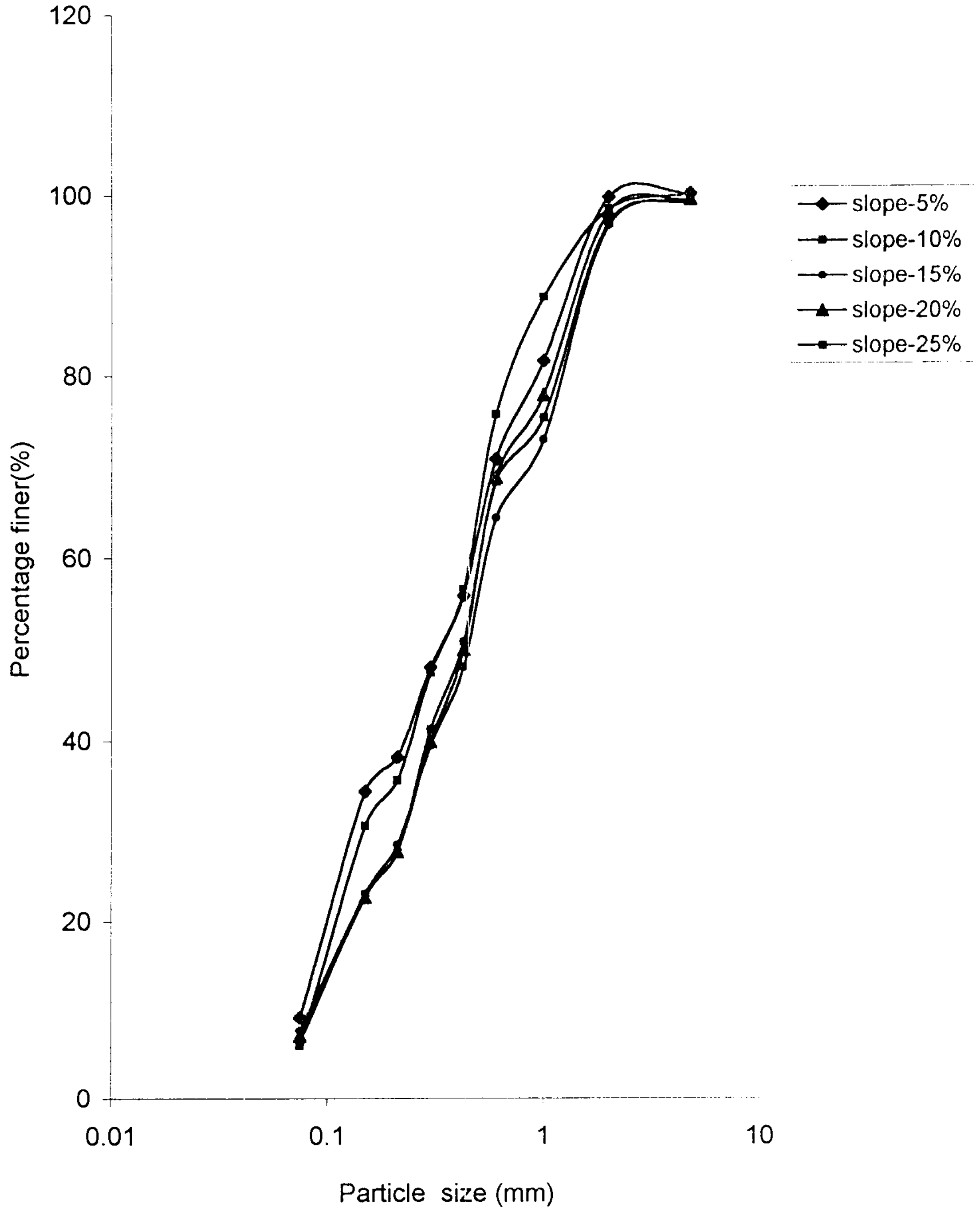


Fig.24 Particle size distribution curve of eroded soil (Mannamkulam series)

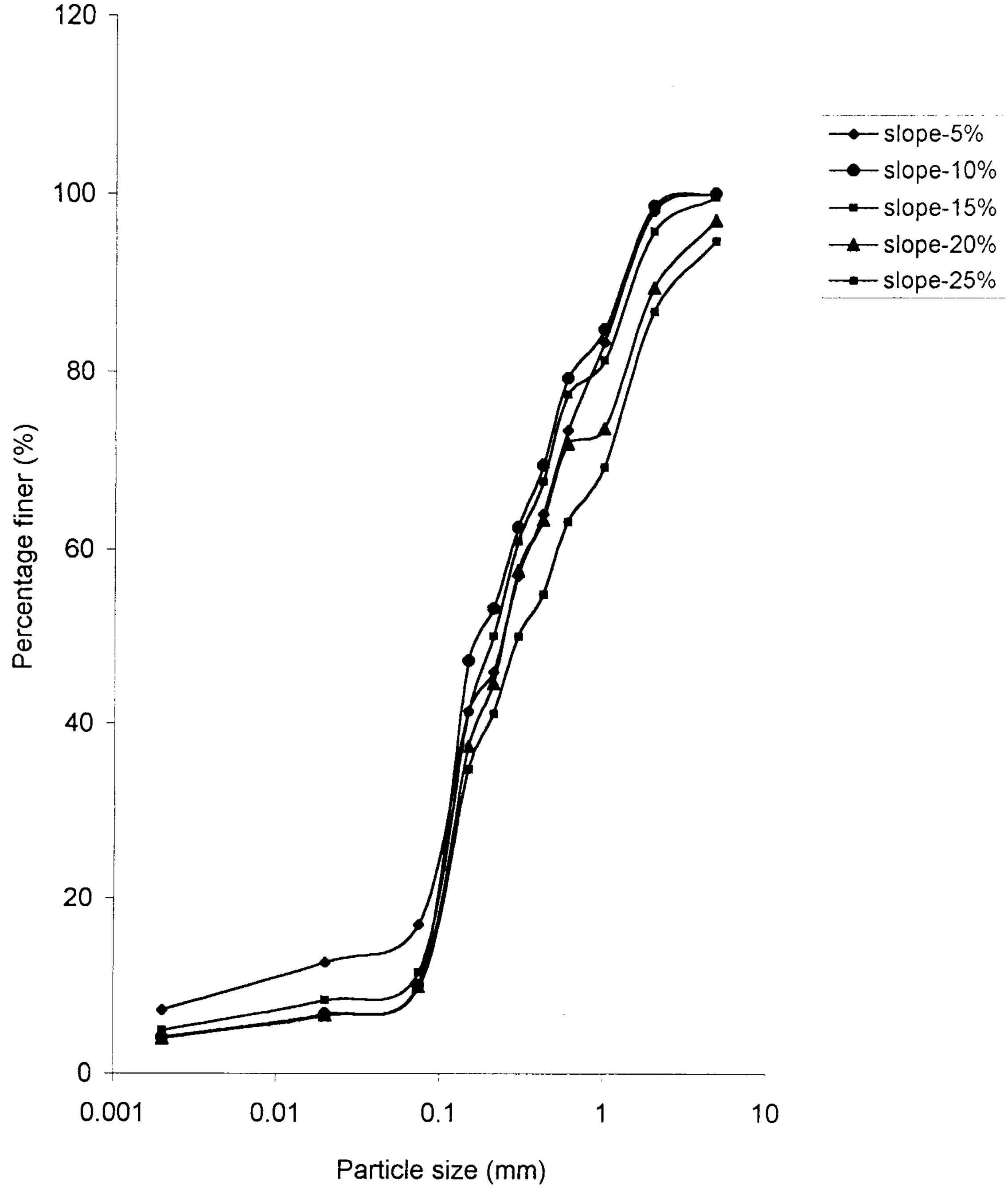


Fig.25 Particle size distribution curve of eroded soil
(Naduvattom series)

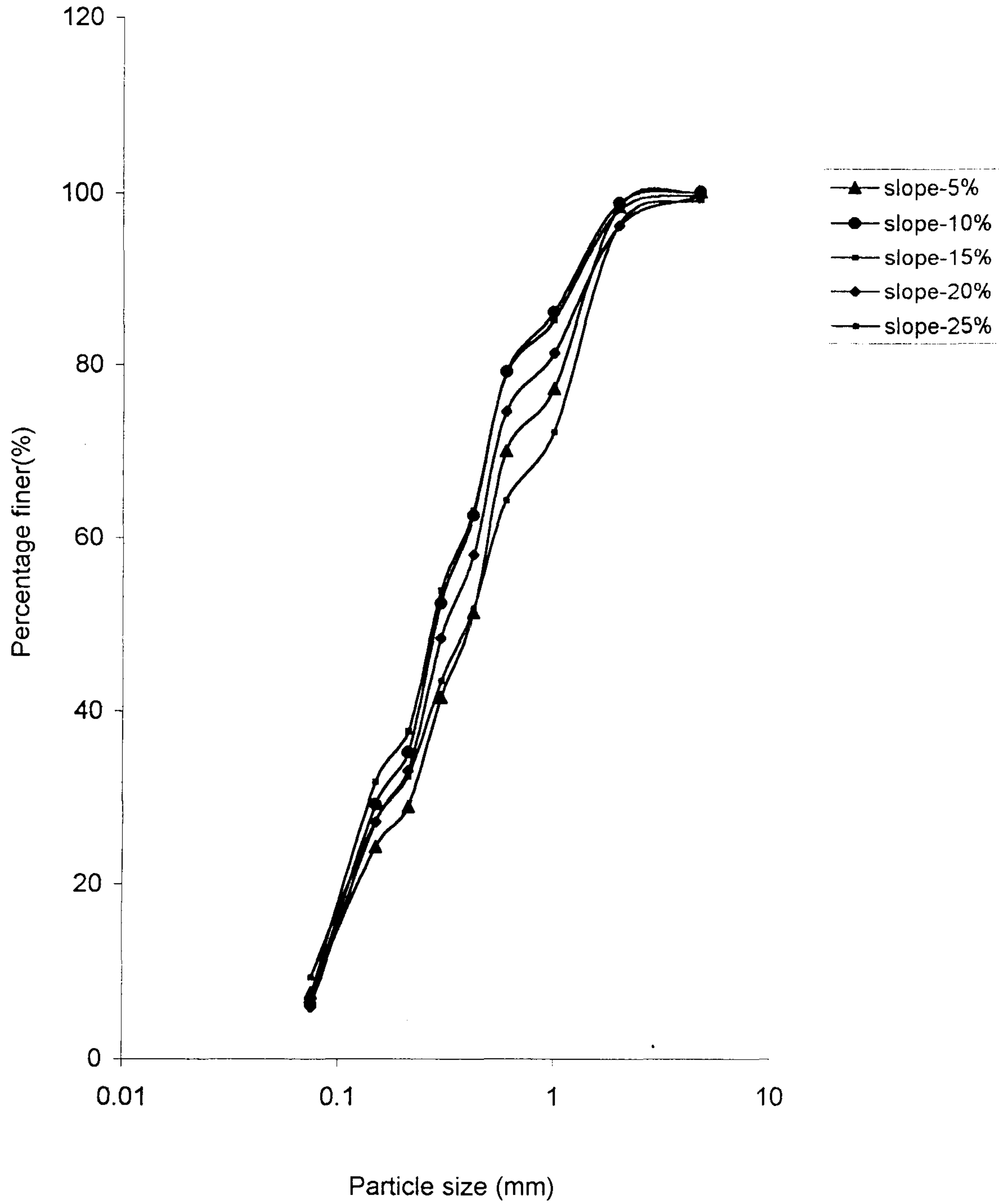


Fig.26 Particle size distribution curve of eroded soil (Vellanikkara series)

Practical/Scientific Utility

Rainfall simulators have been used for many years by researchers to accelerate and extend their study of erosion. Conservationists and planners of erosion control and water management systems need simple methods for determining the basic erodibility and runoff potentials of specific soil sites during the development of land use plans. Research data regarding soil loss from laterite soils are few. This study will provide information in estimating soil loss from laterite soils, which can be effectively used in land use planning, conservation and design of storage structures.

Suggestions for future work

In this study experiments were carried out with short duration of rainfall and for small area. Further studies may be carried out with longer durations of rainfall and for larger areas of exposure.

In the present study, experiments for erosion and runoff studies were conducted on bare soils only. A detailed investigation is suggested to ascertain the influence of vegetative cover on erosion and runoff.

Summary

SUMMARY

The major threat for sustainable crop production is soil erosion. Erosion leads to a reduction in soil quality and soil nutrients and thus decreased agricultural productivity. Another concern with erosion is an increase in turbidity of runoff which has an adverse effect on the quality of surface water and sedimentation in reservoirs and canals. Severe erosion occurs with high rainfall due to improper management of land and water. Rainfall is considered as the most important agent responsible for erosion. Rain drops cause the soil to be splashed and the flowing water carries the detached particles.

Rainfall simulators are used to study the hydrologic processes such as infiltration, erosion, sediment transport and runoff. As rainfall simulators provide control of natural environmental factors such as rainfall intensity and duration, they are used to determine basic information on these hydrologic processes. Soil erosion data can be obtained more rapidly and efficiently by using simulated rainfall than by relying on natural rainfall. Simulators make it possible to produce predetermined storms at any desired time and location. They make the replication of research easier and facilitate the study of storm sequences.

An oscillating hypodermic needle type rainfall simulator and a soil trough were fabricated to conduct the erosion studies. The design of rainfall simulator was based on that designed by Kurien and George (1998). The rainfall simulator consisted of a drop former unit mounted on an angle iron frame work, power

transmission system and water supply unit. The drop former unit consisted of 18 gauge hypodermic needles fitted on a 20 mm diameter GI pipe network. The networks had four transverse pipes and each transverse pipe was fitted with 44 needles. The drop former unit was made to oscillate at 13 oscillations per minute. A centrifugal pump operated by an electric motor was used to supply the water from a tank to the rainfall simulator. A pressure gauge of 0-2 kg/cm^2 range was fixed in the discharge line and the pressure of water supply was controlled by means of two gate valves in the discharge line of pump. The experimental setup was installed at KCAET, Tavanur.

The simulator was tested for different intensities of rainfall by changing the pressure of water supply. From the test results a relationship was established between intensity and the supply pressure of water. as,

$$I = -87.205p^2 + 108.61\,P - 10.786\ (R = 0.99)$$

Where,

I = intensity of rainfall, cm/h.

P = supply pressure, kg/cm^2.

The simulated raindrop size was determined by flour-pellet method. The droplet size decreased with the increased intensity of rainfall. Christiansen's uniformity coefficients were worked out for different intensities. Higher uniformity coefficients were obtained at higher intensities. The maximum value of uniformity coefficient was found to be 91.53 per cent for an intensity of 23 cm/h.

A soil trough of size 1m x 1m was fabricated with a stand of adjustable legs to hold the soil at the required slope for erosion studies. Three series of laterite soils were collected from three different locations. Physical properties of these soils were determined. The particle size distribution curves when plotted showed that the soils are coarse grained and the particle size distribution of three series of soils are similar. The liquid limit and plastic limit of the soils were determined by standard methods.

Experiments were conducted to study soil loss and runoff from the three series of laterite soils. Studies were conducted for 7.41, 14.05, 18.63, 21.71 and 23.00 cm/h intensities of rainfall at 5 slopes varying from 5 to 25 per cent for each series of soil.

The soil loss increased with increase in the intensity of rainfall for all the slopes in the three series of soils studied. When compared to Vellanikkara series and Mannamkulam series, the soil loss from Naduvattom series was low. The nature of the curves obtained from the three series of soils for all the slopes studied were similar.

A general trend of increase in the soil loss with increase in the slope was observed for all the simulated intensities of rainfall from each series of soil.

Tests were conducted to study the effect of intensity and land slope on runoff for each series of soil. Similar trend was observed in all cases. In general the runoff increased with intensity and slope. The amount of runoff obtained from each series of soil are almost same.

Empirical equations were developed for estimating soil loss and runoff for various intensities of rainfall and land slopes for three series of soils.

The equations are:

For Mannamkulam series

$$E = 1167.797\ I + 835.109\ S - 21686.07 \quad (R = 0.90)$$

$$Q = 65.016\ I + 16.747\ S - 235.923 \quad (R = 0.99)$$

For Naduvattom series

$$E = 324.766\ I + 112.799\ S - 3912.219 \quad (R = 0.97)$$

$$Q = 74.542\ I + 19.434\ S - 394.323 \quad (R = 0.99)$$

For Vellanikkara series

$$E = 1115.662\ I + 431.064\ S - 11512.284 \quad (R = 0.98)$$

$$Q = 58.742\ I + 26.837\ S - 310.019 \quad (R = 0.99)$$

Where,

E = soil loss in kg/ha/h,

Q = runoff in m^3/ha/h,

I = intensity of rainfall in cm/h, ranging from 7.41 cm/h to 23 cm/h,

S = land slope in %, ranging from 5% to 25%.

Statistical analysis were carried out with the help of the computer package 'Systat 8.0' for checking any significant difference in soil loss and runoff between three series of soils studied. There was no significant difference in soil loss between Mannamkulam series and Vellanikkara series. But there was significant difference in soil loss between Mannamkulam series and Naduvattom series and also in Vellanikkara series and Naduvattom series. In the case of runoff, no significant difference was observed between these three soils.

Particle size analysis of the eroded soil samples obtained from all slopes at 23 cm/h intensity for each series of soils were carried out. Curves obtained for each series of soils are almost similar in nature. Particles finer than 75 micron was more in the case of Naduvattom series, which is in agreement with the low soil loss from this series of soil.

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* Originals not seen

Appendices

APPENDIX - I

Determination of hypodermic needle diameter

The intensity of rainfall selected are

I_1 = 4.80 cm/h I_2 = 5.6 cm/h
I_3 = 7.0 cm/h I_4 = 8.80 cm/h

Taking I_1 = 4.8 cm/h

= 1.89 inch/h

As per Mc Gregor and Mutchler (1976)

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

Where,

I - intensity of rainfall, inch/h

$$D_{50} = 2.76 + 11.40\, e^{(-1.04 \times 1.89)} - 13.16\, e^{(-1.17 \times 1.89)}$$

= 2.9137 mm

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

= 12.9518 mm^3

Weight of the drop w_1 = 0.01295 g

Substituting in the equation suggested by Mutchler (1965)

$$W = 4.925 \frac{\sigma^{0.943}\, d^{0.832}\, r^{0.093}}{g^{1.018}} \quad \text{------------------- (2)}$$

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	= 2.6 x 2.2
	= 5.72 m^2
Intensity I_1	= 4.8 cm/h
Total volume of rainfall	= 0.27456 m^3/h
Total number of needles	= 112
Flow per tube Q_1	= 0.681 g/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

$$d = 0.04889 \text{ cm}$$

ie

diameter of the needle = 0.04889 cm = 25 gauge

Similarly,

Taking I_2 = 5.6 cm/h

Diameter of the needle d_2 = 0.0429 cm = 25 gauge

Taking I_3 = 7 cm/h

Diameter of the needle d_3 = 0.0456 cm = 26 gauge

Taking I_4 = 8.80 cm/h

The diameter of the needle = 0.0429 cm = 27 gauge.

APPENDIX-II

Effect of intensity of rainfall on soil loss at different slopes (Mannamkulam series)

Slopes	Intensity (cm/h)	Soil loss for 5 min (g)	Soil loss (kg/ha/h)
5	7.41	5.70	684.0
	14.05	18.64	2236.8
	18.63	35.25	4230.0
	21.71	41.20	4944.0
	23.00	64.25	7710.0
10	7.41	5.95	714.0
	14.05	26.42	3170.4
	18.63	49.50	5940.0
	21.71	56.75	6810.0
	23.00	72.25	8670.0
15	7.41	6.70	804.0
	14.05	34.60	4152.0
	18.63	60.15	7218.0
	21.71	106.30	12756.0
	23.00	143.00	17160.0
20	7.41	10.00	1200.0
	14.05	59.75	7170.0
	18.63	173.28	20793.6
	21.71	198.50	23820.0
	23.00	273.55	32826.0
25	7.41	14.45	1734.0
	14.05	72.62	8714.4
	18.63	188.14	22576.8
	21.71	209.94	25152.8
	23.00	298.19	35762.8

Appendix-II (Contd.)

Effect of intensity of rainfall on soil loss at different slopes (Naduvattom series)

Slopes	Intensity (cm/h)	Soil loss for 5 min (g)	Soil loss (kg/ha/h)
5	7.41	1.76	211.2
	14.05	8.75	1050.0
	18.63	20.10	2410.0
	21.71	29.00	3480.0
	23.00	30.43	3651.0
10	7.41	2.55	306.0
	14.05	9.25	1110.0
	18.63	22.00	26.40.0
	21.71	34.65	4158.0
	23.00	43.85	5262.0
15	7.41	3.75	450.0
	14.05	11.38	1365.6
	18.63	35.25	4230.0
	21.71	39.50	4740.0
	23.00	46.80	5616.0
20	7.41	5.25	630.0
	14.05	18.50	2220.0
	18.63	38.75	4650.0
	21.71	46.55	5586.0
	23.00	52.35	6282.0
25	7.41	10.80	1236.0
	14.05	23.00	2760.0
	18.63	40.65	4878.0
	21.71	48.25	5790.9
	23.00	60.76	7291.2

Appendix-II (Contd.)

Effect of intensity of rainfall on soil loss at different slopes (Vellanikkara series)

Slopes	Intensity (cm/h)	Soil loss for 5 min (g)	Soil loss (kg/ha/h)
	7.41	9.60	1152.0
	14.05	33.65	4038.0
5	18.63	88.48	10617.6
	21.71	124.25	14910.0
	23.00	158.52	19022.4
	7.41	12.21	1465.2
	14.05	43.87	5264.4
10	18.63	95.08	11403.6
	21.71	137.06	16447.2
	23.00	168.08	20169.6
	7.41	35.40	4248.0
	14.05	95.09	11410.8
15	18.63	121.37	14564.4
	21.71	165.69	19862.8
	23.00	176.88	21225.6
	7.41	40.88	4905.6
	14.05	113.85	13662.0
20	18.63	148.29	17794.8
	21.71	173.28	20793.6
	23.00	190.82	22898.4
	7.41	61.71	7405.2
	14.05	129.39	15526.8
25	18.63	168.29	20194.8
	21.71	192.64	23116.8
	23.00	206.06	24727.2

APPENDIX-III

Effect of land slope on soil loss at different intensities (Mannamkulam series)

Intensity of rainfall (cm/h)	Slopes (%)	Soil loss for 5 min (g)	Soil loss (kg/ha/h)
7.41	5	5.70	684.0
	10	5.95	714.0
	15	6.70	804.0
	20	10.00	1200.0
	25	14.45	1734.0
14.05	5	18.64	2236.8
	10	26.42	3170.4
	15	34.60	4152.0
	20	59.75	7170.0
	25	72.62	8714.4
18.63	5	35.25	4230.0
	10	49.50	5940.0
	15	60.15	7218.0
	20	173.28	20793.6
	25	188.14	22576.8
21.71	5	41.20	4944.0
	10	56.75	6810.0
	15	106.30	12756.0
	20	198.50	23820.0
	25	209.94	25152.8
23.00	5	64.25	7710.0
	10	72.25	8670.0
	15	143.00	17160.0
	20	273.55	32826.0
	25	298.19	35762.8

Appendix-III (Contd.)

Effect of land slope on soil loss at different intensities (Naduvattom series)

Intensity of rainfall (cm/h)	Slopes (%)	Soil loss for 5 min (g)	Soil loss (kg/ha/h)
7.41	5	1.76	211.2
	10	2.55	306.0
	15	3.75	450.0
	20	5.25	630.0
	25	10.80	1236.0
14.05	5	8.75	1050.0
	10	9.25	1110.0
	15	11.38	1365.6
	20	18.50	2220.0
	25	23.00	2760.0
18.63	5	20.10	2410.0
	10	22.00	2640.0
	15	35.25	4230.0
	20	38.75	4650.0
	25	40.65	4878.0
21.71	5	29.00	3480.0
	10	34.65	4158.0
	15	39.50	4740.0
	20	46.55	5586.0
	25	48.25	5790.9
23.00	5	30.43	3651.0
	10	43.85	5251.0
	15	46.80	5616.0
	20	52.35	6282.0
	25	60.76	7291.2

Appendix-III (Contd.)

Effect of land slope on soil loss at different intensities (Vellanikkara series)

Intensity of rainfall (cm/h)	Slopes (%)	Soil loss for 5 min (g)	Soil loss (kg/ha/h)
7.41	5	9.60	1152.0
	10	12.21	1465.2
	15	35.40	4248.0
	20	40.88	4905.6
	25	61.71	7405.2
14.05	5	33.65	4038.0
	10	43.87	5264.4
	15	95.09	11410.8
	20	113.85	13662.0
	25	129.39	15526.8
18.63	5	88.48	10617.6
	10	95.08	11403.6
	15	121.37	14564.4
	20	148.29	17794.8
	25	168.29	20194.8
21.71	5	124.25	14910.0
	10	137.06	16447.2
	15	165.69	19862.8
	20	173.28	20793.6
	25	192.64	23116.8
23.00	5	158.52	19022.4
	10	168.08	20169.6
	15	176.88	21225.6
	20	190.82	22898.4
	25	206.06	24727.2

APPENDIX - IV

Results of statistical analysis for soil loss

Row	Soil type
1	1. Mannamkulam series
2	2. Naduvattom series
3	3. Vellanikkara series

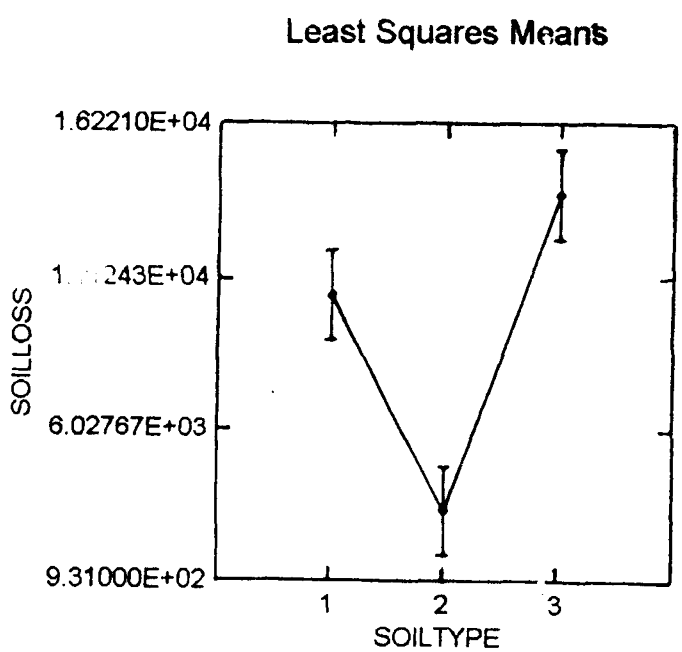
Using least squares means
Post HOC test (Tukey) of soil loss

Using model MSE of 55458875.736 with 72 dt. Matrix of pairwise mean differences:

	1	2	3
1	0.000		
2	-7272.172	0.000	
3	3321.185	10593.357	0.000

Tukey Multiple Comparisons
Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.003	1.000	
3	0.262	0.000	1.000



APPENDIX-V

Effect of intensity of rainfall on runoff at different slopes (Mannamkulam series)

Slopes	Intensity of rainfall (cm/h)	Runoff for 5 min (l)	Runoff (m^3/ha/h)
5	7.41	2.85	342.0
	14.05	7.20	864.0
	18.63	9.10	1092.0
	21.71	10.19	1222.8
	23.00	10.30	1236.0
10	7.41	2.95	354.0
	14.05	7.53	903.6
	18.63	9.70	1164.0
	21.71	11.32	1358.4
	23.00	12.10	1452.0
15	7.41	3.20	384.0
	14.05	8.18	981.6
	18.63	10.20	1224.0
	21.71	11.50	1380.0
	23.00	12.65	1518.0
20	7.41	4.60	552.0
	14.05	8.80	1056.0
	18.63	10.75	1290.0
	21.71	12.80	1536.0
	23.00	13.10	1572.0
25	7.41	5.86	703.2
	14.05	9.20	1104.0
	18.63	11.35	1362.0
	21.71	13.40	1608.0
	23.00	14.05	1686.0

Appendix-V (Contd.)

Effect of intensity of rainfall on runoff at different slopes (Naduvattom series)

Slopes	Intensity of rainfall (cm/h)	Runoff for 5 min (l)	Runoff (kg/ha/h)
5	7.41	2.23	267.6
	14.05	6.66	799.2
	18.63	8.94	1072.8
	21.71	10.55	1266.0
	23.00	12.44	1492.8
10	7.41	3.07	368.4
	14.05	7.95	954.0
	18.63	9.86	1183.2
	21.71	11.25	1350.0
	23.00	13.30	1596.0
15	7.41	4.15	498.0
	14.05	8.76	1051.2
	18.63	10.60	1272.0
	21.71	11.80	1416.0
	23.00	14.10	1692.0
20	7.41	4.98	597.6
	14.05	9.05	1086.0
	18.63	11.50	1380.0
	21.71	12.70	1524.0
	23.00	14.79	1774.8
25	7.41	5.16	619.2
	14.05	9.76	1171.2
	18.63	12.10	1452.0
	21.71	13.09	1570.8
	23.00	15.15	1818.0

Appendix-V (Contd.)

Effect of intensity of rainfall on runoff at different slopes (Vellanikkara series)

Slopes	Intensity of rainfall (cm/h)	Runoff for 5 min (l)	Runoff (m^3/ha/h)
	7.41	2.58	309.6
	14.05	5.86	703.2
5	18.63	7.41	889.2
	21.71	8.72	1046.4
	23.00	9.95	1194.0
	7.41	3.85	462.0
	14.05	6.98	837.6
10	18.63	8.68	1041.6
	21.71	9.70	1164.0
	23.00	10.30	1236.0
	7.41	4.41	523.2
	14.05	7.44	892.8
15	18.63	9.54	1144.8
	21.71	11.21	1345.2
	23.00	12.32	1478.4
	7.41	5.36	643.2
	14.05	8.53	1023.6
20	18.63	10.92	1310.4
	21.71	12.61	1513.2
	23.00	13.94	1672.8
	7.41	6.10	732.0
	14.05	9.50	1140.0
25	18.63	12.10	1452.0
	21.71	13.89	1666.8
	23.00	14.96	17.95.2

APPENDIX-VI

Effect of land slope on runoff at different intensities (Mannamkulam series)

Intensity of rainfall (cm/h)	Slopes (%)	Runoff for 5 min (l)	Runoff (m^3/ha/h)
7.41	5	2.85	342.0
	10	2.95	354.0
	15	3.20	384.0
	20	4.60	552.0
	25	5.86	703.2
14.05	5	7.20	864.0
	10	7.53	903.6
	15	8.18	981.6
	20	8.80	1056.0
	25	9.20	1104.0
18.63	5	9.10	1092.0
	10	9.70	1164.0
	15	10.20	1224.0
	20	10.75	1290.0
	25	11.35	1362.0
21.71	5	10.19	1222.8
	10	11.32	1358.4
	15	11.50	1380.0
	20	12.80	1536.0
	25	13.40	1608.0
23.00	5	10.30	1236.0
	10	12.10	1452.0
	15	12.65	1518.0
	20	13.10	1572.0
	25	14.05	1686.0

Appendix-VI (Contd.)

Effect of land slope on runoff at different intensities (Naduvattom series)

Intensity of rainfall (cm/h)	Slopes (%)	Runoff for 5 min (l)	Runoff (m^3/ha/h)
7.41	5	2.23	267.6
	10	3.07	368.4
	15	4.15	498.0
	20	4.98	597.6
	25	5.16	619.2
14.05	5	6.66	799.2
	10	7.95	954.0
	15	8.76	1051.2
	20	9.05	1086.0
	25	9.76	1171.2
18.63	5	8.94	1072.8
	10	9.86	1183.2
	15	10.60	1272.0
	20	11.50	1380.0
	25	12.10	1452.0
21.71	5	10.55	1266.0
	10	11.25	1350.0
	15	11.80	1416.0
	20	12.70	1524.0
	25	13.09	1570.8
23.00	5	12.44	1492.8
	10	13.30	1596.0
	15	14.10	1692.0
	20	14.79	1774.8
	25	15.15	1818.0

Appendix-VI (Contd.)

Effect of land slope on runoff at different intensities (Vellanikkara series)

Intensity of rainfall (cm/h)	Slopes (%)	Runoff for 5 min (l)	Runoff (m^3/ha/h)
7.41	5	2.58	309.6
	10	3.85	462.0
	15	4.41	523.2
	20	5.36	643.2
	25	6.10	732.0
14.05	5	5.86	703.2
	10	6.98	837.6
	15	7.44	892.8
	20	8.53	1023.6
	25	9.50	1140.0
18.63	5	7.41	889.2
	10	8.68	1041.6
	15	9.54	1144.8
	20	10.92	1310.4
	25	12.10	1452.0
21.71	5	8.72	1046.4
	10	9.70	1164.0
	15	11.21	1345.2
	20	12.61	1513.2
	25	13.89	1666.8
23.00	5	9.95	1194.0
	10	10.30	1236.0
	15	12.32	1478.4
	20	13.94	1672.8
	25	14.96	1795.2

APPENDIX - VII

Results of Statistical analysis for runoff

Row	Soil type
1	1. Mannamkulam series
2	2. Naduvattom series
3	3. Vellanikkara series

Using least squares means
Post Hoc test (Tukey) of RUNOFF
Using model MSE of 166778.779 with 72 df.

Matrix of pairwise mean differences.

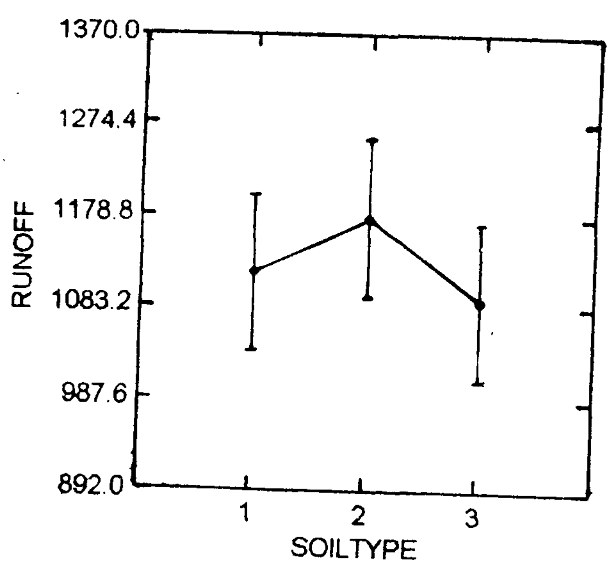
	1	2	3
1	0.000		
2	57.088	0.000	
3	-29.152	-86.240	0.000

Tukey Multiple comparisons

Matrix of pair wise comparison probabilities

	1	2	3
1	1.000		
2	0.874	1.000	
3	0.966	0.737	1.000

Least Squares Means



APPENDIX – VIII

Grain size distribution of the eroded soil (Mannamkulam series)

Slopes (%)	Particle size (mm)	Weight retained	Percentage retained	Cumulative percentage retained	Percentage finer
	4.75	0.00	0.00	0.00	100.00
	2.00	0.38	0.38	0.38	99.62
	1.00	18.11	18.11	18.49	81.51
	0.600	10.70	10.70	29.19	70.81
5	0.425	15.01	15.01	44.20	55.80
	0.300	07.78	7.78	51.98	48.02
	0.212	8.90	8.90	61.88	38.12
	0.150	3.77	3.77	65.65	34.35
	0.075	25.07	25.07	90.72	9.28
	<0.075	9.28	9.28	100.00	0.00
	4.75	0.00	0.00	0.00	100.00
	2.00	2.54	1.69	1.69	98.31
	1.00	14.55	9.70	11.39	88.61
	0.600	19.40	12.93	24.32	75.68
10	0.425	28.85	19.23	43.55	56.45
	0.300	13.56	9.04	52.59	47.41
	0.212	17.73	11.82	64.41	35.59
	0.150	7.63	5.09	69.50	30.50
	0.075	36.75	24.51	74.01	5.99
	<0.075	8.99	5.99	100.00	0.00
	4.75	0.86	0.57	0.57	99.43
	2.00	4.31	2.87	3.44	96.56
	1.00	35.54	23.69	27.13	72.87
	0.600	12.69	8.46	35.59	64.41
	0.425	24.50	16.33	51.92	48.08
15	0.300	12.99	18.66	60.58	39.42
	0.212	16.50	11.00	71.58	28.42
	0.150	8.15	5.43	77.01	22.99
	0.075	22.83	15.24	92.25	7.75
	<0.075	11.63	7.75	100.00	0.00
	4.75	0.95	0.63	0.63	99.37
	2.00	2.08	1.39	2.02	97.98
	1.00	31.18	20.79	22.81	77.79
	0.600	12.61	8.41	31.22	68.78
20	0.425	28.26	18.84	50.06	49.44
	0.300	15.09	10.06	60.12	39.88
	0.212	18.30	12.20	72.32	27.68
	0.150	7.56	5.04	77.36	22.64
	0.075	23.37	15.57	92.93	7.07
	<0.075	10.60	7.07	100.00	100.00
	4.75	1.25	0.83	0.83	99.17
	2.00	3.52	2.35	3.18	96.82
	1.00	32.24	21.49	24.67	75.33
	0.600	10.42	6.95	31.62	68.38
	0.425	26.36	17.57	49.19	50.81
25	0.300	14.39	9.59	58.78	41.22
	0.212	20.45	13.63	72.41	27.59
	0.150	6.84	4.56	76.97	23.03
	0.075	24.82	16.56	93.53	6.47
	<0.075	9.71	6.47	100.00	0.00

Appendix – VIII (Contd.)

Grain size distribution of the eroded soil (Naduvattom series)

Slopes (%)	Particle size (mm)	Weight retained	Percentage retained	Cumulative percentage retained	Percentage finer
	4.75	0.00	0.00	0.00	100.00
	2.00	1.88	1.92	1.92	98.08
	1.00	14.40	14.72	16.64	83.36
	0.600	9.89	10.11	26.75	73.25
	0.425	9.15	9.35	36.10	63.90
	0.300	6.43	6.97	43.07	56.93
5	0.212	10.78	11.02	54.09	45.91
	0.150	3.44	4.54	58.63	41.37
	0.075	23.88	24.40	83.03	16.97
	0.020	4.30	4.30	87.42	12.58
	0.002	5.29	5.41	92.83	7.17
	0.002	6.91	7.17	100.0	0.00
	4.75	0.00	0.00	0.00	100.00
	2.00	1.37	1.37	1.37	98.63
	1.00	13.88	13.88	15.25	84.75
	0.600	5.48	5.48	20.73	79.27
	0.425	9.87	9.87	30.60	69.40
	0.300	6.95	6.95	37.55	62.45
10	0.212	9.23	9.23	46.78	53.22
	0.150	6.05	6.05	52.83	47.17
	0.075	37.25	37.25	90.08	9.92
	0.020	3.22	3.22	93.30	6.70
	0.002	2.69	2.69	95.99	4.01
	0.002	4.01	4.01	100.00	0.00
	4.75	0.47	0.47	0.47	99.53
	2.00	3.76	3.76	4.23	95.77
	1.00	14.52	14.52	18.75	81.25
	0.600	3.88	3.88	22.63	77.37
	0.425	9.82	9.82	32.45	67.55
	0.300	6.71	6.71	39.16	60.84
	0.212	10.86	10.86	50.02	49.98
	0.150	8.78	8.78	58.80	41.20
15	0.075	29.76	29.76	88.56	11.44
	0.020	3.21	3.21	91.77	8.23
	0.002	3.42	3.42	95.19	4.81
	0.002	4.81	4.81	100.00	0.00
	4.75	4.48	2.99	2.99	97.01
	2.00	11.33	7.55	10.54	89.46
	1.00	23.95	15.97	26.51	73.49
	0.600	2.56	1.71	28.22	71.78
	0.425	12.73	8.49	36.71	63.29
	0.300	8.71	5.81	42.52	57.48
20	0.212	19.47	12.98	55.50	44.50
	0.150	10.82	7.21	62.71	37.29
	0.075	41.26	27.50	90.21	9.79
	0.020	4.83	3.22	93.43	6.57
	0.002	4.04	2.69	96.12	3.88
	0.002	5.82	3.88	100.00	0.00
	4.75	7.90	5.27	5.27	94.73
	2.00	11.97	7.98	13.25	86.75
	1.00	26.39	17.59	30.84	69.16
	0.600	9.08	6.05	36.89	63.11
	0.425	12.43	8.29	45.18	54.82
25	0.300	7.29	4.86	50.04	49.96
	0.212	13.27	8.85	58.89	41.11
	0.150	9.58	6.39	65.28	34.72
	0.075	37.63	25.09	90.37	9.63
	0.020	4.72	3.15	93.52	6.48
	0.002	3.98	2.64	96.16	3.84
	0.002	5.76	3.84	100.00	0.00

Appendix – VIII (Contd.)

Grain size distribution of the eroded soil (Vellanikkara series)

Slopes (%)	Particle size (mm)	Weight retained	Percentage retained	Cumulative percentage retained	Percentage finer
5	4.75	0.00	0.00	0.00	100.00
	2.00	4.16	1.66	1.66	98.34
	1.00	52.94	21.18	22.84	77.16
	0.600	17.99	7.20	30.04	69.96
	0.425	46.86	18.74	48.78	51.22
	0.300	24.43	9.77	58.55	41.45
	0.212	31.32	12.53	71.08	28.92
	0.150	11.62	4.65	75.73	24.27
	0.075	40.69	16.73	92.46	7.54
	<0.075	18.99	7.54	100.00	0.00
10	4.75	0.00	0.00	0.00	100.00
	2.00	3.07	1.23	1.23	98.77
	1.00	32.11	12.84	14.07	85.93
	0.600	17.05	6.82	20.89	79.11
	0.425	41.38	16.55	37.44	62.56
	0.300	25.73	10.29	47.73	52.27
	0.212	42.68	17.07	64.80	35.20
	0.150	15.14	6.06	70.86	29.14
	0.075	56.96	22.78	93.65	6.35
	<0.075	15.88	6.35	100.00	0.00
15	4.75	0.82	0.33	0.33	99.67
	2.00	4.36	1.74	2.07	97.93
	1.00	32.28	12.91	14.98	85.02
	0.600	15.33	6.13	21.11	78.89
	0.425	39.36	15.74	36.85	63.15
	0.300	23.67	9.47	46.32	53.68
	0.212	40.10	16.04	62.36	37.64
	0.150	14.64	5.86	68.22	31.78
	0.075	61.42	24.57	92.79	7.21
	<0.075	18.02	7.21	100.00	0.00
20	4.75	0.94	0.47	0.47	99.53
	2.00	6.77	3.39	3.86	96.14
	1.00	29.70	14.85	18.71	81.29
	0.600	13.45	6.73	25.44	74.56
	0.425	33.32	16.66	42.10	57.90
	0.300	19.32	9.66	51.76	48.24
	0.212	30.34	15.17	66.93	33.07
	0.150	11.81	5.91	72.84	27.16
	0.075	42.32	21.16	94.00	6.00
	<0.075	12.03	6.00	100.00	0.00
25	4.75	1.43	0.95	0.95	99.05
	2.00	4.09	2.73	3.68	96.32
	1.00	36.32	24.21	27.89	72.11
	0.600	11.73	7.82	35.71	64.29
	0.425	18.98	12.65	48.36	51.64
	0.300	12.41	8.27	56.63	43.37
	0.212	16.43	10.95	67.58	32.42
	0.150	7.71	5.15	72.73	27.27
	0.075	26.83	17.89	90.62	9.38
	<0.075	14.07	9.38	100.00	0.00

ERODIBILITY AND RUNOFF POTENTIAL OF LATERITE SOILS UNDER SIMULATED RAINFALL CONDITIONS

By
SAJEENA, S.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree

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in
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ABSTRACT

Soil erosion is one of the most serious environment degradation problems. However reliable measurement of erosion remains limited and estimates of soil productivity are even rarer. Assessing the extent and seriousness of erosion therefore remains a difficult task. Nevertheless, identification and assessment of erosion problems could have an important role in influencing better land use and conservation practices.

Rainfall simulators are considered as an effective tool in soil conservation research. Simulators make it possible to produce predetermined storms at any desired time and location. They make the replication of research easier and facilitate the study of storm sequences.

Laterite soils are by far the most important soil group occurring in Kerala and cover the largest area. The objective of this study was to estimate the erodibility and runoff potential of laterite soils of three well defined series under simulated rainfall conditions.

The rainfall simulator designed and fabricated by Kurien and George (1998) was modified for better performance. The modified simulator could produce rainfall intensities varying from 7.41 to 23.00 cm/h. Also uniformity of the rainfall produced could be increased to higher values of 88.10 and 91.53 per cent, thus giving a better performance. Intensity of rainfall increased as the

pressure of supply water to the simulator increased and a relationship was established between intensity and the supply pressure of water as

$$I = -87.205 P^2 + 108.61 P - 10.786 \quad (R = 0.99)$$

Experiments were also conducted to study soil loss and runoff from three different series of laterite soils, i.e.Mannamkulam series, Naduvattom series and Vellanikkara series. The soil loss and runoff increased with increase in the rainfall intensity for all slopes studied for each series of soil. A general trend of increase in soil loss and runoff with increase in the slope was observed for all the three series of soils.

Empirical equations were developed for estimating soil loss (E) and runoff (Q) for various intensities of rainfall and land slopes for the three series of soils selected for the study.

The equations are:

Mannamkulam series

$$E = 1167.797 I + 835.109 S - 21686.07 \quad (R = 0.90)$$

$$Q = 65.016 I + 16.747 S - 235.923 \quad (R = 0.99)$$

Naduvattom series

$$E = 324.766\ I + 112.799\ S - 3912.219 \quad (R = 0.97)$$

$$Q = 74.542\ I + 19.434\ S - 394.323 \quad (R = 0.99)$$

Vellanikkara series

$$E = 115.662\ I + 431.064\ S - 11512.284 \quad (R = 0.98)$$

$$Q = 58.742\ I + 26.837\ S - 310.019 \quad (R = 0.99)$$