EFFECT OF RAINFALL INTENSITY AND LAND SLOPE ON SPLASH EROSION UNDER SIMULATED RAINFALL

A thesis submitted to the

Mahatma Phule Krishi Vidyapeeth, Rahuri – 413 722,
Dist. Ahmednagar, Maharashtra State, India

by

AKURDE ATUL BHIVA
(Reg. No. 2007/10)

In partial fulfilment of the requirements for the degree

of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in

SOIL AND WATER CONSERVATION ENGINEERING

Department of Soil and Water Conservation Engineering
Dr. Annasaheb Shinde College of Agricultural Engineering
Mahatma Phule Krishi Vidyapeeth, Rahuri,
Dist. Ahmednagar, M. S. (India)

JUNE 2009

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Approved by

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JUNE 2009

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
thereof has not been submitted
by me or any other person
to any other University
or Institute for
Degree or
Diploma

Place : MPKV, Rahuri

Dated: / / 2009 **(A. B. Akurde)**

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CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF RAINFALL INTENSITY AND LAND SLOPE ON SPLASH EROSION UNDER SIMULATED RAINFALL",** submitted to the Faculty of Agricultural Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (M.S.) in partial fulfilment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** (**AGRICULTURAL ENGINEERING)** in **SOIL AND WATER CONSERVATION ENGINEERING** embodies the results of *bonafide* research work carried out by **Er. Atul Bhiva Akurde** under my guidance and supervision.

The results embodied in this thesis have not been submitted to any other university or institute for the award of Degree or Diploma.

The assistance and help received during the course of this investigation has been duly acknowledged.

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Date : / / 2009 **(V. N. Barai**)

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CERTIFICATE

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Place: MPKV. Rahuri

Date : / / 2009 (**H. G. More**)

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Place : MPKV, Rahuri

Dated: / /2009 **(Akurde A.B.)**

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LIST OF ABBREVIATIONS

Agril.	:	Agricultural
Am.	:	American
Approx.	:	Approximately
B.Tech.	:	Bachelor of Technology
cm	:	centimetre
cm h^{-1}	:	centimetre per hour
Contd.	:	Continued
dia.	:	Diameter
Engg.	:	Engineering
et al.	:	and others
etc.	:	et cetera
Fig	:	Figure
g	:	gram
geophy.	:	Geophysics
G.I.	:	Galvanized iron
H.I.	:	Horizontal interval
hp	:	Horse power
Hydro.	:	Hydrology
i.e.	:	that is
J m^{-2} h^{-1}	:	joules per square metre per hour
J.	:	Journal
kg m^{-2} h^{-1}	:	kilogram per square metre per hour
kg m^{-2} min^{-1}	:	kilogram per square metre per minute
kg m^{-3}	:	kilogram per cubic metre
lit.	:	litre
m	:	metre
M.S.	:	Maharashtra state
Mg m^{-3}	:	Mega gram per cubic metre
min	:	minute
ml	:	millilitre
mm	:	millimetre

mm h^{-1}	:	millimetre per hour
No.	:	Number
Pub.	:	Publication
PVC	:	Poly vinyl chloride
Res.	:	Research
Sci.	:	Science
Soc.	:	Society
t ha^{-1}	:	tonnes per hectare
Trans.	:	Transaction
Uc	:	Uniformity coefficient
V.I.	:	Vertical interval
viz.	:	namely
Vol.	:	Volume
%	:	per cent
<	:	less than
>	:	greater than
^{0}	:	degree
^0C	:	degree centigrade
r	:	Regression coefficient
Σ	:	Summation
γ	:	Bulk unit weight
μ	:	Micron
ρ	:	Bulk density
Ø	:	diameter

ABSTRACT

EFFECT OF RAINFALL INTENSITY AND LAND SLOPE ON SPLASH EROSION UNDER SIMULATED RAINFALL

by

Atul Bhiva Akurde

Mahatma Phule Krishi Vidyapeeth, Rahuri-413 722,

Dist. Ahmednagar (M.S.)

JUNE, 2009

Research Guide	**:**	**Prof. V. N. Barai**
Department	:	Soil and Water Conservation Engineering

Rainsplash erosion is an important first step action in the soil erosion process. The quantity of soil provided by this initial process would determine the total amount of eroded material that could be carried away by the surface wash process. This process transports the splashed as well as the top soil downstream from the source area. The impact of soil removed in this manner could be further accelerated by human activities such as land clearing and earthwork often associated with economic development. Accelerated soil erosion could have serious impacts on the environment in the way that it affects soil fertility, reduces water quality and causes excessive siltation downstream. Such impacts should be mitigated by practicing the soil conservation strategy so as to ensure long term sustainability of the soil. Therefore, present study was carried out with prime objective to compare and quantify the effects of various combinations of input variables i.e. rainfall intensity and land slope on splash erosion using Morgan's splash cup technique. Attempts were also made to fabricate splash cup by changing the size of catching tray i.e. 60 cm outer diameter to compare the results obtained by both the splash cups.

The study was conducted under laboratory condition, on the experimental farm of Department of Soil and Water Conservation Engineering Dr. A. S. College of Agricultural Engineering, by using rainfall simulation system, capable of generating artificial rainfall almost similar to natural rainfall. Before starting the

Abstract contd....... **Akurde A. B.**

experiment, physical properties of soil were determined which indicated that soil type was clay. Uniformity coefficient of simulating rainfall was above 90 per cent for all the three rainfall intensities viz. 6.21, 9.69 and 12.75 cm h^{-1}.

The directional splash soil loss rate (kg m^{-2} h^{-1}), i.e. upslope and down slope were found increasing with increase in rainfall intensity and land slope. The rate of increase in down slope splash was comparatively more than upslope. The highest soil splash i.e. 7.58 kg m^{-2} h^{-1} was observed for combination of 15 per cent land slope and 12.75 cm h^{-1} rainfall intensity. The splash soil loss obtained with Modified splash cups showed increment over Morgan's cup in each case. Thus, splash-cup modification allowed the proportion of sediment lost as airsplash, therefore not deposited within the splash-cup was quantified to allow calculation of realistic soil detachment rates, and hence realistic soil detachabilities.

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1. INTRODUCTION

Splash erosion or rain drop erosion represents the first stage in the erosion process. Splash erosion results from the bombardment of the soil surface by rain drops. Raindrops behave as little bombs when falling on exposed or bare soil, displacing soil particles and destroying soil structure. During rainfall, drop impact on the soil surface dislodges soil particles, lifts them into the air and transports them away from the point of drop impact. On level ground the soil particles splash uniformly in all directions and, assuming a uniform distribution of raindrops, the net transport is zero. However, on a slope more soil is transported downhill by the splash resulting in a net downslope transport. If the infiltration rate is less than the rainfall intensity, overland flow occurs. Overland flow increases soil erosion by transporting the particles dislodged by raindrop impact further downhill before they settle back on the soil surface.

The soil detachment process is primarily influenced by the rainfall properties i.e. intensity, duration and kinetic energy of falling raindrop. Rainfall is an important factor in the process of runoff and soil erosion. The fundamental cause of soil erosion is the rain which acts upon the soil, and the study of erosion can be divided into as how it will be affected by different kinds of rain, and how it will vary for different condition of soil. The amount of erosion, therefore, depends upon a combination of the power of the rain to cause erosion and ability of soil to withstand the rain or its susceptibility to get eroded.

Rainfall intensity, duration and distribution are beyond our control. Therefore, it is not possible to vary these quantitatively for studies of their effect on splash erosion, runoff and soil loss. Alternatively, to understand the effect of rainfall factors, a rainfall simulator is developed, which can produce the desirable range of rainfall.

Simulated rainfall means water applied artificially in a form similar to natural rainfall. Simulated rainfall has numerous advantages over natural rainfall for many erosion studies. Simulated rainfall provides rapid results over natural rainfall; as the simulation can be conducted more efficiently from the stand point of time and labour. The storm characteristics can be more carefully controlled and the approach is more adaptable for certain type of studies.

Although, detachment of soil particles by raindrop impact is the first and fundamental phase of sediment production on hill slopes, no satisfactory system has been devised for instantaneous monitoring of splash erosion; an alternative approach, field splash cup techniques can be used. In which block of soil is isolated by enclosing it in a central cylinder and the material splashed out is collected in a surrounding catching tray. Splash erosion of various soils can be studied using Morgan's splash cup.

Soil erosion is one of the major threats to agricultural productivity and environmental quality, especially water and soil quality. With increasing amount of soil loss at the hill slope scale, agricultural productivity is decreasing and environmental quality is deteriorating. Erosion by water is caused by rainfall as well as surface runoff. The physical processes dominating the movement of soil particles caused by rainfall or shallow surface flow are very complex. Soil erosion processes can be divided into two major components, interrill and rill erosion, based on different detachment and transport processes involved.

Rainfall causes considerable amount of soil loss every year. This soil loss affects the agricultural production to high degree. It is almost need of today to establish relationship between rainfall and runoff for average rainfall of particular region. Information of splash erosion and soil detachment under different rainfall characteristics and land slopes is not available. This information can be generated with the help of rainfall simulator and then can be used for predicting runoff and soil loss to make specific recommendations for conservation and water resource planning in a given region. These and future results will help managing afforestation projects in giving implications which of the species (resp. species compositions) may reduce most effectively potential splash erosion.

The detachment of particles by raindrop impact i.e. splash, is primary factor in soil availability for interrill flow transport; it appears to be necessary to quantify splash soil loss. Raindrop impact has been shown to be an extremely important factor in the erosion process - at least at the onset of rainfall. Borst and Woodburn (1942) showed that eliminating raindrop impact on a soil surface can be more effective in reducing soil loss than reducing overland flow velocities. Young and Wiersma (1973) experimentally studied the role of rainfall impact on soil detachment and transport. They showed that reducing raindrop impact energy by 89 % without a reduction in rainfall intensity resulted in a 90 % reduction in soil erosion. Consequently, understanding soil detachment and its effect on the erosion process has promise for learning how to reduce or control some aspects of soil loss.

The importance of the soil erosion problem and its impact on soil management and conservation led to the recent study, in which an attempt has been made to study splash detachment process for various combinations of land slopes and rainfall intensities with the help of rainfall simulation system and Morgan’s splash cup. The study was under taken with following specific objectives:

1. To study the effect of rainfall intensity on splash erosion.

2. To study the effect of land slope on splash erosion.

3. To observe and quantify the directional splash soil loss rate for various combinations of rainfall intensity and land slope.

4. To observe and quantify the splash soil loss rate with modified splash cup.

2. REVIEW OF LITURATURE

The detachment of soil particles by raindrop impact i.e. splash is mainly influenced by rainfall characteristics, viz., intensity, duration, terminal velocity, kinetic energy etc., soil characteristics, viz., soil texture, bulk density, infiltration rate, moisture content and topographic characteristics mainly land slope.

The relevant literature pertaining to some of the most important parameters affecting the splash is dealt in this chapter:

Rose (1959) conducted laboratory studies on two soils of Uganda to examine the soil detachment caused by rainfall. The soil mass detached was measured for rainfall durations of 15, 30 and 50 minutes at a rate of 2 inch h^{-1}; for durations of 15 and 30 minutes at 4 inch h^{-1}; and for 15 minutes at 6 inch h^{-1}. He found that the mass of soil detached was simply proportional to the duration of rainfall.

Smith and Wischmeir (1962) explained that the different movement between upslope and downslope soil splash was caused by the rainsplash impact. The downslope movement went further downslope before re-contacting the soil surface and that the resulting angle of impact was greater in a downslope direction. Overall, the mean height of downslope soil splash was higher than that of the upslope.

Moldenhaur and Koswara (1968) studied the effects of initial clod size on characteristics of splash and wash erosion. The samples of clods from continuous brome grass and continuous corn were filled in 30 cm x 45 cm erosion pan and set at 9 percent slope for 90 min duration at constant rainfall intensity of 6.35 cm h^{-1}. It was found that for larger clods size from brome grass, total losses increased as size of clods increased. Rates of splash and wash showed delayed detachment peaks with larger clod size. It was found that splashed material was larger than washed material and both were larger than the material forming the seal.

Mazurak and Mosher (1970) conducted experiments to determine the detachment of soil aggregates by simulated rainfall. Sharpsburg silty clay loam soil was separated into 11 aggregate fractions of 9, 250, -4, 760µ + ---- + 297 -

210µ and <210µ diameter. Krillium solution was added to half of each aggregate fraction to make the water stable. The aggregate fractions were packed into splash cups and exposed to simulated rainfall intensities of 2 to 12 cm h^{-1}. They found linear relationship between the amount of aggregate and rainfall intensity. The amount of splash from water stable Krillium treated aggregates was less as compared to the non-treated aggregates.

Sharma and Rao (1972) conducted experiment at Kharagpur to determine the splash erosion of loam and silty loam soils under simulated rainfall with intensities of 4.5, 6.5, 8.0 and 9.5 cm h^{-1} for 5, 10, 20, 30, and 40 min time of exposure. They found a positive relationship between soil detachment and time of exposure and a curvilinear linear relation between rates of detachment of the standard sand was practically constant throughout the time of exposure. The equation correlating time of exposure to the rate of detachment for loam soils respectively as follows:

$$S= 0.0588 + 1.585\, t^{-1.668} \qquad (r=0.96)$$

$$S= 0.1466 + 10^{-0.0113t} \qquad (r=0.835)$$

Where S is the rate of detachment in Kg m^{-2} min^{-1} and t is the time of exposure in min.

Kinnell (1974) conducted experiments under artificial rainfall conditions and showed that the initial, excessive loss from the type of splash cup frequently used in splash-cup experiments was attributable not only to material being pushed sideways over the edge of the cup by the impact of drops near the perimeter of the exposed surface, but also to a decrease in the rate of splash loss. The amount of excess material lost during this initial period was not significantly influenced by the frequency of drop impact, but was significantly influenced by the force of drop impact. Consequently, it is unlikely that the effect was attributable to changes in the hydraulic conditions within the erodible material, but may have been attributable to changes in the roughness of the exposed surface. A calibration, specific to the size, shape and velocity conditions of the impacting drops, may therefore be required where the initial loss makes a significant contribution to the total loss from a splash cup. It is also probable that such a calibration may also be specific to the physical nature of the erodible material and to the hydraulic characteristics of the splash-cup system.

Bolline (1977) measured soil splash in the field with an apparatus for splash measurement. The results obtained from 1974 to 1977 show that although the quantities of soil moved by splash are varying high, the splash erosion. The splash is also positively correlated with the erosion index and with the erosion. The splash is also influenced by structural stability.

Ghadiri and Payne (1977) studied soil splash using Cine-photography. A photographic study of raindrop impact and soil splash showed that soil loss depended on the presence of sufficient water in the surface material to ensure the formation of water droplets large enough to carry the soil particles.

Morgan (1978) studied method of measuring splash erosion on field. He designed a splash cup to study the rain splash erosion and installed two cups at each site to get the average value. It was consisted of an inner tube of 100 mm diameter, which was inserted into the ground until it flushed with the soil surface. An outer circular tray sunk to depth 25 mm around the inner tube. This tray catches material from inner tube and eliminating the entry of overland flow. Material splashed into them was collected and weighed.

Quansah (1981) studied the effect of soil type, slope, rainfall intensity and interactions on splash detachment and transport. From an experiment using graded sand and three soils (sand, clay loam and clay), four slopes viz., 0.0, 3.5, 7.0 and 14.0 % and four intensities viz., 50, 80, 110 and 140 mm h^{-1} splash detachment and splash transport were described in terms of the direct effects. The amount of material transported was in the order of graded sand > clay > clay loam. For each soil type there was significant increase in splash detachment and splash transport with increasing intensity.

Kinnell (1982) studied on splash erosion of sand subjected to a drainage suction in splash cups in relation to three variations in size of the drops (2.7, 3.8 and 5.1 mm) impacting at close to their terminal velocity. Splash lost per drop varied with the square of the drop mass. This result indicates that drops of different sizes travelling at terminal velocities may vary more in their ability to cause splash erosion than was previously supposed.

Pawar and Sonawane (1986) studied the soil erosion under simulated rainfall condition both by splash cup and soil tray to know extend of splash erosion. Three intensities 1, 2 and 3 cm h^{-1} were used and four types of soil, viz. silty clay loam, silty loam, silty clay and silty loam, were studied in the experiment. They found that irrespective of the soil type the soil loss increased with increase in rainfall intensity and the average soil splash varied from 31.2 to 46.18 t ha^{-1}. The percent soil loss was higher for storms of 2 and 3 cm h^{-1} intensities for all indices due to more kinetic energy. The splash erosion values were very high in Ellision cups compared with those from soil tray as soil detached and splashed out from the cups and hence these values were high.

Proffitt *et al*. (1989) measured temporal changes in soil loss rates as a result of rainfall detachment in modified splash-cups (kc) for two contrasting soil types with 5 mm depth of surface water at two constant rainfall rates (56 and 100 mm h^{-1}). Results were compared with those from a flume (kf) for the same rainfall duration, rainfall rates, soil types and water depth. Splash-cups are not a true measure of soil detachment by rainfall when surface water is present. In order to yield the true rate of soil detachment, the measured net rate of soil loss must be augmented by a correction accounting for the rate of deposition. Theory for the net outcome of rainfall detachment and sediment deposition was used to interpret net soil loss data at equilibrium from splash-cups to yield true soil detachment rates (eTc), and compared those from a flume (eTf). The two soil types were cracking clay (black earth or Vertisol) and a slightly dispersive sandy clay loam (solonchak or Aridisol). Splash-cup modification allowed the proportion of sediment lost as airsplash (and therefore not deposited within the splash-cup) to be quantified to allow calculation of true soil detachment rates, and hence true soil detachabilities. Under constant rainfall rates and water depth, kc decreased significantly (5% level) with time until an equilibrium detachment rate was reached. Values of kc were higher for the solonchak than the black earth, and increased with rainfall rate. At equilibrium, eTc and qf were approximately three orders of magnitude greater than kc and kf, illustrating the importance of recognizing the deposition process in determining true rates of soil detachment and soil detachabilities. There was no significant difference (5% level) between kc and kf at equilibrium for the black earth, but values of kc were significantly higher (5% level) than kf for the solonchak.

Truman and Bradford (1990) conducted experiments to determine the effect of antecedent soil moisture on splash detachment and on soil and hydraulic variables that control splash under simulated rainfall. Five soils ranging in texture from sandy loam to clay were exposed to simulated rainfall with an intensity of 64 mm h^{-1} for 1 h. Wash, splash, runoff and infiltration were measured for nearly saturated and air dried soils in 0.14 m^2 aluminium erosion pans. It was found that prewetting significantly decreased the splash and wash losses. The greater splash for the dry condition as compared to the prewetted condition resulted partially from a greater water depth layer on the dry condition surface and a lower water depth layer on the prewetted surface. Prewetted wash and splash sediment size was larger than that for air dried sediment. The results also showed that antecedent soil moisture conditions prior to rainfall influenced the amount of splash detachment and the physical processes that control the amount of splash.

Kahlon and Khera (1997) studied effect of rainfall intensity and land use on runoff and soil loss under simulated rainfall. Surface soil samples from 5 different representative sites varying in texture and land uses. Bare, arable, grass and forest were exposed to three rainfall intensities (18, 38 and 68 mm h^{-1}) using rainfall simulator. Runoff increases from 1.5 to 11.5 mm and soil loss from 2.1 to 42.5 t ha^{-1} when rainfall intensity was increased from 18 mm h^{-1} to 68 mm h^{-1}. High intensity rains increased raindrop impact on the soil surface causing detachment of soil particles and surface sealing resulting in greater loss of soil and water compared to bare soil conditions. Runoff and soil loss significantly decreased from 61 to 48 % and 23 to 13.8 t ha^{-1} under forest land use.

Wan and El-Swaify (1998) conducted laboratory studies to examine the geometric mean diameter (GMD) of splash and wash processes using a drip type rainfall simulator and soil plot of 0.6 m x 0.3 m in size. Soil samples of Wahiawa silty were collected from the field of Oahu, Hawaii. Aggregate size distribution of directional splash and wash was measured with 45, 65, 90, and 135 mm h^{-1} intensities at 4, 9, 18, 27 and 36 per cent slopes under simulated rainfall. They found that wash sediment GMD significantly increased with increasing rainfall intensity and slope but splash sediment GMD was much less influenced by rainfall intensity and slope. The average GMD values for 45 mm h^{-1} were significantly smaller than those for other intensity. This is possibly due to limited rainfall kinetic flux under this study.

Sumathi and Padmakumari (1999) studied the effect of rainfall intensity and antecedent moisture on infiltration rate under simulated rainfall. Infiltration rate and runoff of three different surface conditions viz.; barren, cropped and tilled were investigated by simulated rainfall. The hydrological response factors of infiltration were greatly controlled by the soil surface condition and the part of which was depend upon rainfall intensity and antecedent moisture condition. The infiltration observed to be 3.5, 6 and 9 mm h^{-1} on barren field. 12, 18 and 20 mm h^{-1} on cropped field and 20, 24 and 28 mm h^{-1} on tilled land for 7, 10 and 13 cm h^{-1} simulated intensities.

Takuma *et al.* (2000) used a rainfall simulator to evaluate the effect of varying rainfall intensity (increasing, decreasing and constant) on soil loss in a short period of time. They found that soil loss attained its peak soon after the test started and then levelled off under constant intensity. In case of increasing rainfall intensity, soil loss gradually increased with the passage of time. This can be explained by changes in percolation rate. It was concluded that a change in rainfall intensity strongly affects clay soil in terms of splash rate.

Van Dijk *et al.* (2002) developed a theory that can be used to interpret splash experiments. It was based on the assumption that the spatial distribution of particles splashed from a point source could be described by an exponential decay function, for which there was considerable support in the literature. The theory was evaluated for the cited experimental techniques, partly with the use of a numerical model. It was made clear that conventional measurements of splash and the true rate of detachment by splash are two different entities that can be linked if the average splash length is known. In principle, the theory is not valid for a sloping surface, but analysis of the magnitude of the error involved indicates that in many cases good estimates of detached amounts can still be obtained.

Rejman (2003) conducted splash measurements with splash cup technique. Cups of five different diameter ranging from 1.6 cm to 14.5 cm were placed on erosion plots kept in bare conditions (12% slope). Each to the cup diameter class was represented by four replicates. After rainfall, splash cups were collected and replaced with the new ones. Then, collected soil material was removed from cups and weighed with accuracy of 0.001 gm. During measurements, surface tillage implements were applied to destroy surface seal. From eleven measurement periods, splash was evaluated four times on tilled and seven times on sealed surface. Rainfall parameters were monitored with rain gauge placed near the plots. On the basis of rainfall amount and its intensity, kinetic energy was calculated. Studies showed that splash amount per unit area decrease with increase of cup diameter in exponential function.

Sharifah *et al.* (2003) studied the quantities of material being splashed upslope and downslope and the height to which material is lifted, using the splash board method. They used various slope gradient and rainfall parameters to explain the erosion process and concluded that quantity and the height of soil splashed upslope and downslope varied from storm to storm and according to rainfall amount, energy, intensity, and erosivity. The study showed that there were marked variations in the upslope and downslope splashing of soil. However, the relationship with gradient was not very clear and more intensive work therefore is needed. Overall results revealed that there was clear evidence of splash erosion process occurring under forest reserve land use in this study. The average amount of soil splashed indicated that splash erosion could increase manifolds in areas of disturbed ground.

Van Dijk *et al.* (2003) studied splash on bare, cropped, or mulched sub-horizontal (2–3°) terrace beds using splash cups of different sizes, whereas transport of sediment on the predominantly bare and steep (30–40°) terrace risers was measured using a novel device combining a Gerlach-type trough with a splash box to enable the separate measurement of transport by wash and splash processes. Measurements were made during two consecutive rainy seasons. The results were interpreted using a recently developed splash distribution theory and related to effective rainfall erosive energy. Splash transportability (i.e. transport per unit contour length and unit erosive energy) on the terrace risers was more than an order of magnitude greater than on bare terrace beds. This was caused primarily by a greater average splash distance on the short, steep risers (>11 cm versus c. 1 cm on the beds). Splashed amounts were reduced by the gradual formation of a protective 'pavement' of coarser aggregates, in particular on the terrace beds. Soil aggregate size exhibited an inverse relationship with detachability (i.e. detachment per unit area and unit erosive energy) and average splash length, and therefore also with transportability, as did the degree of canopy and mulch cover. On the terrace risers, splash-creep and gravitational processes transported an additional 6–50 % of measured rain splash, whereas transport by wash played a marginal role.

Truman (2004) conducted a laboratory rainfall simulation study to evaluate the effects of soil surface roughness and rainfall intensity on interrill erosion processes. There different initial soil surface conditions (aggregates < 20 mm) simulating effects of different tillage tools were examined. Following rainfall distribution was investigated: constant intensity (40 and 60 mm h^{-1}) increasing intensity (20-40-60 mm h^{-1}) and decreasing intensity (60-40-20 mm h^{-1}). Rainfall durations ranged between 90 and 180 min. Soil loss, splash erosion, splash water, runoff and percolation were measured in five minutes interval throughout each experiment. Results were used to calculate various parameters describing soil surface roughness.

Sophie *et al.* (2005) studied the splash distribution of different size fractions for aggregated soils. They used a recently proposed theory for spatial distribution by splash to interpret experimental data on the radial distribution of soil fragments splashed by simulated rainfall. A laboratory device with five concentric rings was used to determine average splash lengths for 16 fragment size fractions (0.05 to > 2000 µm) of four soils. Sieved soil (3 to 5 mm size fraction) was exposed to simulated rainfall at 29 mm h^{-1} and with a time-specific kinetic energy of 252 J m^{-2} h^{-1}. Interpreted the measured masses of fragments splashed into the different rings using an approximate solution of the exponential splash distribution theory applied to the experimental design. They demonstrated that the theory is valid for bulk aggregated soil as well as for individual fragment size fractions. The derived average splash lengths ranged from 4 to 23 cm, depending on the fragment size and soil. Splash lengths were greatest for soil fragments of 100 to 200 µm, and decreased for finer and coarser size fractions. Comparison of these findings with physically-based theory suggests that the coarser fragments, 50 to 2000 µm, are transported as single airborne particles, whereas the smaller ones, <50 µm, are transported in groups in splash droplets. This interpretation was consistent with observations reported in the literature.

Rejman (2006) studied water erosion contained measurements of splash, and runoff and soil loss from a system of plots of various length (2.5, 5, 10 and 20 m), and tillage erosion measurements of soil translocation due to shallow plough (10 cm) and cultivator (5 cm). Splash measurements were carried out with splash cup of various diameters (3.2, 5.0, 7.3, 11.7 and 14.5 cm). To calibrate splash amounts, the exponential theory of splash distribution of Van Dijk *et al.* (2002) was applied. Results of splash studies showed that splash amount depended on rainfall parameters, and splash distance on micro-relief of the soil surface and presence of running water. He developed a simple model on the basis of relation between splash and 10 minute rainfall intensity and tested to evaluate splash amounts. Results of measurements showed that splash amounts were many times larger in comparison to measured soil loss. Only in the case of rill erosion, splash amounts were lower than soil loss.

Geibler *et al.* (2009) used different methods of rainfall characterization (splash cups, tipping-bucket rain gauge, laser distrometer) to reveal the various mechanisms from the canopy through different vegetation layers to the ground. First results of splash cup measurements (revised after Ellison 1947) showed that sand loss under vegetation is 2.5 times higher than in open field despite the fact that only 60 per cent of open field rainfall reaches the ground. The results also indicated that sand loss was a function of the age of the specific forest stand and the variability of sand loss under different species with respect to space and time.

From various research papers reviewed it can be concluded that it is necessary to quantify the soil loss due to splash so as to understand the soil detachment process. Splash erosion is a major component of interrill erosion, which results from the impact of water over the soil surface. It has been mentioned by some research workers viz., Proffitt *et al.* (1989), Rejman (2003) and Sophie *et al.* (2003) that the splash soil loss rates are estimated less than actual due to airsplash. This necessitates to increase the dimensions of Morgan's splash cup to obtain more realistic splash soil loss rates.

3. MATERIAL AND METHODS

This chapter deals with the details of various components of experimental set-up, soil and the experimental technique employed to carry out the present study.

A field experiment was conducted in clay soil during the year 2008-2009 on the experimental farm of Department of Soil and Water Conservation Engineering, Dr. A.S. College of Agricultural Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri.

The area falls in semi arid subtropical zone with average annual rainfall of 553 mm and the rainfall intensities range from 60 mm/h to 204 mm/h (Barai,1997). The distribution of rains concentrates during the monsoon months from June to October. The annual mean minimum temperature ranges from 12.9ºC to 21.9ºC and mean maximum temperature ranges from 27ºC to 42ºC in December and May respectively.

3.1 Experimental setup

The experimental set up mainly consists of a rainfall simulation system and Morgan's splash cups.

3.1.1 Rainfall simulation system

Rainfall simulation system (Plate 3.1) available in the experimental farm of Department of Soil and Water Conservation Engineering, Dr. A.S. College of Agricultural Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri was made operational for the present study.

The details of rainfall simulator are as under.

Size of rainfall simulator = 2.65 m X 2.18 m

Size of soil plot = 2.12 m X 1.22 m

Size of tanks collecting runoff = 60 X 60 X 60 cm

Capacity of water supply tank = 1327 lit.

Motor used = 0.5 hp

The various components of the rainfall simulation system are elaborated in the following sections:

3.1.1.1 Rainfall generation and control unit

This was the main unit of rainfall simulation system, which was used for the generation and control of simulated rainfall. This unit was made of PVC and Aluminium pipes of size 25 mm diameter and 19 X 19 mm square section respectively. PVC pipes were pierced at every 10 cm and takeouts were inserted. The aluminium pipes were connected to those takeouts. The sprinkling was done by providing only orifices in aluminium pipes. The rainfall generation unit of size 2.65 X 2.18 m receives water from the water source by using a centrifugal pump at different pressure. The unit was mounted on a rectangular supporting angle iron frame. Details of this unit are given in Fig. 3.1 and 3.2. Its main components are:

3.1.1.2 Flow regulating valve

In order to supply water to the simulation unit from the water source at different operating pressure, a brass made 15 mm diameter flow regulating valve was fitted, on the bypass line. By regulating this valve the water inflow rate to the simulation unit is controlled to obtain the desired intensity of generated rainfall.

3.1.1.3 Pressure gauge

A pressure gauge having a dial diameter of 6 cm was mounted on the main supply line to monitor the pressure at which water was being supplied to the simulation unit the range of pressure gauge was from 0 to 6 kg cm^{-2}. In the present study, the pressure was varied between 0.4 to 0.5 kg cm^{-2} at an equal increment of 0.05 kg cm^{-2}.

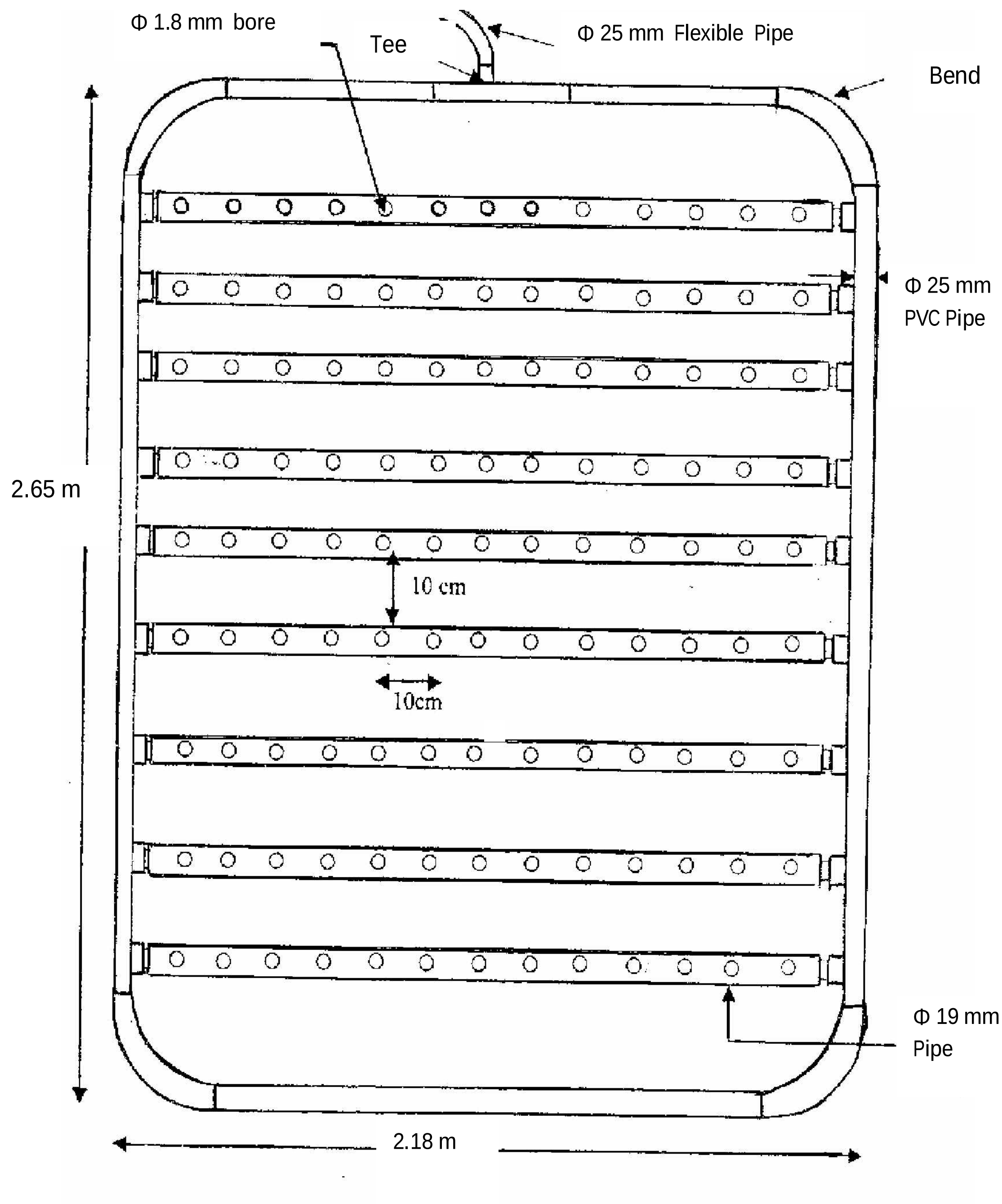


Fig. 3.1 Rainfall simulator

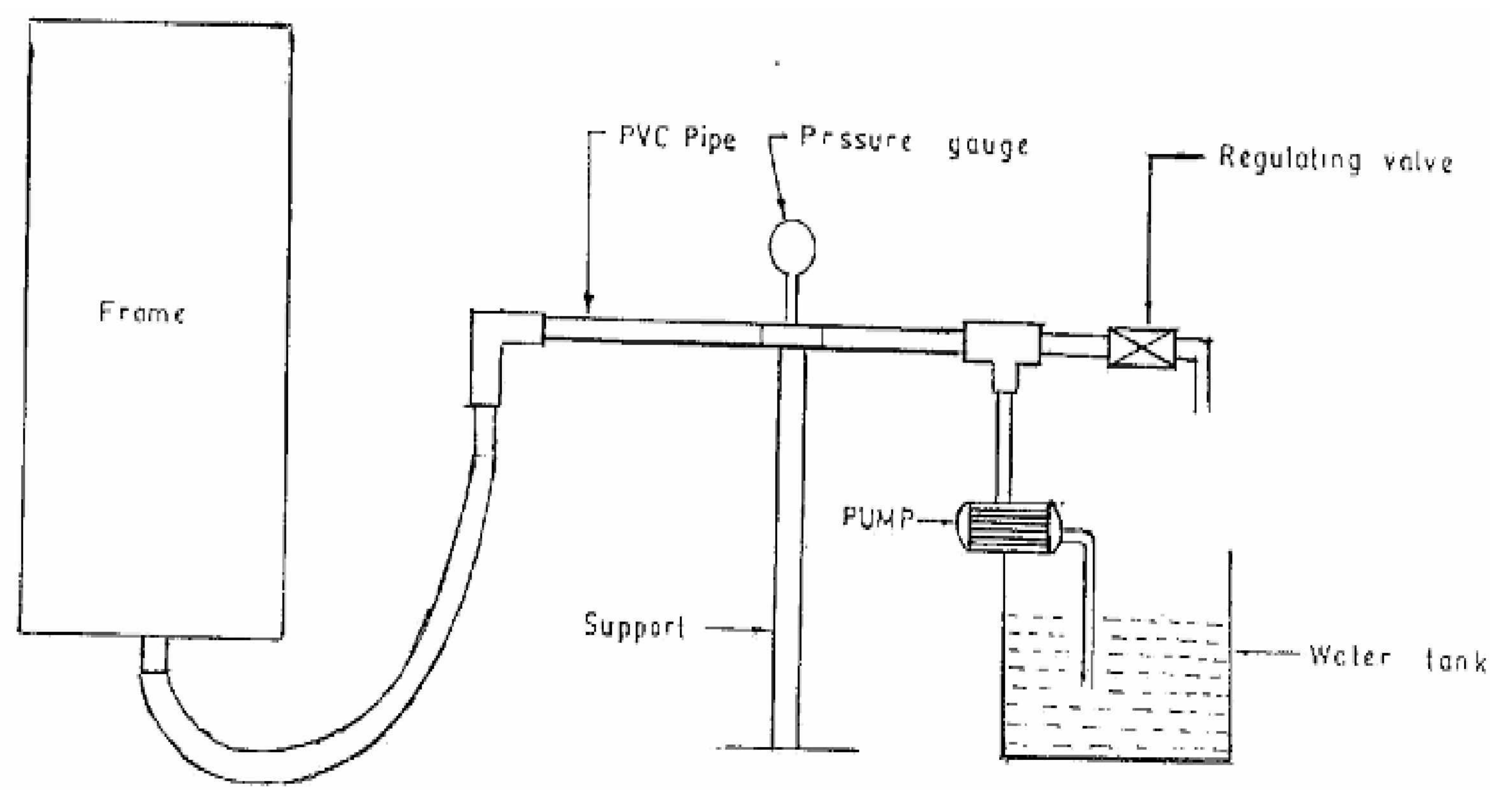


Fig. 3.2 Schematic diagram of rainfall simulator

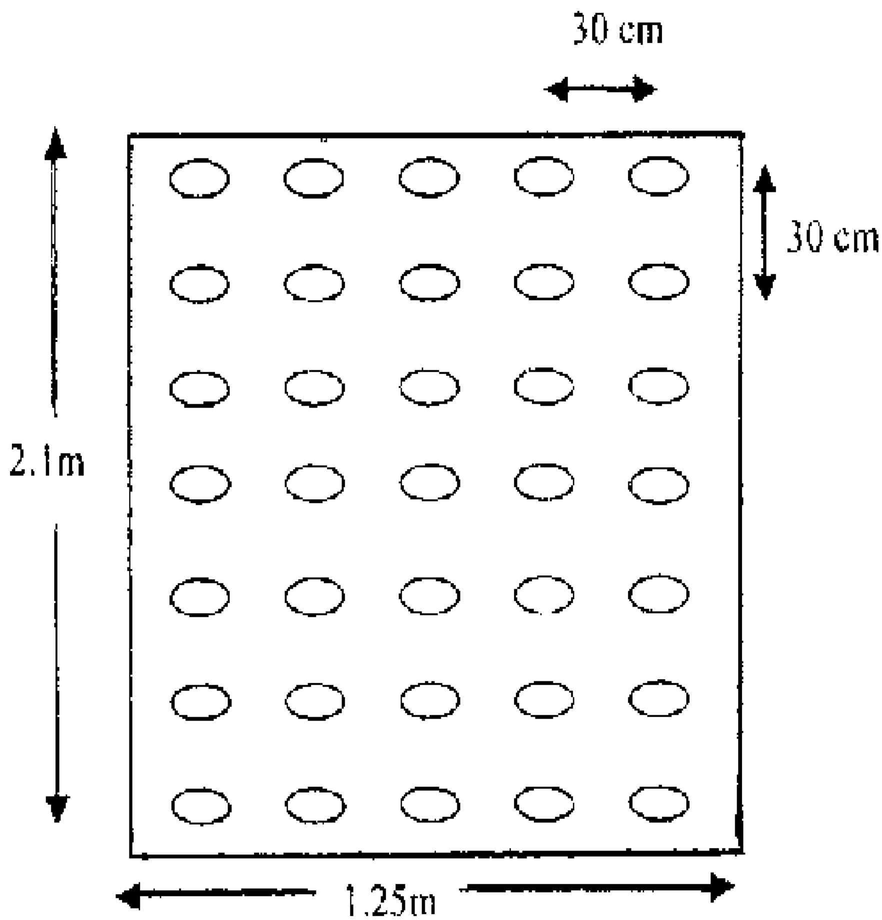


Fig. 3.3 Arrangement of catch-cans

3.1.1.4 Centrifugal pump

A single phase 0.5 hp centrifugal pump was used to supply water at various pressures to the simulation unit. The pump was operated through a three phase electric supply line of 5 A and 220 V. A flexible pipe of 25 mm diameter was used to supply water from the pump to simulation unit.

3.1.1.5 Reservoir tank (water source)

A cement concrete tank of 122 cm diameter and 110 cm depth was used as reservoir to store water. It receives water from the regular water supply through a PVC pipe. The reservoir tank was connected to the centrifugal pump by G.I. pipe of 25 mm internal diameter. A bypass line made of G.I. pipe of 25 mm diameter was used to restore the water in the reservoir tank, which was diverted back from the simulation unit.

3.1.1.6 Soil plot

The simulated rain was received over properly oriented soil plot (Plate 3.2) below the sprinkling system. Soil plot of 2.10 m X 1.22 m size was made of masonary work of 25 cm thickness on four sides. The bottom of soil tray was kept open i.e. connected with natural soil. The condition of the plot was maintained as natural as possible during the experiment.

3.1.2 Design and development of Morgan’s splash cup

The basic design requirement of any splash measurement device is that it should provide data on the total weight of soil particles splashed by raindrops, i.e. splash detachment. To do this the system must adequately isolate splash from the effects of sediment movement by overland flow and runoff creep; it must not be affected by relative changes in the height of the device with respect to the soil surface as a result of ground lowering, compaction, frost or swelling and shrinking of the soil, the so called rim effect, characteristic of splash cups used in laboratory experiments where, as the soil level in the cup falls, soil particles are less and less likely to bounce over the rim; and it must not interfere with the properties of the rainfall close to the ground surface. It should also be acceptable environmentally.

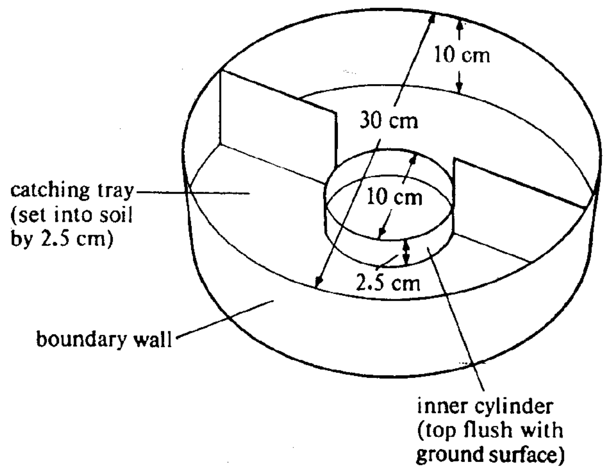


Fig. 3.4 Morgan's splash cup (30 cm outer dia.)

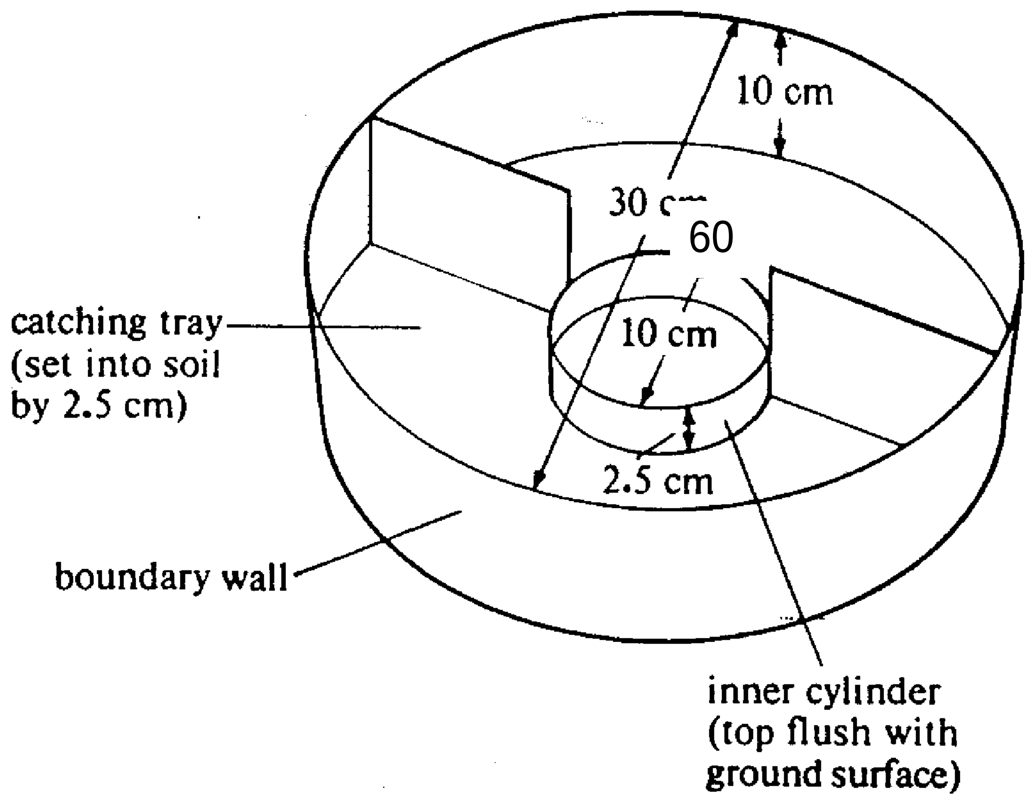


Fig. 3.5 Modified splash cup (60 cm outer dia.)

The design requirements depend on whether the objective is solely to determine splash detachment or to obtain sufficient information to model the splash process, in which case, data are required on the direction, height and distance of movement of the splashed particles (Moeyersons and De Ploey, 1976). Two types of splash cups were fabricated:

3.1.2.1 Morgan's splash cup (with standard dimensions)

This device (Plate 3.4 and Fig.3.4), described fully by Morgan (1978) was fabricated using G.I. sheet (28 gauge) consists of an inner hollow cylinder, 100 mm in diameter, 25 mm high inner wall, surrounded by a circular catching tray, 300 mm in diameter, with a l00 mm high boundary wall, and partitioned into upslope and downslope compartments by 100 X 100 mm square G.I. sheet (28 gauge). Problems were encountered with rainwater being unable to drain from the catching tray (Morgan, 1981), the floor of the catching tray was replaced with a wire mesh sheet covered with muslin. This will allow free drainage of the rainwater whilst still allowing the collection of splashed particles. Two semicircular rings were made with G.I. wire to fix the muslin cloth over catching tray properly and for easy replacement of muslin cloth. When set up on a horizontal surface as shown in Plate 3.4 and Fig.3.4, the apparatus will catch all particles splashed from the soil in the inner cylinder for distances less than the radius of the catching tray and those particles splashed greater distances with angles of ejection up to 20°.

3.1.2.2 Modified splash cup (by changing lateral dimension)

Modified Morgan's splash cups were fabricated by changing the diameter of catching tray as 600 mm and keeping all other dimensions same. This is shown in Plate 3.5 and Fig. 3.5.

3.2 Determination of soil properties

Before starting the experiment, the data was collected in order to determine percent sand, silt and clay, soil type, bulk density of soil and initial moisture content of soil. These are the factors, which influence the splash soil loss rate of soil under similar operating conditions.

3.2.1 Particle size analysis

As per the USDA textural classification the ranges of size of soil particles is as follows:

Sand – 0.05 mm to 2 mm

Silt - 0.05 mm to 0.005 mm

Clay – less than 0.05 mm

Sand, from the soil under study is separated from silt and clay by using mechanical sieve analysis. The percentage of silt and clay was obtained by using hydrometer method (Black et al., 1965). Sand content was 29.45 percent in the soil under study. The percentage of silt and sand was obtained by using Hydrometer method (Black et al., 1965).

3.2.2 Bulk Density

The dry bulk density of soil under different land uses was determined by core sampling method. The samples were taken at depth of 0 to 15 cm using standard core sampler. The diameter of the core sampler was 10 cm and its height 12 cm. The undisturbed sample was collected prior to start observations. The dry bulk density was calculated as:

$$\text{Dry bulk densty} = \frac{\textit{Total mass dry soil}}{\text{Total volume of soil mass in core sampler}}$$

and it is expressed in Mg m^{-3} calculation are given in Appendix- A. The bulk density and percent particle size distribution for depth 0-15 cm of soil is given in Table 3.1.

Table 3.1 Mechanical analysis of soil

Survey No.	Depth (cm)	Particle Size distribution (%)				Bulk Density (Mg m^{-3})	Textural Class
		Coarse Sand	Fine sand	Silt	Clay		
73	0-15	17.3	12.15	28.75	41.2	1.26	Clay

3.2.3 Determination of moisture content

The moisture content of soil sample was determined by gravimetric method. Soil sample was taken from required depths using screw auger. The samples were put in sampling boxes. These samples were dried in an oven at 105 ^{0}C till constant weight was obtained up to 24 hrs. Weights of soil samples before and after drying were recorded.

Moisture content (%) on dry basis

$$= \frac{\text{Weight of sample before drying} - \text{Weight of sample after drying}}{\text{Weight of sample after drying}} \text{ X } 100$$

3.2.4 Hydrologic soil groups

There are four hydrologic soil groups given by soil conservation services (1964).

3.2.4.1 Group A

Soils having high infiltration rates when thoroughly wetted consisting chiefly of deep, well to excessively drained sand or gravels and infiltration rate ranging from 7.5 to 11.25 mm h^{-1}.

3.2.4.2 Group B

Soils having moderate infiltration rate when thoroughly wetted consisting chiefly of moderately deep to deep, moderately well to well drain soil with moderately fine to moderately coarse texture and infiltration rate ranging from 3.75 to 7.5 mm h^{-1}.

3.2.4.3 Group C

Soils having low infiltration rate when thoroughly wetted consisting chiefly of moderately deep to deep, moderately well to well drained soil with moderately coarse texture and infiltration rate ranging from 1.25 to 3.75 mm h^{-1}.

3.2.4.4 Group D

Soils having low infiltration rate when thoroughly wetted consisting chiefly clay soils with high swelling potential, soils with a permanent high water table and soils with clay layer at or near the surface and infiltration rate ranging from 0 to 1.25 mm h^{-1}.

The soil under the study comes under the hydrologic group B, because it has the following characteristics.

i. Type of soil is clay.

ii. The soil has high runoff potential as the infiltration rate is 5.6 mm h^{-1} which falls in the range infiltration rate (3.75 to 7.5 mm h^{-1}) for hydrologic soil group ‘B’.

3.3 Experimental Technique

The experimental technique employed basically involves installation of splash cups, recording the splash soil loss data and their analysis under various combinations of rainfall intensity and land slope for specific time of exposure. The techniques employed while conducting this study are described in the following sub sections:

3.3.1 Installation of splash cups

On a properly levelled surface of soil plot, bottom of upslope catching tray was kept at ground level while the bottom of downslope catching compartment pushed into the ground until the ground level flush with the markings made on its boundary wall to give desired slope to soil in the inner hollow cylinder, 100 mm in diameter, surrounded by a circular catching tray, 300 mm in diameter, with a l00 mm high boundary wall, and partitioned into upslope and downslope compartments.

Three splash cups were installed at each slope to get average values. Arrangement of 9 splash cups (i.e. 3 cups at each slope for 3 different land slopes) is shown in Plate 3.6 and Fig. 3.6.

In the same way, two modified splash cups of 600 mm outer diameter were installed at each slope. Arrangement of 6 cups (i.e. 2 cups at each slope for 3 different slopes) is shown in Plate 3.7 and Fig.3.7.

3.3.2 Slope measurement

Since the perpendicular distance between two opposite edges of bottom of catching tray is 300 mm, the vertical difference between same edges for slopes 5, 10 and 15 % were 15, 30 and 45 mm respectively. Similarly for Modified splash cup with 600 mm outer diameter, the vertical differences were 30, 60 and 90 mm for 5, 10 and 15 % slopes respectively.

These distances were marked over the outer surface of boundary wall of downslope compartment to push it into the ground until it flush with ground level, by keeping bottom of upslope compartment at ground level.

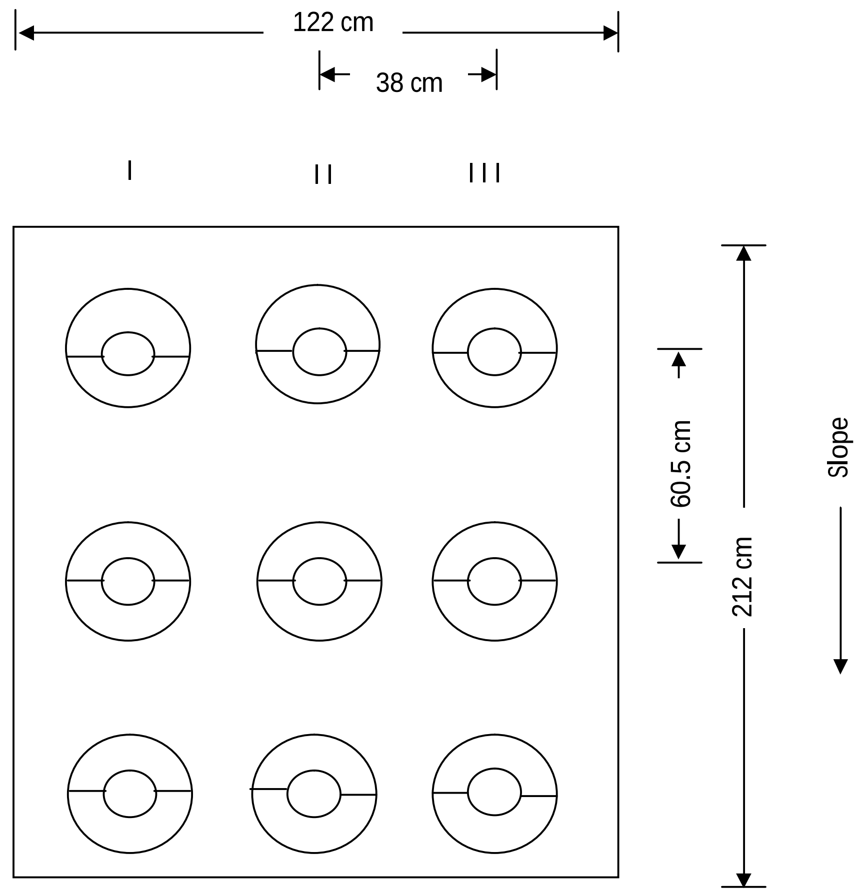
The vertical intervals between two edges for different slopes were calculated by using following formula:

$$\text{Vertical interval} = \text{Horizontal interval X Slope (in fraction)}$$

The sample calculation is given in Appendix- D.

3.3.3 Rainfall intensity

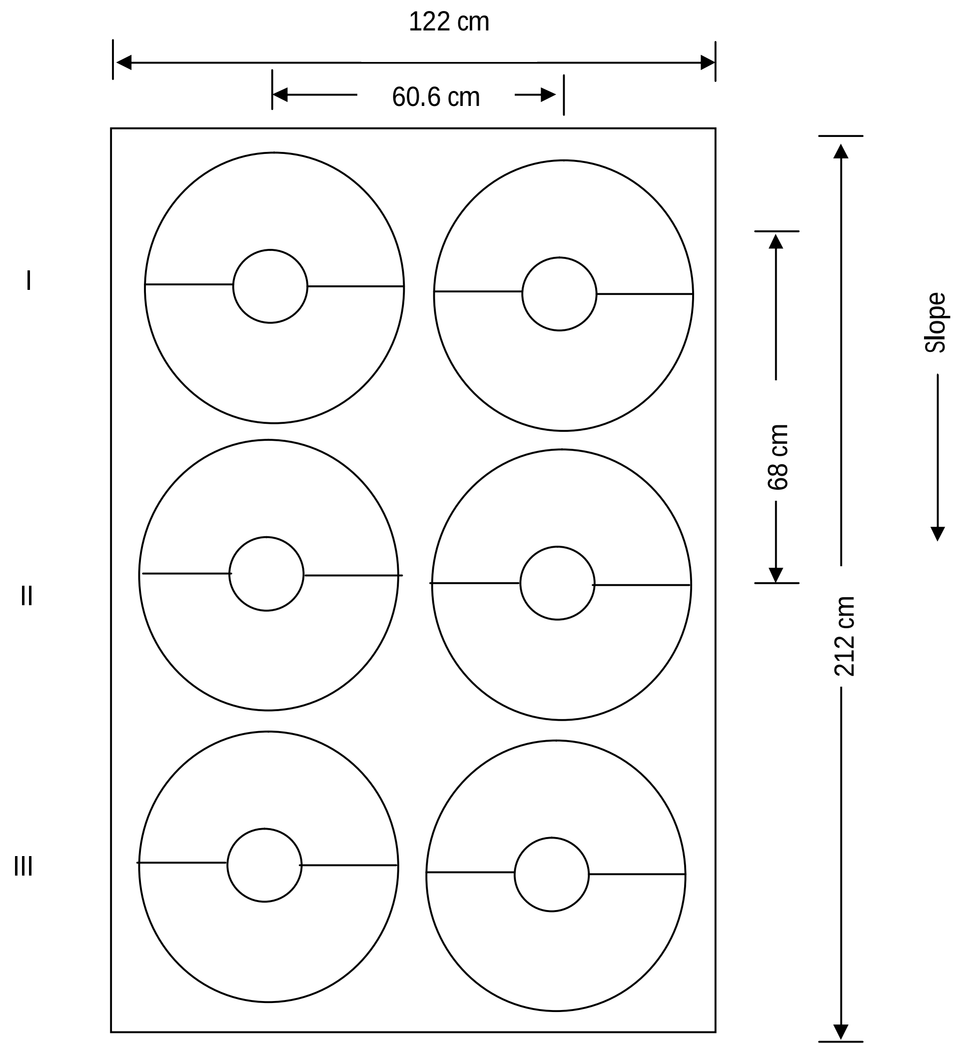
Calculations for rainfall intensity were based on amount of water used during each time interval. By knowing the diameter of tank and depth of water used, the amount of water used was calculated. This gave the volume of water delivered per unit time through the simulating unit. The area of simulating unit is known as 4.35 m^2 and thus the rainfall intensity in cm h^{-1} was computed; by dividing the volume of water delivered per unit time by area of simulating unit.



Slopes

1. I column having three splash cups was given 5% slope
2. II column having three splash cups was given 10 % slope
3. III column having three splash cups was given 15 % slope

Fig. 3.6 Arrangement of Morgan's splash cups (30 cm outer dia.) on soil plot



Slopes

1. I row having two splash cups was given 5% slope
2. II row having two splash cups was given 10 % slope
3. III row having two splash cups was given 15 % slope

Fig. 3.7 Arrangement of modified splash cups (60 cm outer dia.) on soil plot

3.3.4 Splash soil loss

For estimating the splash soil loss, soil is collected separately from the upslope and downslope compartments of the catching tray. Muslin cloth with splashed soil particles is shown in Plates 3.8 and 3.9. The muslin cloth covered over the floor of catching tray was removed by removing the semicircular G.I. wire frame, and washed with water in a bucket to detach the soil particles. This water with soil is taken in sample bottles (Plate 3.10) and kept for 3 to 4 hours for settlement of suspended soil particles (Plate 3.11). The clear suspension was decanted off and remaining sample with little water is stirred thoroughly and filtered (Plate 3.12). Soil on filter paper was oven dried at 105^0C for 24 h and weighed. The upslope and downslope weights combined are a measure of splash detachment. Data may be expressed on a unit width per unit time or a unit area per unit time basis (Morgan, 1978).

3.4 Determination of uniformity coefficient of simulated rainfall

For determining the uniformity coefficient (Uc) of the simulated rainfall, the rain water was collected in catch can for a specified duration. The catch cans were placed over the experimental plot at specified position. Arrangement of catch can is shown in Plate 3.3 and Fig. 3.3.

The uniformity coefficient of the simulated rainfall was determined by using following relationships.

$$Uc = \left[1 - \frac{\sum_{i=1}^{N} Xi}{M\ N}\right] X\ 100$$

Where,

Uc = uniformity coefficient of simulated rainfall (%)

N= total number of catch cans

Xi= deviation of collected depth of i^{th} from the mean depth (cm)

M= mean depth rain collected in the cans (cm)

A sample calculation is given in Appendix-B.

4. RESULTS AND DISCUSSION

This study was undertaken to observe the soil loss due to splash as influenced by rainfall intensity and land slope for bare soil condition under simulated rainfall. Accordingly, Morgan's splash cup and modified splash cup were fabricated with two different outer diameters, viz., 30 cm and 60 cm and partitioned into two compartments i.e. up slope and down slope to quantify directional splash. This study was conducted at three rainfall intensities i.e. 6.21, 9.69 and 12.75 cm h^{-1} for three different land slopes i.e. 5, 10 and 15 %. The percentage of sand, silt and clay in the soil under study were 29.45, 28.75 and 41.2 per cent respectively. The bulk density and textural class was 1.26 Mg m^{-3} and clay respectively. The moisture content of soil during the experiment was observed in the range of 16 to 17 per cent. Other factors such as soil condition, soil type and height of rainfall simulator were kept constant. The time of exposure of 4 min i.e. up to runoff generation, was maintained in each case as splash cups are not a true measure of soil detachment by rainfall when surface water is present (Proffitt *et al*., 1989). Three Morgan's splash cups were used for each slope and rainfall intensity. While two modified splash cups were used at each slope under same rainfall intensity for two different sets of observations. The splash soil loss for different combinations of rainfall intensities and land slopes were observed and the results obtained are described below:

4.1 Effect of rainfall intensity on splash soil loss

For different combinations of rainfall intensities and land slopes for specific time of exposure, the soil splash in both the direction i.e. upslope and down slope were collected separately as per the procedure described in Article 3.4.3. The collected soil splash in different direction is then converted to splash soil loss rate in kg m^{-2} h^{-1} i.e. the rate of soil splash from 1 m^2 exposed area in 1 h rainfall duration. The observations taken for all rainfall intensities with three replications for each slope are given in Appendix H and the average values thus obtained are given in Table 4.1.

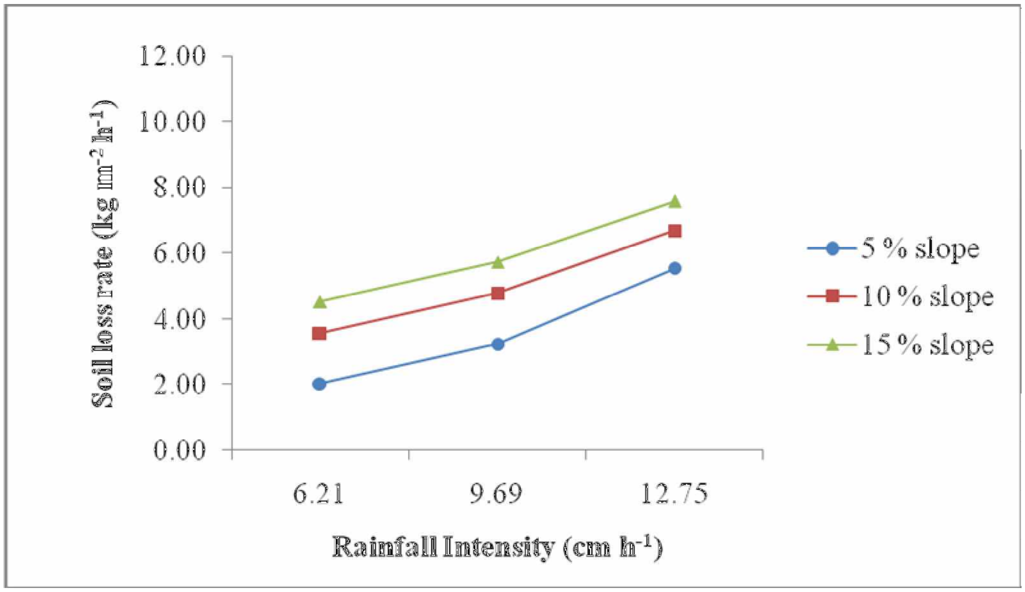


Fig. 4.1 Variation in splash soil loss rates with rainfall intensity using Morgan's splash cup.

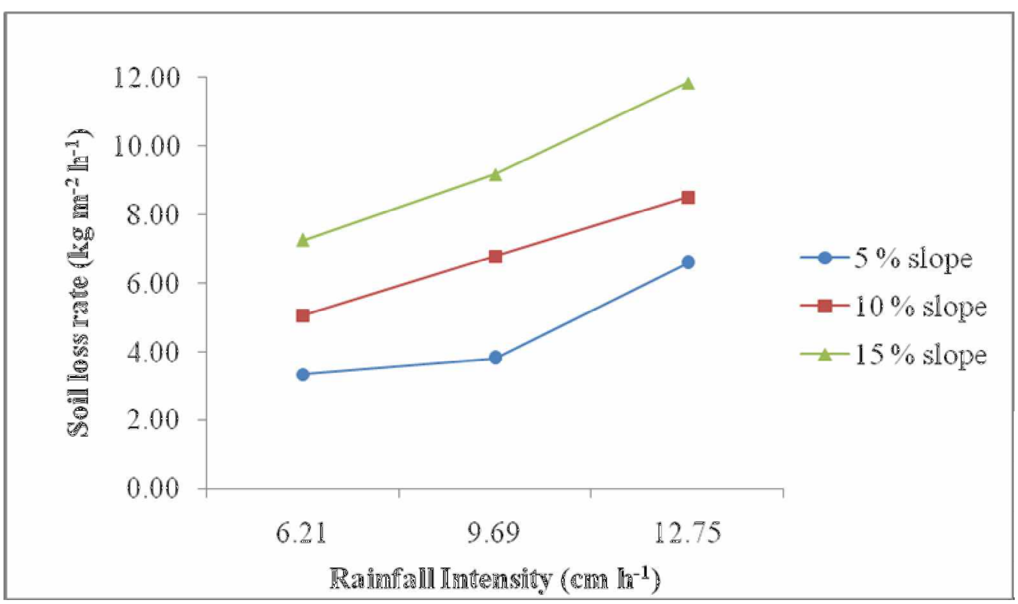


Fig. 4.2 Variation in splash soil loss rates with rainfall intensity using modified splash cup.

It is revealed from Table 4.1 and Fig. 4.1 that with the increase in rainfall intensity, upslope and downslope splash soil loss rates increased for all selected land slopes viz., 5, 10, 15 %; thus increase in total splash soil loss rate (upslope + downslope) with increase in rainfall intensity for all given land slopes. Similar results have also been reported by Quansah (1981).

At 5 % land slope, average splash soil loss rate increased from 2.04 to 5.54 kg m^{-2} h^{-1} as rainfall intensity increased from 6.21 to 12.75 cm h^{-1}, similarly at 10 % and 15 % land slope, the average splash soil loss rate increased from 3.57 to 6.69 kg m^{-2} h^{-1} and 4.52 to 7.58 kg m^{-2} h^{-1} as rainfall intensity increased from 6.21 to 12.75 cm h^{-1}, respectively.

The maximum value of total splash soil loss rate i.e. 7.58 kg m^{-2} h^{-1} was observed for combination of 12.75 cm h^{-1} as rainfall intensity and 15 % as land slope, whereas 2.04 kg m^{-2} h^{-1} was the minimum value of total splash soil rate for combination of rainfall intensity and land slope as 6.21 cm h^{-1} and 5 % respectively.

4.2 Effect of land slope on splash soil loss

As already described under Article 4.1 the upslope and down slope splash soil loss rate were estimated using Morgan's splash cup and are tabulated in Table 4.1 for different combinations of rainfall intensity and land slope. It was found that with increase in land slopes, splash soil loss rate increased for all selected rainfall intensities.

The splash soil loss rate increased from 2.04 to 4.52 kg m^{-2} h^{-1} as land slope increased from 5 to 15 % at 6.21 cm h^{-1} rainfall intensity. Similar trend was observed for all rainfall intensities with increase in land slope (Fig. 4.3). The maximum value of splash soil loss rates were observed at 15 % land slope, whereas minimum values were observed at 5 % land slope for all selected rainfall intensities.

Table 4.1 Directional splash soil loss rate (kg m^{-2} h^{-1}) at different combinations of rainfall intensities and land slopes using Morgan's splash cup.

Land slope (%)	Direction of splash soil loss	Rainfall intensities (cm h^{-1})		
		6.21	9.69	12.75
5	Up slope	0.57	0.89	1.46
	Down slope	1.46	2.36	4.08
	Total	2.04	3.25	5.54
10	Up slope	0.89	1.08	1.53
	Down slope	2.68	3.69	5.16
	Total	3.57	4.78	6.69
15	Up slope	0.96	1.21	1.53
	Down slope	3.57	4.52	6.05
	Total	4.52	5.73	7.58

4.3 Effect of rainfall intensity and land slope on upslope and down slope splash soil loss

Experiment was conducted to determine the directional splash soil loss rate i.e. upslope and down slope under various combinations of rainfall intensity and land slope. Effect of rainfall intensity and land slope on upslope and down slope splash soil loss is given in Table 4.1. The effect of rainfall intensity and land slopes on upslope and down slope splash soil loss rate is shown in Fig. 4.5.

It can be clearly seen from Table 4.1 that rate of increase in down slope splash soil loss rate is comparatively more than up slope for all selected rainfall intensities and land slopes. The difference between quantities of soil splashed both upslope and downslope increased positively with increase in either slope gradient or rainfall intensity.

It was also revealed that down slope splash soil loss rate nearly 2.5 times that of upslope splash soil loss rate for all selected land slopes at 6.21 cm h^{-1} rainfall intensity and 4 times at 12.75 cm h^{-1} rainfall intensity. The greater amount of soil particles were splashed towards down slope because of gravity force, compared to up slope.

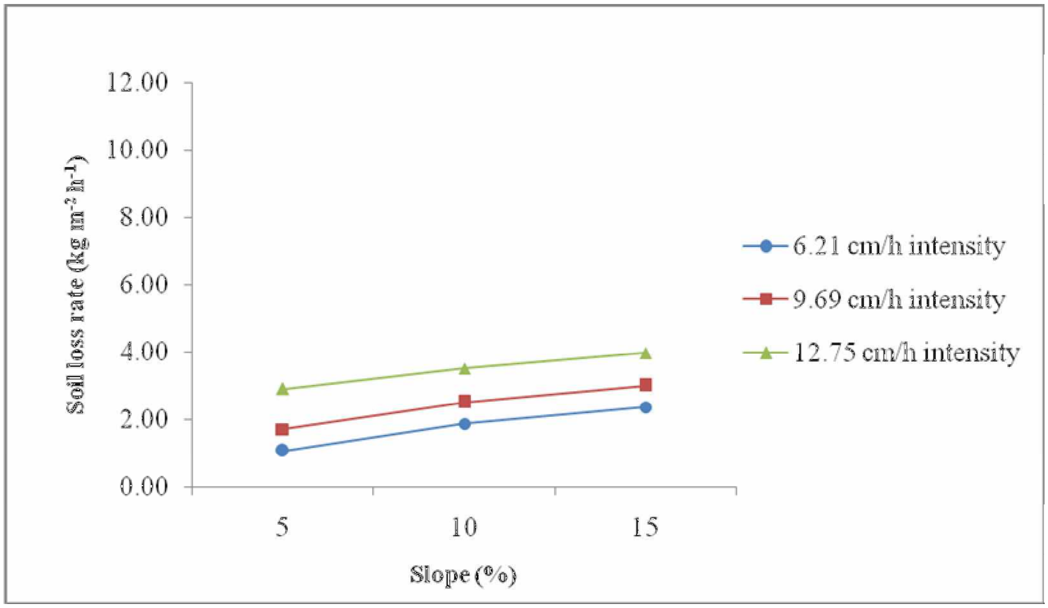


Fig. 4.3 Variation in splash soil loss rates with land slope using Morgan's splash cup.

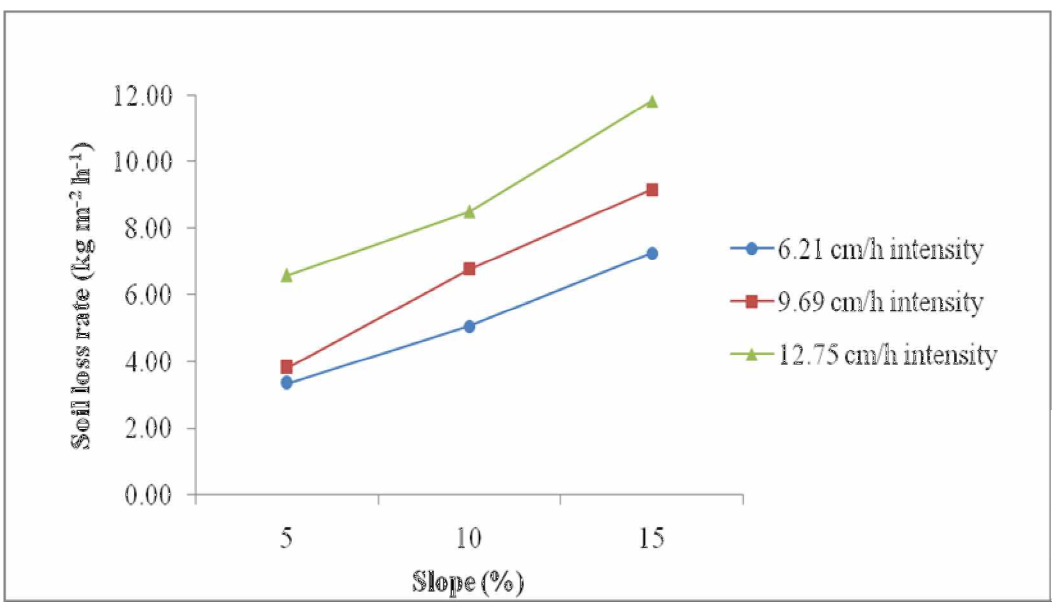


Fig. 4.4 Variation in splash soil loss rates with land slope using modified splash cup.

4.4 Modified splash cup

In order to determine the effect of change in lateral dimension of splash cup on quantity of splash soil collected in catching tray of Morgan's splash cup, modified splash cup with 60 cm outer diameter was fabricated. The results obtained as per the procedure described in Article 3.4.3 were tabulated in Table 4.2.

At 5 % land slope, average splash soil loss rate increased from 3.34 to 5.06 kg m^{-2} h^{-1} as rainfall intensity increased from 6.21 to 12.75 cm h^{-1}, similarly at 10 % and 15 % land slope, the average splash soil loss rate increased from 3.73 to 8.50 kg m^{-2} h^{-1} and 7.26 to 11.85 kg m^{-2} h^{-1} as rainfall intensity increased from 6.21 to 12.75 cm h^{-1}, respectively.

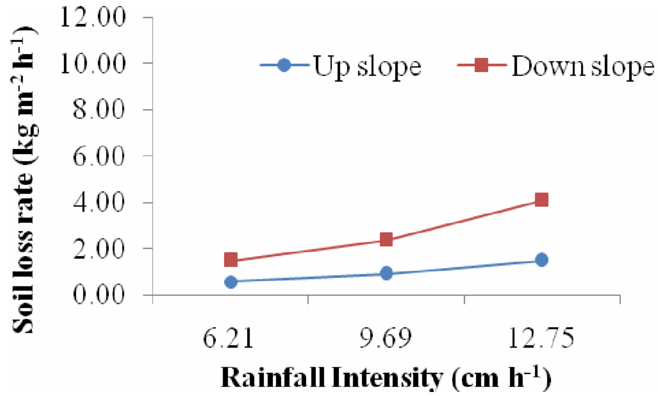
The trends of increase in splash soil loss rate under different combination of rainfall intensity and land slopes using Modified splash cup were same as that of Morgan's splash cup as can be seen from Table 4.2 and Fig. 4.2 and Fig.4.4. It was also noticed from Table 4.3 and Figs. 4.5 and 4.6 that there was increment in splash soil collected with modified splash cup, especially down slope splash soil compared to Morgan's splash cup. At 15 % land slope, the down slope splash soil loss rate is nearly double than that of Morgan's splash cup. This is attributed to sediment lost as airsplash and therefore not deposited within the splash cup was caught in modified splash cup to give more soil loss compare to Morgan's splash cup. These results are in agreement with those presented by Proffitt *et al.* (1989).

Table 4.2 Directional splash soil loss rate (kg m^{-2} h^{-1}) at different combinations of rainfall intensities and land slopes using modified splash cup.

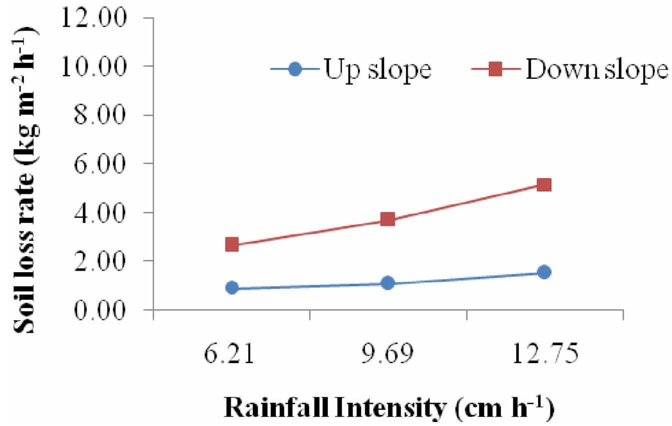
Land slope (%)	Direction of splash soil loss	Rainfall intensities (cm h^{-1})		
		6.21	9.69	12.75
5	Up slope	1.05	1.15	1.53
	Down slope	2.29	2.68	5.06
	Total	3.34	3.82	6.59
10	Up slope	1.34	1.15	1.82
	Down slope	3.73	5.64	6.69
	Total	5.06	6.78	8.50
15	Up slope	1.53	1.43	1.82
	Down slope	5.73	7.74	10.03
	Total	7.26	9.17	11.85

Table 4.3 Comparison between Morgan's splash cup and modified splash cup based on splash soil loss rate (kg m^{-2} h^{-1})

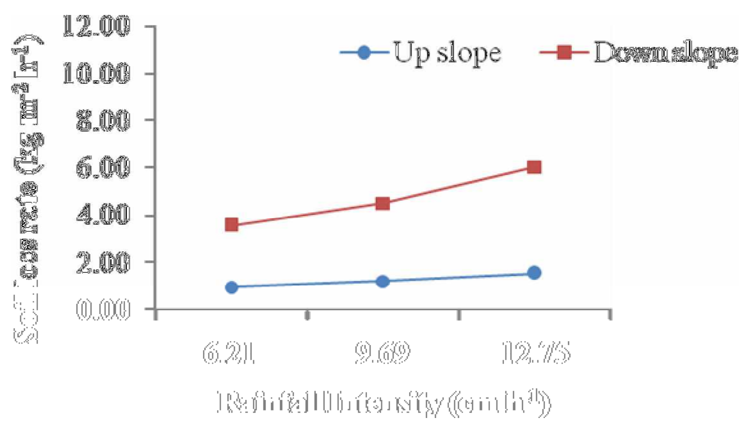
Land slope (%)	Direction of splash soil loss	Rainfall intensity (cm h^{-1})					
		6.21		9.69		12.75	
		Morgan's cup	Modified cup	Morgan's cup	Modified cup	Morgan's cup	Modified cup
5	1. Up slope	0.57	1.05	0.89	1.15	1.46	1.53
	2. Down slope	1.46	2.29	2.36	2.68	4.08	5.06
	(2) – (1)	**0.89**	**1.24**	**1.46**	**1.53**	**2.61**	**3.54**
10	1. Up slope	0.89	1.34	1.08	1.15	1.53	1.82
	2. Down slope	2.68	3.73	3.69	5.64	5.16	6.69
	(2) – (1)	**1.78**	**2.39**	**2.61**	**4.49**	**3.63**	**4.87**
15	1. Up slope	0.96	1.53	1.21	1.43	1.53	1.82
	2. Down slope	3.57	5.73	4.52	7.74	6.05	10.03
	(2) – (1)	**2.61**	**4.20**	**3.31**	**6.31**	**4.52**	**8.22**



(a) 5 % land slope

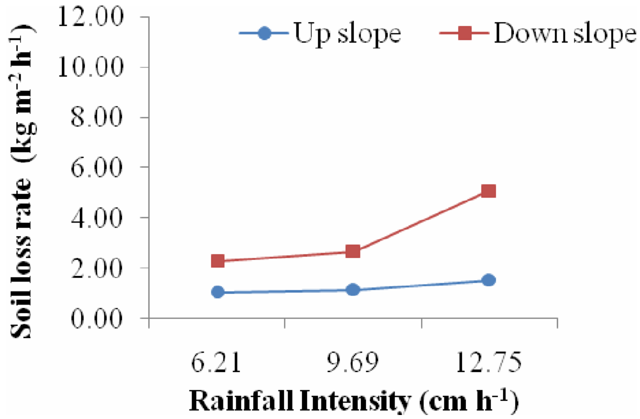


(b) 10 % land slope

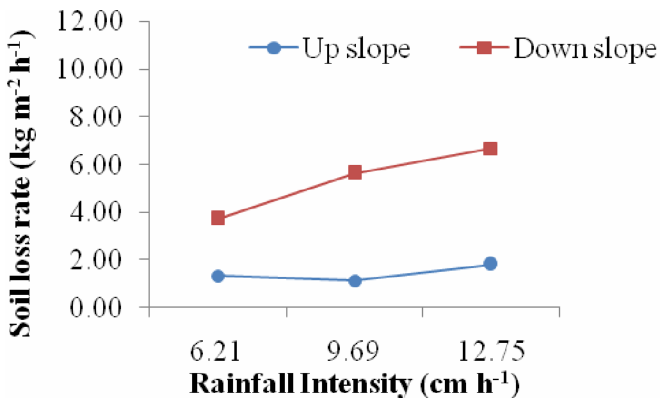


(c) 15 % land slope

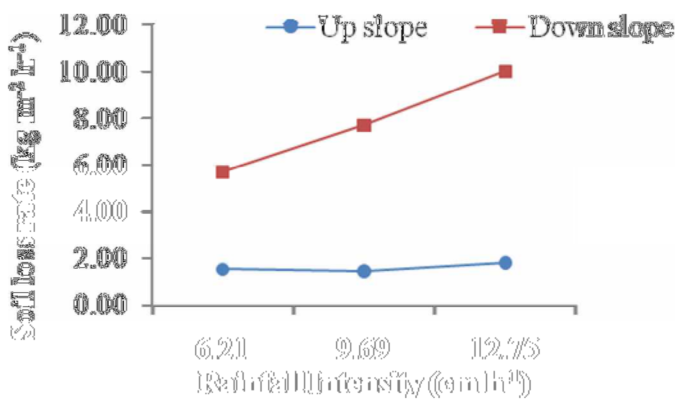
Fig. 4.5 Variation in upslope and downslope splash soil loss rate with rainfall intensity at 5, 10 and 15 % land slopes using Morgan's splash cup.



(a) 5 % land slope



(b) 10 % land slope



(c) 15 % land slope

Fig. 4.6 Variation in upslope and downslope splash soil loss rate with rainfall intensity at 5, 10 and 15 % land slopes using modified splash cup.

5. SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The present study was undertaken with the prime objective to quantify effects of rainfall intensity and slope steepness for varying rainfall intensities, viz., 6.21, 9.69 and 12.75 cm h^{-1} and land slopes, viz., 5, 10 and 15 % using Morgan's splash cup and modifying the splash cup with 60 cm as outer diameter to compare the results obtained by both the cups. Each land slope was replicated thrice at single rainfall intensity and simultaneously observations were recorded for different rainfall intensities using Morgan's splash cup, whereas two replications were used for each land slope using Modified splash cup. The rainfall simulator was operated for different intensities and the splashed soil was collected separately from upslope and down slope compartments of catching tray. In this way, the upslope and down slope splash soil loss were obtained for different combinations of selected rainfall intensities and land slopes. Various properties of the soil like particle size distribution, bulk density, soil texture, initial moisture content etc. were determined before conducting the experiment in order to specify its nature. For simulated rainfall the uniformity coefficient was more than 90 per cent indicating that rainfall is quite uniformly distributed for the pressure ranging from 0.4 to 0.5 kg cm^{-2}.

It was observed that at 5 % land slope, average splash soil loss rate increased from 2.04 to 5.54 kg m^{-2} h^{-1} as rainfall intensity increased from 6.21 to 12.75 cm h^{-1}, similarly at 10 % and 15 % land slope, the average splash soil loss rate increased from 3.57 to 6.69 kg m^{-2} h^{-1} and 4.52 to 7.58 kg m^{-2} h^{-1} as rainfall intensity increased from 6.21 to 12.75 cm h^{-1}, respectively. The maximum value of splash soil loss rates were observed i.e. 7.5 kg m^{-2} h^{-1} for the combination of 15 % land slope and 12.75 cm h^{-1} rainfall intensity, whereas minimum values were observed i.e. 2.04 kg m^{-2} h^{-1} for combination of 5 % land slope and 6.21 cm h^{-1} rainfall intensity. It was also found that the greater amounts of soil particles were splashed towards down slope because of gravity force, compared to up slope. Modified splash cup retained more splash soil particle than Morgan's splash cup as its outer diameter (60 cm) is twice that of Morgan's splash cup (30 cm).

5.2 CONCLUSIONS

On the basis of results obtained following conclusions are drawn:

1. The splash soil loss rate increased with increase in rainfall intensity for all selected land slopes (5, 10 and 15 %).

2. Splash soil loss rate increased with increase in slope for all selected rainfall intensities (6.21, 9.69 and 12.5 cm h^{-1}).

3. Both upslope and downslope splash soil loss increased with increase in rainfall intensity and land slope, However there was marked variation in upslope and downslope splashing of soil. Out of total soil splashed, nearly 20 to 25 per cent was splashed towards upslope and remaining 75 to 80 per cent (approx.) downslope.

4. Down slope splash soil loss rate was nearly 2.5 times that of upslope for all selected land slopes at 6.21 cm h^{-1} rainfall intensity and 4 times at 12.75 cm h^{-1} rainfall intensity.

5. Splashed soil collected with modified splash cup was more than that of Morgan's splash cup. This indicates the need to increase the diameter of Morgan's splash cup to obtain realistic splash soil loss.

6. SUGGESTIONS FOR FUTURE WORK

In view to make Morgan's splash cup technique more versatile and perfect to measure splash erosion, the following few suggestions would be useful for future work.

1. Open area around the splash cup, which is directly exposed to the rain need to be covered with plastic sheet or any other mulching material so that splashed particles from this open area entering into the catching tray can be restricted.

2. Height of the boundary wall can be increased to minimize the entry of splashed material into the catching tray from the open area around the splash cup and splashing of soil from the cup to the outside as well as.

3. The apertures of wire mesh floor used for the catching tray should be too small to avoid the entry of soil below it, which sticks to muslin cloth.

4. Instead of using 'U' pins to attach muslin cloth to the upper edge of boundary wall, circular rubber band would speed up the operation.

5. Muslin cloth can be replaced with any other water resistive or water proof material like nylon cloth for easy detachment of soil particles in water for its measurement and also it has more useful life.

6. As far as possible very less cloth should be kept over the rim of boundary wall as surrounding soil particles stick to it.

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9. VITA

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of

MASTER OF TECHNOLOGY

(Agricultural Engineering)

in

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8. APPENDICES

APPENDIX – A

Determination of bulk density

Steps involved and sample calculation in determining bulk density

1.	Mass of core cutter + wet soil	= 2200 g
2.	Mass of core cutter	= 950 g
3.	Mass of wet soil	= 1250 g
4.	Volume of core cutter	= 990 ml
5.	Bulk density (ρ) ρ = (3)/(4) Mg m^{-3}	= 1.26
6.	Bulk unit weight γ= 9.81 ρ (kg m^{-3})	= 12.39

APPENDIX – B

Determination of Uniformity coefficient of Simulated Rainfall

Steps involved in determining surface area of catch-can and depth of water collected in catch –can.

Diameter of catch-can (d) = 15 cm

Total number of catch cans (N) = 35

Depth of water collected in catch cans = D

Mean depth of water collected = M

Top surface area of catch can is calculated as,

$$A = \frac{3.14\ X\ 15\ X 15}{4}$$

= 176.71 sq. cm

$$\text{Depth of water} = \frac{\text{Volume of water collected in Catch-can (cm}^3)}{\text{Top surface area of catch-can (cm}^2)}$$

= 540 / 176.71

= 3.05 cm

Steps involved to determine the value of Uniformity coefficient (Uc)

(sample calculation, rainfall intensity 6.21 cm h^{-1})

$$M = \frac{\Sigma D}{N}$$

= 98.5 / 35

= 2.815

$\Sigma X = (M - D)$

$= 6.825$

Uniformity coefficient,

$$Uc = \left[1 - \frac{\sum_{i=1}^{N} Xi}{M\ N}\right] X\ 100$$

$=[1- (6.825 / 2.815 X 35)] X 100$

$= 93.07$ %

Uc for various rainfall intensities,

Rainfall intensity (cm h^{-1})	Uc (%)
6.21	93.07
9.69	94.02
12.75	95.75

Uniformity coefficient of simulated rainfall at 6.21 cm h^{-1} rainfall intensity

Catch-can no.	Vol. of water (ml)	Depth of water (cm)	Deviation from mean
1	540	3.05	0.235
2	565	3.19	0.375
3	505	2.85	0.035
4	460	2.6	0.215
5	440	2.49	0.325
6	510	2.88	0.065
7	505	2.85	0.035
8	520	2.94	0.125
9	460	2.6	0.215
10	500	2.82	0.005
11	545	3.08	0.265
12	455	2.57	0.245
13	550	3.11	0.295
14	500	2.82	0.005
15	435	2.46	0.355
16	585	3.31	0.495
17	540	3.05	0.235
18	560	3.16	0.345
19	450	2.54	0.275
20	505	2.85	0.035
21	500	2.82	0.005
22	470	2.65	0.165
23	555	3.14	0.325
24	550	3.11	0.295
25	500	2.82	0.005
26	535	3.02	0.205
27	430	2.43	0.385
28	495	2.8	0.015
29	480	2.71	0.105
30	505	2.85	0.035
31	410	2.32	0.495
32	490	2.77	0.045
33	475	2.68	0.135
34	425	2.4	0.415
35	495	2.8	0.015
		$\sum D = 98.54$	$\sum X = 6.825$

APPENDIX C

Sample calculations for determination of moisture content

1.	Weight of box + weight of wet soil	=	26 g
2.	Weight of box + weight of dry soil	=	24.4 g
3.	Weight of box	=	14.6 g
4.	Weight of dry soil (2)-(3)	=	9.8 g
5.	Moisture content (%) $= \frac{(1)-(2)}{(4)}$ X 100	=	16.33

APPENDIX D

Sample calculation for slope measurement

Horizontal interval (perpendicular distance between opposite edges of splash cup) ,

H.I. = 30 cm

Vertical interval between two opposite edges at 5 % land slope,

V.I. = 30 X 5/100

= 1.5 cm

Vertical interval for different slopes for Morgan's splash sup

Land slope required (%)	Vertical interval (cm)
5	1.5
10	3.0
15	4.5

Similarly, for Modified splash cup with 60 cm outer diameter, vertical interval for different slopes

Land slope required (%)	Vertical interval (cm)
5	3.0
10	6.0
15	9.0

APPENDIX E

Steps involved and sample calculation of splash soil loss rate at 6.21 cm h^{-1} rainfall intensity and 5 % land slope using Morgan's splash cup

1. Total dry weight of soil (upslope + down slope) collected from catching tray = 1.07 g
2. Exposed area (cross sectional area of inner hollow cylinder with 10 cm dia.)

   = (3.14 X 10 X 10) / 4

   = 78.5 sq. cm

   = 0.00785 sq. m
3. Time of exposure = 4 min
4. Splash soil loss rate $= \frac{1.07 \text{ X } 60}{1000 \; X \; 4 \; X \; 0.00785}$

   = 2.04 kg m^{-2} h^{-1}

APPENDIX – F

Splash soil loss at selected land slopes and rainfall intensities for 4 min time of exposure using Morgan's splash cup (30 cm outer dia.)

Average moisture content (dry basis) at 15 cm soil depth = 16.33 %

Rainfall Intensity (cm h^{-1})	Splash soil loss (g)	5 % slope			Average splash soil loss (g)	10 % slope			Average splash soil loss (g)	15 % Slope			Average splash soil loss (g)
		R_1	R_2	R_3		R_1	R_2	R_3		R_1	R_2	R_3	
6.21	Up slope	0.30	0.40	0.20	0.30	0.40	0.50	0.50	0.47	0.90	0.80	0.60	0.77
	Down slope	0.70	0.90	0.70	0.77	1.30	1.50	0.90	1.23	1.90	2.10	2.40	2.13
	Total	1.00	1.30	0.90	1.07	1.70	2.00	1.40	1.70	2.80	2.90	3.00	2.90
9.69	Up slope	0.50	0.50	0.40	0.47	0.70	0.40	0.60	0.57	0.70	0.90	0.80	0.80
	Down slope	1.30	1.50	1.40	1.40	1.90	2.20	1.70	1.93	2.50	2.60	3.00	2.70
	Total	1.80	2.00	1.80	1.87	2.60	2.60	2.30	2.50	3.20	3.50	3.80	3.50
12.75	Up slope	0.40	0.60	0.50	0.50	0.50	0.60	0.80	0.63	0.80	0.90	0.70	0.80
	Down slope	2.10	1.80	1.70	1.87	2.60	2.30	2.20	2.37	2.90	3.20	3.40	3.17
	Total	2.50	2.40	2.20	2.37	3.10	2.90	3.00	3.00	3.70	4.10	4.10	3.97

APPENDIX - G

Splash soil loss at selected land slopes and rainfall intensities for 4 min time of exposure using Modified splash cup (60 cm outer dia.)

Average moisture content (dry basis) at 15 cm soil depth = 16.53 %

Rainfall Intensity (cm h^{-1})	Splash soil loss (g)	5 % slope		Average splash soil loss (g)	10 % slope		Average splash soil loss (g)	15 % Slope		Average splash soil loss (g)
		R_1	R_2		R_1	R_2		R_1	R_2	
6.21	Up slope	0.60	0.50	0.55	0.70	0.50	0.60	0.90	0.70	0.80
	Down slope	1.30	1.10	1.20	1.30	1.50	1.40	2.80	2.50	2.65
	Total	1.90	1.60	1.75	2.00	2.00	2.00	3.70	3.20	3.45
9.69	Up slope	0.70	0.70	0.70	0.50	0.70	0.60	1.00	0.90	0.95
	Down slope	2.10	1.80	1.95	2.70	3.20	2.95	3.20	3.80	3.50
	Total	2.80	2.50	2.65	3.20	3.90	3.55	4.20	4.70	4.45
12.75	Up slope	0.60	1.00	0.80	0.80	0.70	0.75	1.00	0.90	0.95
	Down slope	2.80	3.20	3.00	3.80	4.30	4.05	5.10	5.40	5.25
	Total	3.40	4.20	3.80	4.60	5.00	4.80	6.10	6.30	6.20

APPENDIX – H

Splash soil loss rate at selected land slopes and rainfall intensities for 4 min time of exposure using Morgan's splash cup (30 cm outer dia.)

Average moisture content (dry basis) at 15 cm soil depth = 16.33 %

Rainfall Intensity (cm h^{-1})	Splash soil loss rate (kg $m^{-2}h^{-1}$)	5 % slope			Average Splash soil loss rate (kg $m^{-2}h^{-1}$)	10 % slope			Average Splash soil loss rate (kg $m^{-2}h^{-1}$)	15 % Slope			Average Splash soil loss rate (kg $m^{-2}h^{-1}$)
		R_1	R_2	R_3		R_1	R_2	R_3		R_1	R_2	R_3	
6.21	Up slope	0.57	0.76	0.38	0.57	0.76	0.96	0.96	0.89	1.72	1.53	1.15	1.46
	Down slope	1.34	1.72	1.34	1.46	2.48	2.87	1.72	2.36	3.63	4.01	4.59	4.08
	Total	1.91	2.48	1.72	2.04	3.25	3.82	2.68	3.25	5.35	5.54	5.73	5.54
9.69	Up slope	0.96	0.96	0.76	0.89	1.34	0.76	1.15	1.08	1.34	1.72	1.53	1.53
	Down slope	2.48	2.87	2.68	2.68	3.63	4.20	3.25	3.69	4.78	4.97	5.73	5.16
	Total	3.44	3.82	3.44	3.57	4.97	4.97	4.39	4.78	6.11	6.69	7.26	6.69
12.75	Up slope	0.76	1.15	0.96	0.96	0.96	1.15	1.53	1.21	1.53	1.72	1.34	1.53
	Down slope	4.01	3.44	3.25	3.57	4.97	4.39	4.20	4.52	5.54	6.11	6.50	6.05
	Total	4.78	4.59	4.20	4.52	5.92	5.54	5.73	5.73	7.07	7.83	7.83	7.58

APPENDIX – I

Splash soil loss rate at selected land slopes and rainfall intensities for 4 min time of exposure using Modified splash cup (60 cm outer dia.)

Average moisture content (dry basis) at 15 cm soil depth = 16.53 %

Rainfall Intensity (cm h^{-1})	Splash soil loss rate (kg $m^{-2}h^{-1}$)	5 % slope		Average Splash soil loss rate (kg $m^{-2}h^{-1}$)	10 % slope		Average Splash soil loss rate (kg $m^{-2}h^{-1}$)	15 % Slope		Average Splash soil loss rate (kg $m^{-2}h^{-1}$)
		R_1	R_2		R_1	R_2		R_1	R_2	
6.21	Up slope	1.15	0.96	1.05	1.34	0.96	1.15	1.72	1.34	1.53
	Down slope	2.48	2.10	2.29	2.48	2.87	2.68	5.35	4.78	5.06
	Total	3.63	3.06	3.34	3.82	3.82	3.82	7.07	6.11	6.59
9.69	Up slope	1.34	1.34	1.34	0.96	1.34	1.15	1.91	1.72	1.82
	Down slope	4.01	3.44	3.73	5.16	6.11	5.64	6.11	7.26	6.69
	Total	5.35	4.78	5.06	6.11	7.45	6.78	8.03	8.98	8.50
12.75	Up slope	1.15	1.91	1.53	1.53	1.34	1.43	1.91	1.72	1.82
	Down slope	5.35	6.11	5.73	7.26	8.22	7.74	9.75	10.32	10.03
	Total	6.50	8.03	7.26	8.79	9.55	9.17	11.66	12.04	11.85