ESTIMATION OF WATER EROSION OF A NIGERIAN GUINEA SAVANNA SOIL

BY

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A Thesis Submitted to the Post Graduate School, Ahmadu Bello University, Zaria in fulfilment of the Requirements for the Degree of Doctor of Philosophy in Engineering.

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December, 1998.

DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

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Date: 16/12/98

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Date: 16/12/98

CERTIFICATION

This thesis entitled **'ESTIMATION OF WATER EROSION OF A NIGERIAN GUINEA SAVANNA SOIL'** by **ADEWUMI JOHNSON KAYODE** meets the regulations governing the award of the degree of Doctor of Philosophy (Agricultural Engineering) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to God and to the memory of my late Mother, Mrs Maria Folake and to late Dr. J.S. Adeoti who died in ghastly motor accidents along Kaduna - Birnin/Gwari highway and Ilorin - Jebba highway on 16th March, 1993 and 29th March, 1998 respectively.

May their gentle souls continue to rest with the Lord in perfect peace. Amen.

ACKNOWLEDGEMENTS

I am deeply indebted to many individuals who gave me assistance and encouragment in the preparation of this thesis.

I would like to express my deepest gratitude to my project advisor, in the person of Dr. O.J. Mudiare whose overwhelminghly unmeasurable magnitude of aid, through vivid and precise scrutiny and step by step criticisms and corrections to the work, saw me through the periods of depressions often associated with research work. He has made this project a success. My immense delight goes to Prof. J.J. Owonubi, my project co-supervisor, an able consultant and a stimulating mentor whose advice and suggestions contributed substantially to the success of this work. A special thanks goes to Dr. A.L. Bello of Geography department for his valuable, useful suggestions and criticisms during the experimental and writing stage of this work. My thanks goes to Prof. O. Oladipo formerly of the Geography department, A.B.U. Zaria, for his initial contribution before leaving for UNDP job.

Many thanks also goes to my colleagues in the department of Agricultural Engineering and Faculty of Engineering for their numerous advice, suggestions, encouragements and their support both morally and financially. May God continue to bless their families and enrich their various sources of income. These colleagues are too many to mention. However, my warmest indebtedness goes to Mr. O.O. Osasona and Mr. Ranti Idowu (both are my chilhood friends), Dr. M.A. El-Okene, Dr. B.A. Raji, Engr. M.A. Oyebode, Profs. C.A. Okuofu, A.K. Oyinlola, V.A. Kolawole, S.T.Lagoke, O.A. Adebisi, C.O. Folayan, Dr. S.P. Ejeh, Dr. J.O. Afolayan,

Dr. M.L. Suleiman, Dr.O.Oludipe, Dr. J.O. Afolayan, Mr. J.S. Awe, Mr. F. Alayande, Dr. V.I.O. Ndirika, Dr. A.B. Fashina, Dr. A.A. Adeoti, Dr. M.L. Suleiman and Apostle Felix Giwa for their unmeasurable level of concern about this project.

I gratefully acknowledged the help and advice, I recieved from Prof. R.P.C. Morgan, of the Cranfield University, Silsoe College, Bedford, England. U.K.,where I carried out my preliminary research attachment and the financial support I recieved from the World Bank (Under Staff Development Programme) for their assistance.

Finally, I am grateful to my family, my wife, Mrs Ruth Bose Adewumi, my son, master Biodun Adewumi, my daughter, miss Bola Adewumi, my twins, Taiye and Kehinde Adewumi and our able assistance (my wife's niece) miss Fadeke Jacob, for their prayer and patience. To the Adio's, Nwahas's, and Adu's families, Joshua Adio and Femi Adio in particular, I owed them my gratitude.

I thank you all.

ABSTRACT

The possibility of establishing an equation for estimating soil loss in Samaru - Zaria environment was investigated using measured values and two erosion computer models.

Three experimental plots were established namely: bare soil, vegetated soil and cultivated soil to measure soil detachment, soil loss and runoff on a storm by storm basis at Ahmadu Bello University farm, Shika - Samaru during the 3 years of study.

Soil detachment losses were measured by collecting all splash losses in a 25mm x 31mm hollow rectangular plastic container buried in the soil in a grid pattern to catch soil splash at a maximum of one meter radius. Similarly, both runoff and soil loss were also collected inside a drum buried at the end of each plot.

The results indicate high erosion rate of 2.62 kg/m^2/yr was measured for bare soil on 5.8% slope while 1.15 kg/m^2/yr was recorded as mean erosion rate for vegetated plot on 6.6% slope. Slight over prediction of tested model was experienced. However, the European Soil Erosion Model (EUROSEM) is recommended for erosion prediction for bare and vegetated soil in Samaru - Zaria environment, while the Water Erosion Prediction Project Model (WEPP) is recommended for further experimentation in the southern part of Nigeria where a substantial amount of rainfall per single storm normally occurs.

The study concludes with emphasis on using a soil conservation planning guide of 2.7 kg/m2/yr erosion rate in Samaru - Zaria, Northern Guinea Savanna zone of Nigeria.

Table of Contents

Chapter	Title	Page
	Title page	i
	Declaration	ii
	Certification	iii
	Dedication	iv
	Acknowledgement	v
	Abstract	vii
	Table of Contents	ix
	List of Tables	xiii
	List of Figures	xv
	List of Plates	xiv
	List of Plates	xvii
	CHAPTER ONE	1
1.0	INTRODUCTION	1
1.1	Statement of Problem	3
1.2	Justification of Study	4
1.3	Objectives of Study	6
	CHAPTER TWO	7
2.0	LITERATURE REVIEW	7
2.1	Introduction	7
2.2	Soil Detachment and Transportation	8

2.2.1 Soil Detachment 10

2.2.2 Soil Transportation 10

2.3 Physical Empirical Erosion Equations 11

2.4 Erosion Studies in 19

2.5 European Soil Erosion Model (EUROSEM):

Model 1 22

2.5.1 Rainfall interception 22

2.5.2 Infiltration 25

2.5.3 Soil Surface Condition 26

2.5.4 Surface Runoff 27

2.5.5 Soil Detachment by Raindrop Impact 28

2.5.6 Soil Detachment by Runoff 29

2.6 Water Erosion Prediction Project (WEPP):

Model 2 30

2.6.1 Soil Albedo (SALB) 31

2.6.2 Initial Saturation 32

2.6.4 Effective Rainfall Intensity 33

2.6.5 Flow Shear Stress 34

2.6.6 The Discharge Rate 34

2.6.7 Sediment Transport Capacity (TC) 35

2.6.8 Hydrologic Inputs to the Model 35

CHAPTER THREE 36

3.0	MATERIALS AND METHODS	36
3.1	Study Area	36
3.2	Climate	36
3.2.1	Rainfall	36
3.2.2	Temperature	39
3.2.3	Potential Evapotranspiration (ETp)	41
3.3	Geology and Geomorphology	41
3.4	Soils	42
3.5	Vegetation and Land Use	43
3.6	Field Measurements and Equations Used	43
3.6.1	Chemical analysis of sediment collected	45
3.7	Computer Erosion Models	46
3.8	Layout of Experimental Field	47
3.8.1	Strategy Adopted for the Field Work	48
3.8.2	Measurement of Rainfall Splash	52
3.8.3	Sources of Error from the Experimental Plots	53
3.8.4	Measurement of Runoff and Soil Loss	55
3.8.5	Measurement of Rainfall Intensity	56
3.8.6	Estimation of unmeasured parameters	63
3.8.6.1	Net Capillary Drive	64
3.8.6.2	Maximum Interception Storage	64
3.8.6.3	Soil Cohesion	65

3.9	Data Analysis	66
3.10	Sensitivity and Data Error Analysis	67
	CHAPTER FOUR	71
4.0	RESULTS AND DISCUSSIONS	71
4.1	Pluvio-edaphic Pattern	71
4.2	Physical and Chemical Properties of the Experimental plots	71
4.3	Measured and Computed Rainfall Parameters	75
4.4	Measured and Predicted Soil Detachment and Soil Loss	88
4.5	Results Validation	115
4.6	Inferences from Discussion of Results	116
	CHAPTER FIVE	118
5.0	SUMMARY AND CONCLUSION	118
5.1	Summary	118
5.2	Conclusions	120
5.3	Suggestions for Further Work	122
	References	124
	Appendices	138

LIST OF TABLES

	Title	Page
3.1	Rainfall amount with dates for 1968 and 1995	61
3.2	Rainfall amount with dates for 1969 and 1993	63
4.1	Physical properties of the	72
4.2	Chemical properties of the surface soils in 1995	73
4.3	Chemical properties of the surface soils in	73
4.4	Measurement and computation of rainstorm parameters day by day for	76
4.5	Measurement and computation of rainstorm parameters day by day for	77
4.6	Measurement and computation of rainstorm parameters day by day for	78
4.7	Comparison of measured soil loss with predicted model 1 soil loss (kg/m2) as a storm by storm event (1993)	89
4.8	Comparison of measured soil loss with predicted model 1 soil loss (kg/m2) as a storm by storm event (1995)	90
4.9	Comparison of measured soil loss with predicted model 1 soil loss (kg/m2) as a storm by storm event (1996)	91
4.10	Summary of data analysis month by month for 1993 rainy season	92
4.11	Summary of data analysis month by month for 1995 rainy season	93

4.12 Summary of data analysis month by month for 1996 rainy season 94

4.13 Comparison of soil loss on monthly basis without soil detachment for 1993, 1995 and 1996 95

4.14 Comparison of soil loss incorporating soil detachment component on monthly basis for 1993, 1995 and 1996 96

4.15 Selected rainfall amount for soil loss comparison 114

LIST OF FIGURES

	Title	Page
2.1	A Comparison of kinetic energy and momentum as functions of intensity	16
3.1	Nigerian vegetation zones	37
3.2	The approximate location of erosion plot in the University farm	38
3.3	Distribution pattern of rainfall in Zaria area	40
3.4	Field experimental layout	49
3.5	Detailed drawing of pipe conveying plot runoff into the drum	50
3.6	Splash trap positioned in the field to collect splash erosion	51
3.7	Cross sectional view of a sample splash trap	54
4.1	Relationship of rainfall amount to intensity	80
4.2	Relationship of rainfall amount to kinetic energy	81
4.3	Relationship of soil detachment to kinetic energy	82
4.4	Soil loss and kinetic energy relationship	83
4.5	Observed versus predicted soil loss for bare soil in 1993	97
4.6	Observed versus predicted soil loss for bare soil in 1995	98

4.7 Observed versus predicted soil loss for bare soil in 1996 99

4.8 Observed versus predicted soil loss for vegetated soil in 1993 100

4.9 Observed versus predicted soil loss for vegetated soil in 1995 101

4.10 Observed versus predicted soil loss for vegetated soil in 1996 102

4.11 Predicted versus measured soil loss using model 1 for bare soil 1993, 1995 and 1996 103

4.12 Predicted versus measured soil loss using model 2 for bare soil 1993, 1995 and 1996 104

4.13 Predicted versus measured soil loss using model 1 for vegetated soil 1993, 1995 and 1996 105

4.14 Predicted versus measured soil loss using model 2 for vegetated soil 1993, 1995 and 1996 106

LIST OF PLATES

	Title	Page
I.(a)	Layout of Experimental Plot for bare soil	57
(b)	Experimental runoff collecting point for bare soil	57
II.(a)	Bare soil plot showing splash trap in position	58
(b)	Bare soil plot showing soil splash trap with sediments after rain	58
III.(a)	Picture of a drum installed at the end of each plot	59
(b)	Runoff volume measurement from the drum installed at the end of each plot	59
IV.(a)	Collection of soil washed from the plot into the drum after the rain	60
(b)	Location of splash trap in the vegetated plot	60

CHAPTER 1

1.0 INTRODUCTION

There is considerable scope for increasing agricultural production by effecting general improvement on the soil condition. By this means, more land area can be put into cultivation without wasting time and energy in the practice of shifting cultivation because of bad land due to erosion. The effective management of the land is essential in securing food for the future generation, particularly where there is competition for available land for other interests.

If we fail to protect our fertile fields from erosion, the fields will become infertile stony ground and wasting gullies, the resultant effect is that our future generations will be adversely affected as they will potentially face starvation. It is in the light of the above fact that quantifying the rate of soil loss from our fields becomes an important aspect of any sustainable agricultural system. Not only is the estimation of soil dislodged important, but the total soil loss after any rainstorm event is equally essential.

Much of the literature on erosion modelling create an impression that model development and use are complex mathematical exercises requiring high level of numerical analysis and skills. The most important thing is that the techniques used should adequately describe the processes or phenomena represented by the model (Morgan, 1986). The study reported herein does not deal specifically with any complex and

detailed mathematics in predicting soil detachment and soil loss, but is intended to employ adequate but simple techniques for collecting field data and comparing the field data with some chosen predictive models in areas where sophisticated equipment is not available.

Soil erosion, soil loss and sediment yield are terms with distinct meanings in soil erosion technology. Soil erosion is the gross amount of soil moved by raindrop detachment or runoff; soil loss is the soil moved off a particular slope or field; and sediment yield is the soil loss delivered to a point under evaluation (Mitchell and Bubenzer, 1980). For example, most slopes have topographic and cultural irregularities that cause both erosion and deposition to occur. Thus, the erosion at selected points on the slope often differs from the soil loss at the base of the slope. Further deposition often occurs in field boundaries and water course borders, thereby reducing the sediment yield of the watershed (Mitchell and Bubenzer, 1980).

In the tropics, soil erosion is a very serious problem which is hazardous to human survival as it has rendered inhabitants homeless and farm lands unfarmable. In the Northern Guinea Savannah zone of Nigeria, where there is little vegetation covering the soil surface, the portion of rainfall contributing to surface runoff on the soil surface is high. It is therefore expected that the amount of soil loss that is likely to be experienced will be quite high, depending on the

type of soil in the area. The soils of the Northern Guinea Savannah zone of Nigeria, which are ferruginous tropical soils on sandy parent material and crystalline acid rock (Klinkenberg and Higgins, 1968), are mainly used for the production of crops such as maize, sorghum, groundnut, soyabeans, cotton and millet. The lands are more or less continually and intensively used for crop and livestock production. Because of the climate and vegetation of the area, the lands are subject to soil erosion, bush burning, continous cultivation, and over grazing (Jones and Wild, 1975)

The increasing incidence of soil degradation, and the consequent impoverishment of the soils have generated concern for proper evaluation of the characteristics of the soils, rainfall amount and rate of soil loss. The long-term objective is to come up with an equation for quantifying soil loss which will be used in the planning of a protective conservation measure for the fields.

It is therefore, important that quantitative studies on methods to measure soil detachment and soil loss in our agricultural fields be carried out and the efficacy of these techniques be compared to other methods in order to improve our knowledge of estimating soil erosion.

1.1 Statement of Problem

The weather system over Samaru in the Northern Guinea Savannah zone which was described as being distinct and

consistent over several decades (Kowal and Knabe, 1972) shows that there are two factors that are mainly responsible for soil erosion and soil loss in our land namely:-

(1) the rainfall amount and impact on the soil surface, and

(2) the soil characteristics

Having understood that the factors mentioned above are intricate variables and interwoven, and based on the physical phenomenon observed in the area of study, the measurements of soil detachments, soil loss, runoff and computation of impact energy of raindrop on the soil surface become important within the context of the factors of soil erosion.

Predictive techniques for soil loss have been developed over many years in different parts of the world. As the understanding of the erosion process is still being expanded through research, the refinement of the predictive techniques must necessarily continue. In Samaru - Zaria, the nature of the soils, the topography and agronomic variabilities responsible for erosion constitute priority areas of investigation.

1.2 Justification of Study

For over thirty (30) years, various research investigations have been conducted mainly by the Institute for Agricultural Research (IAR) on the soil fertility status of the University and IAR farms located at Samaru (11° 11'N, 07° 38'E).

But physical observation even around Zaria where the

experiments were conducted, still shows some soil deterioration. A major reason for the inadequate application of the research results is because the recommended remedies have not been reduced into adaptable engineering conservation measures. Further more, the recent changes in rainfall pattern, particularly in sub-saharan Africa, requires up-dates of erosion estimates and more dynamic prediction capability.

Roose (1977) conducted some erosion studies in Sefa, Senegal which has a similar climate and soil characteristics to that experienced in Samaru - Zaria area. He found that a mean erosion rate of 2.3 kg/m2/yr on 2.0% slope of land resulted from runoff water. Kowal (1970a) estimated an annual soil loss of 1.15 kg/m2/yr under crop cover in Samaru on 0.3% average slope. This is indicative of the extent of soil erosion which might be occuring in Samaru under arable conditions. Such an amount of soil loss constitutes a great problem to any agricultural activity.

Thus, this study is aimed at contributing to the solution of soil deterioration problems in the Nigerian Guinea Savanna through:

(1) Validation of soil loss data in the area of study, and

(2) Finding easier ways of estimating soil loss in future and recommending appropriate soil conservation measures for the area.

1.3 Objectives

This study was undertaken with the following specific objectives in view:

1. To measure soil detachment, soil loss and runoff in field plots and estimate the kinetic energy, from well established equations available for the area.
2. To establish a relationship for estimating soil loss from the measured and predicted data in Samaru, Northern Guinea Savanna zone of Nigeria.
3. To recommend appropriate conservation techniques based on erosion rates computed using the adopted equation for the area.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction

Rainfall characteristics play an important part in determining the amounts of runoff and soil loss from agricultural lands. Soil type, slope, land management and conservation practices, must also be accounted for in prediction equations (Elwell and Stocking, 1975). These prediction equations including the Universal Soil Loss Equation (USLE) did not contain all the necessary factors in their development. In the present-day needs for evaluating percolation, runoff, erosion/sediment transport, and associated dissolved solids and sediment adsorbed by chemicals which become losses from farms, one simple relationship is insufficient. Also, long-term averages may be meaningless, as in the case of a toxic pesticide that may only be a problem for a few days after application. Interactions between the various components of the transport system prevent the use of single straight forward calculations. However, the physical processes can be represented by a logical series of mathematical expressions which can be solved repetitively and easily with high-speed computers. Of recent, computer soil erosion programme for predicting soil loss have successfully been in use (Morgan, 1994).

The remaining part of this chapter is therefore focussed on the review of past work and the various equations used in

predicting erosion as related to this study and based on the use of process base erosion model for computer execution. Also, detailed equations employed in predicting soil loss by European Soil Erosion Model (EUROSEM) and Water Erosion Prediction Project (WEPP) are presented.

2.2 Soil Detachment and Transportation

Soil erosion can be regarded as two separate ordered processes - detachment followed by transportation (Ellison, 1947). Where intense rainfall is experienced, as in tropical and sub-tropical regions of the world, these processes of rain-drop detachment and runoff transportation can give rise to serious agricultural, animal-grazing, or soil and water conservation problems.

Sediment entrainment into flowing water is the most important aspect of soil erosion. It occurs as splash, detachment by running water, and by other miscellaneous processes such as suffusion and the burrowing activity of animals (Thornes, 1980). The energy for particle detachment and transportation is provided by raindrop impact and running water. Detachability is a process by which soil particles are detached from soil matrix before they are entrained in flowing water. It is affected by particle size distribution, organic matter, presence of cementing materials such as oxides of iron and aluminium, carbonates and cations on the exchange complex (Lal, 1977). Soil loss as result of splash detachment is a very

serious threat to any agricultural activity.

When raindrop falls on the soil surface or a thin layer of water film, its energy is dissipated in breaking loose the soil aggregates. The higher the impact velocity the greater the amount of soil splashed (Bisal, 1960). About two-thirds of the energy of the raindrop is expended in forming an impact crater and moving soil particles (Mihara, 1957). When a thin film of water covers the soil surface, the drop impact is more effective and maximum dispersion of soil particles occurs (Palmer, 1963). Free (1960) claimed that although splash erosion can be an important process, especially on fine sandy soils, soil particles are not moved far. The process is mainly significant for providing material which is entrained and removed by sheet wash which is another aspect for consideration for soil conservation planners. There seems, however, to be an exponential relation between splash and soil slope. Splash in this context means, soil particles dislodged from one part to another as a result of raindrop.

The most efficient movement of soil particles occurs when both rain splash and sheet wash interact because particles brought in suspension are immediately entrained by sheet flow. Reported velocities of sheet flow range from 0.015 to 0.04 m/s (Young and Wiersma, 1973) to about 0.30 m/s (Ellison, 1947b). It is estimated that a velocity of 0.16 m/s is required to erode a 0.3mm size particle.

2.2.1 Soil Detachment

Soil detachment due to rainfall may be quantitatively defined as the mass of soil actually dislodged per unit area. Adopting such a definition, it is apparent that in an erosional sense, soil detachment cannot be said to be the same with soil loss. When a raindrop hits the soil surface, soil particles are splashed and the higher the impact kinetic energy the greater the amount of soil splashed. The process by which a raindrop hits the soil which is splashed into dispersion is termed soil detachment. In other words, soil detachment is the process of extracting soil particles from their original position in the soil system, so that these particles are forced or dislodged from the normal attractive forces of the soil mass and thus easily transported by moving water (Rose,1960). The process of detachment is enhanced by three factors which are: raindrop splash, kinetic energy of raindrop water and the soil characteristics. The energy released by falling drops is enough to detach most of the surface soil particles. This process which is known as splash erosion is accountable for most of the soil detachment in soil erosion. Also, the process is mainly important for providing materials which are entrained and removed by sheet wash.

2.2.2 Soil Transportation

As rainfall progresses, water starts to collect and run in small streams down the slope. This occurs first in minute rills

which then join down slope to form small streams and subsequently, gullies. Also, Ellison (1952) found that when runoff water is present in sufficient quantity and moving with sufficient velocity, it can initiate soil detachment, by the scouring action as well as cause its subsequent transportation. The resultant effect of the above fact is "rill" and "gully" erosion which is detrimental to any meaningful agricultural activity. Hence the process of transportation which is the movement of the splashed soil particles away from their initial position begins. Rills and small or minute streams then carry away particles in suspension to larger channels. The erosive action of the moving water and its scouring action along the bed of flowing water also picks up some soil particles which are eventually deposited at the tail end of the channel. Understanding the mechanics of soil detachment and transportation as presented above is important in modelling of the soil erosion process and also in suggesting approaches to erosion control.

2.3 Physical Empirical Erosion Equations

Initially, physical empirical equations were developed to describe soil loss using a single independent variable such as given by (Zingg,1940):

$$A = C.S^{m}.L^{n-1} \qquad (2.1)$$

where

A = Average Soil loss per unit area from a land slope of unit width (kg/m2/yr).

C = a constant of variation (combines the effects of rainfall, soil, crop and management)
S = degree of land slope (%)
L = horizontal length of land slope (m)
m,n = exponents of degree and horizontal length of land slope, respectively.

Values of 1.4 and 1.6 were proposed by Zingg (1940) for m and n, respectively. As can be observed by comparing this equation with later developments, the constant of variation, C, combines the effect of rainfall, soil, crop and management. Equation 2.1 relates soil loss to steepness and length of slope (Zingg,1940). Using plots under simulated rainfall and field conditions, Zingg (1940) demonstrated that doubling the degree of slope increased the soil loss 2.61 to 2.80 times and doubling the horizontal length of slope increased the soil loss in runoff 3.03 times.

Smith (1941) evaluated the effects of mechanical conservation practices for four combinations of crop rotation and soil treatment on one soil. He found that:-

(a) the soil loss from contouring is 57% of that from up-and-down hill operation.
(b) the soil loss from rotation strip cropping is 25% of that from up-and-down hill operation, and
(c) the soil loss from terracing is 3% of that from up-and-down hill operation.

Curves were presented to enable the field conservationist to evaluate the need for mechanical practices for each of the four crop - treatment combinations on shelby soil with an allowable soil loss of 0.9kg/m^2 per year. Browning et al.(1947) expanded the procedure proposed by Smith (1941) for several crop rotations and for most soils of Iowa State in the United States of America. Smith (1941) made an additional estimate of the

effect of soil treatment practices on soil loss.

The relationship of rainfall characteristics to the amount of soil eroded was determined by Musgrave (1947) using data from several stations. The equation proposed by Musgrave (1947) is given by:

$$E = (0.00527).I.R.S^{1.35}.L^{0.35}.P_{30}^{1.75} \quad (2.2)$$

where

E = the soil loss, mm per year,

I = the inherent erodibility of a soil at 10 percent slope and 22m slope length, mm per year,

R = a vegetal cover factor,

S = degree of slope, percent

L = length of slope, meters, and

P_{30} = the maximum 30-minute rainfall, mm

Erosion was determined to be proportional to $P_{30}^{1.75}$. The larger data base analysed at that time indicated that the slope steepness and length factor exponents should be 1.35 and 0.35, respectively. Equation 2.2 was used extensively for estimating gross erosion from watersheds.

In 1954, soil erosion prediction research was consolidated in a cooperative effort aimed at overcoming many of the disadvantages inherent in local or regionalized research projects. More than 8000 plot - years of erosion research data were compiled from 36 locations in 21 states of the United States of America. A re-evaluation of the various factors affecting soil loss (Smith & Wischmeier, 1957; Wischmeier & Smith, 1958 and Wischmeier et al., 1958) was made which led to the development of the widely used soil loss prediction method called the Universal Soil Loss Equation. Concurrently, Musgrave equation known as shape - practice equation was presented by

Hudson (1961):

$$E = T.S.L.P.M.R \qquad (2.3)$$

where

E = mean erosion (tons/acre)

T = soil type

S = slope gradient (%)

L = length (ft)

P = agronomic or agricultural practice

M = mechanical protection and

R = rainfall amount (in)

The problems of adequately evaluating each of these factors were discussed by Hudson (1961) who also reported an extensive research on the erosivity of rainfall in the sub-tropics of Africa. According to Hudson (1965), the Wischmeier and Smith (1958)'s equation (the Universal Soil Loss Equation, USLE) appears less valid in Southern Africa and Zimbabwe. He found that erosion occurred generally when rainfall intensity was more than 25 mm/hr. Consequently, he developed the following equation:

$$K.E. = 29.8 - 127.5/I \qquad (2.4)$$

where:

K.E.= Kinetic energy (J/m^2) and

I = Intensity of rainfall (mm/hr).

The development of equations 2.3 and 2.4 implies that the values of the kinetic energy can be derived from records of rainfall intensity. Rainstorms, however, show many discrete changes of intensity in their occurrences. It is therefore necessary to regard each rainstorm as being composed of many composite parts with their corresponding kinetic energies (see Appendices B and C).

From theoretical considerations, kinetic energy and momentum are parameters of rainfall events which are significant to erosion. This is because erosion is a work process which requires the expenditure of energy in detaching the soil particles. It was assumed by Wischmeier (1958) and Hudson (1965) that soil detachment is dependent only on the kinetic energy and the resulting expression can be given as:

$$K.E. = 1/2.M.V^2 \qquad (2.5)$$

where:

K.E. = kinetic energy (J/m^2)

M = Mass of soil detached (g)

V = Velocity of fall (m/s)

However, work by Rose (1960) and Williams (1969) showed that the raindrop momentum, that is, the product of the mass and velocity or any other functions of mass and velocity could equally have been valid. Rose (1960) argued that the mass of soil detached per unit area is more closely related to the momentum than the kinetic energy of a rainstorm. Nevertheless, since kinetic energy and momentum have similar relationship with rainfall intensity, as shown in Fig.2.1, the issue of whether momentum can be used instead of kinetic energy is therefore not very important.

Further, Elwell and Stocking (1981) developed another framework for predicting soil erosion with the use of a Soil Loss Estimation Model for Southern Africa (SLEMSA).The model which was developed in Tanzania, is given as:

$$Z = K.C.X \qquad (2.6)$$

where:

Z = is Predicted mean annual soil loss (kg/m2)

X = the ratio of soil lost from a plot of length L (m)

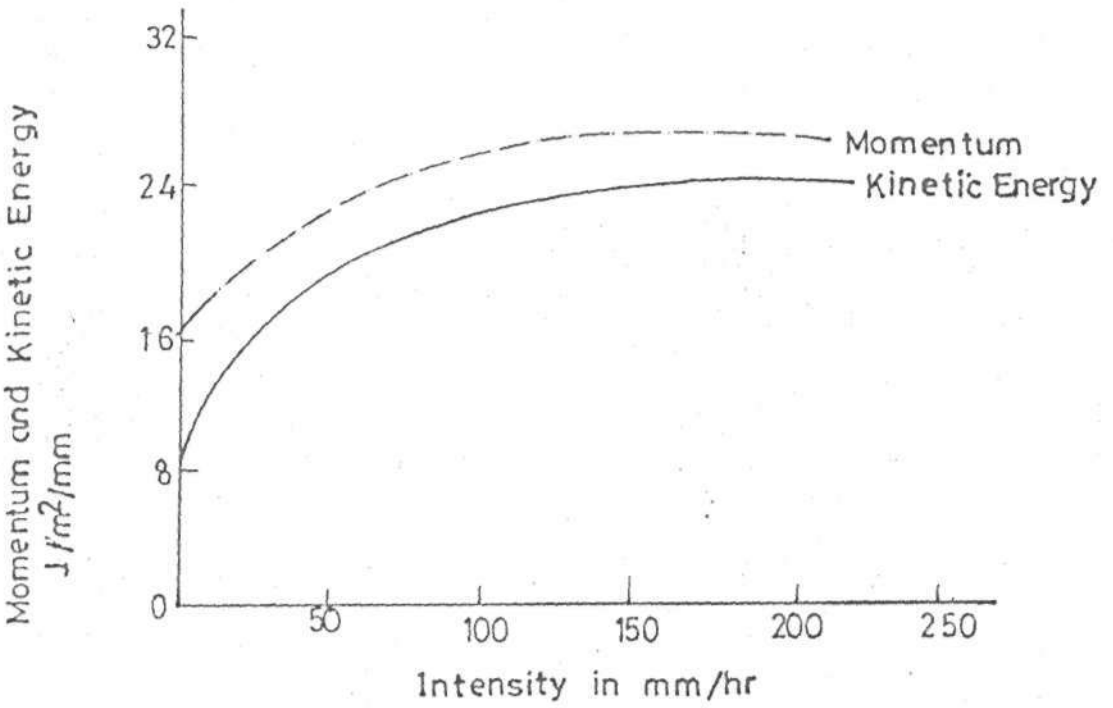


Fig 2.1 A comparison of kinetic energy and momentum as function of intensity (Source: Hudson, 1971)

and slope S (slope steepness in degree) to that lost from the standard plot.

C = the crop cover factor,which is a function of the percentage rainfall energy intercepted (%) and is determined from a crop cover distribution curve for the assumed crop and the distribution of rainfall energy.

K = is a factor dependent on rainfall kinetic energy and soil erodibility (E.F)

E = rainfall energy (J/m2)

F = soil erodibility index obtained by rating all soils from 1 to 10

These single factor equations such as equations 2.1 to 2.6 were developed for local situations where other contributing factors were reasonably constant. Multiple factor equations were developed as more data became available and researchers were better able to describe contributing factors.

These analyses culminated in the equation most widely used today for soil loss prediction - the Universal Soil Loss Equation (USLE) given as:

$$A = RKLSCP \qquad (2.7)$$

where:

A = Average annual soil loss (kg/ha)

R = An average annual erosivity factor (dimensionless)

K = Soil erodibility factor (dimensionless)

L = Slope length (m)

S = Slope gradient (%)

C = Cover management factor (dimensionless)

P = Soil conservation or engineering practice factor (dimensionless)

The USLE is a simple mathematical model that relates the average annual soil loss (A) to the average values of the parameters. The USLE is a much used and powerful model for estimating long-term erosion. However, the USLE is a static model in the sense that it does not describe changes arising for example from a single rainfall event. Thus, the USLE cannot be used to estimate the soil loss from a single rainfall event in catchments (Wischmeier, 1978). Recent investigations have focussed on re-defining the parameters of the USLE for a greater range of conditions.

The first scientific study of erosion effects is thought to have been done by Wollny in the late nineteenth century as reported by Hudson,(1971). The first quantitative experiments in the United State of America were begun by the Forest Service in 1915 as reported by Hudson,(1971). In 1917, Miller as reported by Hudson (1971) began a plot study of the effects of crops and rotations on runoff and erosion. The widespread concern of the damages of soil erosion in the 1920s and early 1930s resulted in an increase in scientific erosion research.

The importance of raindrop impact in the erosion process was not fully appreciated until the natural rainfall studies of

Laws (1940) and the analysis of the mechanical action of raindrops by Ellison (1947a). Thereafter, extensive investigations of the erosion process have been carried out in most parts of the world for the past sixty years (Obiechefu,1985). However, most of the work was carried out in the United States of America and partly in most of the European countries.(Benneth,1939;Zingg,1940;Musgrave,1947;Ellison,1946 and 1947a;Ekern,1950;Smith and Wischmeier,1957, 1958). Thus, several scientists began to develop empirical equations for soil erosion predictions as data became accumulated and exchanged.

2.4 Erosion Studies in Nigeria.

In Nigeria, several studies have also been made (Ansile, 1935; Grove, 1952; Lloyd, 1962; Floyd, 1964 & 1965; Ofomata, 1965, 1985a,b; Kowal 1970a,b; Kowal and Kassam, 1976; Lal, 1976; Aina et al.,1977; JeJe, 1972; Okeoma, 1982; Obiechefu, 1985 and Adewumi & Lalong, 1989). Sheet erosion which is wide-spread in Nigeria has been investigated by Uzoamaka, (1979), Kowal (1970a) and Lal (1973). Sheet erosion is more serious than it is usually appreciated. It gradually depletes the soil and sets the stage for more spectacular gully erosion and flood (Obiechefu, 1985).

The equations reviewed above either written or mentioned are complex. In fact one of the criticisms levelled against the USLE is that the USLE is a static model in the sense that it does not describe changes arising in response to the changes in

system being modelled. In other words USLE uses a lumped approach method to give predictions of mean annual soil loss. This criticism will therefore apply to soil loss estimation model developed in other countries.

Most soil erosion models developed for predicting soil loss and runoff on agricultural fields are aimed at incorporating all the factors involved such as climatic, soil characteristics - both physical and chemical. However, the temporal and spatial scales involved vary from one model to another. For example, the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965) is designed to predict long term mean annual soil loss from runoff in the field.

Chemicals, Runoff and Erosion from Agricultural Management Systems "CREAMS" (Knisel, 1980) and Areal Non-point Source Watershed Environment Resources Simulation "ANSWERS" (Beasley, et.al.,1980) are more of the process-based models developed to estimate soil loss from agricultural fields.However, the parameters required in the aforementioned models would be difficult to measure on the field, hence the difficulty in their adoption in Nigeria because of sophiscated equipments needed. More importantly, erosion models such as the USLE, CREAMS and ANSWERS lump interill and rill erosion together, thereby making it difficult to separate soil detachment and soil deposition due to either of the two phenonmena.

The European Soil Erosion Model (EUROSEM) is a single

event process-based model for predicting soil erosion by water from fields and small catchments (Morgan, et.al.,1993). It can also be used to assess the risk of erosion and to evaluate the effects of soil protection measures. It is being developed as a collaborative project involving 25 scientists from ten European Countries. The model operates by taking rainfall and then considering in turn, the interception of the rain by the plant covers; the detachment of soil particles by raindrop impact and by flow; the volume of runoff; and the deposition of sediment.

The USDA-Water Erosion Prediction Project (WEPP) was developed as a new generation soil erosion prediction technology for use in soil and water conservation planning and assessment (Foster and Lane, 1987). The WEPP was designed to estimate rill and interrill soil losses and sediment yields from a complex shaped slope profile. It is process-based and developed from fundamentals of hydrologic and erosion science. The WEPP computer program which replaces Universal Soil Loss Equation (USLE) produces many different kinds of output, in various quantities. The most basic output contains the runoff and erosion summary information, which may be produced on storm by storm, monthly, annual, or average annual basis. The program predicts detachment and deposition at the end of each slope (Ascough et al.,1994).

European Soil Erosion Model (EUROSEM) (Morgan, et.al.,1990) in addition to estimating the risk of erosion, has

the following advantages:-

(a) applicable at field and small catchment scales

(b) allows the contribution of sediment to water bodies to be determined

(c) provides reliable estimates of erosion for comparison with acceptable standards

(d) operates on an event basis for the two individual storms each year which contribute most of the annual soil loss; and

(e) is useful as a design tool for selecting soil conservation measures.

The detailed equations used in each of the two models is presented in the following sections.

2.5 European Soil Erosion Model (EUROSEM): Model 1

The model computes soil loss as a sediment discharge, defined as the product of the volume of runoff (m^3/s) and the sediment concentration in the flow (m^3/m^3), to give a volume (or mass) of sediment passing a given point in a given time. The computation is based on the dynamic mass balance equation (Bennett, 1974; Kirkby, 1980).

$$q_s\,[x,t] = \frac{\delta\,(AC)}{\delta t} + \frac{\delta\,(QC)}{\delta x} - e[x,t] \qquad 2.8$$

In which,

C = Sediment concentration (m^3/m^3)

A = Cross sectional area of the flow (m^2)

Q = Discharge (m^3/s)

q_s = external input or extraction of sediment per unit length of flow ($m^3/s/cm$)

e = net detachment rate or rate of erosion of the bed per unit length of flow ($g/s/m^2$)

x = horizontal distance, and

t = time (mins)

The term, e, in Eq. 2.8 is defined by two major components:

$$e = DET + DF \quad (2.9)$$

where

DET = the rate of soil particle detachment by raindrop impact (g/s/m2) and

DF = the balance between the rate of soil particle detachment by the flow and the deposition rate of sediment in the flow (g/s/m2)

In solving Eq. 2.8 for the soil erosion the parameters needed include: rainfall interception by vegetation, soil infiltration rate, soil surface condition and surface runoff. The procedure for estimating the magnitude of the parameters are presented as follows.

2.5.1 Rainfall Interception

Rainfall input (R) to the model is in the form of a depth (mm) for each time step during a storm event and from this input, rainfall intensity I (mm/hr) and rainfall volume (m3) (depth x area) are calculated. On reaching the canopy of the vegetation, the rainfall is divided into two parts. These are: that reaching the soil surface as direct throughfall (DT), and

that falling either on open ground or passing through gaps in the canopy.

$$DT = R - IC \quad (2.10)$$

where DT is the Direct Throughfall

Merriam (1973) defined the volume of the interception store (IC_{store}) as

$$IC_{store} = Cover.IC_{max}.(1 - \exp(Rcum)) \quad (2.11)$$

where:

Rcum = Cummulative rainfall from start of storm to the end of storm

$$SF = 0.5.TIF.(\cos PA.\sin^2 PA) \quad (2.12)$$

for grass or

$$SF = 0.5.TIF.(\cos PA) \quad (2.13)$$

for other species (Van Elewijck,1989a&b)

where:

SF = stem flow

TIF = temporarily intercepted throughfall or the difference between IC and IC_{store}

$$TIF = IC - IC_{store} \quad (2.14)$$

PA = average acute angle of plant stems to the ground

The leaf drainage (LD) is estimated as

$$LD = TIF - SF \ (mm) \quad (2.15)$$

where:

$$IC = R.COVER \quad (2.16)$$

where:

IC = the depth of rainfall intercepted by the vegetation (mm)

IC_{max} = Maximum volume of interception

R = rainfall input (mm) and

COVER = the percentage cover of vegetation (%)

2.5.2 Infiltration

Infiltration is accounted for in the KINEROS MODEL which generates runoff as excess rainfall using Smith and Parlange, (1978) equation. A detailed description of KINEROS model can be found in Woolhiser, Smith and Goodrich, (1990). The maximum rate at which water can enter the soil or infiltration capacity (f_c in mm/hr) is defined as:

$$f_c = K_s.\exp(F/B)/(\exp(F/B) - 1) \quad (2.17)$$

where:

K_s = the saturation hydraulic conductivity of the soil (mm/hr)

F = the amount of rain already absorbed by the soil (mm) and

B = the saturation deficit of the soil (mm)

The term B is obtained from

$$B = h.\Phi.(S_{max} - S_i) \quad (2.18)$$

where:

h = the effective net capillary drive (mm)

Φ = the soil porosity (%)

S_{max} = maximum value of relative saturation of the soil

S_i = initial value of relative saturation

Relative saturation is defined as the water content of the soil (L^3/L^3) divided by the porosity (L^3/L^3) The term h is derived from:

$$h = \frac{1}{K_{sat}} \cdot \int_{-\infty}^{0} K(\psi) . d\psi \qquad (2.19)$$

in which:

ψ = the soil matric potential and

$K(\psi)$ = hydraulic conductivity, function of

$$K_{satveg} = K_{sat} + 1/(1 - P_{base}) \qquad (2.20)$$

where:

K_{satveg} = saturated hydraulic conductivity of the soil with vegetation

K_{sat} = saturated hydraulic of bare soil

P_{base} = total area of base of plant stems expressed as proportion of total area of plant.

2.5.3 Soil Surface Condition

The roughness of the soil surface including roughness brought about by tillage determines the volumes of water that can be held on the surface as depression storage (D_s). The basis for modelling depression storage is extremely limited as only a few studies are available for quantifying the depths of water likely to be involved (Morgan, et.al.,1992). Depth (mm) of surface depression storage is estimated as:

$$D_s = 0.15[(1 - RR)/DEPNO] \qquad (2.21)$$

where:

DEPNO = the number of depressions (individual low points) along the transect of roughness measurement.

RR = the ratio of the straight line distance between two points on the ground to the actual distance measured over-all the microtopographic irregularities. Strictly, this ratio describes the degree of smoothness of the surface. It is advised that 15% of actual value calculated should be used because of microtopographic irregularities (Morgan, et. al.,1992).

2.5.4 Surface Runoff

(i) Discharge

The discharge (m^3/s) of surface runoff within the model equation is computed based on manning's equation for flow velocity as:

$$Q = A.S^{1/2}.R^{2/3}/n \qquad (2.22)$$

where

Q = runoff discharge in (m^3/s)

A = cross-sectional area of plot (m^2)

S = field slope (m/m)

R = hydraulic radius (m)

n = Manning roughness coefficient for flow velocity ($s/m^{1/3}$)

2.5.5 Soil detachment by raindrop impact

The energy of the rainfall reaching the ground surface as direct throughfall (KE(DT); J/m2/mm) is assumed to be the same as that of the natural rainfall. It is estimated as a function of rainfall intensity (I; mm/hr) from the equation derived by Brandt (1989), assuming that the raindrop size distribution follows that described by Marshall and Palmer (1948):

$$KE(DT) = 8.95 + (8.44 \log I) \quad (2.23)$$

Where

I = Rainfall Intensity (mm/hr)

The energy of the leaf drainage or drip fall (KE(LD); J/m2/mm) is estimated from the following relationship developed experimentally by Brandt (1990):

$$KE(LD) = (15.8 PH^{0.5}) - 5.87 \quad (2.24)$$

Where

PH = effective height of the plant canopy (m)

Soil detachment by raindrop impact (DET; g/m2) is calculated from the equation:

$$DET = K.KE^{1.0}.e^{-bh} \quad (2.25)$$

where:

K = an index of the detachability of the soil (g/J)

KE = the total kinetic energy of the rain (J/m2)

b = an exponent

h = the depth of the surface water layer (m)

Soil detachability depends on soil texture. Values for the index, K are given in the User's Guide (Morgan, et.al.,1993).

They are taken from graphs and tables presented by Poesen (1985), Govers (1991) and Everaet (1992), and corrected acccording to the procedure proposed by Poesen and Torri (1988) to allow for differences in the size of the measuring plots used by the various researchers (Morgan, et.al.,1993).

2.5.6 Soil detachment by runoff

Soil detachment by runoff is modelled in terms of a generalised erosion-deposition theory proposed by Smith (Morgan, et.al.,1993). This assumes that the transport capacity of the runoff (TC) reflects a balance between the two continous counteracting processes of erosion and deposition. It implies that the ability of flowing water to erode its bed is independent of the amount of material it carries and is only a function of the energy expended by flow. This condition was expressed in the model as:

$$DF = y.w.v_s.(TC - C) \qquad (2.26)$$

where:

DF = net detachment rate of soil particles by the flow ($g/s/m^2$)

y = overland flow (s)

w = flow area ($1/m^2$)

v_s = settling velocity of the particles (m/s)

TC = transport capacity (g/m/s)

C = sediment concentration (g/m/s)

2.6 Water Erosion Prediction Project (WEPP): MODEL 2

Water Erosion Prediction Project (WEPP) represents an advance on CREAMS as it has replaced the USLE relationship for modelling soil erodibility and crop management with more dynamic procedures. WEPP does not compute chemical movement but is concerned instead, with day - to - day field operations as they affect crop canopy cover, crop residue and surface roughness. WEPP contains a dynamic water balance calculator which is driven by separate sub-models dealing with climate, crop growth and crop residue decay. Details of the equation used in WEPP are also presented below.

The WEPP erosion model computes estimates of net detachment and deposition using a steady state sediment continuity equation, which is

$$dS/dX = D_f + D_i \qquad (2.27)$$

where:

X = distance downslope (m)

S = sediment load (kg/s/m)

D_i = interill erosion rate (kg/s/m2)

D_f = rill erosion rate (kg/s/m2)

Net soil detachment in rills is calculated for the case when hydraulic shear stress exceeds the critical shear stress of the soil and when sediment load is less than sediment transport capacity. Therefore,

$$D_f = Dc[1 - S/Tc] \qquad (2.28)$$

where:

Dc = detachment capacity by flow (kg/s/m2) and

Tc = sediment transport capacity in the rill (kg/s/m)

When hydraulic shear stress exceeds critical shear stress for the soil, detachment capacity, Dc is expressed as

$$D_c = K_r(\tau_f - \tau_c) \quad (2.29)$$

K_r = a rill soil erodibility parameter (s/m)

τ_f = flow shear stress acting on the soil (Pa)

τ_c = the rill detachment threshold parameter or critical shear stress, of the soil (Pa)

$$\tau_c = 2.67 + 0.065.CLAY - 0.058.VFS \quad (2.30)$$

where:

VFS = percent very fine sand

CLAY = percent CLAY

The equations above are for soils containing 30% or more of sand. The rill soil erodibility parameter can be estimated as:

$$K_r = 0.00197 + 0.00030*VFS + 0.03863exp(-1.84*ORGMAT) \quad (2.31)$$

where

ORGMAT = percent organic matter in the surface soil (and the model assumes that organic matter equals 1.724 times organic carbon content)

$$K_i = 2728000 + 192100.VFS \quad (2.32)$$

Rill detachment is considered to be zero when shear stress is less than critical shear stress of the soil.

The basic parameters needed in the solution of Eq. 2.27 include: Soil albedo, initial saturation, initial plant

available water content, effective rainfall intensity, flow shear stress, the discharge rate, sediment transport capacity and the hydraulic inputs. These parameters are presented.

2.6.1 Soil Albedo (SALB)

Albedo is the fraction of the solar radiation which is reflected back to the atmosphere. Ascough, et.al.,(1994) estimated it as:

$$SALB = 0.6/\exp(0.47ORGMAT) \quad (2.33)$$

2.6.2 Initial Saturation

The definition of initial saturation is the fraction of the porosity filled by water at the beginning of the simulation. This parameter is used to initialize the soil water content for each soil layer and is given by (Ascough et al.,1994):

$$SOILWA = (SAT.POR.RFG).DG \quad (2.34)$$

$$POR = 1 - \frac{bd}{2.65} \cdot \frac{100}{1} \cdot 100 \quad (2.35)$$

where:

SOILWA = The total soil water content (mm)

RFG = correction of porosity for rock content, (fraction by volume)

DG = thickness of soil layer (m)

POR = Soil porosity (%)

Bd = Bulk density (g/cm^3).

2.6.3 Initial Plant available water content

The initial plant available water content (ST) at the beginning of simulation is also described by (Ascough et al.,1994):

$$ST = (SAT.POR.(1 - RFG) - thetdr).DG \quad (2.36)$$

where:

ST = inintial plant available water content (m/layer)

thetdr = volumetric soil water content at 1500 kpa tension, (m3/m3)

$$D_i = K_i . I_e^2 . C_e . G_e . (Rs/w) \quad (2.37)$$

where:

D_i = interrill detachment rate (kg/s/m)

K_i = baseline interrill erodibility (kgs/m4)

I_e = effective rainfall intensity (m/s)

C_e = effect of canopy on interrill erosion (m)

G_e = effect of ground cover on interrill erosion (m)

Rs = rill spacing (m)

w = computed rill width (m)

$$C_e = 1 - Fc.\exp(-0.34H) \quad \text{(Laflen et al.,1987)} \quad (2.38)$$

where:

Fc = fraction of soil protected by canopy cover (%)

H = effective canopy height (m)

$$G_e = \exp(-2.5gi) \quad (2.39)$$

where:

gi = the fraction of interrill surface covered by residue (m)

2.6.4 Effective rainfall intensity I_e

This variable (Ie) is calculated by the hydrologic component of the WEPP model which generates breakpoint precipitation information and runoff hydrographs (time and amount) to

estimate interrill soil loss and calculated from equation (Nearing, et.al.,1989):

$$I_e = [\frac{\int I^2.dt}{t_e}]^{1/2} \quad (2.40)$$

where:

I = rainfall intensity (m/s)

t = time (s)

t_e = total time during which the rainfall rate exceeds infiltration rate (min).

2.6.5 Flow shear stress

Shear stress of rill flow is computed at the end of an average uniform profile length by assuming a rectangular rill geometry. The shear stress from the uniform profile is used as the normalisation term for hydraulic shear along the profile. Width, w(m), of the rill is calculated using the relationship:

$$w = c.Q_e^d \quad (2.41)$$

where:

Q_e = flow discharge at the end of the slope valid for small plot and slope (m^3/s)

c and d = are coefficients derived from data from the study of Laflen et al. (1987).

2.6.6 The discharge rate

The quantity of runoff collected at the end of field plot is computed using equation:

$$Q_e = P_r.L.Rs \quad (2.42)$$

where:

P_r = peak runoff rate (m/s)

L = slope length (m)

Rs = distance between flow channels (m)

2.6.7 Sediment Transport Capacity (TC)

Sediment transport capacity (TC) as well as sediment load, is calculated on a unit channel width basis within the erosion component. Sediment load is converted to a unit field width basis when the calculations are completed. The transport capacity, TC (g), as a function of X is calculated using equation given by (Ascough et al.,1994):

$$TC = K_r . T_f^{3/2} \quad (2.43)$$

where:

TC = sediment transport capacity (kg/s/m)

T_f = is the hydraulic shear stress acting on the soil (kpa)

K_r = transport coefficient (s/m)

2.6.8 Hydrologic inputs to the model

The three hydrologic variables are:-

- Peak runoff rate, P_r (m/s)
- effective runoff duration, t_r (s)
- effective rainfall intensity, I_e (m/s)

These variables are calculated by the hydrologic component of the WEPP model which generates breakpoint precipitation information and runoff hydrographs.

In both EUROSEM (Model 1) and WEPP (Model 2), an attempt was made initially to distribute the flow on each slope segment into unconcentrated and concentrated flow components, dependent upon the roughness of the soil surface and the width of the concentrated flow paths. Runoff estimation in these two models are treated as a single one - dimensional flow (Morgan, 1994).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Study area

The experimental site is located at the Institute for Agricultural Research (IAR) experimental farm which is part of the Ahmadu Bello University farm, Samaru on Zaria - Sokoto highway, on Longitude 7° 38'E and Latitudes 11° 11'N within the Northern Guinea Savannah zone of Nigeria (Fig.3.1). Figure 3.2 shows the location of the University farm, the Institute for Agricultural Research (IAR) farm and the Meteorological station (marked **M**), northwest of Samaru village.

3.2 Climate

3.2.1 Rainfall

In general terms, the rainfall pattern of Samaru and particularly that of the study area follows the same pattern every year except for some few exceptional cases. In other words, the climate shows a distinct and fairly regular pattern over the years (Kowal and Knabe, 1972). The rainfall pattern in Samaru is characterised by cool dry North-easterly winds which yield virtually no rains between October to March (Awujoola, 1979). The climate has a well-defined wet season between June and September with early rain starting between late April and May while few rains can also occur around October (Kowal and

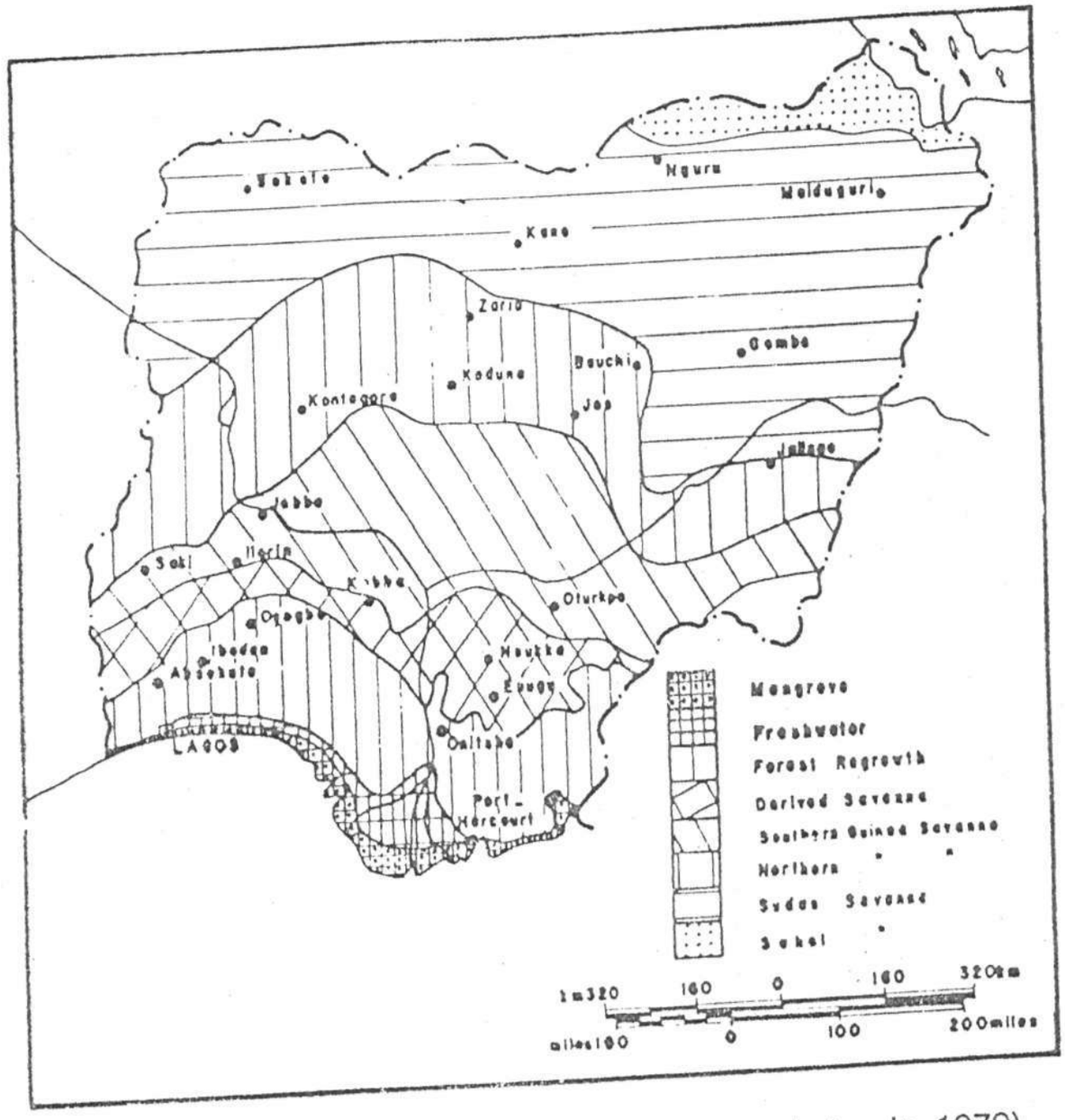


Fig. 3.1 : Nigeria : Vegetation Zones (Source : Agboola, 1979).

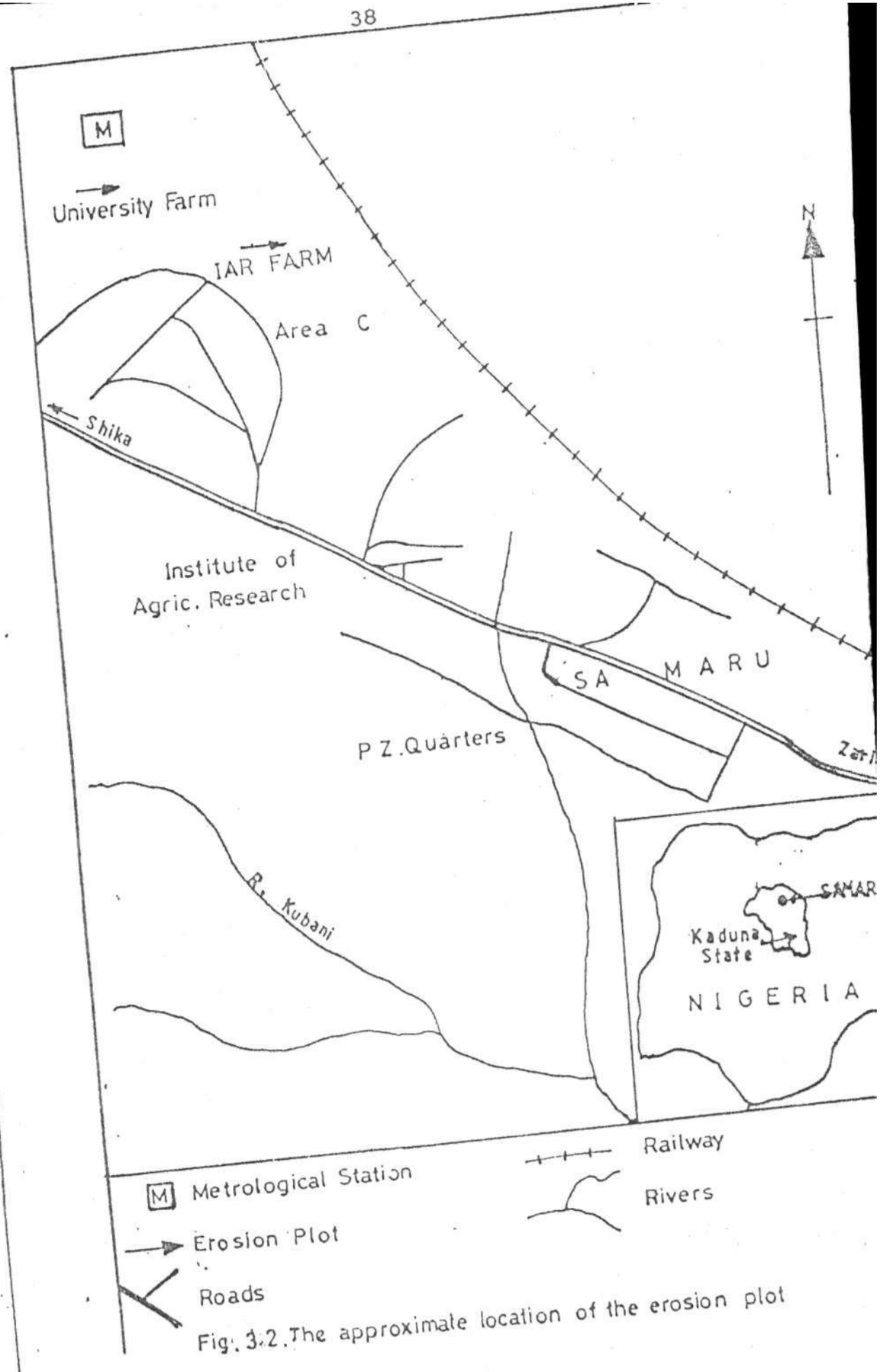


Fig. 3.2. The approximate location of the erosion plot

Knabe, 1972). The annual rainfall amount for Samaru ranges from 840 to 1150mm, with a mean of 927mm (Kowal and Kassam, 1976).

The monthly rainfall amounts for the rainy season for the months of June to August for the period 1980 to 1995 range from 118mm in June to 700mm in August. This indicates that the highest rainfall amount could be expected in August (Akintola, 1986), (see Fig.3.3).

It can therefore be confirmed that adequate rainfall was recieved during the periods of measurements (July to October), since the average annual amount of rainfall in Samaru from January to December is 1118mm (Kowal and Knabe, 1972), while the average rainfall amount during the period of measurement was found to be 829.31mm. This constitutes 74% of the total rain recorded for each year.

3.2.2 Temperature

The mean minimun temperature ranges between 15.2 to 21.8°C, While the mean maximun temperature is between 29.8 and 34.7°C. The mean minimun temperature is found in the month of December and January while the mean maximun is found in the month of April. (Kowal and Knabe, 1972). Therefore, the temperature is at maximun during the month of April while the minimun is found to be in the month of December and January, and the temperature decreases progressively as the rainfall season sets in.The cooling effect of the rains reduces the mean monthly maximum temperatures normally experienced in the month of April. This

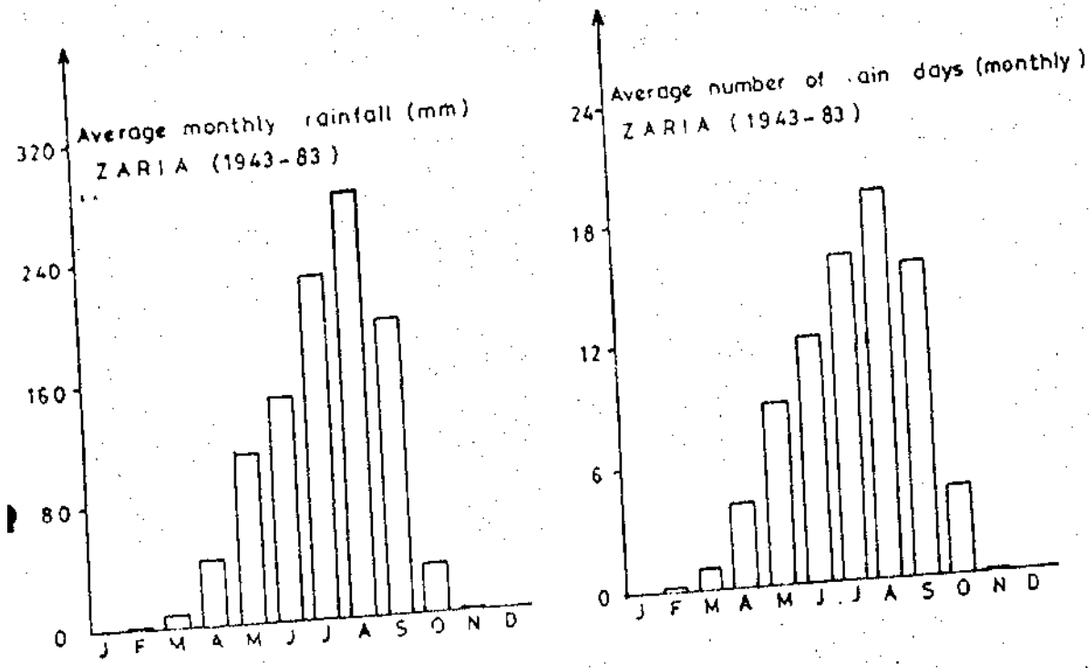


Fig 3.3 Distribution of rainfall pattern in Zaria area
(Source: Akintola 1985)

is mostly pronounced in the months of April, May and early June. The low temperatures experienced during the month of December and January is due to the combined effects of the harmattan dust suspended in the air, which at times can be as effective in reducing the solar radiation by producing an over-cast sky (thick shadow that would otherwise be referred to as cloud). Generally, the temperature experienced in Samaru is optimum and favourable for the type of rainfed agricultural crop practice and crop production for the area.

3.2.3 Potential Evapotranspiration (ETp)

Monthly potential evapotranspiration (ETp) values vary between 97 and 154mm, with a mean of 122mm during the rainy season. The annual mean potential evapotranspiration of 1461mm is greater than the mean total rainfall amount of 927mm for the 1980 - 1996 period. There are, however, periods of the year, that is, June to September when rainfall amounts exceed potential evapotranspiration (Kowal and Knabe,1972). This, however, indicates that potential evapotranspiration is low and thus, surface runoff is expected to be high for the period July to September under consideration.

3.3 Geology and Geomorphology

Ojanuga (1980), Wright and McCurry (1970) and Korofi (1972) noted that Zaria area is underlain by low lying and often deeply weathered biotite gneisses. Porphyroblastic granites

form the prominent inselbergs of Kufena hills and several other small hills in the Zaria area. Gneisses form part of a crystalline complex, which occurs within the gneisses and alternating with them in some places are schists. A close examination of these schists shows that they contain muscovite, quartz, feldspars, and traces of biotite. Zaria Field Society (1978) confirms the above statements, and observes that the plains around Zaria are underlain by ancient crystalline rocks, which inspite of their great hardness are usually deeply rooted. The most wide-spread rocks around Zaria are the metamorphic biotite gneisses, and granite of the Nigerian basement complex. In the Ahmadu Bello University Farm Zaria and the Institute for Agricultural Research Farm, there are no bare rocks (rock-out-crops) exposed, but quartz veins and mica schists traverse the rooted rock in places as is evident in the top soils.

3.4 Soils

Soils in these area are generally classified into "Alfisols" order using the United States Department of Agriculture (USDA),(1975) system of soil classification. In the Food and Agriculture Organization (FAO), (United Nations Educational, Social and Cultural Organization (UNESCO), 1974) system, the soils are classified as "Nitosols", "Luvisols" and "Gleysols" (Awujoola, 1979). The Gleysols are commonly located within the backswamps and low land areas bordering the Kubani River. The

soils are mainly a mantle of residue overlain by aeolian deposits and have a surface texture of loamy sand to sandy loam (Aremu, 1980;).

3.5 Vegetation and Land use

The land area surrounding Samaru within the Kubani River catchment area belong to an open Savannah woodland within the Northern Guinea Savannah zone of Nigeria. Land area within the river's catchment have commonly : isoberlina - doka, isoberlina tomentosa, Monotes Kerstingn, Daniella Oliver, and Clapaca togenitis as common woody trees. At the Institute for Agricultural Research experimental farm and the Ahmadu Bello University Farm, Zaria, the savannah woodland has been disturbed by farming, and felling for firewood, leaving open shrubby woodland in varying stages of regrowth (Odunze, 1997). Common grasses of the backswamp and flood plain areas include Elionanas pobeguini and Paspalum orbiculare which characteristically flourishes during the middle of the dry season in the study area. (Awujoola, 1979).

3.6 Field Measurements and Equations Used

In order to fully understand the soil detachment process and soil loss from a field plot, the researcher undertook a research attachment with Professor R.P.C. Morgan at Cranfield University, Silsoe Campus, Bedford, United Kingdom in 1994. During the attachment period, all major erosion predictive

models were reviewed and all the field parameters to be measured (inputs into the models) were also identified.

In order to overcome the error normally encountered during field measurements, an equation for correcting the effect of Soil detachment during field measurement was proposed by (Poesen and Torri, 1988 ; Savat and Poesen, 1981)

$$A = B.\exp(0.054D) \quad (3.1)$$

where:

A = the real mass of splashed soil (g/cm^3)

B = the measured mass of splashed soil (g/cm^3)

D = the diameter of splashed traps. The correction depends only on the trajectories of splashed material.

For the purpose of comparison, the energy of the rainfall used in dislodging the soil particles were calculated from established expression developed by Kowal and Kassam (1976). The equation is presented as:

$$K.E. = 41.1Ra - 120 \quad (J/m^2) \quad (3.2)$$

where :

Ra = rainfall amount (mm) recorded in the rain guage (Kowal and Kassam, 1976; Adeoye, 1986)

K.E. = Kinetic Energy of the rain (J/m2) and

$$Dv = 1.77 + 0.93Ra \quad (3.3)$$

where :

Dv = drop volume, (mm^3/mm^2).

The Kinetic energy per unit depth of rain is calculated by

dividing K.E in (J/m^2) (Eq. 3.2) with Dv in (mm) from Eq. 3.3 to obtained the Kinetic Energy in $J/m^2/mm$. Other field parameters measured and analysed with the use of the already established equations include the physical and chemical properties of the soils. The physical property measured were:- bulk density,total porosity, soil moisture content and air-fiiled porosity deduced from the difference between total porosity and volumetric moisture content. Similarly, the chemical property measured were:- pH, Organic carbon, total Nitrogen, exchange acidity and cation exchange capacity.

The determination of bulk density was done by the use of standard core sampler provided by the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria. Undisturbed soil sample was taken by driving the sharp end of the core sampler into the soil at a specified depth of 20cm. This depth is known to be very vital for crop production and is, also prone to erosion. The soil sample was weighed wet and after oven drying. The core sampler was weighed and its volume (V) determined. The Total and Air-filled Porosities were determined by the use of the Eq. 2.34

3.6.1 Chemical analysis of sediment collected

The sediment collected in each plot was subjected to chemical analysis to determine any loss of nutrients within the runoff which may be detrimental to crop production. Specific analysis on the sediment includes :- Particle size, pH, Organic

Carbon, total Nitrogen, exchange acidity and cation exchange capacity.

3.7 Computer Erosion Models (Process based erosion models)

During the research attachment, Computer models that were reviewed include:-

i. Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS).(Knisel, 1980; Foster et al, 1980, Foster et al, 1981).

ii Areal Nonpoint Source Watershed Environment Resource Simulation (ANSWERS). (Beasley et al., 1980; Beasley and Huggins, 1980).

iii Water Erosion Prediction Project (WEPP). (Nearing et al, 1994).

iv European Soil Erosion Model (EUROSEM). (Morgan et al, 1992).

The major computer models reviewed were finally screened down to two (2). The main considerations for the screening were:-

1. To adopt erosion model for estimating soil loss and runoff accurately under the present condition of low technology in Africa.

   and

2. That the erosion model should be simple to use and all the factors needed to operate the chosen model can be obtained with no difficulty.

Various techniques (Adewumi and Morgan, 1994) were employed to estimate soil loss and soil detachment. These include:-

(i) Soil detachment by raindrop impact: a comparison of predictive models.

(ii) Soil detachment impact under vegetation cover: comparison of two predictive models

and

(iii) The role of soil conditions in determining soil detachment by raindrop impact: comparative study of 3 predictive models.

3.8 Layout of experimental field

Four experimental plots namely:- A, B, C, and D, each 4m wide and 6m long were laid-out as shown in Fig 3.4. Plots A and B were weeded and constructed to the specifications in Fig 3.4 and named as bare soil plots because they were constantly weeded to keep them free from weeds while plot C was similarly constructed but the vegetation which was grass-like was maintained on the plot throughout the period of measurement. The last plot, D was cultivated and sown to maize crop. Each plot was bunded on all sides to prevent any interference from adjacent plots both in terms of soil detachment and surface runoff. The bund was 30cm in height and 20cm wide. This dimension was maintained throughout the duration of the measurement (Hudson, 1957). The detailed features of the plots

are shown in Figs. 3.5 and 3.6.

3.8.1 Strategy adopted for the field work

In order to meet the stated objectives, the work was carried out in three (3) phases as detailed below.

(A) First Phase: This was the preliminary stage which included the evaluation and/or determination of existing field conditions before the rains commenced. The field parameters determined include:

(i) Infiltration rates of the field soils

(ii) Bulk density, Total Porosity and Air-filled Porosity of the field

(iii) The type of soil existing in the study area

(iv) Chemical composition of the Soil.

(v) The layout of the experimental field as shown in Fig 3.4 and plate 1 (a & b).

(B) Second Phase: Period of field measurement. The parameters measured were:

(i) Precipitation (mm)

(ii) Soil detachment in (g/m^2). Collecting trays or splash-traps as installed on the field (see Fig.3.6 and plate 2 (a & b).

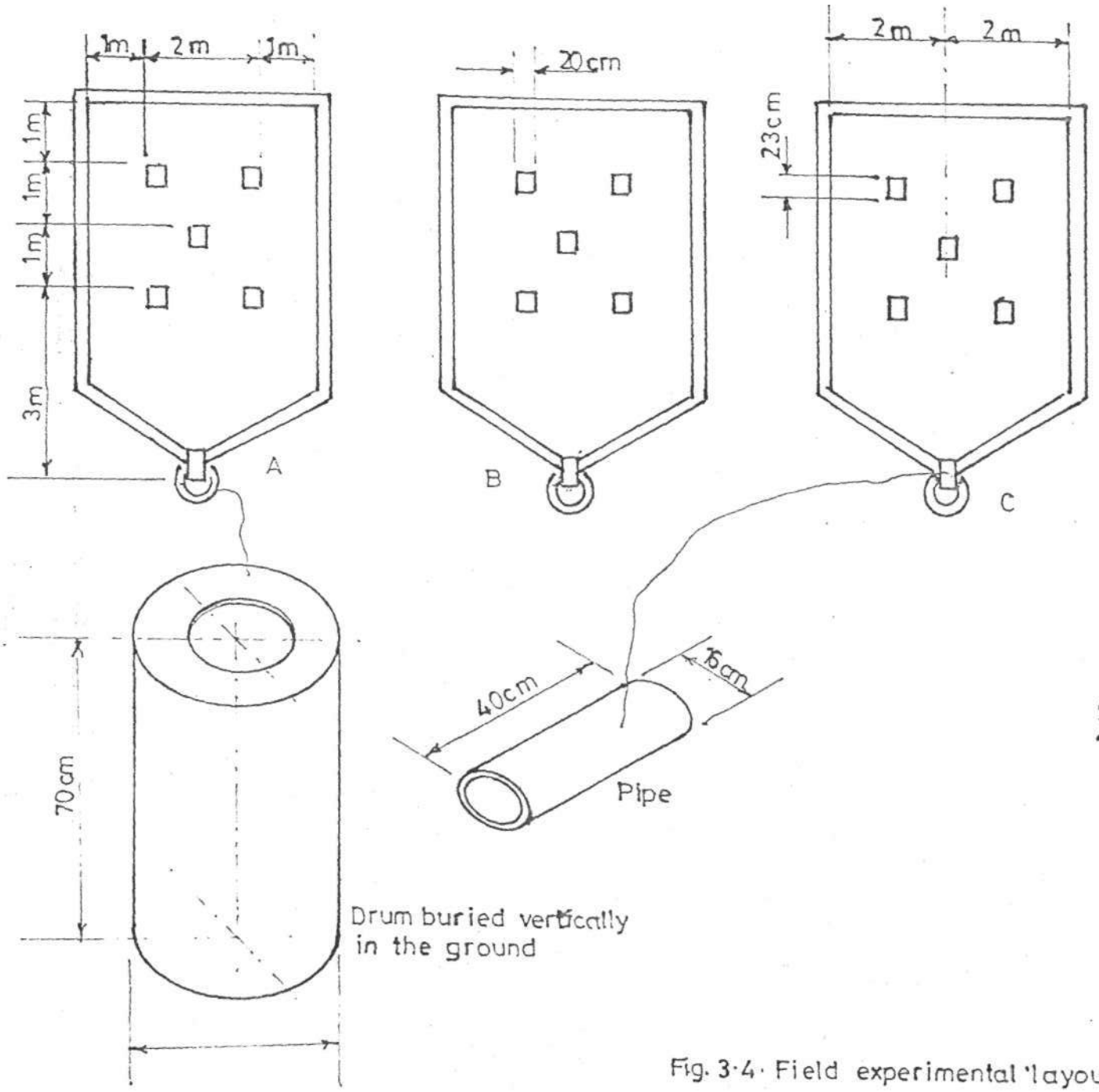


Fig. 3·4· Field experimental layout

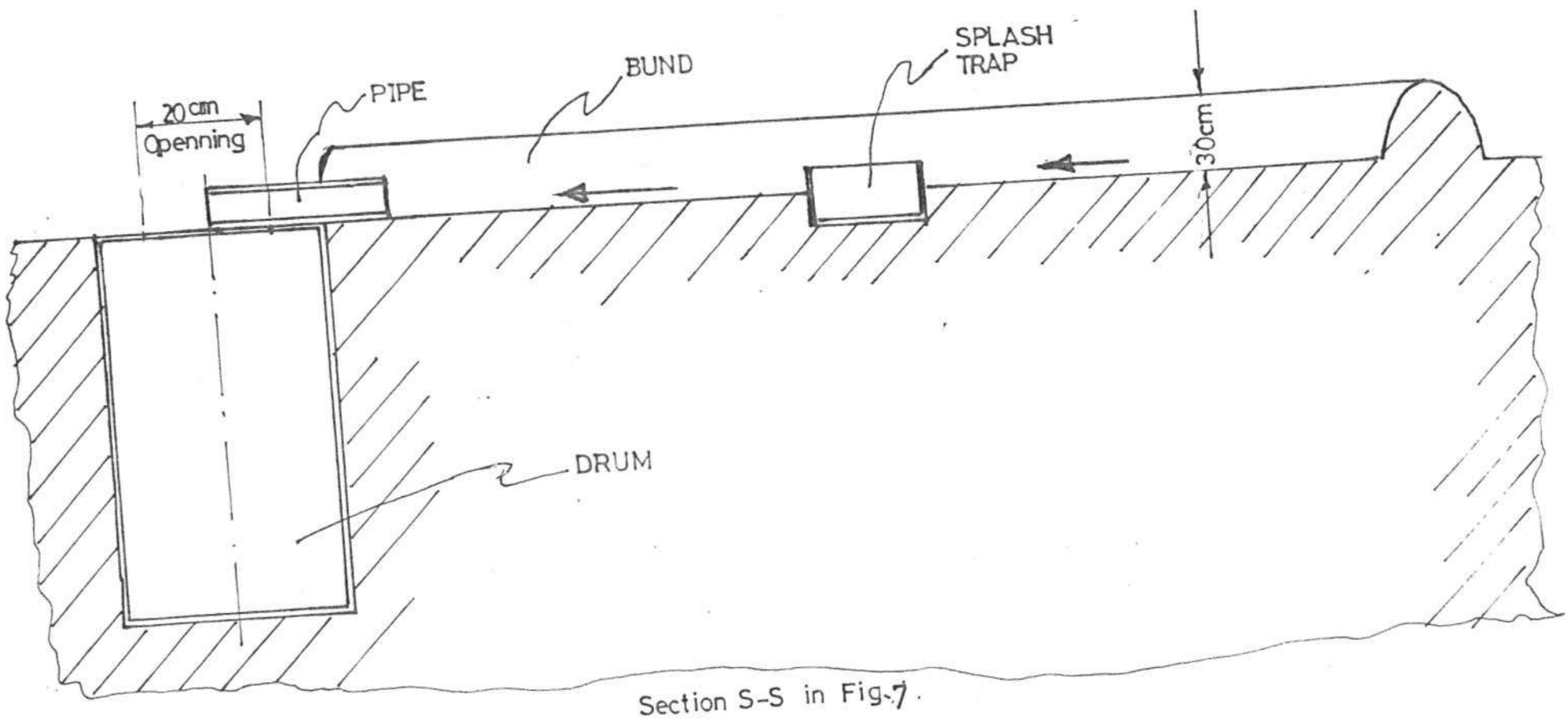
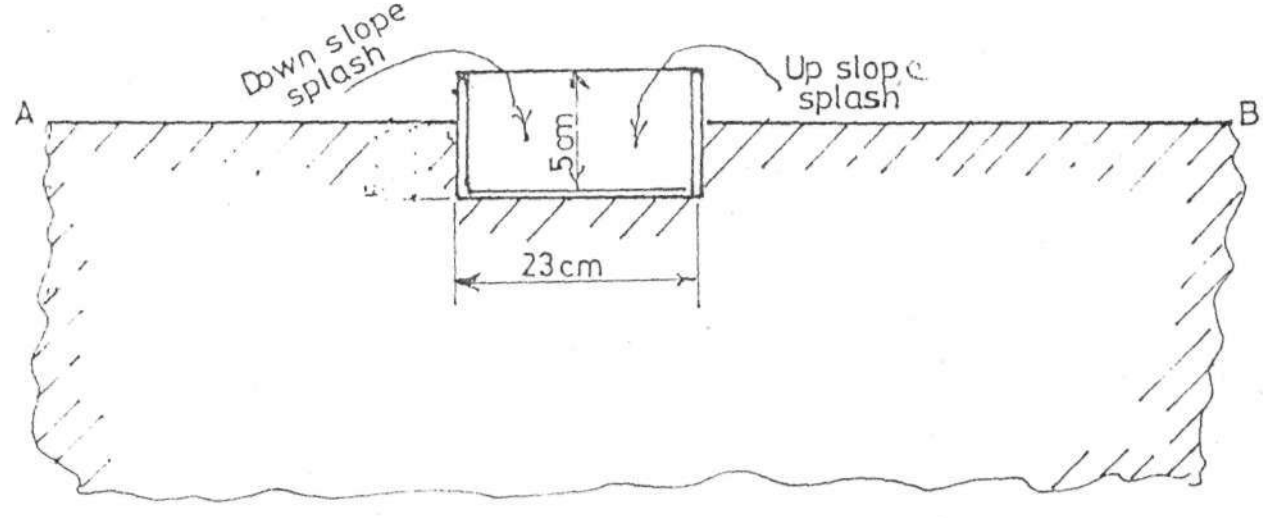


Fig 3.4 Detailed drawing of pipe conveying plot runoff into the drum.



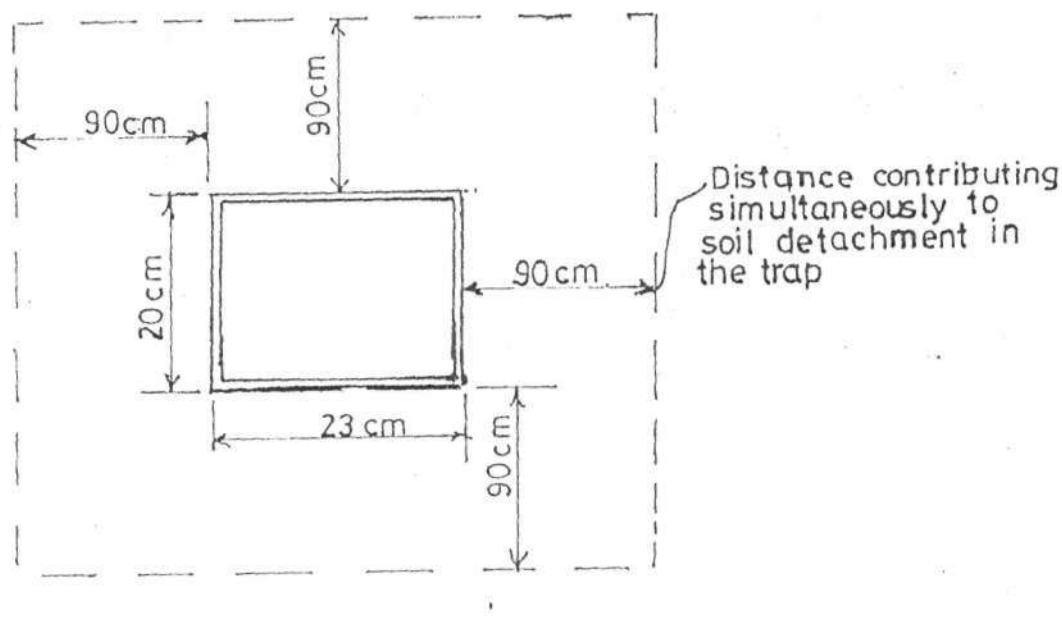


Fig. 3.6. Splash trap positioned in the field to collect splash erosion.

(iii) Runoff volume in (cm^3). In the drum installed at the end of the plot (see Fig.3.5 and plate 3 (a & b).

(iv) Soil washed off from the plots in (Kg/m^2) was also collected from the drum (Plate 4a).

All measurements were taken immediately after each rainfall event for each year.

(C) The Third Phase : Comparison of measured values with the result obtained from erosion model equation computations using:

(i) European erosion model (EUROSEM referred to as Model 1); and

(ii) Water Erosion Prediction Project (WEPP referred to as Model 2) erosion model.

3.8.2 Measurement of rainfall splash

The material used for measuring the splashed soil consisted of a split-open standard 4-litre Motor engine-oil plastic container with dimensions of 23cm long, 20cm wide and 10cm deep (see Fig.3.7). The container was cut longitudinally along the 10cm depth portion to give a splash trap of size 23cm long, 20cm wide and 5cm deep. The use of these containers is consistent with the work of Leow (1982). It was also assumed that throughout the duration of measurement that:-

i. the sediment surface, which is very flat, is perfectly homogeneous with respect to splash, and isotropic in any direction since rainfall is vertical.

ii. that rainfall was homogeneously distributed over the entire area of the experimental site where the splash-tray was installed.

3.8.3 Sources of error from the experimental plots

Although the bounded runoff plots give probably the most reliable data on soil loss per unit area, there are several sources of error involved with its use (Hudson, 1957). These include:-

(1) Silting of the collecting drum

(2) Silting of the pipes leading to the drum

(3) The maintenance of a contant level between the soil surface and the sill or lip of the drum.

(4) Other problems are that runoff may collect along the boundaries of the plot and form rills which would not otherwise have developed because of constant update of the plot and

(5) The experimental plot itself is a partially closed system, being cut off from the input of sediment and water from upslope.

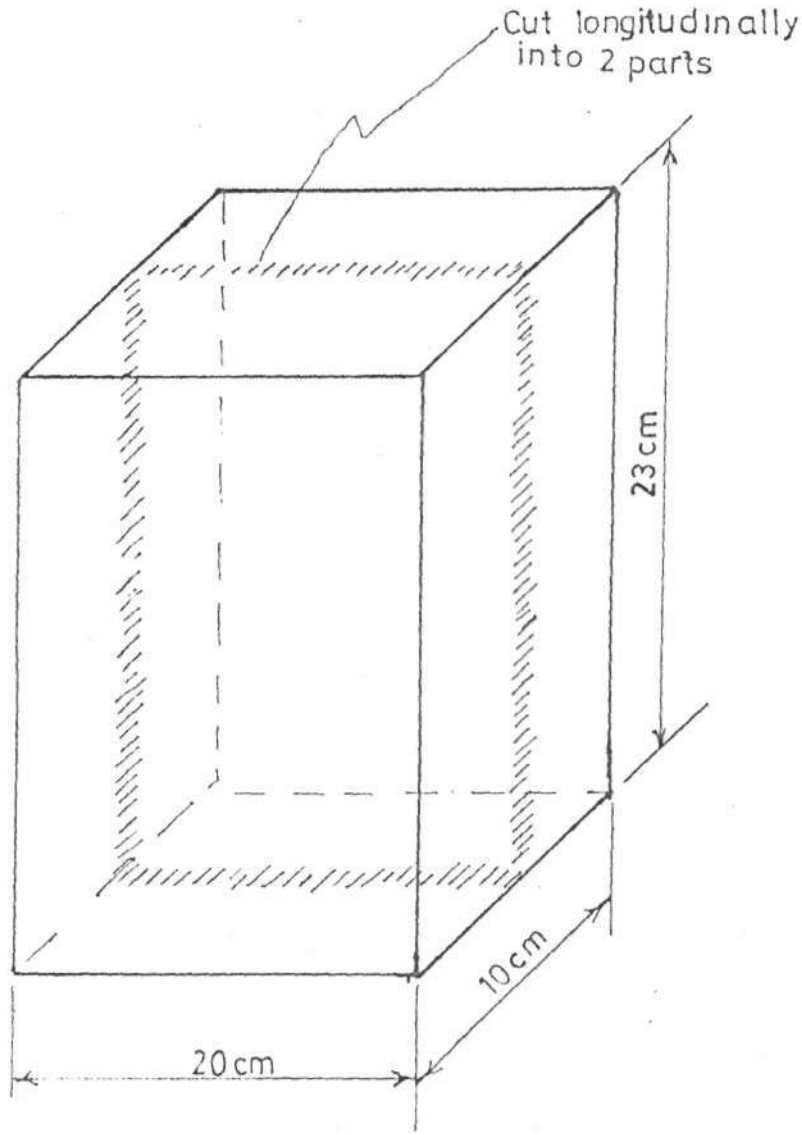


Fig.3.7. Cross sectional view of a sample splash trap.

3.8.4 Measurement of runoff and soil loss

Measuring soil loss on the erosion plots on which the splash-traps were installed involved embedding the splash-traps on the plots which measured 24m^2 each and a drum also embedded at the lower end of the plot for both runoff and soil loss collection as shown in Fig.3.5 and Plate 3(a & b). In this investigation, 20 splash-traps were installed in the four runoff plots (five in each plot) with an average slope of 0.058 for plots A and B while plots C and D had slopes of 0.066 and 0.0083, respectively.

Five splash - traps were arranged for each plot at equal spacings between each other down the slope in order to catch the detached soil particles that were expected to splash at about a radius of between 0.7m to 1.0m (Morgan, 1986). The plots were weeded with hoe frequently to keep A, B and D bare of vegetation, while C was left unweeded to allow the effect of vegetation on soil detachment to be pronounced throughout the period of measurement. Detached soil from each tray was removed, oven dried and the average from each plot was obtained. A radius of 90cm was assumed to be contributing simultaneuosly into the splash-trap and the measured weight was therefore expressed per unit area contributing to the splash-trap (g/m^2) (Morgan, 1982; 1986). A correction factor (Eq. 3.1) was used to correct for any error during field measurement.

Four drums (Length = 75cm, Diameter = 40cm) and a cylindrical pipe (Length = 40cm, Diameter = 14cm) for directing runoff into the drum were also embedded at the tail end of each plot (see Fig.3.5) to collect both the runoff and the sediment. The volume of runoff in cm^3 after each rain was measured out (Plate 3(b)) in each plot and the sediment that was also carried along with the runoff but settled at the bottom of the drum was carefully collected into another container, oven dried and recorded against each plot (see Table 4.4, 4.6, and 4.8).

3.8.5 Measurement of rainfall intensity

The measurement of rainfall intensity I (mm/hr) was discontinued by the IAR Meteorological Unit in 1982. The past rainfall data were used to determine the years with a similar rainfall patterns as 1993 and 1995. It was discovered that 1968 rainfall pattern is highly correlated with that of 1995 as shown below:

	1995	1968
size	74	71
Total	867.0mm	890.0mm
Maximum	65mm	40.6mm
Minimum	0.3mm	0.33mm
Std. Dev.	10.63	9.8
Std. Error	1.24	1.19
95% Confidence	2.42	2.32
99% Confidence	3.19	3.06

Because of the similarity of the rainfall pattern of 1968 and 1995, the rainfall amount with incremental time of 1968 data was therefore analysed and the rainfall amount with the corresponding intensities was estimated from the 1968 rainfall



Plate 1(a). Layout of Experimental plot for bare soil.



Plate1(b). Experimental runoff collecting point for bare soil

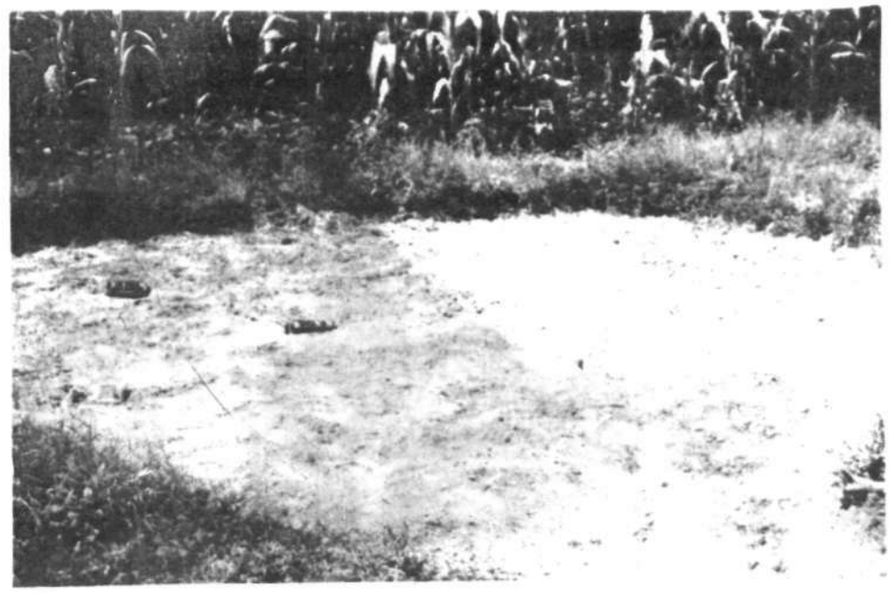


Plate 2(a). Bare soil plot showing splash trap in position



Plate 2(b). Bare soil plot showing soil splash trap with sediments after rain

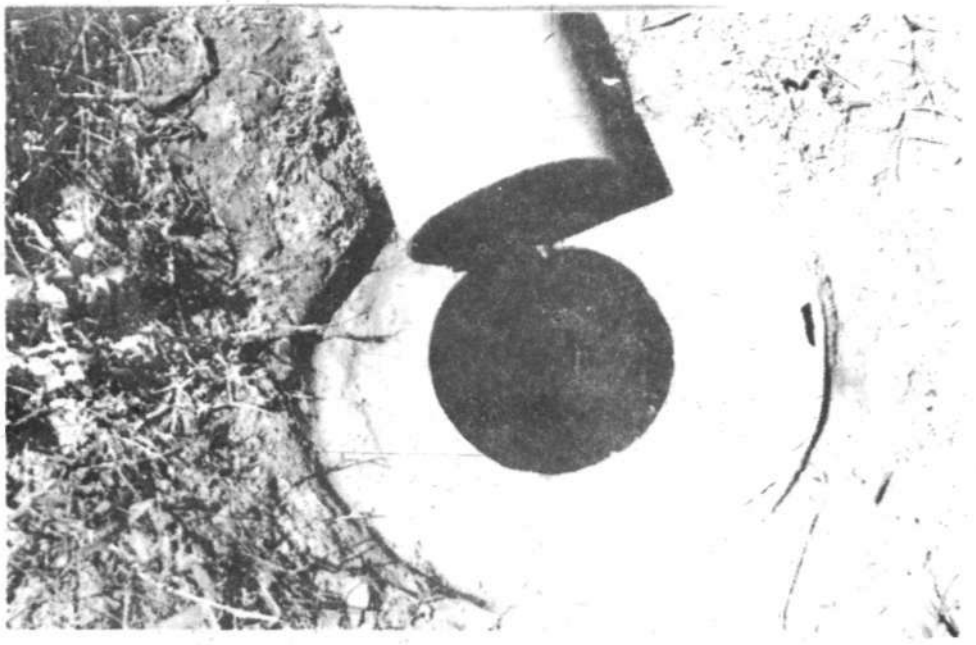


Plate 3(a). Picture of a drum installed at the end of each plot



Plate 3(b). Runoff volume measurement from the drum installed at the end of each plot



Plate 4(a). Collection of soil washed from the plot into the drum after the rain

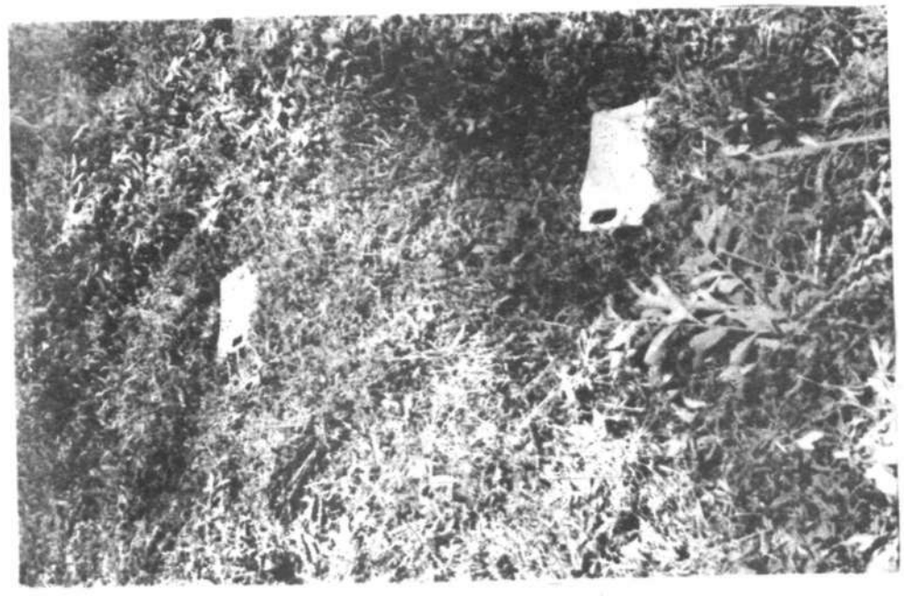


Plate 4(b). Location of splash trap in the vegetated plot

chart. The result is presented in Table 3.1 and detailed in Appendix B.

Table 3.1: **Rainfall amount with dates for 1968 and 1995.**

1968			1995	
Date	Rainfall Amount	I(mm/hr)	Year	Rainfall Amount
	JULY			**JULY**
5/7/68	13.97mm	20.3	5/7/95	13.2mm
24/7/68	6.4mm	30.5	23/7/95	6.8mm
18/7/68	1.91mm	5.1	19/7/95	1.7mm
	AUGUST			**AUGUST**
7/8/68	22.86mm	23.7	3/8/95	24.4mm
12/8/68	16.51mm	16.5	10/8/95	15.7mm
14/8/68	13.34mm	53.3	14/8/95	16.6mm
22/8/68	13.97mm	6.77	26/8/95	13.1mm
23/8/68	22.86mm	3.4	18/8/95	22.0mm
	SEPT.			**SEPT.**
6/9/68	2.54mm	50.8	7/9/95	2.6mm
15/9/68	16.51mm	33.0	16/9/95	18.8mm
22/9/68	5.72mm	16.9	15/9/95	5.1mm
25/9/68	3.8mm	30.5	24/9/95	6.6mm
29/9/68	16.51mm	33.0	28/9/95	15.2mm

For example, the Month of August in 1995 and 1968 were checked for the daily rainfall amounts. This was to determine whether or not the rainfall amount recorded over the same period was within a difference of $\pm$3mm difference (Bello, 1995; Oladipo, 1985). It was found that the rainfall amounts were within the ranges specified above which confirms the similarity in the pattern of rainfall in Samaru over several decades. Thus, the rainfall intensities for the corresponding periods are expected to be approximately the same. The rainfall

intensities for 1968 rains were therefore taken to be the same as those of 1995. This has been possible because rainfall characteristics in Samaru over the years has the same characteristics for the same week of the same month (Aiyepeku, 1992). The formation of clouds in Samaru and the resulting outburst normally experienced in the area is the same for about 95% of the rainfall amount received while 5% accounts for the exceptional cases (Aiyepeku, 1992; Oladipo, 1985). Similar procedures were adopted for the 1993 rainfall which was found to have the same pattern with the 1969 rainfall. In 1996, two rain gauges were installed in the experimental plot to record rainfall amount. The duration of fall was recorded by the farm manager. The ratio of rainfall amount and the total time recorded gives an average rainfall intensities I, (mm/hr) recorded for 1996 rainfall season. Similar procedure was followed in establishing intensities for 1993 rainfall season. After analysis, it was also found that 1969 rainfall was highly correlated with 1993 rainfall pattern and is presented below.

	1993	**1969**
Size	63	**71**
Total	989.9	882.246
Mean	15.71	12.43
Maximun	75	45
Minimum	0.5	0.64
Std. Dev.	15.37	9.93
Std. Error	1.94	1.17
95% Confidence	3.8	2.31
99% Confidence	4.99	3.04

Table 3.2: Rainfall Amount with dates for 1969 and 1993

1969			1993	
Year	Rainfall Amount	I (mm/hr)	Year	Rainfall Amount
	JULY			JULY
10/7/69	14.72mm	25.2	10/7/93	13.5mm
19/7/69	15.30mm	61.2	19/7/93	15.60mm
27/7/69	8.26mm	6.77	27/7/93	8.50mm
	AUGUST			AUGUST
3/8/69	21.98mm	26.4	3/8/93	22.30mm
8/8/69	17.45mm	34.9	8/8/93	17.70mm
12/8/69	12.10mm	48.4	12/8/93	12.30mm
18/8/69	32.70mm	38.1	18/8/93	37.70mm
	SEPT.			SEPT.
6/9/69	12.40mm	49.6	6/9/93	12.70mm
8/9/69	1.91mm	1.91	8/9/93	1.90mm
10/9/69	16.70mm	66.8	10/9/93	16.80mm
17/9/69	6.70mm	6.7	17/9/93	6.90mm
20/9/69	8.10mm	13.9	20/9/93	8.40mm

3.8.6 Estimation of unmeasured parameters

During the course of field investigations, three (3) parameters namely:-

(i) Net Capillary drive (h; cm)

(ii) Soil Cohesion (COH; kPa)

(iii) Maximum interception storage (DINTR; mm)

could not be measured because of lack of equipment. Sensitivity analysis was used to determine the relative importance of the unmeasured variables as given in section 3.10. Thereafter, optimization technique was used to estimate the variable values.

3.8.6.1 Net Capillary drive (h; cm)

Input data into model 1 requires soil properties which influence the generation of runoff, the detachability of soil particles by raindrop impact and flow, and the transport of those particles by the flowing water. The properties that affect the generation of runoff are taken from those used in the KINEROS MODEL (Woolhiser, Smith and Goodrich, 1990) to describe the infiltration of water into the soil. Model 1 employes an aspect of soil properties taken from KINEROS MODEL. The required parameter is the value of the effective net capillary drive G (cm) which can be thought of as the net or effective value of capillary head. Where it is not possible to measure these values accurately, recommended values are given in available literature depending on the type of soil (Morgan, Quinton and Rickson, 1993). The recommended values of h ranged from 98 to 526. Sensitivity analysis showed that the generated erosion was not sensitive to h and therefore an average value of 230 was used as the input value of h.

3.8.6.2 Maximum interception storage (DINTR; mm)

The maximum interception storage depends upon the canopy cover of the vegetation and the size, shape and roughness of the leaves. Since it is extremely

difficult to measure this parameter, values recommended for the type of soil for a range of vegetation types found in literature was also used. Similarly, it was discovered that the estimated value of 1.2 used in this study and for the type of soil, had no significant effect on the output results generated by model 1 when compared with the measured value.

3.8.6.3 **Soil Cohesion (COH; kPa)**

Morgan, et al.(1993) stated that cohesion should be measured with a torvane (Soil Test CL - 600) in the field after the surface soil has been saturated. At least six replications should be made on a single slope plane; if the variability is greater than 15%, the number of replicates should be increased to 10. Some typical values of cohesion for saturated soils of different textures are given in the literature (Morgan, Quinton and Rickson, 1993). In order to choose from the recommended range of values of 2 - 8 that were given in the literature, optimization technique was used to determine the required value by using the 1993 data collected on the field. Different values of COH were used within the range of 2 - 8 to calculate the erosion amount and compared with measured soil loss. The regression

coefficient r was calculated in each case. The value of COH which gave the highest value of r was taken as the estimated value of COH. The resulting COH value of 3.5 was then used to compute soil erosion amount for the 1995 and 1996 data.

3.9 Data analysis

The procedures to be followed for inputing data (field observations) into each model for generating soil loss is explained in detail in each model user's guide. Details of such imput values are given in appendix E for EUROSEM herein refered to as Model 1 and appendix H for WEPP herein refered to as Model 2.

As a basis for comparison with Model 2 results, both the observed values and that of Model 1 was summed up on a monthly basis. Detailed result is found in Tables 4.13 and 4.14 and Figs 4.5 to 4.10.

Comparison of measured values with the predicted on storm by storm basis was done using European Soil Erosion Model (EUROSEM) developed in Europe in 1992 and modified for use in 1994 and USDA Water Erosion Prediction Project (WEPP) developed to replace USLE in 1992 and revised with modifications and also released for use in 1994 as a second version. The Advance graphic software (Statistical Programme) called "slide write" version 3.0 developed in the United States of America in 1988 was used to analyse the result and was found to be simple to

use and reasonably good.

A 't' test was further employed to find out if the adopted equations had intercepts and slopes significantly different from zero and 1.0, respectively or not. This formed a statistical basis of acceptability of the accuracy of the models.

3.10 Sensitivity and data error analysis

Sensitivity is a measure of the effect of change in one factor on another factor (McCuen,1973). It indicates by how much the output of a model alters in relation to a unit change in the value of one or more of the inputs. It is used to evaluate the key variables and parameters of a model and therefore to identify the degree of accuracy with which the values need to be measured or estimated. Another important role of sensitivity analysis is that it helps to assess whether a model is working rationally. In this respect, it should be stressed that the analysis cannot show what factors most strongly influence the soil erosion process; it shows only what factors most influence the output of the model (Morgan,1992). Although, such a definition stated above seems to be vague in terms of the factors involved, it nevertheless implies a quotient of two differentials. McCuen and Snyder,(1983), developed a general mathematical framework of sensitivity that is applicable in all places of the modelling of hydrological systems which can be expressed in mathematical form by

considering a Taylor series expansion of the explicit function as given by:

$$F_o = f(F_1, F_2, \ldots\ldots, F_n) \qquad (3.6)$$

The factor F_o is often a model output or the output of one component of a model. The change in factor F_o resulting from a change in a factor F_i is given by,

$$f\,[\,F_i + \Delta F_i, F_j \,/\, j \neq i] = F_o + \frac{\delta F_o}{\delta F_i}\Delta F_i + \frac{1}{2!}\cdot\frac{\delta^2 F_o}{\delta F_i^2}\cdot\Delta F_i^2 + \ldots \qquad (3.7)$$

Equation 3.7 suggests that the sensitivity of F_o to changes in factor F_i can be estimated by differentiating the explicit relationship of eq. 3.6. It measures the change in factor F_i. The linearized sensitivity equation can be extended to the case where more than one parameter is changed simultaneously. The general definition of sensitivity is derived by combining equation 3.6 and 3.7 and which can be expressed in terms of relative sensitivity:

$$r_s \approx \frac{dF_o/F_o}{dF_i/F_i} \qquad (3.8)$$

Where

r_s = Relative sensitivity

dF_o = Relative change in output

dF_i = relative change in input

F_i = input value

F_o = output value

Equation 3.8 is applicable to a differentiable relationship. In this study, the procedure of sensitivity analysis carried out is applicable to non-differentiable relationship. This was done by putting together all the unmeasured data as related to the model and starting the computation procedure by keeping all other input data constant, and by decreasing and increasing one of the parameters, within the range recommended in the literature for the unmeasured parameter, the output value was obtained by running the model in the incremental order of 1%, 2%, 5% and 10%. The output at these percentages were then compared with the measured data. The output value from the model having almost the same value with the measured was then chosen with their corresponding percentages. The procedure was then repeated by taking another parameter from the unmeasured data and keeping all other parameters constant, (this time, including the previous estimated value) the model was again run to produce an output value. The procedure was repeated until all the estimated parameters that could not be measured have been estimated.

It was generally observed that the sets of output values obtained from the incremental processing as described above, showed a wide range of sensitivity between 1% through 10% as stated above, and the 1% changes produced the most sensitive response for the model. This observation was in accordance with the procedure discussed by Mudiare (1984) and Dawdy and O'Donnell,(1965). These sets of values were then chosen as

being suitable for the model for the environment,in the Northern Guinea savanna, Samaru, Zaria area.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Pluvio-edaphic Pattern

The rainfall intensities, measured rainfall amounts and calculated kinetic energies relationship at Ahmadu Bello University farm, Samaru, Zaria did not show any unusual pattern from what is already known and from the established facts cited in the literature by Greenland and Lal, (1979).

The soils of the study site have been studied in the field and laboratory and have been characterized and classified using the U.S.D.A. Soil Taxonomy (1990) and Food and Agricultural Organization, (FAO) and United Nationa Educational Scientific and Cultural Organization (UNESCO), (1989) systems of soil classification as given by Aremu, (1980).

4.2 Physical and Chemical Properties of the Experimental Plots

Table 4.1 gives the physical properties of the soil measured from the experimental plots while Tables 4.2 and 4.3 give the chemical properties for the 1995 and 1996 rainy seasons, respectively.

The Bulk Density (B.D.) of the soils in the experimental plots of study (Table 4.1) appear to be generally high, it ranged from 1.27 - 1.45 g/cm^3. The high values were obtained for bare soil as well as cultivated soil which does indicate that the presence of organic matter was low and that the macro porosity would be expected to be low hence the soil would

Table 4.1: Physical Properties of the Soil

YEAR	Depth (cm)	Bulk Density (B.D) (g/cm3)			Physical constant		Total Porosity (%) (T.P)			Air Filled Porosity (%) (A.P)			infiltration (mm/hr)		
		Bare Soil	Veg. Soil	Cult. Soil	density of Water g/cm3	Particle density Dp g/cm3	Bare Soil	Veg. Soil	Cult. Soil	Bare Soil	Veg. Soil	Cult. Soil	Bare Soil	Veg. Soil	Cult. Soil
1993	0 - 20	1.43	1.27	1.39	1.0	2.65	46.04	52.08	47.55	43.87	49.74	44.63	61.5 at Qw = 1.52%	13.0 at Qw = 1.84%	41.1 at Qw = 2.1%
1995	0 - 20	1.42	1.38	1.32	1.0	2.65	46.42	47.93	50.19	44.43	45.31	47.53	65.0 at Qw = 1.4%	12.0 at Qw = 1.9%	39.5 at Qw = 2.02%
1996	0 - 20	1.45	1.31	1.33	1.0	2.65	45.28	50.57	49.81	43.18	48.05	47.08	63.0 at Qw = 1.45%	12.5 at Qw = 1.92%	43.0 at Qw = 2.07%

Note: Qw = Moisture Content of the soil at infiltration on dry basis
Veg. Soil = Vegetated Soil
Cult. Soil = Cultivated Soil (furrow)

Table 4.2: Chemical Properties of the surface soils in 1995

Plot	Depth (cm)	pH 1:2:5	Organic Carbon	Total N g/kg	Available P mg/kg	Exchangeable Cations Ca	mg	K	Na	Exchangeable Acidity $H^+ + AL^{3+}$	ECEC	Base Saturation on ECEC %
A Bare Soil	0 - 20	4.38	3.30	0.25	11.42	1.42	.28	.51	.10	0.61	3.18	81.76
B Bare Soil	0 - 20	4.45	2.96	0.32	12.01	1.45	.30	.50	.11	0.57	2.95	80.12
C Vegetated Soil	0 - 20	4.20	2.10	0.14	11.21	1.67	.47	.69	.12	0.53	3.58	77.35
D Cultivated flat Furrow	0 - 20	3.70	3.10	0.60	14.32	1.47	.36	.71	.13	0.65	3.26	83.08

Table 4.3: Chemical Properties of the surface soils in 1996

Plot	Depth (cm)	pH 1:2:5	Organic Carbon	Total N g/kg	Available P mg/kg	Exchangeable Cations Ca	mg	K	Na	Exchangeable Acidity $H^+ + AL^{3+}$	ECEC	Base Saturation on ECEC %
A&B Bare Soil (average)	0 - 20	4.20	2.92	0.21	9.51	1.41	.25	.45	.10	0.55	2.85	78.00
C Vegetated Soil	0 - 20	4.10	2.00	0.14	10.51	1.61	.43	.59	.09	0.50	3.35	75.05
D Cultivated Soil (Furrow)	0 - 20	3.66	2.95	0.53	13.12	1.42	.33	.61	.11	0.61	3.15	80.00

permit high volumes of runoff. The total porosity of the soils ranged from 45.3 to 50.6%. This indicates that the soils were poorly structured. The air-filled porosity (43 - 44%) were generally high and this also would mean that the soils have a high capacity for conducting soil water and for gaseous exchange.

Moisture content (Qw) of the soils under study were not significantly different at the 95% probability level. This implies that within the period of study, the soil was expected to retain soil moisture at about the same level. It would be expected that the same initial moisture conditions would prevail throughout the measurement period. The infiltration rates varied from 62 to 65 mm/hr for bare soil, 12 to 13 mm/hr for the soil covered by vegetation and 40 to 43 mm/hr for the cultivated soil for the three years of study. Low infiltration rate was recorded on vegetation soil because the soil has been subjected to foot path over the years thereby compacting the soil and with clay loamy soil underlay.

4.3 Measured and computed Rainfall Parameters

Tables 4.4, 4.5 and 4.6 give the measured and computed parameters for each rainfall event in 1993, 1995 and 1996, respectively. Figure 4.1 shows the regression curve between intensity of rainfall (mm/hr) and rainfall amount with a correlation coefficient r of 0.87 while Fig 4.2 shows the regression curve between kinetic energy ($J/m^2/mm$) and rainfall amount Ra (mm) with a correlation coefficient r of 0.96. Similarly, Fig 4.3 shows the relationship between soil detachment (g/m^2) and kinetic energy of rainfall with a correlation coefficient r of 0.44 while Fig 4.4 shows how soil loss (kg/m^2) varies with the kinetic energy ($J/m^2/mm$).The correlation coefficient r was obtained as 0.64.

Considering rainfall characteristics in Samaru area, the monthly mean rainfall amounts, during the period of study for July was 16mm, August, 17mm, September, 13mm and October,11mm which attained the 10 to 14 mm/hr erosive rainfall intensity threshold limit when their kinetic energies and rainfall intensities were evaluated (Adewumi and Morgan, 1997). This implies that the rainfall events would have been erosive especially for the months of July and August if the soil was bare.

The relationship between rainfall intensity (mm/hr) and rainfall amount (mm) was established as presented in Fig 4.1. The variation between kinetic energy of raindrop with rainfall amount was also established as presented in Fig 4.2. From Fig

Table 4.4: Measurement and computation of rainstorm parameter day by day for 1993

Plot Slope: bare soil = 0.058, Veg. Soil = 0.066, Cult. Soil = 0.0083

Date	Ra (mm)	K.E J/m2/mm	R.I mm/hr	Observed Soil detachment (g/m2)			Soil detachment after corrected factor (g/m2)			Observed runoff (cm3) x 10^3			Runoff rate (m3/sec)			Observed Soil Loss (kg/m2)		
				bare soil	veg. soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil
10/7/93	13.5	30.36	25.23	9.46	2.33	3.93	9.56	2.36	3.97	32.75	20	15	.0019	.0014	.00064	0.07	0.05	.0038
19/7/93	15.6	32.49	61.2	17.16	2.52	5.91	17.35	2.55	5.97	33	18	12	.0019	.0012	.00052	0.38	0.09	-
20/7/93	32.1	37.66	43.6	18.27	3.36	8.52	18.47	3.40	8.61	39.5	23	16	.0023	.0016	.00069	0.26	0.072	.0121
27/7/93	8.5	23.71	7.11	5.90	1.23	22.65	5.96	1.24	22.90	16.5	9	7.1	.0009	.0006	.0003	0.00	0.00	.0042
3/8/93	22.3	35.39	26.38	13.64	5.33	9.60	13.79	5.39	9.7	43.5	19	12	.0026	.0013	.00052	0.07	0.051	.0104
8/8/93	17.7	33.32	34.9	11.29	3.26	4.84	11.41	3.30	4.89	41.85	10	8.5	.0025	.0007	.00036	0.16	.067	.0038
12/8/93	12.3	29.19	48.4	19.22	2.41	8.77	19.43	2.44	8.87	31.95	11.1	8	.0018	.0007	.00034	0.17	.07	.0033
18/8/93	37.7	38.81	43.6	13.15	1.25	12.65	13.29	1.26	12.79	43.5	28	20	.0028	.0019	.00087	0.24	0.07	.075
21/8/93	19.7	34.33	48.26	18.56	-	4.37	18.76	-	4.42	42.15	21.2	10	.0025	.0014	.00043	0.28	.081	.00104
1/9/93	14.9	31.51	49.6	16.82	-	1.49	17.00	-	1.51	42.2	16	14	.0025	.0011	.0006	0.27	0.09	.0096
6/9/93	12.7	29.60	49.6	5.91	-	3.22	5.97	-	3.26	32.95	13	10	.0019	.0009	.00043	0.26	0.08	.015
8/9/93	1.9	-11.91	1.91	3.11	-	2.22	3.14	-	2.24	-	-	-	-	-	-	-	-	-
10/9/93	16.8	32.60	66.8	6.64	-	3.20	6.71	-	3.23	32.25	5.7	2.1	.0019	.0004	.00009	0.38	0.105	-
17/9/93	6.9	19.98	6.7	7.92	-	4.9	8.01	-	4.95	21.2	9	8	.0012	.0006	.00003	0.00	.006	.0042
20/9/93	8.4	23.51	13.89	10.25	-	4	10.36	-	4.04	31.6	13	12	.0019	.0009	.00052	0.02	.033	.0042
23/9/93	2.3	-6.52	1.6	5.61	-	6.82	5.67	-	6.89	21.4	11	6.1	.0013	.0008	.00026	0.0	0.0	.0033

Table 4.5: Measurement and computation of rainstorm parameter day by day for 1995
Plot Slope: bare soil = 0.058, Veg. Soil = 0.066, Cult. Soil = 0.0083

Date	Ra (mm)	K.E. J/m2/mm	R.I. (mm/hr)	Observed Soil det. (g/m2)			Soil det. after correction factor (g/m2)			Observed runoff (cm3) x 10^{-3}			Runoff rate (m3/sec)			Observed Soil Loss (kg/m2)		
				bare soil	veg. soil	cultss oil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil
5/7/95	13.2	30.08	9.0	8.22	2.26	6.21	8.38	2.30	6.33	53	24	11.5	.0037	.0018	.00038	.002	.013	.013
17/7/95	30.5	37.91	30.48	15.93	10.62	14.57	16.10	10.82	14.85	64.2	40	22	.0045	.00294	.00072	.085	.06	.02
19/7/95	1.7	-14.81	2.54	7.91	8.4	9.87	8.06	8.56	10.06	1	0.1	.05	.00007	.00007	.00001	0.0	0.0	.00009
20/7/95	16.9	33.14	30.5	9.67	3.78	7.18	9.85	3.85	7.32	51	35	15	.0036	.0026	.00049	.09	.064	.0
23/7/95	6.8	19.94	16.9	16.9	8.2	10.8	17.22	8.36	11.01	15.5	5	2.3	.0011	.00037	.00007	.004	.036	.0096
27/7/95	14.1	32.0	61.0	5.4	1.7	3.65	5.5	1.73	3.72	53	30	14	.0037	.0022	.00046	.21	.09	.024
30/7/95	13.0	30.17	55.9	7.3	2.88	4.91	7.44	2.93	5.00	55	25	12	.0039	.0018	.00039	.14	.068	.00042
3/8/95	24.4	36.39	45.7	20.3	6.82	10.07	20.69	6.95	10.26	58	32	16	.0041	.0024	.00052	.17	.09	.015
14/8/95	16.6	32.96	53.4	10.51	3.42	7.85	10.71	3.48	7.90	53	36	17	.0037	.0026	.00056	.19	.083	.045
10/8/95	15.7	32.38	16.5	12.52	5.02	5.81	12.76	5.12	5.92	61	39	20	.0043	.0029	.00065	.02	.035	.013
18/8/95	22.0	35.57	30.5	13.93	6.04	10.34	14.19	6.15	10.54	63	40	21	.0044	.00294	.00069	.10	.066	.0096
24/8/95	32.6	38.32	30.5	13.9	1.48	14.54	14.16	1.51	14.82	65	45	30	.0046	.0033	.00098	.09	.055	.017
26/8/95	13.1	30.28	9.3	18.6	-	9.81	18.95	-	9.99	51	29	12	.0036	.0021	.00039	.002	.014	.0063
28/8/95	19.5	34.52	12.2	8.6	-	5.55	8.76	-	5.66	55	31	16	.0039	.0023	.00052	.01	.024	.0013
7/9/95	2.6	-2.95	1.44	15.9	-	17.4	16.20	-	17.73	-	-	-	-	-	-	-	-	-
12/9/95	3.3	3.43	1.4	20.92	-	6.87	21.32	-	7.00	22	14.5	4.5	.0015	.0011	.00015	0.0	-	.00003
15/9/95	5.1	14.0	33.0	4.61	-	3.46	4.70	-	3.53	14	4	2	.00098	.00029	.00006	.07	.04	.0046
16/9/95	18.8	34.20	58.40	9.1	-	3.96	9.30	-	4.04	55	30	10.5	.0039	.0022	.00034	.18	.10	.0038
23/9/95	8.8	24.56	1.99	6.22	-	1.83	6.40	-	1.86	35	20	10.5	.0025	.0015	.00034	0.0	0.0	.0042
24/9/95	6.6	19.37	30.5	6.93	-	5.58	7.06	-	5.69	42	28	8	.0029	.0021	.00026	.08	.048	.0021
28/9/95	15.2	32.01	33.02	5.64	-	3.56	5.75	-	3.63	43	17	7.5	.003	.0013	.00025	.12	.07	.0042
5/10/95	13.2	30.35	60.96	7.02	-	1.51	7.15	-	1.54	35	26	20	.0025	.0019	.00066	.16	.08	.0013
8/10/95	14.7	31.64	61.00	3.67	-	1.95	3.74	-	1.99	38	3	1.5	.0027	.0022	.00005	.20	.09	-

Table 4.6: Measurement and computation of rainstorm parameter day by day for 1996
Plot slope: Bare soil = 0.058, Veg. Soil = 0.066, Cult. Soil = 0.0083

Date	Ra (mm)	K.E. J/m2/mm	R.I. mm/hr	Observed Soil det. (g/m2)			Soil det. after correction factor (g/m2)			Observed runoff (cm3) x 10^3			Runoff rate (m3/sec)			Observed Soil Loss (kg/m2)		
				bare soil	veg. soil	cults oil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil
4/7/96	46.0	39.74	23.0	13.05	3.24	7.80	13.3	3.30	7.95	68.5	30.0	20.5	0.0048	0.0022	.00068	0.06	0.05	0.02
7/7/96	15.0	31.58	18.0	5.32	1.91	3.99	5.42	1.95	4.07	43.0	12.0	0.9	0.003	.00088	.00003	0.04	0.043	0.014
14/7/96	16.0	32.29	24.0	7.61	1.41	2.59	7.76	1.44	2.64	29.0	21.0	14.0	0.002	0.0015	.00046	0.05	0.048	.0008
16/7/96	12.0	28.86	16.0	32.14	1.40	3.13	32.75	1.43	3.19	62.5	14.0	34.0	0.0044	0.001	.001	0.025	0.035	.0038
19/7/96	15.0	31.58	45.0	3.49	0.09	5.91	3.56	0.093	6.02	20.5	-	-	0.0014	-	-	0.17	-	-
20/7/96	40.0	39.11	48.98	11.08	3.21	3.44	11.29	.27	3.51	52.0	9.0	35.0	0.0036	.00066	0.0012	0.17	0.09	.0042
24/7/96	40.0	39.11	40.0	9.38	2.91	7.20	9.56	2.97	7.34	60.0	8.0	10.0	0.0042	.00059	.00033	0.12	0.078	0.031
25/7/96	35.0	38.42	48.84	8.51	3.45	4.62	8.67	3.52	4.71	60.0	21.0	18.0	0.0042	.0015	.0006	0.16	0.075	0.038
1/8/96	4.0	8.09	6.86	3.78	0.60	3.69	3.85	0.61	3.76	-	-	-	-	-	-	-	-	-
3/8/96	20.0	34.46	40.0	10.78	2.10	5.00	10.99	2.141	5.10	69.5	10.0	12.0	0.0049	.00007	.0004	0.14	-	-
9/8/96	23.0	35.63	24.64	19.16	1.90	5.11	19.53	.94	5.21	39.5	11.0	17.0	0.0028	.0008	.00056	0.15	0.054	0.01
14/8/96	14.0	30.79	10.5	2.20	-	7.80	2.24	-	7.95	27.0	1.0	11.0	0.0019	.00007	.00036	0.005	-	.0042
16/8/96	43.0	39.45	41.62	8.79	3.35	6.49	8.96	3.41	6.61	64.0	9.0	11.0	0.0045	.00066	.00036	0.13	0.082	0.013
17/8/96	39.0	38.98	45.0	9.72	3.12	10.0	9.91	3.18	10.19	40.0	20.0	20.0	0.0028	.00096	.00066	0.18	0.09	0.013
20/8/96	16.0	32.29	16.27	8.22	2.15	3.50	8.38	2.19	3.57	59.5	7.0	11.0	0.0042	.00052	.00036	0.03	0.04	.0042
24/8/96	15.0	31.58	19.56	9.78	1.90	3.35	9.97	1.94	3.41	46.5	15.0	17.0	0.0033	0.0011	.00056	0.05	0.038	.0067
26/8/96	7.0	20.25	6.46	1.96	2.62	2.95	2.00	2.67	3.01	12.5	2.0	4.0	0.0088	.00015	.00013	-	-	-
30/8/96	8.0	22.69	13.71	4.42	-	2.53	4.50	-	2.58	60.0	-	2.0	0.0042	-	.00007	0.02	-	.0021
31/8/96	10.0	26.29	8.57	3.13	-	2.04	3.19	-	2.08	32.0	0.5	9.0	0.0022	.00004	.0003	0.001	-	.0038

Table: 4.6 (cont'd)

Date	Ra (mm)	K.E. J/m2/mm	R.I. (mm/hr)	Observed Soil det. (g/m2)			Soil det. after correction factor (g/m2)			Observed runoff (cm3) x 10^{-3}			Runoff rate (m3/sec)			Observed Soil Loss (kg/m2)		
				bare soil	veg. soil	cults soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil	bare soil	veg soil	cult soil
1/9/96	20.0	34.46	29.27	5.14	1.21	2.49	5.24	1.23	2.54	44.5	10	4.0	0.0031	.00007	.00013	0.08	0.05	.0038
2/9/96	18.0	33.48	19.29	5.91	1.01	2.92	6.02	1.03	2.98	27.0	17	3.5	0.0019	-	.00012	0.04	0.04	.0017
4/9/96	25.0	36.27	36.59	7.47	1.31	3.08	7.61	1.33	3.14	48.0	24	4.5	0.0034	-	.00015	0.12	0.07	.0033
7/9/96	28.0	37.07	52.50	9.29	0.92	6.10	9.47	0.94	6.28	35.5	20	5.0	0.0025	.00022	.00017	0.19	0.08	-
9/9/96	28.0	37.07	21.0	10.9	0.71	6.94	11.11	0.72	7.07	63.0	15	26.0	0.0044	.00022	.00086	0.06	0.049	.018
14/9/96	55.0	40.45	64.71	13.19	0.31	5.48	13.44	0.32	5.59	70.0	20	18.0	0.0049	.00088	.0006	0.21	0.10	.018
15/9/96	2.50	-4.21	3.0	2.85	-	1.20	2.90	-	1.22	19.0	10	2.0	0.0013	-	.00007	0.0	0.0	.0025
16/9/96	2.30	-6.51	2.30	3.61	-	2.42	3.68	-	2.47	13.0	-	1.5	.00091	-	.00005	-	-	-
18/9/96	5.30	14.60	15.9	3.37	0.31	3.12	3.43	0.32	3.18	14.0	5.0	7.5	.00098	.00037	.00025	0.025	-	.0042
23/9/96	3.0	0.72	12.0	5.12	-	3.07	5.22	-	3.13	-	-	-	-	-	-	-	-	-
25/9/96	22.0	35.28	33.0	12.19	2.41	4.60	12.42	2.46	4.69	31.0	2.0	11.0	0.0022	.00015	.00036	0.11	0.06	.0083
2/10/96	18.0	33.48	25.71	8.85	2.61	3.43	9.02	2.66	3.50	39.0	0.5	1.0	0.0027	.00004	.00003	0.08	-	-
4/10/96	14.0	30.79	16.15	7.45	3.41	2.28	7.59	3.48	2.32	39.0	11	14.5	0.0027	.00007	.00048	0.03	0.03	.0042
5/10/96	10.0	26.29	19.35	6.56	1.21	1.81	6.69	1.23	1.84	41.5	17	5.0	0.0029	-	.00017	0.05	0.04	.0021
7/10/96	25.0	36.27	41.67	13.54	3.42	0.71	13.80	3.49	0.72	51.0	25	14.0	0.0036	-	.00046	0.157	0.075	.0008

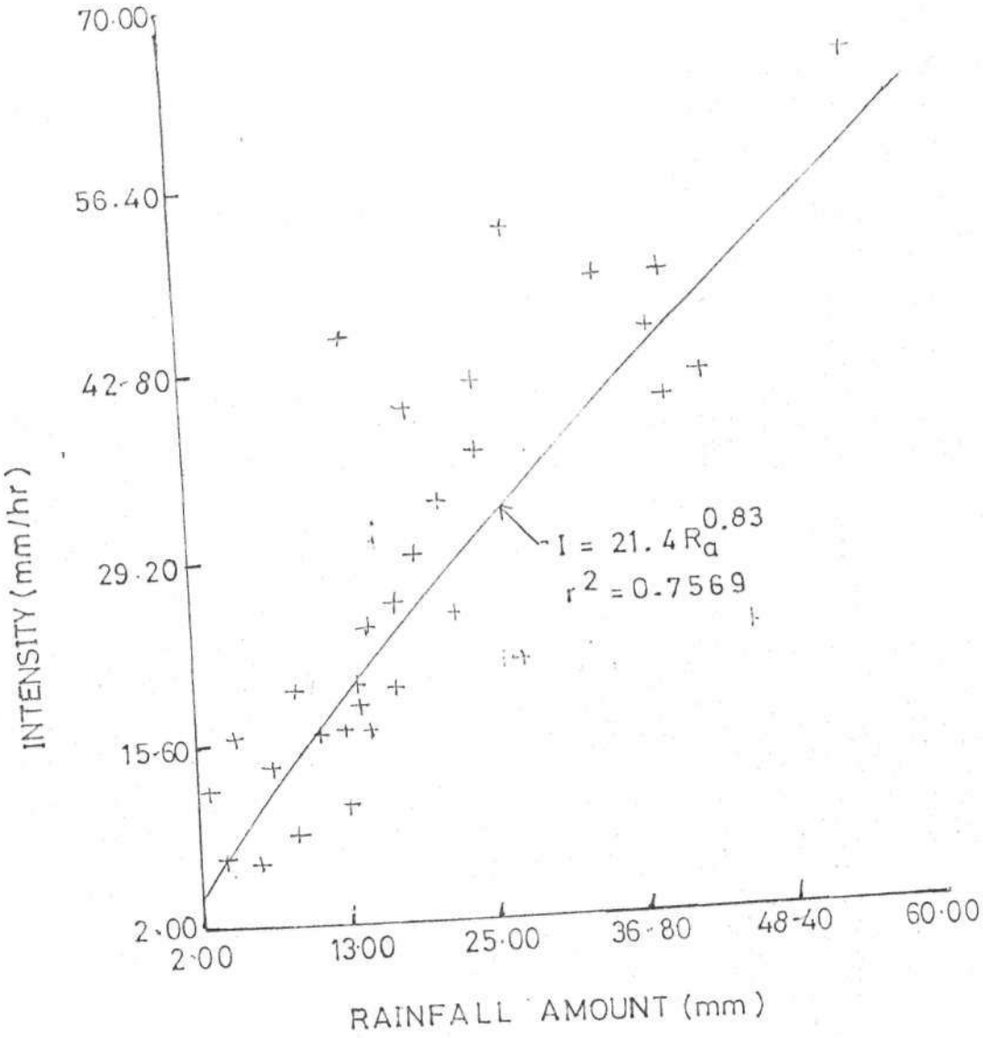


Fig. 4.1 Relationship of rainfall amount to intensity in 1996

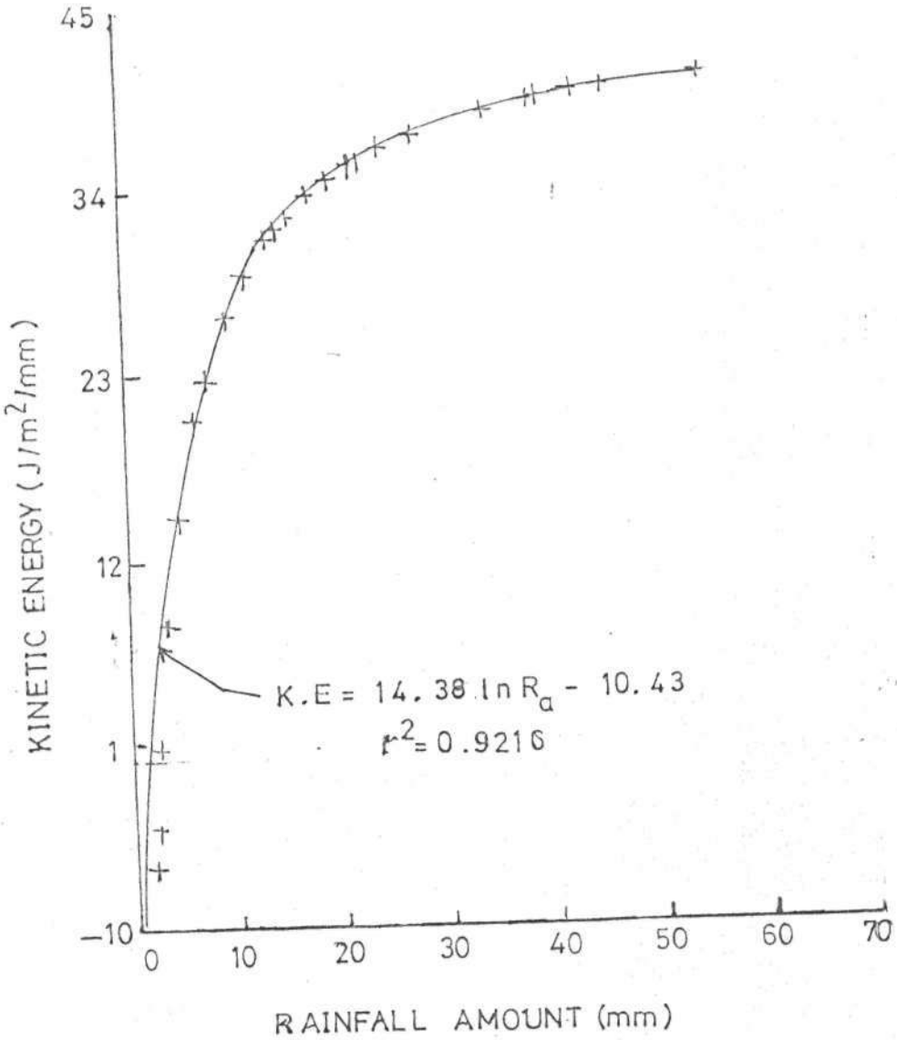


Fig. 4.2 Relationship of rainfall amount to Kinetic Energy in 1996

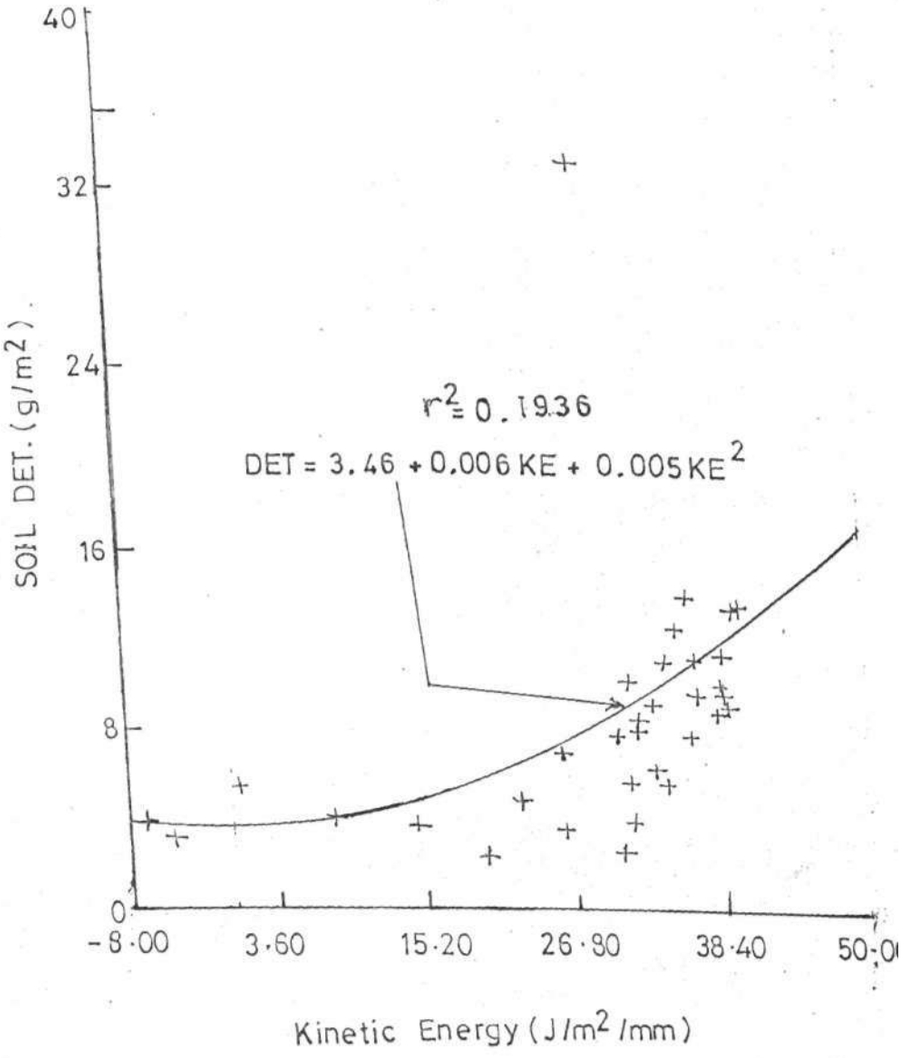


Fig. 4.3: Soil Det. vs Kinetic Energy.

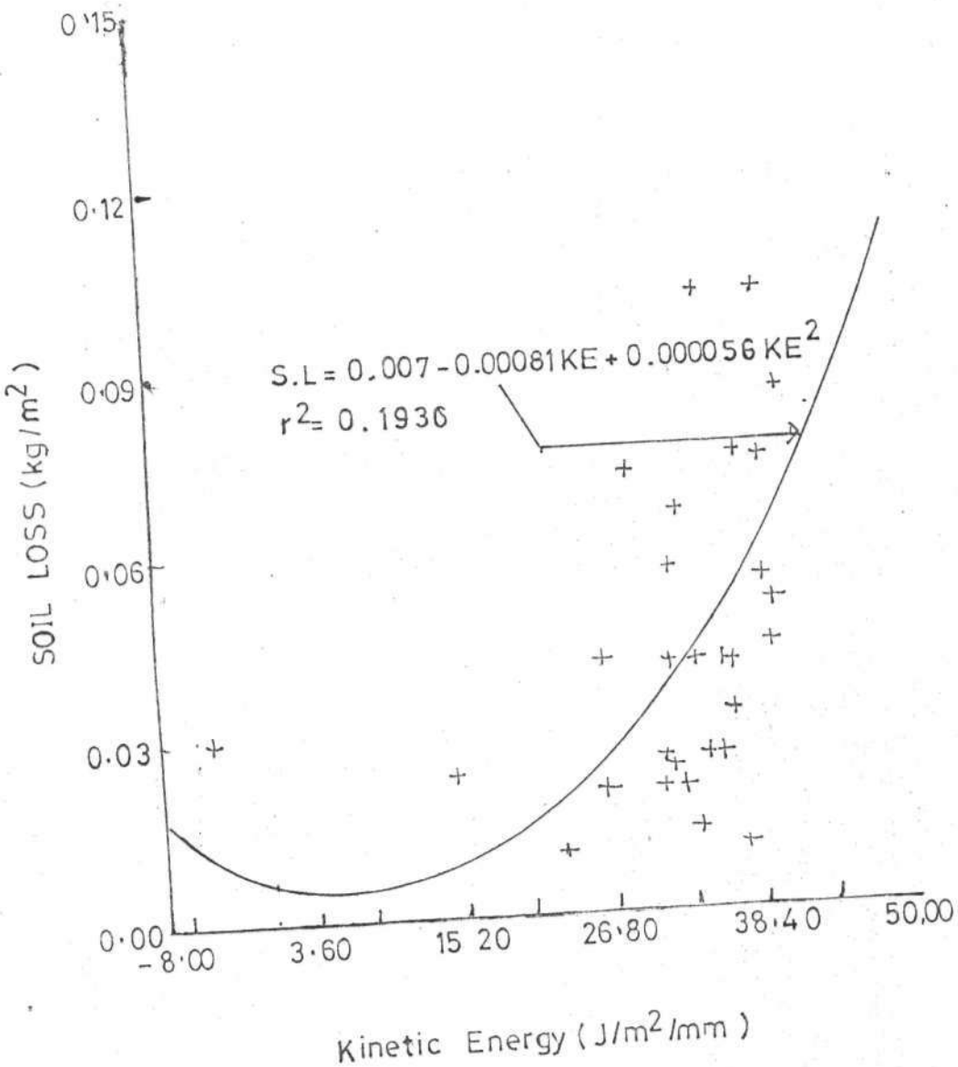


Fig. 4·4 Soil loss vs Kinetic Energy.

4.1, it is observed that the relationship between rainfall intensity and rainfall amount was a power function of rainfall amount Ra.The expression was found to be, $I = 21.4*Ra^{0.83}$. This relationship is given in Eq. 4.3 with a correlation coefficient r = 0.87. This is true for most part of the measured period where the rains were characterized by heavy and destructive storms particularly in 1996. In some instances with short duration. Generally, the relationship could hold for 90% of the rainfall period in Samaru (Oladipo, 1985). Similarly, increase in rainfall amount gives a corresponding increase in kinetic energy as shown in Fig 4.2. The increase in rainfall amount/kinetic energy continues to a point after which the increase in rainfall amount does not yield any corresponding increase in kinetic energy. This is due to the fact that the soil moisture must have reached a saturation level with ponding on the soil surface as rain continues to fall. The resultant effect is that the energy of raindrop impact can no longer affect soil detachment as ponding would have absorbed all the energy of impact. Thus, the kinetic energy tends to be constant with the increase in rainfall amount. The threshold values observed in this study are consistently different from one year to another. This clearly indicates that rainfall patterns also vary with their corresponding impact energy. Therefore, the soil loss that would be experienced with the impact energy of rainfall under these phenomena as explained above will also vary from one rainstorm to another and from one year to another.

The amount of soil detached and the subsequent soil loss were compared with the kinetic energy of the rainfall that dislodged the soil particles. The values of the kinetic energy from Eq.4.1 was correlated with soil detachment obtained from the plot and from the method described above (see section 3.6.4). It was found that there was a poor correlation ($r = 0.44$) between the soil detached and the Kinetic Energy calculated from the method employed by Kowal and Kassam (1976) (see Fig.4.3). The relationship as discussed above can be expressed by a second degree polynomial as:

$$DET = 3.46 + 0.006KE + 0.005KE^2 \qquad (4.1)$$

Where:

DET = Soil detachment (g/m^2)

KE = Kinetic Energy of rain drop ($J/m^2/mm$)

Equation 4.1 does suggest that rainfall and/or raindrop does not follow a particular pattern with respect to soil detachment, and that the energy of raindrop to soil detachment was poorly correlated. Such observation was also made by Morgan (1982) for bare ground with sandy loam soil in Bedfordshire, England, in the United Kingdom. Splash detachment was shown not to be a simple response to raindrop impact as is frequently assumed in laboratory simulations of the process. The interracting effect of size of raindrop, surface crusting and kinetic energy must also be considered. When monitoring splash erosion in the field, it is difficult to isolate adequately the effect of the various controlling factors and the volume of

data needed to be collected over a time period of months or longer in order to obtain measurable quantities of soil that could possibly be said to be reliable. In fact, no satisfactory system of the field measurement of splash erosion has been obtained. Similarly, the corresponding soil loss will also be affected, that is, the soil loss cannot be said to follow a particular pattern, inspite of the fact that the correlation coefficient is higher than that for soil detachment expression with an r value of 0.64 (Fig. 4.4). The regression equation obtained for soil loss and kinetic energy was:

$$S.L. = 0.007 - 0.00081*K.E. + 0.000056*K.E.^2 \qquad (4.2)$$

We cannot therefore estimate soil detachment and soil loss using Eqs 4.1 and 4.2 since the kinetic energy equation of rainfall does not follow a particular pattern. The kinetic energy equation of Kowal and Kassam developed for Samaru was not sensitive to Samaru rainfall when compared with other kinetic energy equations (Adewumi and Morgan, 1997). The reasons advanced for the relationship established between kinetic energy ($J/m^2/mm$), rainfall amount (mm), rainfall intensity (mm/hr), soil detachment (g/m^2) and soil loss (kg/m^2) (Figs.4.2 and 4.3) having logarithmic and polynomial relationships do not follow the same explanations with the relationship between intensity and rainfall amount (Fig.4.1).

From Figs 4.3 and 4.4, it is observed that soil detachment and soil loss versus kinetic energy follow a second degree polynomial. This was so, because, the impact of kinetic energy

on the soil surface breaks down the soil aggregate and because of the low organic carbon present (Tables 4.2 and 4.3), produce a corresponding increase in soil detachment and high soil loss (Tables 4.4, 4.5 and 4.6). This trend was also noted by Ekwue and Ohu (1990).

Inspite of the anomalies observed above the relationship established in this study between rainfall intensity and amount (Fig 4.1) will hold for Samaru-Zaria environment. The relationship is presented in Eq. 4.3:

$$I = 2.14.Ra^{0.83} \quad (4.3)$$

Where:

I = Rainfall Intensity (mm/hr)

Ra = Rainfall Amount per storm (mm)

The kinetic energy versus rainfall amount relationship established in this study (Fig.4.2) is:

$$K.E. = 14.38.\ln.Ra - 10.43 \quad (4.4)$$

Where:

K.E. = Kinetic Energy of the rainstorm ($J/m^2/mm$)

Ra = Total Rainfall Amount per rainstorm (mm)

Equation 4.4 has a correlation coefficient, r = 0.96 and can be used for Samaru - Zaria environment.

4.4 Measured and predicted Soil detachment (g/m^2), and Soil Loss (kg/m^2).

Tables 4.7, 4.8 and 4.9 show the comparison of measured soil loss with those predicted from model 1 on a storm by storm basis for 1993, 1995 and 1996, respectively, while Tables 4.10, 4.11 and 4.12 show the summary of measured and computed rainfall parameters on a monthly basis for 1993, 1995 and 1996 rainfall season, respectively. Table 4.13 shows the comparison between the measured value of soil loss (kg/m^2) and the predicted values for both models 1 and 2 without incorporating soil detachment (g/m^2) on a monthly basis. Similarly, Table 4.14 shows the same comparison between the measured value (measured soil loss + soil detachment) (kg/m^2) and the predicted values for both models 1 and 2. The reasons for producing Table 4.14 is to show the importance of soil detachment in soil loss studies.

Figures 4.5 to 4.10 show the comparison on monthly basis the maximum soil loss between the measured and the predicted for models 1 and 2 for 1993, 1995 and 1996 for both bare and vegetative soil. Figures 4.11 and 4.12 show the linear relationship between measured soil loss per month and the predicted soil loss for bare soil for models 1 and 2, respectively while Figs 4.13 and 4.14 show the linear relationship between measured soil loss per month and the predicted soil loss for vegetated soil for models 1 and 2, respectively.

Table 4.7: Comparison of Measured Soil Loss with Predicted Model 1 Soil Loss (kg/m²) Storm by Storm Event (1993)

Date	Measured Soil Loss (Kg/m^2) (Bare Soil)	Predicted Soil Loss (kg/m^2) Model 1 (Bare Soil)	Measured Soil Loss (kg/m^2) (Veg. Soil)	Predicted Soil Loss (kg/m^2) Model 1 (Veg. Soil)
10/7/93	0.07	0.074	0.05	0.06
19/7/93	0.38	0.396	0.09	0.10
20/7/93	0.26	0.262	0.072	0.09
27/7/93	0.00	0.00017	0.00	0.0083
3/8/93	0.07	0.085	0.051	0.061
8/8/93	0.16	0.174	0.067	0.074
12/8/93	0.17	0.17	0.07	0.085
18/8/93	0.24	0.26	0.07	0.088
21/8/93	0.28	0.298	0.081	0.092
1/9/93	0.27	0.31	0.09	0.092
6/9/93	0.26	0.30	0.08	0.087
8/9/93	0.00	0.00	0.00	0.00
10/9/93	0.38	0.44	0.105	0.103
17/9/93	0.00	0.00008	0.006	0.006
20/9/93	0.02	0.025	0.033	0.03
23/9/93	0.00	0.00	0.00	0.00

Table 4.8: Comparison of Measured Soil Loss with Predicted Model 1 Soil Loss (kg/m2) Storm by Storm Event (1995)

Date	Measured Soil Loss (Kg/m^2) (Bare Soil)	Predicted Soil Loss (kg/m^2) Model 1 (Bare Soil)	Measured Soil Loss (kg/m^2) (Veg. Soil)	Predicted Soil Loss (kg/m^2) Model 1 (Veg. Soil)
5/7/95	0.002	0.0024	0.013	0.018
17/7/95	0.085	0.104	0.06	0.069
19/7/95	0.00	0.00	0.00	0.00
20/7/95	0.09	0.10	0.064	0.067
23/7/95	0.004	0.0004	0.036	0.037
27/7/95	0.21	0.203	0.09	0.094
30/7/95	0.14	0.18	0.068	0.089
3/8/95	0.17	0.19	0.09	0.09
14/8/95	0.19	0.19	0.083	0.097
10/8/95	0.02	0.03	0.035	0.04
18/8/95	0.10	0.104	0.066	0.068
24/8/95	0.09	0.104	0.055	0.069
26/8/95	0.002	0.003	0.014	0.018
28/8/95	0.01	0.012	0.024	0.029
7/09/95	0.00	0.00	0.00	0.00
12/9/95	0.00	0.00	0.00	0.00
15/9/95	0.07	0.094	0.04	0.044
16/9/95	0.18	0.21	0.10	0.103
23/9/95	0.00	0.00	0.00	0.00
24/9/95	0.08	0.092	0.048	0.054
28/9/95	0.12	0.13	0.07	0.070
5/10/95	0.16	0.20	0.08	0.09
8/10/95	0.20	0.21	0.09	0.096

Table 4.9: Comparison of Measured Soil Loss with Predicted Model 1 Soil Loss (kg/m2) Storm by Storm Event (1996)

Date	Measured Soil Loss (Kg/m^2) (Bare Soil)	Predicted Soil Loss (kg/m^2) Model 1 (Bare Soil)	Measured Soil Loss (kg/m^2) (Veg. Soil)	Predicted Soil Loss (kg/m^2) Model 1 (Veg. Soil)
4/7/96	0.06	0.07	0.05	0.057
7/7/96	0.04	0.04	0.043	0.043
14/7/96	0.05	0.07	0.048	0.057
16/7/96	0.025	0.03	0.035	0.038
19/7/96	0.17	0.19	0.00	0.00
20/7/96	0.17	0.17	0.09	0.095
24/7/96	0.12	0.15	0.078	0.084
25/7/96	0.16	0.17	0.075	0.095
1/8/96	0.00	0.00	0.00	0.00
3/8/96	0.14	0.15	0.00	0.00
9/8/96	0.15	0.15	0.054	0.059
14/8/96	0.005	0.0065	0.00	0.00
16/8/96	0.13	0.16	0.082	0.086
17/8/96	0.18	0.19	0.09	0.09
20/8/96	0.03	0.03	0.04	0.041
24/8/96	0.05	0.05	0.038	0.047
26/8/96	0.00	0.00	0.00	0.00
30/8/96	0.02	0.02	0.00	0.00
31/8/96	0.001	0.002	0.00	0.00
1/9/96	0.08	0.10	0.05	0.066
2/9/96	0.04	0.05	0.04	0.047
4/9/96	0.12	0.13	0.07	0.078
7/9/96	0.19	0.20	0.08	0.099
9/9/96	0.06	0.06	0.049	0.052
14/9/96	0.21	0.24	0.10	0.110
15/9/96	0.00	0.00	0.00	0.00
16/9/96	0.00	0.00	0.00	0.00
18/9/96	0.025	0.03	0.00	0.00
23/9/96	0.00	0.00	0.00	0.00
25/9/96	0.11	0.13	0.06	0.072
2/10/96	0.08	0.083	0.00	0.00
4/10/96	0.03	0.031	0.03	0.039
5/10/96	0.05	0.05	0.04	0.044
7/10/96	0.157	0.163	0.075	0.077

Table 4.10: Summary of data analysis Month by Month for 1993 rainy season

Months	Total Ra /Month (mm)	Mean Ra /Month (mm)	Ave. K.E. ($J/m^2/mm$)	Total Soil det./Month with correction factor (g/m^2)			Total Soil Loss Observed/Month (kg/m^2)			Total Runoff Vol. Observed/Month (m^3/m^2)			Ra. conv. to vol. of runoff (m^3/m^2) per Month
				bare Soil	Veg. Soil	Cult. Soil	bare Soil	Veg Soil	Cult. Soil	bare Soil	Veg. Soil	Cult. Soil	All Plot
JULY (10,19,20 & 27)	69.7	17.43	31.06	51.34	9.55	41.5	.71	.212	.02	.005	.003	.002	1.7
AUGUST (3,9,12,18,&21)	109.7	21.94	34.21	76.68	12.39	40.7	0.92	.34	.09	.009	.004	.002	2.6
SEPT. (1,6,8,10,17,20 & 23)	63.9	9.13	16.97	56.86	0	26.1	.93	.314	.04	.007	.003	.002	1.5
Oct. (no rain)	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.11: Summary of data analysis Month by Month for 1995 rainy season

Months	Total Rainfall per Month (mm)	Mean Rainfall per Month (mm)	Average K.E. (J/m2/mm)	Total Soil detachment after correction factor per Month g/m2			Total Soil Loss Observed per Month kg/m2			Total Runoff Volume Observed per Month m3/m2			Amount of Rainfall converted into volume of runoff m3/m2 per Month
				bare Soil	Veg. Soil	Cult. Soil	bare Soil	Veg. Soil	Cult. Soil	bare Soil	Veg. Soil	Cult. Soil	All Plot
JULY (5th-30th)	96.2	13.74	24.06	72.55	38.55	58.29	0.531	0.331	0.067	0.0121	0.0066	0.0032	2.27
AUGUST (3rd-28th)	143.9	20.56	34.35	100.22	23.21	65.09	0.582	0.367	0.107	0.0168	0.0105	0.0056	3.46
SEPT. (7th-28th)	60.4	8.63	17.80	70.73	0	43.48	0.45	0.258	0.019	0.0089	0.0048	0.0018	1.44
Oct. (5th & 8th)	27.9	13.95	31.00	10.89	0	3.53	0.36	0.17	0.0013	0.0031	0.0012	0.00089	0.68

Table 4.12: Summary of data analysis Month by Month for 1996 rainy season

Months	Total Rainfall per Month (mm)	Mean Rainfall per Month (mm)	Average K.E. (J/m2/mm)	Total Soil detachment after correction factor per Month (g/m2)			Total Soil Loss Observed per Month (kg/m2)			Total Runoff Volume Observed per Month (m3/m2)			Amount of Rainfall converted into volume of runoff (m3/m2) per Month
				bare Soil	Veg. Soil	Cult. Soil	bare Soil	Veg. Soil	Cult. Soil	bare Soil	Veg. Soil	Cult. Soil	All Plot
JULY (4th - 25th)	219.0	27.38	35.09	92.31	17.97	39.43	0.795	0.419	0.112	0.017	0.0049	0.0055	5.25
AUGUST (1st - 31st)	199.0	18.09	29.14	83.52	17.97	31.45	0.706	0.304	0.057	0.019	0.0025	0.0048	4.78
SEPT. (1st - 25th)	209.1	19.01	23.52	80.54	8.35	42.29	0.835	0.449	0.06	0.015	0.0011	0.0035	5.02
Oct. (2nd - 7th)	67.0	16.75	31.71	37.10	10.86	8.38	0.317	0.145	0.0071	0.007	0.00006	0.0014	1.61

Table 4.13: Comparison of Soil Loss (Kg/m2) on Monthly basis without soil detachment.

Year	Infiltration Rates (mm/hr)		Cummulative Rainfall Amount (mm)	Month	Observed Values without Soil detachment		MODEL 1 (EUROSEM)		MODEL 2 (WEPP)	
	Bare Soil	Veg. Soil			Bare Soil	Veg. Soil	Bare Soil	Veg. Soil	Bare Soil	Veg. Soil
1993	61.5	13.0	69.7	July	0.710	0.212	0.732	0.258	0.36	2.90
			109.7	August	0.920	0.339	0.987	0.400	3.60	5.73
			63.9	Sept.	0.930	0.314	1.075	0.318	1.31	2.89
			–	Oct.	–	–	–	–	–	–
				Total	2.560	0.865	2.794	0.976	5.27	11.52
1995	65.0	12.0	96.2	July	0.531	0.331	0.590	0.374	2.90	4.96
			143.9	August	0.582	0.367	0.633	0.411	5.30	7.99
			60.4	Sept.	0.450	0.258	0.526	0.271	0.76	2.69
			27.9	Oct.	0.360	0.17	0.410	0.186	–	0.501
				Total	1.923	1.126	2.159	1.242	8.96	16.14
1996	63.0	12.5	219.0	July	0.795	0.419	0.890	0.469	10.98	12.88
			199.0	August	0.706	0.304	0.709	0.323	8.68	11.49
			209.1	Sept.	0.835	0.449	0.940	0.524	11.87	12.34
			67.0	Oct.	0.317	0.145	0.327	0.160	–	2.017
				Total	2.653	1.317	2.866	1.476	31.53	38.73
				Grand Total	7.136	3.308	7.819	3.694	45.76	66.39
				Average Soil Loss (Kg/m2) per year	2.38	1.103	2.610	1.230	15.25	22.13

Table 4.14: Comparison of Soil Loss (Kg/m2) incorporating Soil Det. component on Monthly basis.

Year	Infiltration Rates (mm/hr)		Cummulative Rainfall Amount (mm)	Month	Observed Values with Soil det.		MODEL 1 (EUROSEM)		MODEL 2 (WEPP)	
	Bare Soil	Veg. Soil			Bare Soil	Veg. Soil	Bare Soil	Veg. Soil	Bare Soil	Veg. Soil
1993	61.5	13.0	69.7	July	0.761	0.222	0.732	0.258	0.36	2.90
			109.7	August	0.997	0.351	0.987	0.400	3.60	5.73
			63.9	Sept.	0.987	0.314	1.075	0.318	1.31	2.89
			-	Oct.	-	-	-	-	-	-
				Total	2.745	0.887	2.794	0.976	5.27	11.52
1995	65.0	12.0	96.2	July	0.604	0.370	0.590	0.374	2.90	4.96
			143.9	August	0.682	0.390	0.633	0.411	5.30	7.99
			60.4	Sept.	0.521	0.258	0.526	0.271	0.76	2.69
			27.9	Oct.	0.371	0.170	0.410	0.186	-	0.501
				Total	2.178	1.188	2.159	1.242	8.96	16.14
1996	63.0	12.5	219.0	July	0.887	0.437	0.890	0.469	10.98	12.88
			199.0	August	0.790	0.322	0.709	0.323	8.68	11.49
			209.1	Sept.	0.916	0.457	0.940	0.524	11.87	12.34
			67.0	Oct.	0.354	0.156	0.327	0.160	-	2.017
				Total	2.947	1.372	2.866	1.476	31.53	38.73
				Grand Total	7.870	3.447	7.819	3.694	45.76	66.39
				Average Max. Soil Loss (Kg/m2)/year	2.620	1.150	2.610	1.230	15.25	22.13

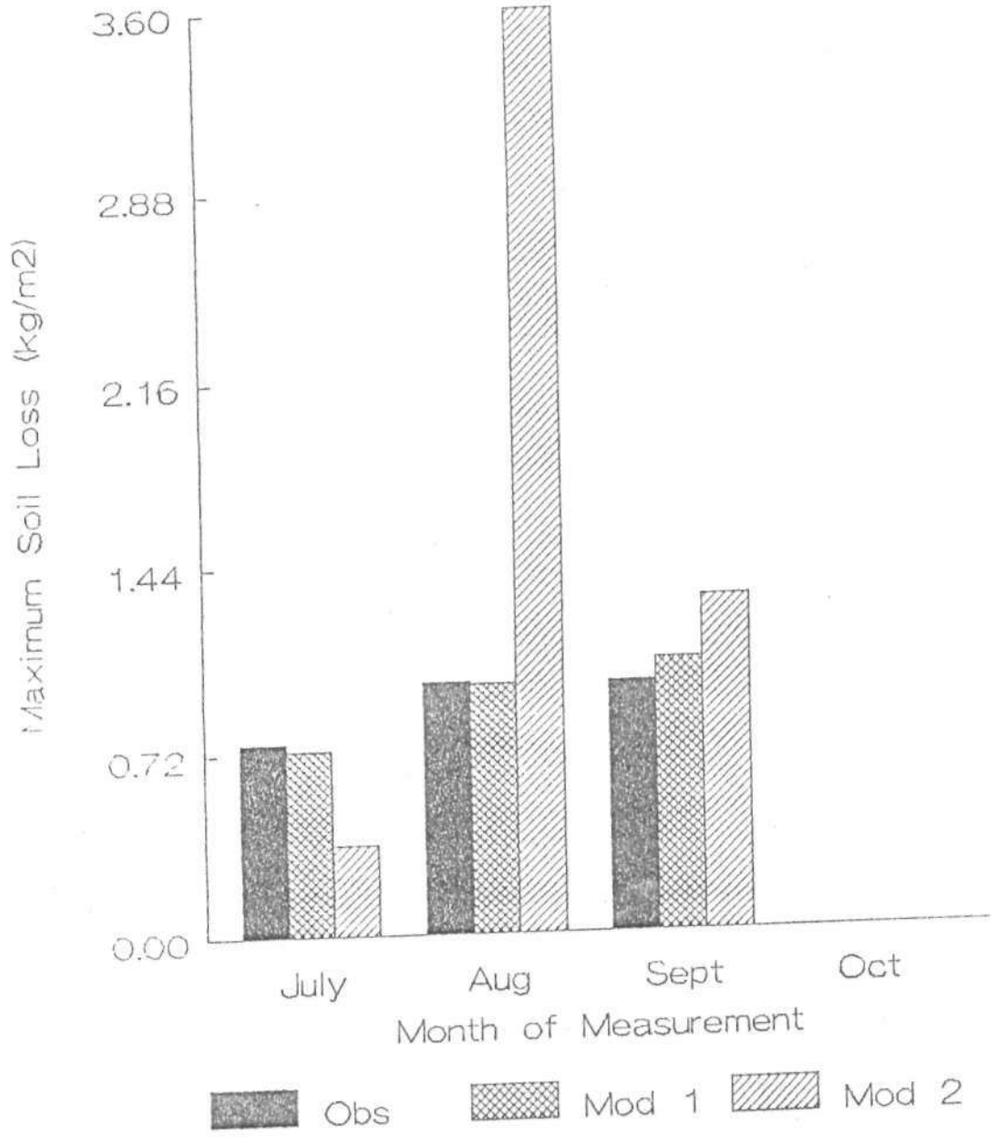


Fig. 4.5 Observed versus predicted soil loss for bare soil in 1993.

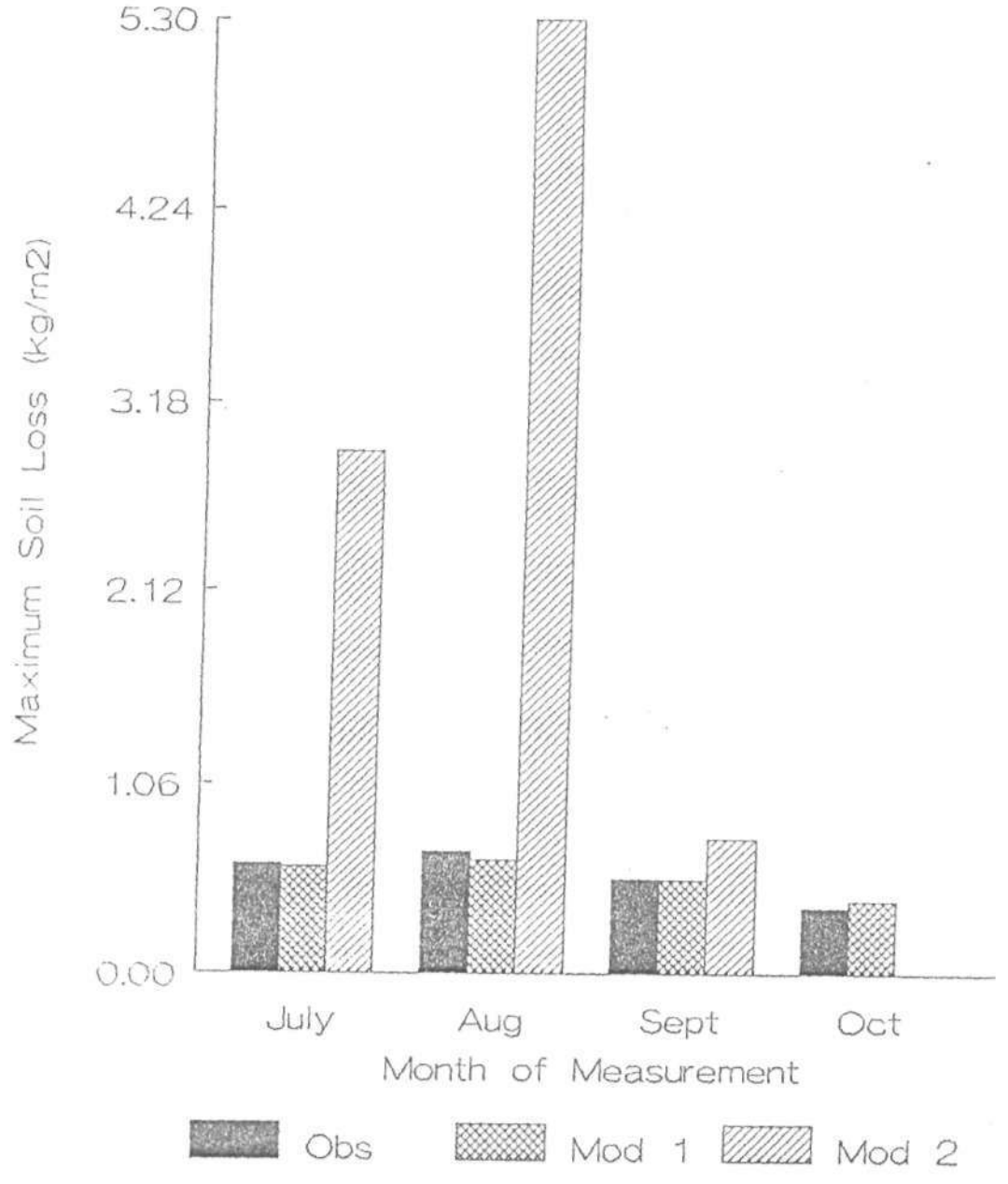


Fig. 4.6 Observed versus predicted soil loss for bare soil in 1995.

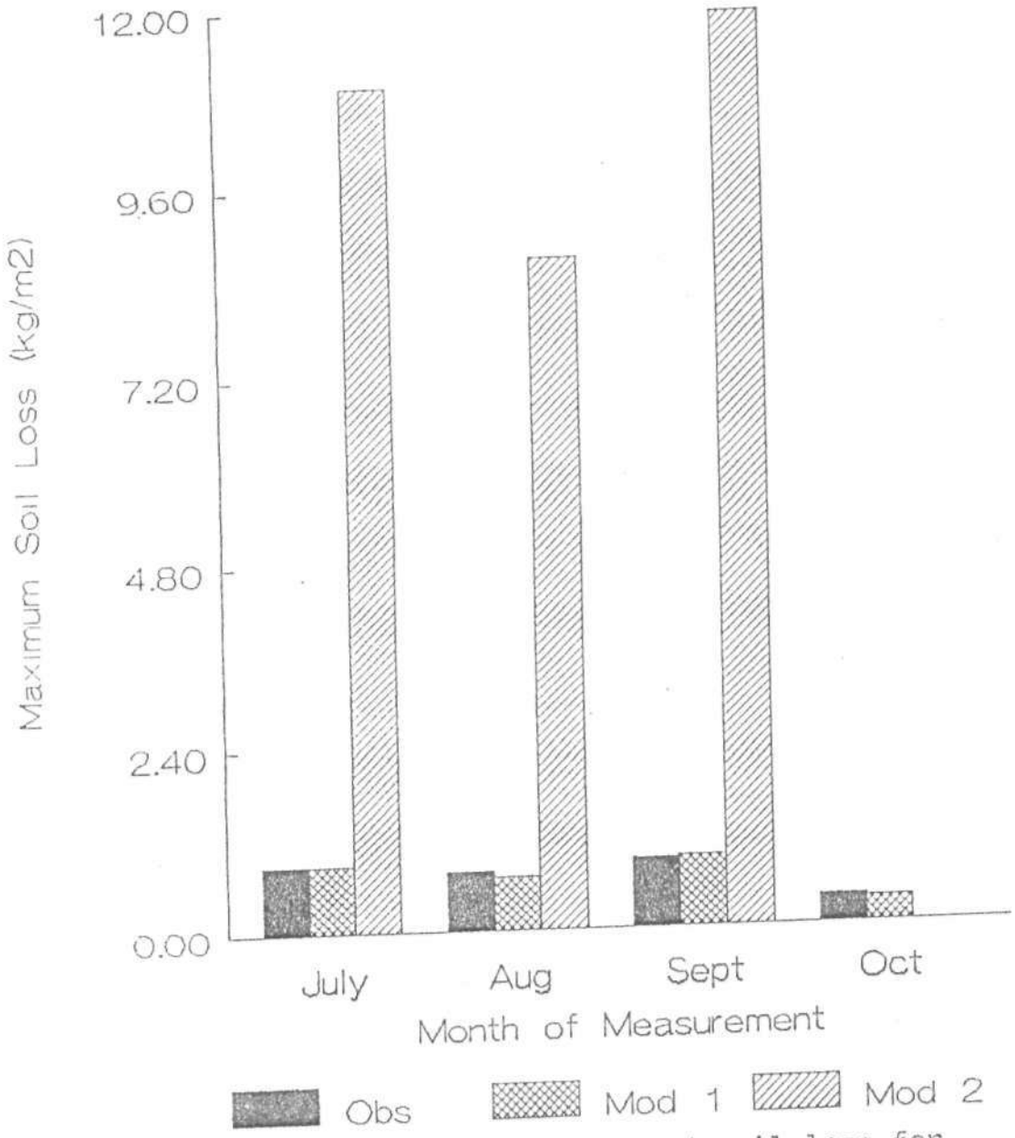


Fig. 4.7 Observed versus predicted soil loss for bare soil in 1996.

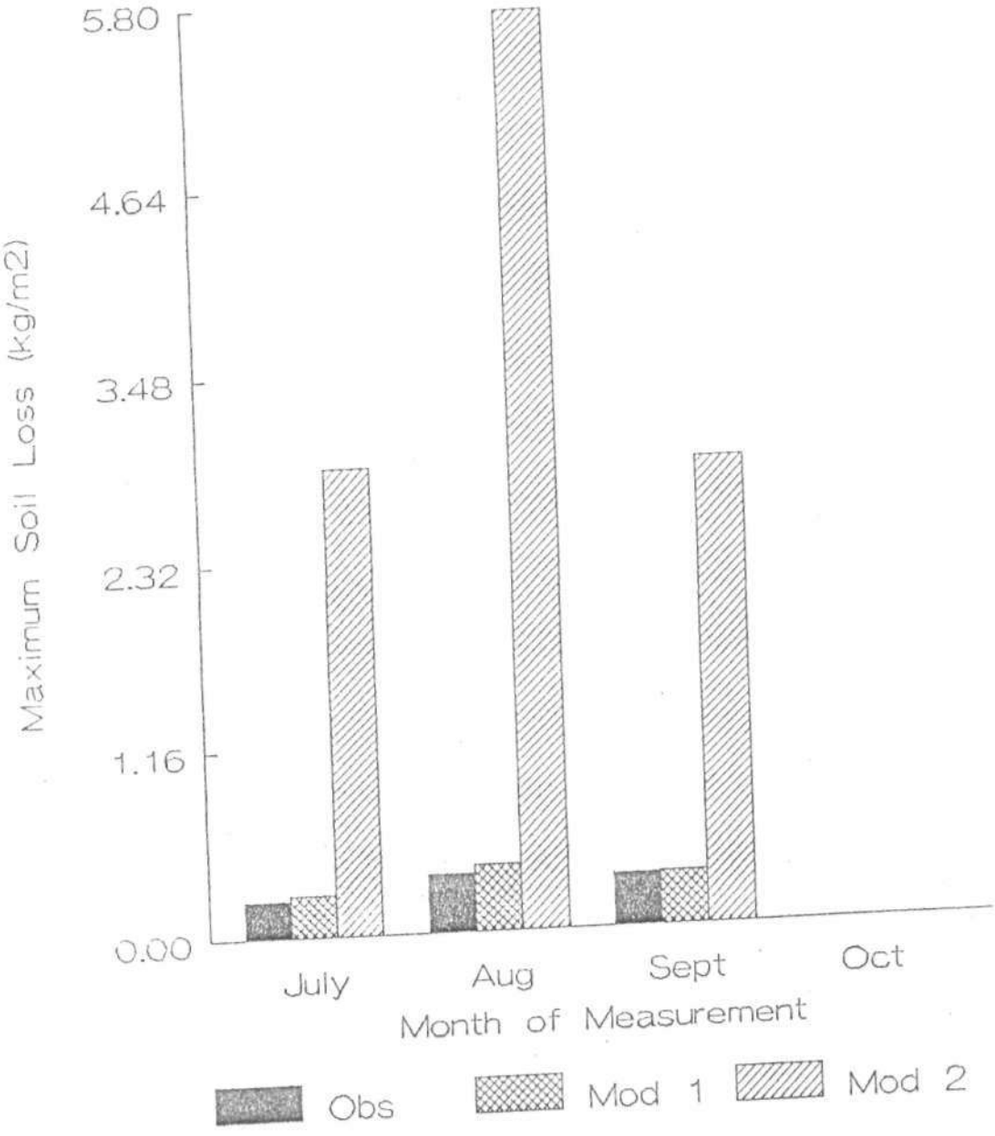


Fig. 4.8 Observed versus predicted soil loss for vegetated soil in 1993.

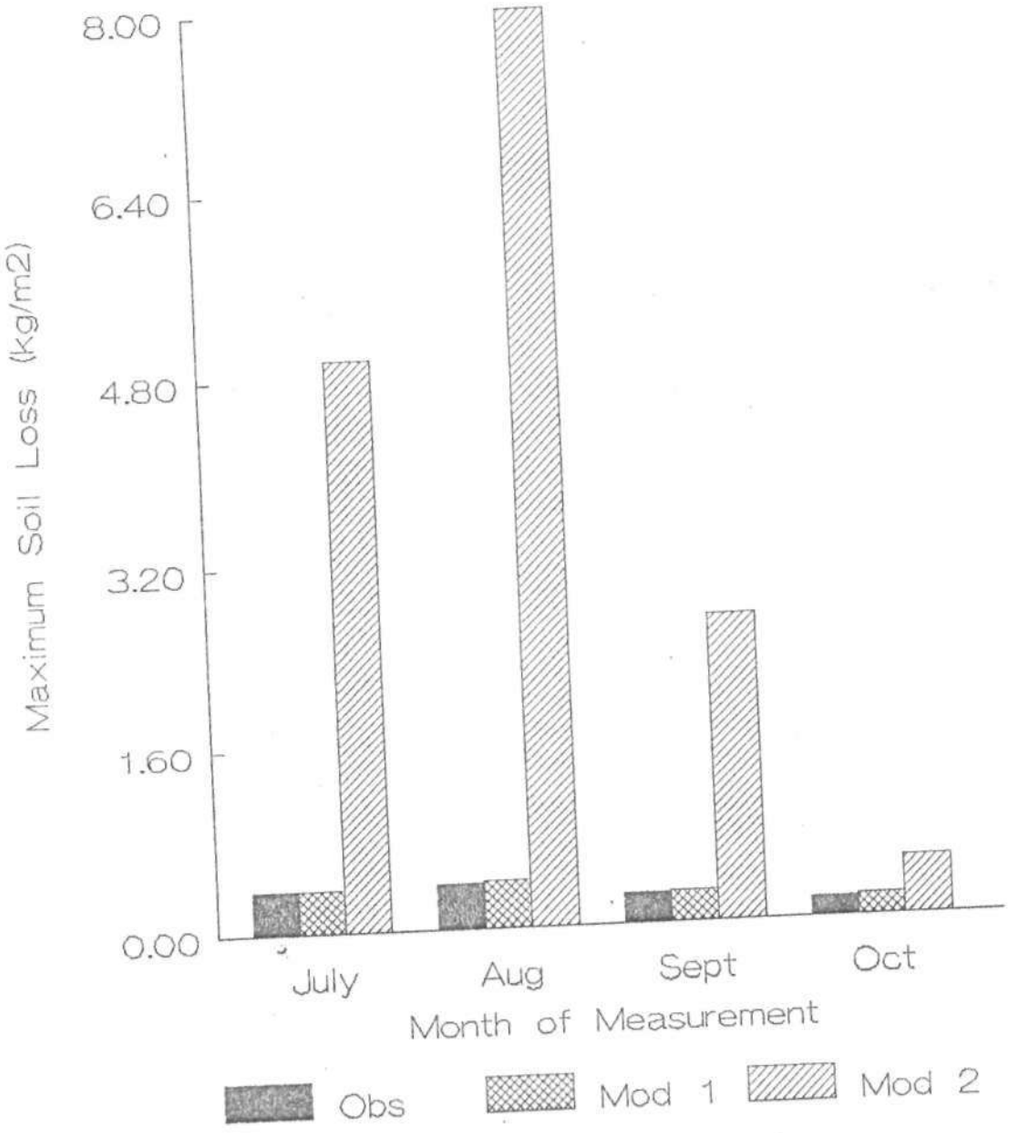


Fig. 4.9 Observed versus predicted soil loss for vegetated soil in 1995.

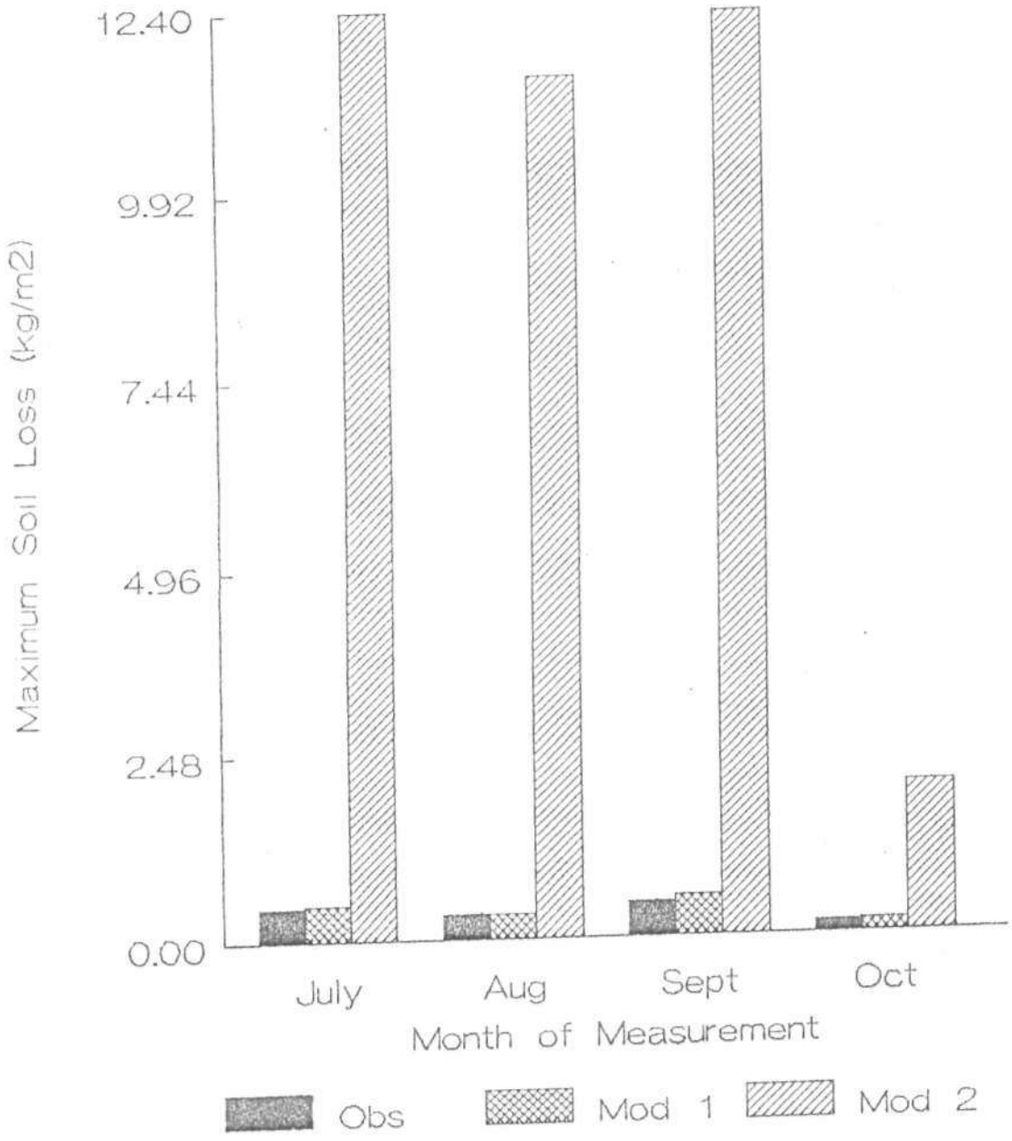


Fig. 4.10 Observed versus predicted soil loss for vegetated soil in 1996.

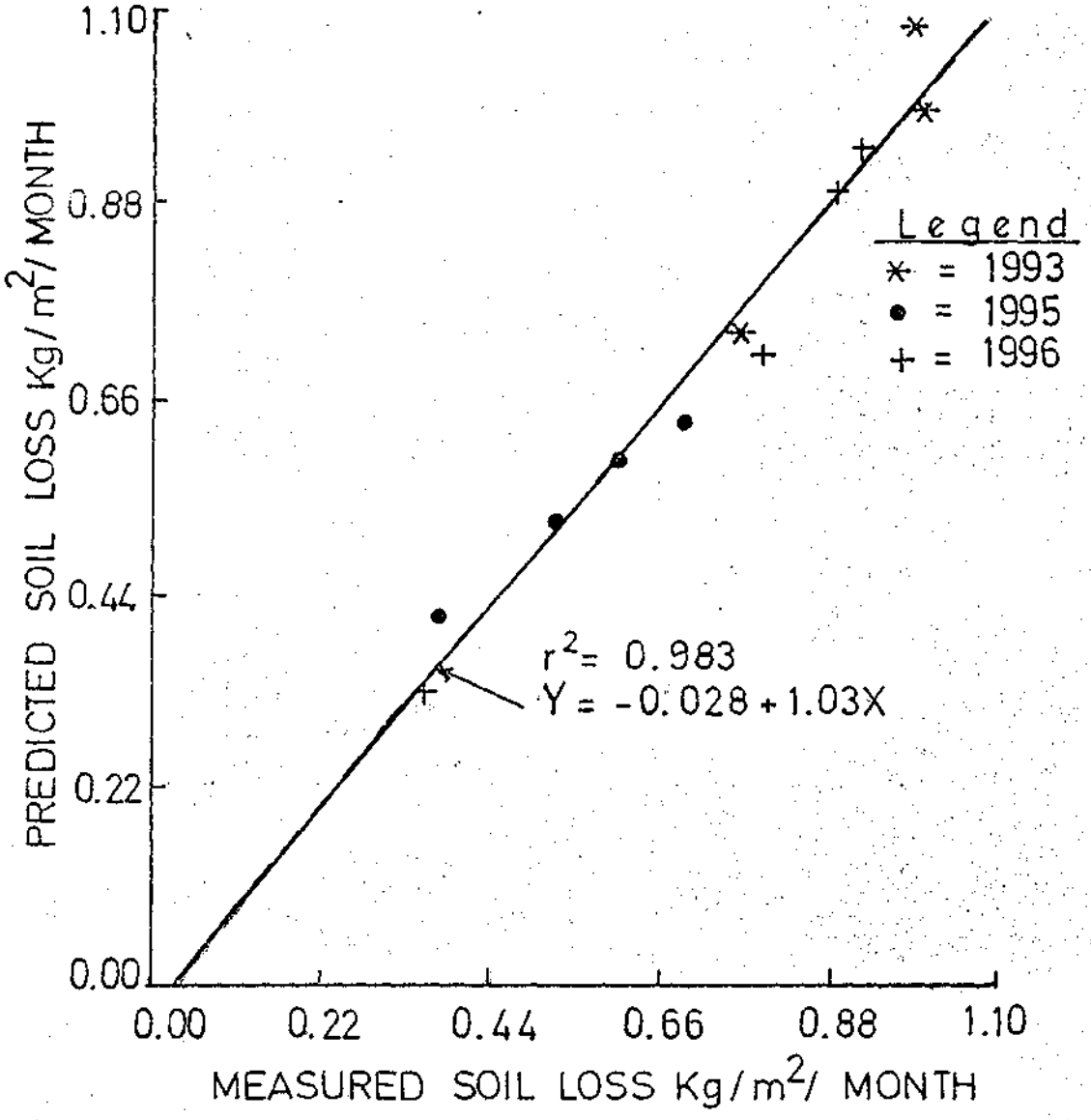


Fig. 4.11 Predicted vs Measured soil loss.
(Bare soil Model 1)

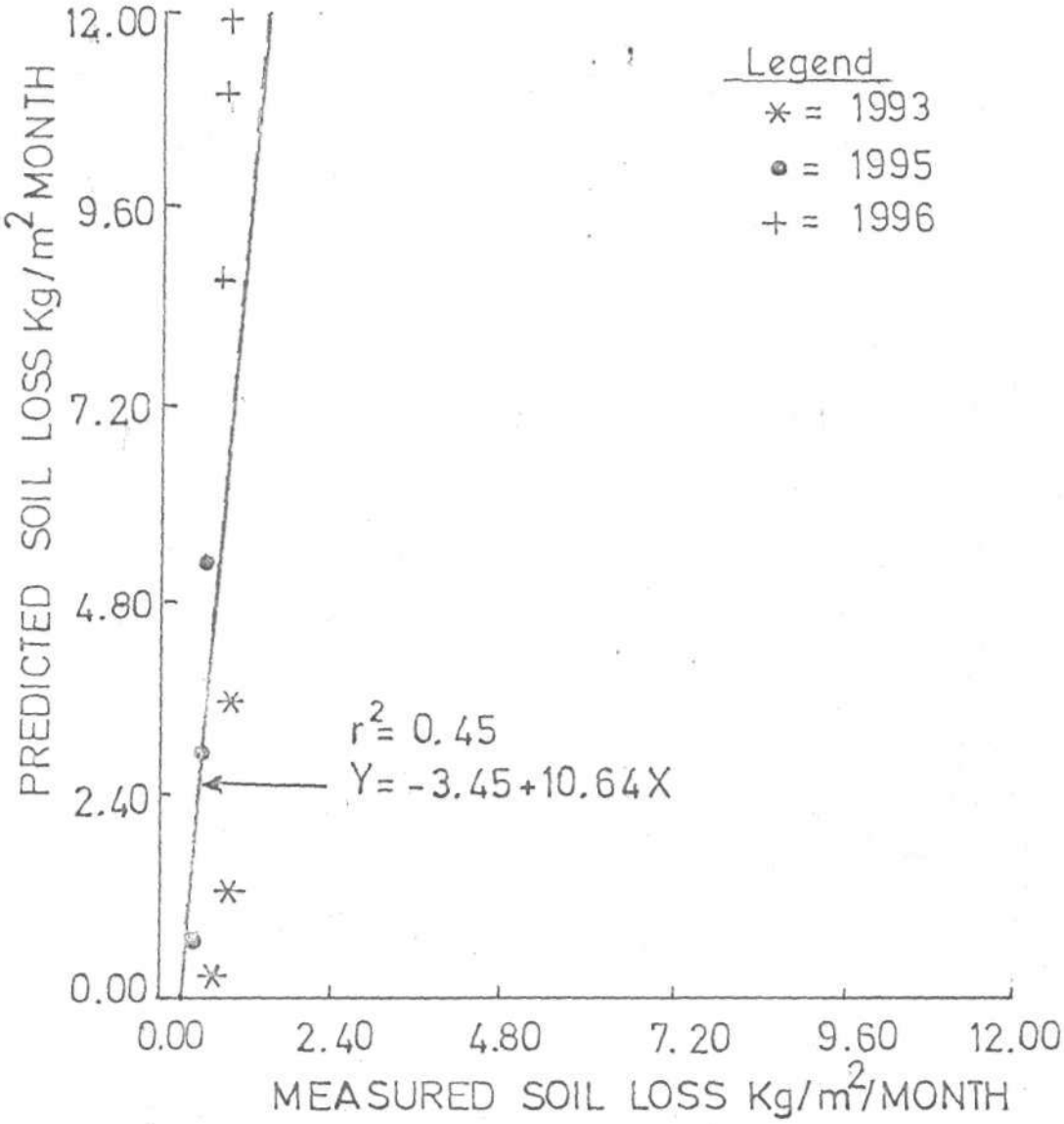


Fig. 4.12 Predicted vs Measured soil loss
(Bare soil Model 2)

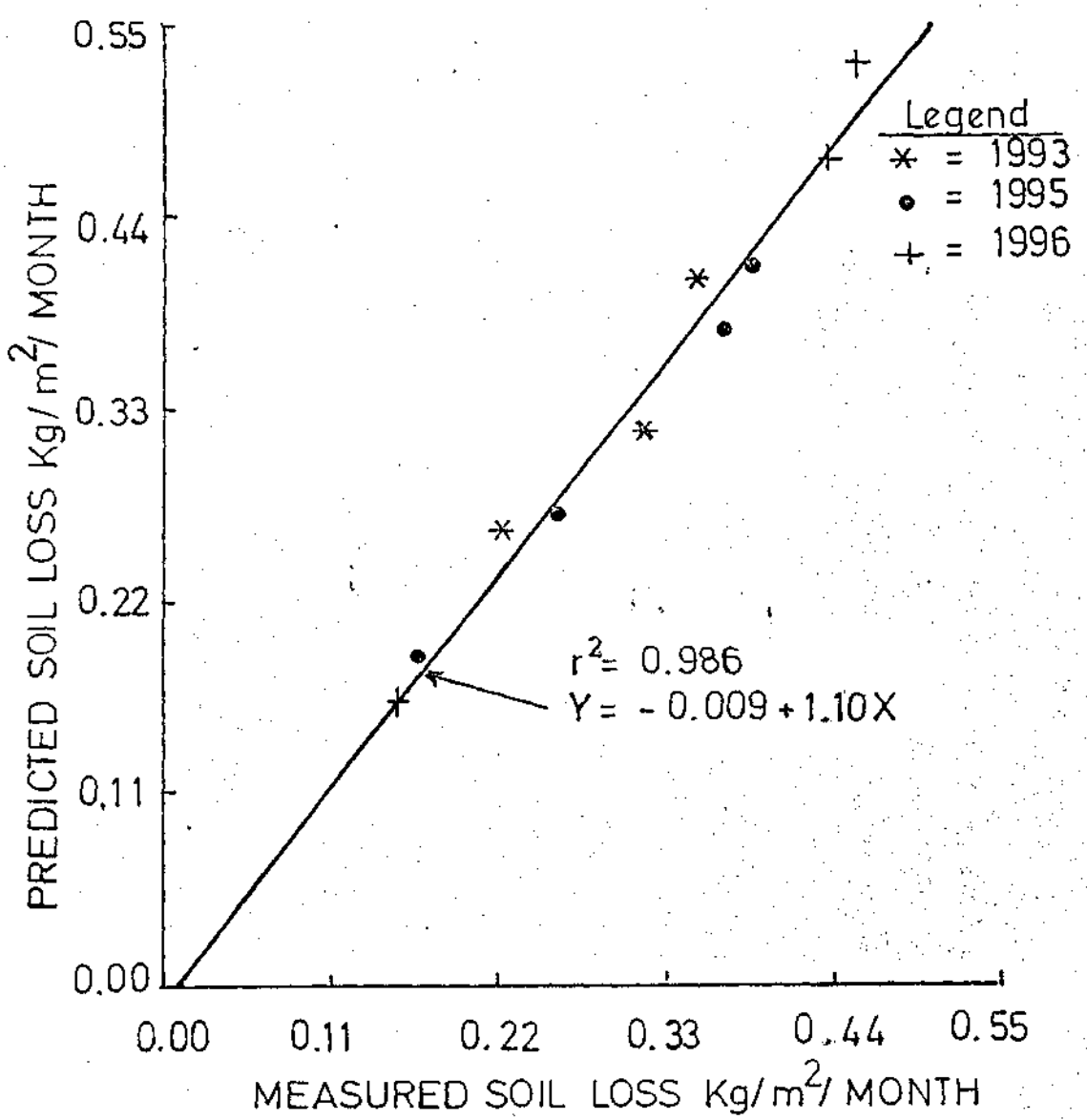


Fig. 4.13. Predicted vs Measured soil loss.
(Veg. soil Model 1)

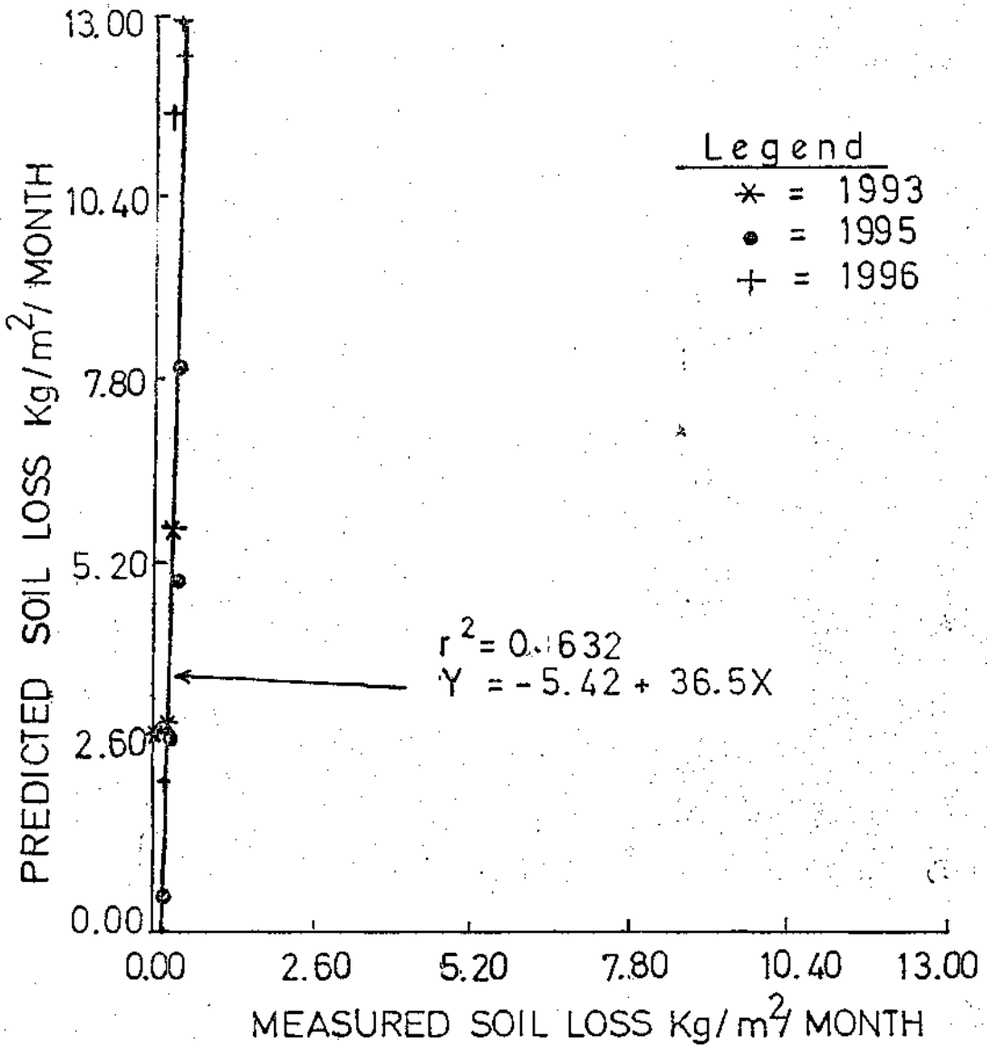


Fig. 4.14 Predicted vs Measured soil loss
(Veg. soil Model 2)

DISCUSSION

It was observed that an average of 0.62 kg/m^2 per month was recorded as soil detachment in 1993, 0.64 kg/m^2 in 1995 and 0.73 kg/m^2 per month in 1996 for bare soil on a natural slope of 0.058 m/m (5.8%). For the vegetative plot, an average of 0.073 kg/m^2 per month was recorded in 1993, 0.15 kg/m^2 per month in 1995 and 0.14 kg/m^2 per month in 1996. For cultivated soil, an average of 0.36 kg/m^2 per month was recorded as soil detachment in 1993, 0.43 kg/m^2 per month in 1995 and 0.30 kg/m^2 per month in 1996. This gives an annual rate of soil detachment as 0.66 kg/m^2/year for bare soil, 0.12 kg/m^2/yr for vegetative soil and 0.36 kg/m^2/yr for the cultivated soil. In Mid-Bedfordshire, England, United Kingdom, Morgan (1982) recorded between 29.0 to 36.5 kg/m^2/yr for bare sandy soil in winter with a slope of 14% and for the same soil type, 22.6 kg/m^2/yr for a portion under vegetation for 3 months measurement period. The results obtained by Morgan (1982) is however different from what has been obtained in Samaru - Zaria on sandy loam soil during the rainy season on a slope of 5.8% for bare and 6.6% for the vegetative soil.The difference between Samaru's and Morgan's (1982) result can be attributed to the slope and soil type. The result is, however, comparable to 2.0 to 8.3 kg/m2 on bare soil obtained by Bolline (1978) on Brussels sand in Belgium for a 4-month period and 0.023 kg/m^2 for one season recorded by Leow and Ologe (1981) on a vegetated soil.

Similarly, an average of 0.92 kg/m^2 per month of soil loss was recorded in 1993, on bare soil plot, 0.30 kg/m^2 per month for vegetative soil plot and 0.05 kg/m^2 for cultivated soil. In 1995, an average soil loss of 0.54 kg/m^2 per month was recorded for bare soil plot, 0.30 kg/m^2 for the vegetated soil and 0.048 kg/m^2 for cultivated soil. In 1996, 0.74 kg/m^2 per month was recorded as an average soil loss on bare soil plot, 0.34 kg/m^2 for vegetated soil and 0.059 kg/m^2 for cultivated soil.

From Table 4.14, a mean erosion rate of 2.62 kg/m^2/yr was measured for bare soil on 5.8% slope, 1.15 kg/m^2/yr was recorded as a mean erosion rate for vegetation plot on 6.6% slope. The value of 2.62 kg/m^2/yr is, however, comparable with 3.46 kg/m^2/yr obtained by Ologe et.al. (1982) on a fine sand soils for Zaria area without reference to the slope; and Roose (1977) in Sefa Senegal having similar climate and soil charateristics to that experienced in Samaru gave a mean erosion rate as 2.3 kg/m^2/yr on 2.0% slope of land. The relatively high values recorded according to their reports indicate a rough terrain on which soil wash may be expected to be relatively high. In a separate study Leow and Ologe (1981), found that from a vegetated plot site, 0.023 kg/m^2 of soil wash was recorded for one year of study. This value is, however, not comparable to an annual average of 1.15 kg/m^2/yr obtained for this study on vegetated soil.

The soil loss estimated using Models 1 and 2 were relatively higher than the measured soil loss for most of the three years studied. It was however discovered that when soil detachment component was added to measured soil loss, predicted soil loss from Model 1 is almost the same with the measured value. Consequently, a curve fitting technique was used to obtain a linear relationship between the measured soil loss and the predicted.

Several factors may account for reasons why Model 2 predicted higher values than the measured values for both bare and vegetative soils and why Model 1 predicted close to the measured value. European Soil Erosion Model (EUROSEM) refered to as Model 1, was developed in European countries where the climate and soil vegetal cover are quite different from the tropical Guinea Savanna zone of Nigeria. Although the European climate and vegetal cover are quite different from those of the Guinea Savanna zone of Nigeria, the annual rainfall is confined to the months of April to October with rainfall sometimes similar to the convective tropical thunderstorms of high intensity and also of relatively short duration. The average monthly distribution of erosive rains is also comparable to that experienced in the middle belt zone of Nigeria (Aiyepeku, 1992). However, the type of vegetation and its distribution is different from what is obtainable in the Samaru-Zaria area. It is expected therefore, that the development of Model 1 must have taken into consideration the weather situation in those

countries even though it is recommended that it should be tried elsewhere.

Water Erosion Prediction Project (WEPP), (Model 2), was developed in the United States of America after the Universal Soil Loss Equation (USLE) from the crop land east of the Rocky Mountains. The rainfall record in the crop land east of the Rocky Mountains of the United States of America where the energy equation, an important component of the model was developed was quite high. Therefore, a high amount of rainfall was expected to be used in the programme. The WEPP can estimate soil loss on an annual basis, cummulative five-year basis, monthly basis and on storm by storm basis. One can see why it requires subtantial amount of rainfall before it can generate runoff. The following reasons account for why Model 2 cannot predict close to the measured value.

1. The threshold value for this model was set for $\geq$ 25mm of rainfall. In other words, it follows Hudson findings in Southern Rhodesia that erosion will not occur for rainfall less or equal to 25mm. That is, rainfall of small amount even with high intensity will not produce any measurable soil loss. Also, it was found that most of the daily rainfall amounts did not meet the criterion for erosion generation. Consequently, the rainfall amount were summed up for each month and then used to generate soil loss. Thus, it is obvious that the predicted soil loss

cannot be close to the measured soil loss. It therefore follows that Model 2 will not predict soil loss close to measured value if the rainfall is less than 25mm even if the infiltration value is low. Secondly, since, bare soil is more vulnerable to rain drop impact than the covered soil, the cummulative effect of soil loss estimated by Model 2 will be quite high as can be seen in Table 4.14.;

2. Model 2 incoporates the effects of tillage implements on the soil properties and residue amounts. This is a vital aspect of farm operations that will affect the computation of soil loss in the WEPP programme. It will also contribute to the total soil loss estimation. The soil under study is, however, left fallow; and
3. From 1992 to date, the amount of rainfall recorded from Institute for Agricultural Research, Ahmadu Bello University, Zaria, has drastically reduced as compared to the previous years. This again may be attributed to the desert encroachment or desertification currently experienced in the northern part of Nigeria. The compounded problem of low rainfall and the effect of desertification in Northern Guinea Savanna of Nigeria further supports why Model 2 cannot predict close to measured value because of low rainfall amount generally recorded on

a storm by storm basis as compared to the United States of America where a single storm can be as high as 200mm or more.

For the purpose of comparison, between measured values and those from Models 1 and 2 under investigation using data in Tables 4.13 and 4.14, it is to be noted that only the data for bare soil and vegetative soil were used, because:

(1) The natural slope of 0.83% for the cultivated soil plot cannot give any measurable amount of soil loss for both Models 1 and 2.

(2) Model 1 has no input provision for cultivated soil.

(3) Another reason that resulted into formation of Tables 4.13 and 4.14 on monthly basis is that the Model 2 cannot predict erosion for rainfall amount below 25mm even if the infiltration rate of the soil is low hence the reason for the summation of rainfall amount on monthly basis for ease of comparison. For example, in Table 4.15, single rainfall events $\geq$ 25mm were extracted from Tables 4.4, 4.5 and 4.6 for 1993, 1995 and 1996 rainfall season, respectively.

The observed soil loss were compared with predicted values of Models 1 and 2 for both bare and vegetated soil plots. It was observed that for all the rainfall event $\geq$ 25mm recorded, Model 1 was able to predict soil loss for both bare and vegetated soil. Model 1 could not predict soil loss despite the fact that the single rainfall event was more than 25mm but was limited by infiltration rate of the soil. Model 2 denotes "no

rainfall excess" where the infiltration rate was higher than the rainfall amount in the case of bare soil and computes zero soil loss where the infiltration was less than the rainfall amount. The reason behind erratic behaviour of Model 2 at this stage can be linked with Horton (1945) who explained that if rainfall intensity is less than the infiltration capacity of the soil, no surface runoff would occur and the infiltration rate equals the rainfall intensity. If the rainfall intensity exceeds the infiltration capacity the excess rainfall will form surface runoff. However, this comparison of rainfall intensity and infiltration capacity does not always hold (Morgan, 1986). The selected rainfall amount as indicated in Table 4.15 indicates that Model 1 produced soil loss as was obtained from field measurements. This is contrary to Model 2 which works on the Horton's theory. The fact is that the important control for runoff production on these soils is not infiltration capacity but a limiting soil moisture content which, when exceeded, results in a reduction of the pore water pressure at the soil surface to zero, allowing ponding of water to take place (Morgan, 1986). This explains why sands, which have low levels of capillary storage produce runoff very quickly even though their infiltration capacity are not exceeded by the rainfall intensity.

Table 4.15: Selected rainfall amount for soil loss comparison

Date and Year	Ra (mm)	Infiltration Rate (mm/hr)	Observed Soil Loss (kg/m2)		Model 1 Soil loss (kg/m2)		Model 2 Soil loss (kg/m2)	
		at steady state	Bare	veg	bare	veg	bare	veg
18/8/93	37.7	61.5	0.24		0.26		-	
		13.0		0.07		0.088		0.0
17/7/95	30.5	65.0	0.085		0.104		-	
		12.0		0.06		0.069		0.0
24/8/95	32.6	65.0	**0.09**		0.104		-	
		12.0		0.055		0.068		0.0
14/9/96	55.0	63.0	**0.21**		0.24		-	
		12.5		**0.10**		0.110		0.0
		12.5					0.92	
	25.00	12.5					-	

The Sign "-" denotes no rainfall excess to generate runoff

Graphs of predicted soil loss against measured soil loss for the bare soil for the three years of study 1993, 1995 and 1996 for Models 1 and 2 were plotted (Figs 4.11 and 4.12). In the same manner, graphs of predicted soil loss (kg/m^2) against measured soil loss (kg/m^2) were plotted for vegetated soil using Models 1 and 2 for the three years namely, 1993, 1995 and 1996 (Figs 4.13 & 4.14).

Four regression equations were finally arrived at, namely:-

BARE SOIL

(1) $Y = -0.028 + 1.03X$ 4.5

from Model 1 having an r value of 0.98

(2) $Y = -3.45 + 10.64X$ 4.6

from Model 2 having an r value of 0.45

where:

Y = Predicted soil loss (kg/m^2)

X = Measured soil loss (Kg/m^2)

VEGETATED SOIL

(1) $Y = -0.009 + 1.10X$ 4.7

from Model 1 having r value of 0.97 and

(2) $Y = -5.42 + 36.5X$ 4.8

from Model 2 having an r value of 0.12

where:

Y = Predicted soil loss (kg/m^2)

X = Measured soil loss (kg/m^2)

4.5 Results validation

In order to validate the use of the model recommended in this study, an attempt was made by comparing the predictions made by the model with the observed data that is, field observations and applying least - squares estimators or some measure of goodness of fit to determine whether or not a close relationship exists between predicted and observed values. In other words, a statistical test is employed to determine whether the regression equations (4.5 and 4.8) have intercepts and slopes that are significantly different from zero and 1.0,

respectively.

Thus, Eqs. 4.5 and 4.7 both from Model 1 were found to have intercepts and slopes that were not significantly different from zero and 1.0, respectively at 95% probability level. Equations 4.5 and 4.7 for estimating soil loss (kg/m2) under bare and vegetated soils, respectively is recommended for use for the Northern Guinea Savanna conditions.

4.6 Inferences from discussion of results

(1) At the end of three rainny seasons, observation of the experimental site and the analysis of measured data, showed a considerable general lowering and flattening of the landscape in the drainage basin towards the direction of the Dam.

(2) For the vegetated soil plot, Net/Maximum deposition was recorded in the middle and small areas of the experimental plot, indicating the importance of processes of soil loss. Applying these processes of soil loss to a fairly large area means that the deposition spot experienced for a smaller area could be surrounded by a fairly extensive area in which no measurable changes appear to have taken place during the study period.

(3) Therefore, from 2 above, the study underscores the importance of vegetation cover in the process of erosion. A vegetation cover also enhances

infiltration of rainwater and so reduces the surface runoff and the rate of soil wash.

(4) This study is relevant in the fight against desertification in the Northern Guinea Savanna Zone.

CHAPTER 5

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary

The possibility of establishing an equation for estimating soil loss in Samaru - Zaria environment was investigated using measured values and two erosion computer models. Three experimental plots were established namely: bare soil, vegetated soil and cultivated soil to measure soil detachment, soil loss and runoff on a storm by storm basis the at Ahmadu Bello University farm in Shika - Samaru . In addition to physical and chemical properties of the soil, some other parameters as required by each model were measured during the 3 years of study.

Soil detachment losses were measured by collecting all splash losses in a 25mm x 31mm hollow rectangular plastic container buried in the soil in a grid pattern to catch soil splash at a maximum of 1.0m radius. Similarly, both runoff and soil loss were also collected inside a drum buried at the end of each plot. The measured and predicted soil loss values relationship from the 3 years of study for Model 1 (EUROSEM) are linear, normal and somehow ramarkably similar for bare and vegetated soils. The 't' tests performed on the adopted regression equations from measured values on bare and vegetated soil shows that both the intercepts and slopes of the equations are not significantly different from the predicted values at

the 95 percent confidence level.

Analysis and comparison of the results indicate high rates of soil detachment of 0.66 kg/m^2 per year for bare soil, 0.12 kg/m2 for vegetated soil and 0.36 kg/m2 for the cultivated soil. An average of 0.73 kg/m2 of soil loss was obtained annually for bare soil, 0.312 kg/m2 for vegetated soil and 0.09 kg/m2 for the cultivated soil. A mean erosion rate of 2.62 kg/m2/yr was measured for bare soil on 5.8% slope while 1.15 kg/m2/yr was recorded as mean erosion rate for vegetated plot on 6.6% slope.

Slight over prediction of tested model was experienced. However, the European Soil Erosion Model (EUROSEM) is recommended for erosion prediction for bare and vegetated soil condition in Samaru - Zaria environment, while the Water Erosion Prediction Project Model (WEPP) (Model 2) is recommended for further experimentation in the southern part of Nigeria where substantial amount of rainfall per single storm normally occurs which can be comparable to the United States of America where the model was developed. The study concludes with emphasis on using a soil conservation planning guide of 2.7 kg/m2/yr erosion rate in Samaru - Zaria, Northern Guinea Savanna zone of Nigeria.

5.2 Conclusions

Modern concepts in agriculture make it imperative that the farming system in Nigeria must meet high stardards of performance. Among this is erosion control which is responsible for high food production. These have been investigated in the present study.

A study of erosion of the University farm reveals a close relationship between rainfall, intensity, kinetic energy and the severity of erosion and landuse on the one hand, and measured value of erosion and the predicted value on the other. The slope forms with their rapidly natural steepening convexity and lengths of varied dimensions within the University farm are typical of erodible areas within the Northern Guinea Savanna zone of Nigeria.

(1) A soil detachment rate of 0.66 kg/m2/yr for bare soil on 5.8% slope was recorded as the average of three years data; 0.12 kg/m2/yr on 6.6% slope for the vegetative soil and 0.36 kg/m2/yr on 0.83% slope for the cultivated soil. Similarly, an erosion rate of 2.62 kg/m2/yr on a 5.8% slope for bare soil on sandy loamy soil was recorded, 1.15 kg/m2/yr for vegetation soil on 6.6% slope and 0.20 kg/m2/yr for the cultivated soil on 0.83% slope. These results has been shown to be comparable to previous researchers.

(2) A relationship to estimate kinetic energy in $J/m^2/mm$ from rainfall amount (mm) was established (Eq 4.2 with r value of 0.96 and Fig.4.2). The accuracy involved in the use of Model 1 was determined by using regression technique for the predicted soil loss versus measured for both bare soil and vegetated soil. The correlation coefficient was found to be 0.983 and 0.986 respectively. Thus, the European Soil Erosion Model (EUROSEM) (Model 1) is recommended for use in Zaria. It is also recommended that further work be done on different soils in Nigeria, while Water Erosion Prediction Project (WEPP) Model 2 is recommended for further work in the southern part of Nigeria where daily rainfall amounts are much higher.

Suggestions for Further Work

The study has established the fact that soil detachment and soil loss related to rainfall impact energy. The impact energy of rainfall on the soil surface with or without vegetation, is therefore, a potential tool for predicting soil loss. In order to fully utilise this parameter for the purpose of concluding which of the two models is best suited for Nigeria's Guinea Savanna situation, the following suggestions for further study are made:

(1) Investigation into the effect of different energy equations used in programming the two models be conducted. It was observed that the two models used different energy equations for Model 1 and for Model 2, and there were no means of investigating into the energy equations used in each model for comparison. If this is done, there will be changes in the outputs of the individual models.

(2) Elaborate field studies on the effect of different slopes on soil loss using the two models be carried out. This study may establish a relationship which may be more practicable for soil loss prediction because of obvious natural topography. All other field parameters like, vegetation, soil type etc., may either affect erosivity, nature of rainfall or infiltration but not the carrying capacity of runoff of which slope is the dominant factor in estimating

soil loss. When such an investigation is conducted, a curvilinear relationship with some constants may prevail. The suggested study is necessary if soil conservation efforts in fighting desertification in Northern Guinea Savanna are required for a long term protection on our soil or if overall field results is to be applied in other areas.

(3) It is also suggested that a similar study be carried out else where to further standadise the results of erosion rates obtained in this study with a view to generalising a soil conservation planning guide recommended in this study.

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APPENDIX A

Date of Measurement:----------
Rainfall Amount for the day:-------
Year : ----------

Slope of Plot A =
" B =
" C =
" D =

SAMPLE OF FIELD DATA SHEET

Bare Soil (no vegetation) A				Bare Soil (no vegetation) B				Vegetation Plot C				Cultivated Plot (furrow) D			
splash trap	wt. of can + wet soil	wt. of can + oven dried soil	wt. of dried soil	splash trap	wt. of can + wet soil	wt. of can + oven dried soil	wt. of dried soil	splash trap	wt. of can + wet soil	wt. of can + oven dried soil	wt. of dried soil	splash trap	wt. of can + wet soil	wt. of can + oven dried soil	wt. of dried soil
A1				B1				C1				D1			
A2				B2				C2				D2			
A3				B3				C3				D3			
A4				B4				C4				D4			
A5				B5				C5				D5			
Averaged soil detached (g/m^2)															
Runoff volume (cm^3)															
Soil Loss (kg/m^2)															

APPENDIX B

Computation of Intensity mm/hr and Rainfall Amount from the rain gauge chart of 1968

Date	Incremental Time (min)	Cummulative Time (min)	Amount of Rain Rain (mm)	Intensity mm/hr
18/4/68	7.5		11.43	91.44
	15		5.08	20.32
	60		1.27	1.27
	135	217.5	3.81	1.69
25/4/68	3.75	3.75	0.33	5.28
24/4/68	15		3.81	15.24
	127.5		0.635	0.23
	7.5	150	1.27	10.16
23/4/68	60		1.27	1.27
	101.25		3.81	2.26
	45	206.25	0.635	0.847
22/4/68	15	15	3.175	12.70
20/4/68	82.5		0.635	0.462
	150	232.5	1.905	0.03
19/4/68	15		30.32	81.28
	30	45	1.905	3.81
13/4/68	90	90	1.905	1.27
29/5/68	15	15	15.24	60.96
28/5/68	90	90	1.27	0.847
27/5/68	82.5	82.5	2.54	1.85
26/5/68	15		8.89	35.56
	30		0.423	0.846
	75	120	5.715	4.572
25/5/68	30	30	1.905	3.81
22/5/68	60	60	1.905	1.905
21/5/68	7.5		0.635	5.08
	11.25		1.905	10.16
	18.75		0.635	2.032
	82.50	120	5.08	3.70
19/5/68	30		20.32	40.64
	75		8.89	7.11
	120	225	1.905	0.95
17/5/68	30	30	19.05	38.10
15/5/68	22.5		20.32	54.19
	18.75		4.445	14.22
	26.25		1.27	2.903
	168.75	236.25	2.54	0.903
11/5/68	15	15	15.24	60.96
9/5/68	30	30	1.905	3.81
29/6/68	15		5.08	20.32
	22.5		2.22	5.92
	120	157.5	4.445	2.22
27/6/68	30		6.35	12.7
	45		4.445	5.93
	120	195	3.175	1.59
24/6/68	180	180	10.16	3.39
18/6/68	22.5		11.43	30.48
	37.5		3.81	6.096
	75		3.81	3.048
	75	210	2.54	2.032
13/6/68	22.5		5.08	13.55
	22.5		1.905	5.08
	97.5		4.76	2.93
	120	262.5	5.715	2.86

	7.5	37.5	1.27	10.16
9/6/68	15		5.08	20.32
	30	45	1.27	2.54
4/6/68	15	15	5.715	22.86
24/7/68	7.5		3.81	30.48
	22.5		6.35	16.93
	60	90	4.445	4.445
22/7/68	45	45	1.27	1.69
18/7/68	7.5		0.635	5.08
	45		1.905	2.54
	15		3.81	15.24
	240		2.54	0.635
	7.5		8.89	71.12
	105	420	7.62	4.37
15/7/68	45		3.81	5.08
	7.5		5.715	45.72
	150	202.5	2.54	1.016
14/7/68	60		1.27	1.27
	30		5.08	10.16
	195		5.08	1.56
	180	465	2.54	0.847
10/7/68	30		5.08	10.16
	7.5		1.27	10.16
	75	112.5	1.59	1.27
5/7/68	7.5		2.54	20.32
	15		13.97	55.88
	45		3.175	4.23
	202.5	270	4.445	1.32
4/7/68	7.5		1.905	15.24
	82.5		2.54	1.85
	405		0.635	0.094
	112.5	607.5	24.13	12.87
3/7/68	11.25		1.905	10.16
	86.25		1.27	0.88
	26.25	123.75	1.27	2.90
1/7/68	15		4.445	17.70
	22.5		3.175	8.47
	24.0	277.5	17.78	4.445
31/8/68	15	15	6.35	25.40
30/7/68	7.5		0.423	3.39
	30	37.5	0.953	1.906
29/8/68	33.75		1.27	2.26
	105	138.75	1.27	0.736
25/8/68	7.5		0.635	5.08
	75	82.5	1.905	1.524
23/8/68	90		5.08	3.39
	45		22.86	30.48
	45	150	11.43	15.24
22/8/68	33.75		3.81	6.77
	90		13.97	9.31
	75		2.54	2.032
	105	303.75	2.54	1.45
19/8/68	15		10.16	40.64
	75		1.27	1.016
	75		15.24	12.19
	60	225	2.86	2.86
18/8/68	60	60	1.905	1.905
17/8/68	90	90	1.905	1.27
16/8/68	15		8.89	35.56
	22.5		7.62	20.32
	45	82.5	0.635	0.847

	30		5.08	10.16
	165	210	11.11	4.04
13/8/68	3.75	3.75	2.22	35.56
12/8/68	60	60	16.51	16.51
11/8/68	15	15	4.445	17.78
7/8/68	22.5		8.89	23.71
	30		22.86	45.72
	75		5.08	4.06
	135	262.5	5.08	2.26
6/8/68	7.5		10.16	81.28
	7.5	15	3.81	30.48
3/8/68	221.25		0.318	0.086
	90		0.423	0.282
	7.5	318.75	7.62	60.96
2/8/68	30	30	15.24	30.48
1/8/68	22.5	22.5	0.635	1.69
29/9/68	30		16.51	33.02
	120	150	1.27	0.635
25/9/68	7.5	7.5	3.81	30.48
22/9/68	67.5		19.05	16.93
	172.5	240	5.72	1.99
16/9/68	15	15	14.61	58.42
15/9/68	30		16.51	33.02
	60	90	1.59	1.59
8/9/68	7.5	7.5	1.27	10.16
7/9/68	30	30	16.51	33.02
6/9/68	11.25		9.53	50.80
	105		2.54	1.44
	45	161.25	4.445	5.93
5/9/68	30		0.635	1.27
	30	60	0.635	1.27
4/9/68	7.5		1.905	15.24
	135	142.5	3.175	1.41
3/10/68	7.5		7.62	60.96
	7.5	15	0.635	5.08

APPENDIX C

Computation of Intensity (mm/hr) and Rainfall Amount from the rain gauge chart of 1969

Date	Incremental Time (min)	Cummulative Time (min)	Rainfall Amount (mm)	Intensity (mm/hr)
29/3/69	30	30	6.985	13.97
12/4/69	10	10	1.016	6.096
24/4/69	4	4	0.635	9.53
26/4/69	10	10	7.62	45.72
9/4/69	90	90	6.35	4.23
11/4/69	60		9.53	9.53
	120	180	6.99	3.49
8/5/69	45	45	17.78	23.71
9/5/69	30		12.7	25.40
	60	90	7.62	7.62
10/5/69	30		8.89	17.78
	240	270	1.91	0.48
13/5/69	20	20	5.08	15.24
14/5/69	40	40	17.78	26.67
15/5/69	150	150	6.35	2.54
27/5/69	15		5.08	20.32
	60	75	2.54	2.54
29/5/69	60	60	1.27	1.27
24/5/69	40	40	1.91	2.86
31/5/69	4	4	2.54	38.10
1/6/69	20		8.89	26.67
	6	26	3.18	31.75
3/6/69	15	15	0.64	2.54
18/6/69	15		12.70	50.8
	60	75	6.99	6.99
19/6/69	15		7.62	30.48
	30		24.13	48.26
	60	105	3.18	3.18
20/6/69	30	30	5.08	10.16
22/6/69	22.5	22.5	16.51	44.03
23/6/69	30	30	10.16	20.32
24/6/69	120		0.64	0.32
	15		3.81	15.24
	60	195	5.72	5.72
27/6/69	7.5		7.62	60.96
	30	37.5	0.64	1.27
28/6/69	45		25.40	33.87
	120	165	11.43	5.72
29/6/69	12		15.24	76.20
	30		0.64	1.27
	7.5		6.35	50.80
	12	61.5	2.54	12.70
1/7/69	50		6.35	7.62
	60	110	6.35	6.35
4/7/69	60		2.54	2.54
	60	120	11.43	11.43
5/7/69	90	90	7.62	5.08
6/7/69	4	4	2.54	38.10

	120	160	3.81	1.91
8/7/69	25		26.67	64.01
	20	45	3.81	11.43
10/7/69	35	35	14.72	25.23
14/7/69	20	20	20.40	76.20
15/7/69	60	60	6.35	6.35
19/7/69	15	15	15.30	61.20
26/7/69	30		24.13	48.26
	50	80	6.35	7.62
27/7/69	90		10.16	6.77
	70	160	8.26	7.11
29/7/69	6	6	2.54	25.40
3/8/69	50		21.98	26.38
	100	150	5.72	3.43
5/8/69	15		4.445	17.78
	30	45	2.54	5.08
6/8/69	30	30	10.16	20.32
7/8/69	15	15	1.27	5.08
8/8/69	30	30	17.45	34.9
9/8/69	30		5.72	11.43
	60		0.64	0.64
	90	180	4.45	2.96
11/8/69	30	30	6.35	12.7
12/8/69	15	15	12.1	48.40
13/8/69	15	15	7.62	30.48
14/8/69	90	90	5.08	3.39
15/8/69	30	30	1.27	2.54
17/8/69	120		1.27	0.64
	360	480	15.24	2.54
18/8/69	10		6.35	38.10
	100		3.81	2.29
	45		22.70	43.60
	60	215	2.54	2.54
19/7/69	30	30	11.43	22.86
20/8/69	180	180	1.27	0.42
21/8/69	50	50	10.16	12.19
22/8/69	15	15	11.43	45.72
24/8/69	30		24.13	48.26
	50		1.91	2.29
	90	170	3.81	2.54
25/8/69	30	30	1.27	2.54
27/8/69	30		10.16	20.32
	150	180	8.89	3.56
29/8/69	45	45	10.16	13.55
31/8/69	15	15	10.16	40.64
1/9/69	10	10	1.27	7.62
6/9/69	15	15	12.4	49.60
8/9/69	60	60	1.91	1.91
10/9/69	15		16.70	66.80
	45	60	18.20	24.27
17/9/69	60		6.70	6.70
	25	85	14.20	34.08
18/9/69	35	35	16.20	27.77
20/9/69	35		8.10	13.89
	45	80	5.70	7.60
23/9/69	90	90	2.40	1.60
28/9/69	65	65	8.20	7.57

APPENDIX D

DEPARTMENT OF METEOROLOGICAL SERVICES

Form Met. 14/5 (revised 1970)

REGISTER OF RAINFALL IN 1973

Station SAMARU.. Station Number 65.030 State KADUNA.

Latitude 11°08'N.. Longitude 07°41'E. Altitude...656.....

Record of Rainfall measured at 06 G.M.T.* in Nigeria and entered against day preceding that on which read, in accordance with the Nigerian instructions in Form Met 111/2.

OSP. 635593. Lagos.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1					18.8			10.2	14.9			
2						29.6	3.3					
3								22.3				
4					3.5		25.4	3.2	53.2			
5						29.4			2.2			
6									12.7			
7					0.5	13.2	TR					
8			TR					17.7	1.9			
9												
10							13.5		16.8			
11												
12						6.1		12.3	33.2			
13												
14			TR									
15			TR					13.1				
16					7.1							
17				3.1				63.3	6.9			
18					5.1			37.7	16.5			
19							15.6					
20				1.2			32.1	11.1	8.4			
21					1.0		75.6	19.7				
22						25.1						
23					2.7	3.0	34.6	21.9	2.3			
24					12.5		1.2	12.1				
25				1.2	22.2		50.0		12.8			
26						4.7						
27					19.8		8.5	6.3				
28												
29				2.8		28.1	8.2					
30		XXX			2.7	16.6	1.6	11.2				
31		XXX			17.7	XXX		31.2	XXX		XXX	
Total	0.0	0.0	TR	8.3	113.6	55.8	269.0	300.8	181.3	0.0	0.0	0.0
Days with 0.3 mm or more												
Days With 1.0 mm or more												

TOTAL FOR THE YEAR = 1029.3

APPENDIX E

(Revised 1978)

DEPARTMENT OF METEOROLOGICAL SERVICES

REGISTER OF RAINFALL IN 1995

Station SAMARU Station Number 65036 State KADUNA

Latitude 11° 12'N Longitude 07° 41'E Altitude 686

Record of Rainfall measured at 06 G.M.T.* in Nigeria and entered against day preceding that on which read, in accordance with the Nigeria

OSP. 635593. Lagos.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1	..											
2							12·3	11·4				
3					30·5			24·4		4·6		
4						21·0		13·0				
5							13·2	2·3		13·2		
6								0·7	2·5			
7					0·3	9·8	11·3	17·4	2·6			
8						1·1		3·0	32·8	14·7		
9						7·5		0·4	1·4			
10								15·7				
11								0·4	30·5			
12						5·3		1·0	3·3			
13								18·0	16·4			
14						13·8		16·6	1·7			
15				14·0					5·1			
16						18·7			18·8			
17							30·5		2·6			
18						20·9	3·2	22·0				
19							1·7	4·1				
20						7·7	16·9	11·5	2·1			
21							25·2	10·5				
22					12·7				8·7			
23				65·0		11·0	6·8		8·8			
24								32·6	6·6			
25												
26				TR			4·3	13·1				
27				3·2		7·4	14·1					
28								19·5	15·2			
29					1·8			5·5				
30	XXX			8·3		1·2	13·0	15·2				
31	XXX		XXX		XXX		3·1	15·2	XXX		XXX	
Total				90·5	45·3	125·4	155·6	258·6	159·1	32·5		
Days with 0.3 mm or more				90·5	135·8	261·2	416·8	675·4	834·5	867·0		
Days with 1.0 mm or more												

EUROSEM 3 STATIC SUMMARY FILE

RUN TITLE: rainfall input data of 14/9/96 VEGETATION

INPUT DATA FOR ELEMENT 1

NU:	0				
W:	4.00 M	XL:	6.00 M	S:	.07
MANN:	.030	FMIN:	12.50 MM/HR	G:	230.00 MM
POR:	.50	THI:	.35	THMX:	.39
ROC:	.00	RECS:	9.00 MM	DINTR:	1.20 MM
DEPNO:	2.00	RS:	.0	RFR:	1.000 %
ZLR:	1.00	RILLW:	.01 M	RILLD:	.01 M
COVER:	.99	SHAPE:	1	PANG:	90.01 o
PBASE:	.00	RHEIG:	.00 M	D50:	200.00 um
EROD:	2.00 G/J	SPLTX:	2.00	COH:	3.50 KPA
RHOS:	2.65kgm3	PAVE:	.00	SIGMA:	.00
SIR:	.660	DERO:	2.00 m		

Derived parameters: MN(IR): .030 SurfStor: .000002 mm

Interrill Flow Length Ratio 1.00
Interrill Velocity Ratio 3.1623

EROSION SUMMARY

GROSS RILL EROSION	.664 kg	.277 t/ha
GROSS INTERRILL EROSION	.000 kg	.000 t/ha
NET EROSION/DEPOSITION (a minus denotes deposition)	2.711 kg	1.130 t/ha

HYDROLOGY SUMMARY, ELEMENT 1

NET RAINFALL	= 21.103	(MM)
PEAK RAINFALL RATE	= 3798.5	(MM/H)
TIME TO RUNOFF	= .30000	(SEC)
DURATION OF RUNOFF	= 19.500	(SEC)
TIME TO PEAK FLOW RATE	= 6.0000	(SEC)
PEAK FLOW RATE	= 3876.7	(MM/H)
TIME TO PEAK SEDIMENT DISCHARGE	= 19.500	(MIN)
PEAK SEDIMENT DISCHARGE	= 11.290	(kg/MIN)

RILL DIMENSION SPATIAL SUMMARY, ELEMENT 1

DISTANCE DOWNSLOPE M	RILL DEPTH mm	RILL WIDTH mm	DEPTH INCREASE mm	WIDTH INCREASE mm

.00	4.47	10.00		
.43	6.22	12.30	.00	.00
.86	6.83	12.46	1.15	2.30
1.29	7.38	12.57	1.23	2.46
1.71	7.88	12.67	1.29	2.57
2.14	8.38	12.81	1.33	2.67
2.57	8.82	12.90	1.41	2.81
3.00	9.23	12.98	1.45	2.90
3.43	9.63	13.05	1.49	2.98
3.86	10.01	13.12	1.52	3.05
4.29	10.37	13.18	1.56	3.12
4.71	10.72	13.24	1.59	3.18
5.14	11.06	13.29	1.62	3.24
5.57	11.36	13.35	1.65	3.29
6.00	11.70	13.40	1.67	3.35
			1.70	3.40

GLOBAL VOLUME BALANCE
=====================

TOTAL RAINFALL DEPTH = 21.103 (MM)

STORAGE REMAINING ON ALL PLANES = 3.96768 (MM)
STORAGE REMAINING IN CHANNELS+CONDUITS = .00000 (MM)
STORAGE REMAINING IN PONDS = .00000 (MM)
TOTAL INFILTRATION FROM ALL PLANES = 1.15359 (MM)
TOTAL INFILTRATION FROM ALL CHANNELS = .00000 (MM)
TOTAL BASIN RUNOFF = 16.31660 (MM)

TOTAL OF STOR., INFIL. AND RUNOFF TERMS = 21.43786 (MM)

*** GLOBAL VOL. ERROR = -1.5880 PERCENT ***

EUROSEM 3 STATIC SUMMARY FILE

RUN TITLE:rainfall input data of 14/9/96 bare soil

INPUT DATA FOR ELEMENT 1

NU:	0				
W:	4.00 M	XL:	6.00 M	S:	.06
MANN:	.030	FMIN:	63.00 MM/HR	G:	230.00 MM
POR:	.45	THI:	.35	THMX:	.39
ROC:	.00	RECS:	9.00 MM	DINTR:	1.20 MM
DEPNO:	2.00	RS:	.0	RFR:	1.000 %
ZLR:	1.00	RILLW:	.01 M	RILLD:	.01 M
COVER:	.00	SHAPE:	1	PANG:	1.00 o
PBASE:	.00	PHEIG:	.00 M	D50:	200.00 um
EROD:	2.00 G/J	SPLTX:	2.00	COH:	3.50 KPA
RHOS:	2.65kgm3	PAVE:	.00	SIGMA:	.00
SIR:	.060	DERO:	2.00 m		
Derived parameters:		MN(IR):	.030	SurfStor:	.000002 mm

Interrill Flow Length Ratio 1.39
Interrill Velocity Ratio 1.0171

EROSION SUMMARY

GROSS RILL EROSION	.432 kg	.180 t/ha
GROSS INTERRILL EROSION	.000 kg	.000 t/ha
NET EROSION/DEPOSITION (a minus denotes deposition)	5.769 kg	2.404 t/ha

HYDROLOGY SUMMARY, ELEMENT 1

NET RAINFALL	=	21.569	(MM)
PEAK RAINFALL RATE	=	3882.4	(MM/H)
TIME TO RUNOFF	=	.30000	(SEC)
DURATION OF RUNOFF	=	19.500	(SEC)
TIME TO PEAK FLOW RATE	=	9.9000	(SEC)
PEAK FLOW RATE	=	3764.3	(MM/H)
TIME TO PEAK SEDIMENT DISCHARGE	=	19.800	(MIN)
PEAK SEDIMENT DISCHARGE	=	29.026	(kg/MIN)

RILL DIMENSION SPATIAL SUMMARY, ELEMENT 1

DISTANCE DOWNSLOPE	RILL DEPTH	RILL WIDTH	DEPTH INCREASE	WIDTH INCREASE
M	mm	mm	mm	mm

.00	4.47	10.90	.60	.60
.43	5.79	11.24	.72	1.44
.86	6.37	11.53	.77	1.53
1.29	6.89	11.59	.80	1.59
1.71	7.37	11.96	.83	1.66
2.14	7.80	12.07	.83	1.67
2.57	8.44	12.15	1.08	2.15
3.00	8.63	11.78	.89	1.78
3.43	9.02	11.83	.92	1.83
3.86	9.30	11.87	.94	1.87
4.29	9.74	11.92	.96	1.92
4.71	10.08	11.96	.98	1.95
5.14	10.40	11.99	.99	1.99
5.57	10.72	12.02	1.01	2.02
6.00	11.03	12.05	1.03	2.05

GLOBAL VOLUME BALANCE

TOTAL RAINFALL DEPTH	=	21.569 (MM)
STORAGE REMAINING ON ALL PLANES	=	6.41247 (MM)
STORAGE REMAINING IN CHANNELS+CONDUITS	=	.00000 (MM)
STORAGE REMAINING IN PONDS	=	.00000 (MM)
TOTAL INFILTRATION FROM ALL PLANES	=	2.65509 (MM)
TOTAL INFILTRATION FROM ALL CHANNELS	=	.00000 (MM)
TOTAL BASIN RUNOFF	=	13.33550 (MM)
TOTAL OF STOR., INFIL. AND RUNOFF TERMS	=	22.40306 (MM)

*** GLOBAL VOL. ERROR = 3.8687 PERCENT ***

USDA WATER EROSION PREDICTION PROJECT

HILLSLOPE PROFILE AND WATERSHED MODELS
VERSION 94.700 August 31, 1994

WARNING : THIS PROTOTYPE VERSION HAS NOT BEEN VALIDATED. TO REPORT PROBLEMS OR TO BE PUT ON THE MAILING LIST FOR FUTURE WEPP MODEL AND DOCUMENTATION RELEASES, PLEASE CONTACT

DENNIS FLANAGAN (HILLSLOPE MODEL)
PHONE: (317) 494-8673

JIM ASCOUGH II (WATERSHED MODEL)
PHONE: (303) 490-8371

AT THE FOLLOWING ADDRESS:

USDA-AGRICULTURAL RESEARCH SERVICE
NATIONAL SOIL EROSION RESEARCH LABORATORY
1196 SOIL BUILDING, PURDUE UNIVERSITY
WEST LAFAYETTE, IN 47907-1196
FAX: (317) 494-5948

PUT DATA FILES - PROTOTYPE VERSION 94.700
August 31, 1994

lled Fallow
ldboard Plow in Spring (May 15)
sked Monthly, June-Nov. and April
MANAGEMENT:C:\WEPP\DIST\INPUT\MAN\DATA\FALLOW.man
SLOPE:C:\WEPP\DIST\INPUT\SLOPE\DATA\ADE.slp
CLIMATE:C:\WEPP\DIST\INPUT\CLIMATE\DATA\ADE3.cli
Station: SAMARU ZARIA (Month of July Bare Soil) CLIGEN VERSION 3.0
3.00
SOIL:C:\WEPP\DIST\INPUT\SOIL\DATA\ADE.sol
PLANE 1 Keith Sandy loam

SINGLE STORM HYDROLOGY

infiltration, rainfall excess, and runoff hydrograph for event of 30
95

hydrology summary

rainfall amount	96.20	(mm)
rainfall duration	26.40	(min)
normalized peak intensity	1.20	
normalized time to peak	0.21	

rainfall

time (min)	intensity (mm/hr)
0.00	224.38
6.43	244.94
12.32	218.87
18.92	192.79
26.40	0.00

****

****
hillslope 1
****

****
overland flow element 1
****

infiltration input parameters

effective saturated conductivity	61.50	(mm/h)
effective matric potential	37.88	(mm)
effective porosity	0.52	(mm/mm)
saturation	30.00	(%)
canopy cover	0.00	(%)
surface cover	0.00	(%)

input runoff parameters

plane length	6.00	(m)
discharge exponent	1.50	
average slope of profile	0.03	

APPENDIX F

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem
0.06	0.330	1
0.12	0.410	1
0.18	0.491	1
0.24	0.572	1
0.30	0.652	1
0.36	0.733	1
0.42	0.814	1
0.48	0.894	1
0.54	0.975	1
0.60	1.056	1
0.66	1.136	1
0.72	1.217	1
0.78	1.297	1
0.84	1.365	1
0.90	1.373	1
0.96	1.373	1
1.02	1.373	1
1.08	1.373	1
1.14	1.373	1
1.20	1.373	1
1.26	1.373	1
1.32	1.373	1
1.38	1.373	1
1.44	1.373	1
1.50	1.373	1
1.56	1.373	1
1.62	1.373	1
1.68	1.373	1
1.74	1.373	1
1.80	1.373	1
1.86	1.373	1
1.92	1.373	1
1.98	1.373	1
2.04	1.373	1
2.10	1.373	1
2.16	1.373	1
2.22	1.373	1
2.28	1.373	1
2.34	1.373	1
2.40	1.373	1
2.46	1.373	1
2.52	1.373	1
2.58	1.373	1
2.64	1.373	1
2.70	1.373	1
2.76	1.373	1
2.82	1.373	1
2.88	1.373	1
2.94	1.373	1
3.00	1.373	1
3.06	1.373	1
3.12	1.373	1
3.18	1.373	1
3.24	1.373	1
3.30	1.373	1
3.36	1.373	1
3.42	1.373	1
3.48	1.373	1
3.54	1.373	1
3.60	1.373	1
3.66	1.373	1
3.72	1.373	1
3.78	1.383	1
3.84	1.416	1
3.90	1.450	1
3.96	1.484	1
4.02	1.519	1
4.08	1.555	1
4.14	1.591	1
4.20	1.627	1
4.26	1.664	1
4.32	1.701	1
4.38	1.739	1
4.44	1.777	1
4.50	1.816	1
4.56	1.854	1
4.62	1.893	1
4.68	1.932	1
4.74	1.972	1
4.80	2.012	1
4.86	2.052	1
4.92	2.092	1
4.98	2.133	1
5.04	2.174	1
5.10	2.215	1
5.16	2.256	1
5.22	2.297	1
5.28	2.339	1
5.34	2.381	1
5.40	2.423	1
5.46	2.465	1
5.52	2.507	1
5.58	2.550	1
5.64	2.592	1
5.70	2.635	1
5.76	2.678	1
5.82	2.721	1
5.88	2.764	1
5.94	2.807	1
6.00	2.851	1

Note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

A. SEDIMENT LEAVING PROFILE for jul 30 1 9.430 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Fraction Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	41.5	0.034 0.044
2	0.010	2.65	0.0	100.0	0.0	0.0	0.146 0.185
3	0.030	1.80	0.0	74.5	25.5	10.6	0.234 0.300
4	0.300	1.60	71.9	17.4	10.7	4.4	0.342 0.271
5	0.200	2.65	100.0	0.0	0.0	0.0	0.244 0.199

SSA enrichment ratio leaving profile for jul 30 1 = 1.15

APPENDIX F

chezy coefficient 2.66 (m**0.5/s)

utput runoff parameters

equivalent sat. hydr. cond.	61.50	(mm/hr)
equivalent matr. potential	37.88	(mm)
average pore fraction	0.52	(m/m)
average saturation fraction	0.15	(m/m)

runoff output

runoff volume	31.36	(mm)
peak runoff rate	114.11	(mm/hr)
effective runoff duration	16.49	(min)
effective length	6.00	(meters)

output runoff hydrograph for hillslope 1

index	time (min)	rate (mm/h)	cumul. depth (mm)
1	0.00	0.00	0.00
2	1.00	0.00	0.00
3	2.00	0.00	0.00
4	3.00	0.00	0.00
5	3.82	0.00	0.00
6	4.00	0.00	0.00
7	5.00	0.00	0.00
8	6.43	0.00	0.00
9	7.00	0.00	0.00
10	8.00	9.60	0.08
11	9.00	38.94	0.48
12	10.00	82.30	1.49
13	11.00	107.23	3.07
14	12.32	114.11	5.51
15	13.00	108.68	6.77
16	14.00	102.31	8.53
17	15.00	99.09	10.21
18	16.00	100.86	11.87
19	17.00	103.39	13.58
20	18.00	105.70	15.32
21	18.92	107.61	16.95
22	20.00	97.08	18.80
23	21.00	90.23	

24	22.00	86.92	20.36
25	23.00	88.28	21.83
26	24.00	89.51	23.29
27	25.00	90.77	24.77
28	26.40	92.38	26.28
29	27.40	55.59	28.41
30	28.40	31.41	29.65
31	29.40	17.11	30.37

runoff hydrograph summary for hillslope 1

rainfall volume	96.20 (mm)
infiltration volume	64.84 (mm)
runoff volume	31.36 (mm)
peak rainfall intensity	244.94 (mm/h)
effective rainfall intensity	215.96 (mm/h)
effective rainfall duration	19.40 (min)
final infiltration rate	99.76 (mm/h)
peak runoff rate	114.11 (mm/h)
duration of rainfall	26.40 (min)
time to first ponding	3.82 (min)
effective runoff duration	16.49 (min)
effective length	6.00 (meters)

ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 1.572 kg/m2 **
** Maximum Soil Loss = 2.851 kg/m2 at 6.00 meters **

** Interrill Contribution = 1.373 kg/m2 for OFE #1

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 6.00	1.572	0.532	2.851	6.00	0.330	0.0