THE ERODIBILITY OF SOME GHANAIAN SOILS IN RELATION TO THEIR PHYSICAL AND CHEMICAL PROPERTIES.

BY

RANDY TEYE-MENSAH

A DISSERTATION PRESENTED TO THE DEPARTMENT OF PHYSICS, UNIVERSITY OF GHANA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF PHILOSOPHY (M. PHIL) PHYSICS DEGREE.

DEPARTMENT OF PHYSICS

UNIVERSITY OF GHANA

LEGON

SEPTEMBER 1997

DECLARATION

I hereby declare that apart from certain papers and sources which I had cause to cite and which have been duly acknowledged, this work is the result of my own research, and that this study has neither in whole nor in part, been presented elsewhere for another degree.

R. TEYE-MENSAH
(STUDENT)

DR. K. ODURO-AFRIYIE
(SUPERVISOR)

DATE: 7-9-98

DATE: 07/09/98

DEDICATION

This work is dedicated to my wife, Mrs. Annie Teye-Mensah and the children; Naki, Naki Wendy, Reagan and Nakwor for their prayers, patience and forbearance during my absence from home to read this M. Phil Course in Physics.

TABLE OF CONTENTS

CHAPTER TWO: THE UNIVERSAL SOIL LOSS EQUATION

CHAPTER THREE: MATERIALS AND EXPERIMENTAL METHODS

ABSTRACT

The erodibility of soils from six different rainfall erosivity areas in Ghana were investigated. The soils were sampled and packed into wooden boxes maintained at 9% slope. Soil erosion was measured by applying simulated rainfall storms over the soil samples. The erodibility factor K for each soil type was calculated from USLE, $K=A/EI_{30}LSCP$. The results showed a variability in erodibility factor values which ranged from 0.36 to 0.62. The physical and chemical properties of the soils were also measured and correlated with K values using regression techniques. The statistical analysis showed that the most important properties which related and predicted the K values for the soils studied were, permeability , pH and percentages of fine sand, clay and very fine sand .

ACKNOWLEDGEMENTS

Many individuals have played a decisive role in helping me to do this work. I particularly thank Dr. K. Oduro-Afriyie, Senior Lecturer in Physics, my supervisor, who proposed this work and made a number of very useful contributions towards its completion.

It is also my pleasure to record my indebtedness to all senior members of the Department of Physics, University of Ghana. I wish to mention, in particular, Prof. G. K. Tetteh, Prof. R. D. Baeta, Prof. K. G. Adanu, Prof. E. K. Adjei and Mr. V. C. K. Kakane for their concern and inspiration during the period of this research.

I express my gratitude to the Director and staff of Ghana Meteorological Services Department, for making available to me the use of their automatic rainfall recorder.

I am also grateful to Mr. Boakye Frimpong of the Ghana Water and Sewerage Corporation for providing me with a water pressure gauge used in this study.

The assistance of Mr. Julius Nartenor of the Soil Science Department, University of Ghana in helping to perform some of the laboratory analysis is gratefully acknowledged.

Special thanks go to Mr. Erasmus Achianor of the Computer Science Department, who made available to me an efficient computer programme for some of the analysis.

I want to express my special appreciation to my colleagues: Messrs., Akufo Kumi-Kissiedu, T.A. Kuuyuor, E. Vorwotor and J. D. Intsiful for their words of encouragement and moral support throughout the period of this study.

Further, I wish to express my sincerest thanks to my sister, Comfort Mensah, who sacrificed her time and energy to type this work.

Finally, I am grateful to Almighty God whose abundant Grace and Mercies saw me through this work.

CHAPTER ONE

INTRODUCTION

Uncovered soils are subject to erosion during storms and excessive winds. Much of soil loss caused by water erosion is the result of excessive runoff. Starting with thin sheets, this excessive runoff, muddied by soil and other materials, can grow into a mammoth flood that can destroy not only the soil but roads, bridges, buildings, food supplies and even towns in its path.

The soil lost through water erosion is usually the fertile soil containing plant nutrients, humus, and any fertilizers that the farmer may have applied. Millions of tonnes of fertile surface soil can be lost forever if it is washed into the sea. What is left is usually less productive and may become completely barren. The grave danger which soil erosion posses to agricultural land and crop production has necessitated the adoption of conservation methods and practices in many countries to reduce the damage due to erosion. Some of the conservation methods are terracing, contouring and strip cropping. Several pioneer workers (Laws and Parsons,1943; Wischmeir and Smith, 1958; Hudson and Jackson, 1959) have identified the factors that contribute to soil loss by water.

1.1 FACTORS THAT INFLUENCE SOIL LOSS

Moldenhauer and Long (1964) found that the most important factor influencing soil loss was the infiltration rate. McIntire (1958) and Tacket & Pearson (1965) stated that the formation of a surface crust reduced infiltration and permeability resulting in greater runoff losses. Adams et. al. (1958) established that there are significant negative correlations between wash and splash erosion and the percentage of water stable aggregates greater than 2 mm. One of the factors that have also been identified to influence soil erosion is soil erodibility. It is defined as the inherent tendency of soil to erode at different rates due solely to differences in the soil properties. For a given soil, erodibility is a function of its physical and chemical properties. Information on the erodibility of soils is important in soil erosion prediction and control as well as in planning of modern farming techniques. Olson and Wischmeir (1963) using field plot data indicated that the erodibility of medium textured soils generally increased as silt content increased.

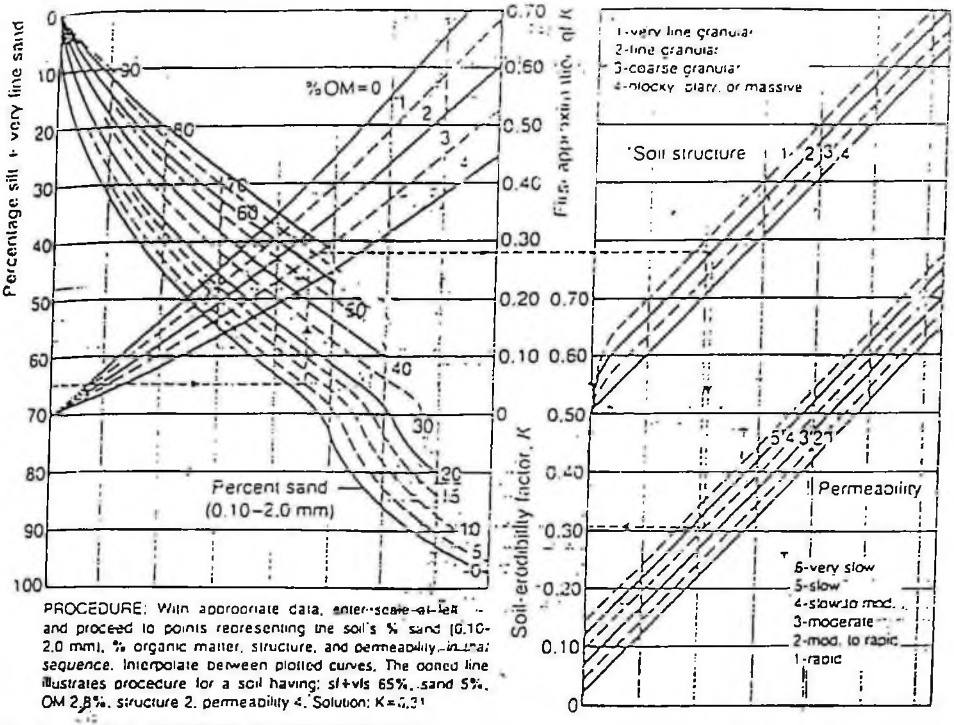
Acccording to Bryan (1968), clay mineralogy, bulk density, permeability, electrochemical bond and indices of aggregate stability may be important predictors of erodibility.

Probably the most extensive of the modern soil erodibility studies was undertaken by Wischmeir and Mannering (1969). Correlating an array of soil properties with erodibility for 55 corn belt soils, they found that soil texture, organic matter, structure and pH were among the most important soil properties that affect soil erodibility.

1.2 THE NOMOGRAPH

A number of statistical (or mathematical) models have been developed for the determination of K values, (Zingg, 1940; Musgrave 1947; Douglas, 1967). One of such models, called the statistical nomograph, was developed by Wischmeir et al. (1971) for predicting K values. This nomograph (Fig.1) utilizes particle size, organic matter, structure and permeability to assign a relative erodibility value between 0 and 1 to each soil. The procedure for reading the erodibility of soil is as follows:-

The sum of the percentage silt and very fine sand is entered at the left. A horizontal line is drawn from that point until it meets the curve for the percentage sand. A vertical line is then drawn from this meeting point to locate the percentage organic matter. From there a horizontal line is drawn to the structure curve and then to the permeability curve, from where the



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K=0.31

Fig.1 SOIL-ERODIBILITY NOMOGRAPH

Nomograph for computing the K value of soil erodibility for use in the Universal Soil-Loss Equation (after Wischmeier, Johnson and Cross, 1971).

erodibility value, K, is read.

These models, however, appear to have limitations when applied to some soils whose properties lie outside the range of properties of the soils used in their formulations. Ronkens et al. (1977), in their study of the erodibility of several midwestern clay subsoils in USA, found that extractable Fe and Al combined with the texture term could predict erodibility more accurately than the erodibility nomograph of Wischmeir et al. (1971).

El Swaify and Danglar (1977) found that parameters such as clay mineralogy, sesquioxide content ,cation content and indices of aggregate stability that are not considered in the nomograph were important in predicting erodibility of several tropical soils in Hawaii. Singer et al. (1980) measured the erodibility of two California soils that did not fit the nomograph's predictions. It was suggested that the high iron content of these soils might be responsible for their generally lower than predicted erodibilities.

1.3 MEASUREMENT OF ERODIBILITY

Soil erodibility has been measured directly from soil loss and rainfall erosivity values by several workers (Middleton, 1930; Browning et al., 1947; Olson and Wischmeir, 1963). Most of these studies were carried out using field plots under natural rainfall. Because of high cost and time consumption these studies were limited to a few benchmark soils. The use of rainfall simulators by many workers (Bryan, 1968; Wischmeir et al. 1971; Rubio-Montoya and Brown 1984) have reduced these limitations. It should be noted, however, that the use of a small plot in the simulator restricts erosion process studies to sheet erosion. Even when the validity of predicting natural soil losses under simulated rainfall is debatable (Bryan, 1968, 1970) the process of erosion under simulated rainfall is essentially the same as sheet erosion under natural rainfall, and an index that accurately predicts soil loss under simulated rainfall should also be accurate under natural conditions Rubio-Montoya and Brown (1984). Work on erodibility studies in West Africa was pioneered by Lal, (1987).

1.4 OBJECTIVE AND SCOPE OF STUDY

Soil loss by water is a function of both the erosivity and erodibility factors, (Wischmeir & Mannering, 1969). Since the rainfall erosivity indices of several locations in the country have been computed based on (Oduro-Afriyie, 1996), and (Ayensu, 1987) the erodibility values of the soils of some of these locations are to be measured to determine their relationship with soil loss.

The unavailability of adequate information on the erodibility of Ghanaian soils and the widespread erosion problem in the country has necessitated this study to be carried out. It is intended to determine the most important physical and chemical properties that affect the erodibility of soils from some these areas.

CHAPTER TWO

THE UNIVERSAL SOIL LOSS EQUATION (USLE)

2.1 DEVELOPMENT OF THE EQUATION

The Universal Soil Loss Equation (USLE) is widely used to estimate soil loss due to rainfall erosion. It is an empirical equation that is simple to use. Besides, it is based on extensive data set of more than 10,000 plot years of data from natural rainfall plus additional data from a variety of studies using rainfall simulators. Foster and Wischmeir (1972) described the development of the USLE, while Wischmeir and Smith (1978) prepared a user handbook for the equation. The equation is written as

$$A=RK_sLSCP \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

where **A**= annual soil loss t/ha

R= erosivity of the rainfall J/ha

K_s= erodibility of the soil t/J

L= the length of slope factor

S= the steepness of slope factor

C= cropping management factor

P= factor for the practices to control erosion

2.2 THE UNIT PLOT CONCEPT

The USLE unit plot concept isolates complex interactions so that individual factors in the equation can be evaluated (Wischmeir and Smith, 1978). A unit plot is defined as a slope 22.1 m long, with a uniform steepness of 9%, and is maintained in a continuous fallow with a periodic cultivation up and down slope to break the crust and to control weeds. Continuous fallow separates soil effects from cover and management effects. All USLE variables except R are in terms of the unit plot concept, and consequently when a new R variable is defined, a new K should also be defined. A new slope steepness relationship must be relative to the 9% slope or K must be adjusted.

2.3 SOME METHODS FOR CALCULATING RAINFALL EROSIVITY

2.3.1 THE EI_{30} EROSIVITY FACTOR

The erosivity factor (R) in equation 2.1 is a numerical value which expresses the capacity of the expected rainfall to erode soil from an unprotected (fallow) field. The erosivity factor includes the erosivity of both rainfall and runoff. Effective erosivity at the soil surface depends on canopy and ground cover. Runoff erosivity depends on runoff volume and rate. These, in turn, depend on the rainfall infiltration, ground cover and surface roughness.

To find a suitable measure of the erosion potential of a rainstorm, scientists of the United States Department of Agriculture (USDA) analysed extensive soil-loss data and associated rainfall records. The data showed that when factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to the product of two rainfall characteristics. These are: (a) total kinetic energy of the storm, and (b) its 30-minute intensity,(Wischmeir, 1959). This energy-intensity product $E.I_{30}$., called the erosivity factor is expressed in joules per millimeter on 1 square meter and its 30-minute intensity in millimeters per hour. The sum of the individual storm E.I. values for a given time provides a numerical evaluation of the erosivity of the rainfall within the period. Thus, adding together the $E.I_{30}$. values for storms occurring within a year at a certain location would give an annual $E.I_{30}$. value for that location.

Based on the work of Laws and Parsons (1943), Wischmeir and Smith (1958) obtained the equation of the kinetic energy as

$$K.E. = 11.87 + 8.73 \log I \qquad 2.2$$

where I is the rainfall intensity (mmh^{-1}) and K.E. is the kinetic energy ($Jm^{-2}\ mm^{-1}$).

For tropical rainfall, Hudson (1965) gives the equation as

$$K.E. = 29.8 - 127.5 / I \qquad 2.3$$

based on measurement of rainfall properties in Zimbabwe.

Zanchi and Torri (1980) carried out similar research in Italy and obtained the kinetic energy as

$$K.E. = 9.81 + 11.25 \log I \qquad 2.4$$

Equations 2.2 and 2.3 show that at intensities greater than 75 mm h^{-1}, the kinetic energy levels off at a value of about 28 $Jm^{-2}mm^{-1}$. The Italian research, (Zanchi and Torri, 1980) equation 2.4 however, indicates energy values as high as 34 $Jm^{-2}mm^{-1}$ when the intensity is 150 mmh^{-1}.

To compute the kinetic energy of a storm, a trace of the rainfall from an automatically recording rain gauge is analysed and the storm divided into small time increments of uniform intensity. For each time period and knowing the intensity of the rain, the kinetic energy of the rain at that intensity is estimated from any of the above equations. The sum of the kinetic energy values for all the time periods gives the total kinetic energy, **E** $Jm^{2}mm^{-1}$ of the storm.

The erosivity factor, **R**(J/ha) is then computed from the relation:

$$R = EI_{30} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

where I_{30} is the maximum 30 minutes intensity. In order to obtain convenient units, EI can be divided by 1000, (Hudson, 1971). The erosivity factor can therefore be calculated from the equaton,

$$R' = EI_{30}/1000 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

2.3.2 MODIFICATION OF THE RAINFALL EROSIVITY FACTOR

The USLE is designed to predict long-term average annual soil loss and is not recommended for prediction of individual soil loss events (Wischmeir and Smith, 1978). A major weakness of the USLE for short term soil loss prediction is the failure of the rainfall erosivity factor (R) to adequately express hydrology, as it affects total volume of surface runoff. Modifications of the rainfall factor of the USLE were evaluated so that individual soil loss predictions could be improved (Foster et al, 1973; Onstad & Foster 1975; Williams, 1975). Replacememt for the erosivity factor of the USLE , as given by Williams (1975), can be expressed as

$$R_w = 27.06\ A^{0.12}\ Q^{0.56}\ q_p^{0.56} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

Where A is the watershed area (ha), Q is the runoff (mm), and q_p is the peak flow rate (mmh^{-1}). The USLE, when used with Williams erosivity replacement is named Modified Universal Soil Loss Equation, MUSLE, Williams (1975).

Another replacement for the erosivity factor (R_o) as given by Onstad and Foster (1975) can be expressed as

$$R_o = 0.5R + 3.42\ Q\ q^{0.33} \quad \ldots\ldots\ldots\ldots\ldots 2.8$$

Where R is the usual USLE rainfall erosivity factor in SI units (Foster et al, 1981).

The MUSLE does not include rainfall variable, even though it is recognised that rainfall energy is important in soil erosion (Young & Wiersman, 1973). The MUSLE would not predict soil loss without runoff, whereas the Onstad-Foster (O.F.) method would predict a soil loss of half that of the USLE if there were no runoff. If runoff is high relative to rainfall erosivity, as may be the case for high antecedent moisture conditions and/or for certain relatively impermeable soils with little water holding capacity, MUSLE soil predictions would exceed those of the O-F method. As compared with USLE predicted soil loss for an individual storm, if runoff relative to rainfall erosivity is low, soil predictions are less than

USLE values when either the MUSLE or O-F methods are used. If runoff erosivity is large relative to rainfall erosivity, soil loss predicted by either MUSLE or O-F methods should be greater than that of USLE.

2.2.3 UNIVERSAL INDEX FOR CALCULATING EROSIVITY

The new index for calculating rainfall erosivity was developed on the basis of the critical quantitative characteristics- amount and intensity of rainfall not inducing runoff- used for separating the active erosive part in every rainfall. Many researchers (Arsov, 1963; Biolchev, 1959; Hudson, 1971; Onchev, 1977) have underlined the primary importance of quality and intensity of rainfall as factors in rainfall erosivity. Therefore almost all rainfall characteristics tested have been obtained as derivatives of these two characteristics. The reason for this is the universally known regularity that, under certain conditions, runoff is induced only by rainfall that is sufficient in quantity and intensity to overcome water retention (by the soil surface and vegetation cover) and the intensity of water permeability of the surface soil layer after its saturation. Rainfall with an intensity lower than the intensity of permeability does not induce runoff since the water is absorbed into the soil. On the other hand, intensive rainfall can induce runoff only if it is sufficient in quantity so that the water absorbing and water holding capacities of soil and soil cover will be exceeded. No specific critical values of rainfall quantity and intensity at which rainfall becomes erosive are quoted by researchers, but most agree that rainfall quantity should be 10 to 12 mm or more for it to be erosive (runoff inducing).The critical values of erosive rainfall vary within a wider range because they are measured under different conditions. The critical value of rainfall intensity at which no runoff can be produced, irrespective of rainfall quantity is assumed to be 0.180 mm min^{-1}. This is based on results of studies by Onchev & Petrov (1974) and Lazarova (1980). On the basis of critical values of erosive quantity (> 9.5 mm) and erosive intensity (>0.180 mm min^{-1}), it is possible to separate the active erosive part of rainfalls. Given that the index for calculating rainfall erosivity is the ratio of only the periods in a rainfall with an intensity > 0.180 mm min^{-1} and a quantity > 9.5 mm to the square root of their total duration, it follows that the calculation of rainfall erosivity using the Universal index is performed with the formula (Onchev, 1978)

$$R' = p / \sqrt{t} \qquad 2.9$$

Where R′ is the Universal Index (UI), P is the quantity of rainfall > 9.5 mm with I.> 0.180 mm min^{-1}, and t is the duration of rainfall with I > 0.180 mm min^{-1}. The average annual value of UI is calculated using the formula (Onchev, 1978)

$$R = \sum_{j=1}^{n} p / \sqrt{t} \qquad \text{..........} 2.10$$

where n is the number of years.

2.2.4 THE QE_A EROSIVITY INDEX

On the basis of experiments with bare surface and soil loss plots under natural rainfall, Kinnel (1983,1985) proposed that the product of the runoff rate (Q) and the rate of expenditure of rainfall kinetic energy (E_A) would provide a useful index of the capacity of rainfall associated with sheet erosion. He also observed that the excess rainfall rate (I_x) could be used as a surrogate for Q. Recently developed theory on erosion by rain impacted flows provides theoretical support for the QE_A index (Kinnel, 1993). The kinetic energy E_A as calculated by Kinnel (1993) for the QE_A index is given by

$$E_A = 29.0I\ [1 - 0.596 \exp\ (- 0.0404I)] \qquad \text{.........} 2.11$$

where E_A is in $Jm^{-2}h^{-1}$ and I is in mmh^{-1}. The equation resulted from an analysis of dropsize data collected at Gunnedah using Distromet distrometer (Rosewell, 1986). Kinnel (1994) proposed that for bare soil surfaces where sheet erosion is the dominant form of energy,

$$\mathbf{A_e = K_e\ L_f\ S_f} \sum_{\mathbf{j=1}}^{\mathbf{T}} (QE_A) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{2.12}$$

Where $\mathbf{A_e}$ = soil loss for a rainstorm

$\mathbf{K_e}$ = soil erodibility factor

$\mathbf{L_f}$ = slope length factor

$\mathbf{S_f}$ = slope gradient factor

$\mathbf{T}$ = number of time units in the rainstorm.

where the $\mathbf{QE_A}$ index = $\sum_{\mathbf{j=1}}^{\mathbf{T}} (QE_A)$ with the units of Jmm $m^{-2}s^{-1}$. When I_x is used as a surrogate for Q, equation (2.12) becomes

$$\mathbf{A_e = K_e\ L_f\ \ S_f} \sum_{j=1}^{T} (I_x\ E_A) \quad \ldots\ldots\ldots\ldots\ldots\ldots\mathbf{2.13}$$

2.4 SOIL ERODIBILITY FACTOR (K_s)

This factor reflects the fact that different types of soils erode at different rates when other factors affecting erosion are held constant. Physical properties of the soil greatly influence the rate at which different soils erode. Some of the more important ones are: soil texture, size and stability of soil structure, type of clay, soil permeability and infiltration, organic matter content and soil depth. Some severely eroded phases of soils are more erosive than slightly or moderately eroded phases of the same soil. For other soils the opposite may be true. Consequently, different factors are sometimes given to eroded phases as compared to relatively uneroded ones.

Definition: K_s, the soil erodibility factor in the Universal Soil Loss Equation, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. This plot is defined as a 22.1 meter length of uniform 9% slope in continuously clean tilled fallow (Wischmeir & Smith, 1978). Implicit in this definition is the representation of K_s as an integrated soil response to several erosion and hydrologic processes. K_s, then, is a simplistic constant or lumped parameter: it cannot be an equation with the process-specific constant ''soil erodibility''. That is, while soil erodibility represents soil response to a specific erosive force or mechanism such as shear forces in surface flow, impact of raindrops, or scouring by flow in torrents, K_s lumps all these together.

Yearly variation in storm frequencies and intensities at a given location is a major problem in K_s value evaluations. Cultivation at a different soil water regime is another source of variation, but this can be offset by computing the K factor on an average annual basis for a long observation period, preferably one or more rainfall cycles. A rainfall cycle is taken to be 20 to 22 years (Wischmeir, 1976).

K_s- value observations for soils in arid or semi arid regions pose a different problem; in that storms causing runoff and soil loss are infrequent to rare. In these regions, soil erosion is infrequent and the soil erodibility factor is invariably small. Yet substantial soil losses may occur during a storm because of the absence of a plant cover.

2.4.1 Rainfall simulation - based K_s - values

To describe K_s value accurately in terms of a few measurable soil characteristics is difficult, if not impossible. The physical, chemical and mineralogical constituents of the soil are many. Their variability is great and their structural interactions are many and varied, and several soil mechanisms may be present simultaneously. Yet many studies have assumed that K value was primarily related to soil properties and sought to predict it from them without need for expensive and time consuming direct field measurements. This approach has led to the development of rainfall simulators. The design and size of these rainfall simulators are many and varied. Rainfall simulators have therefore made it possible for laboratory-based studies to be carried out in the determination of K_s values for some soils.

All rainfall simulators should have certain basic characteristics if the data from them are to be interpreted in terms of what might be expected from natural storms. These are:

1 The rainfall simulator should apply the water uniformly at a controlled rate over the plot area and the adjoining board area.

2 The raindrop sizes and rainfall intensities should be comparable to those occurring during natural storms of reasonably high intensity.

3 Rate of fall of raindrops should approach terminal velocity.

4 Total energy values of the falling water drops should be comparable to that of natural storms.

A universally applicable prediction equation for K_s values may not exist. Within the limits of the definition, however, accurate K_s value estimates are best obtained from direct measurements on natural runoff plots if a sufficiently long observation period is used and unit conditions are met. Good estimates may be obtained from rainfall simulator studies, provided storm weighting reflects the frequency pattern for the location and unit plot conditions are met. Indirect estimates based on the nomograph, fig 1, or other predictive relationships of soil properties need to be carefully considered in relation to the type of soils for which the relationships were derived. In the absence of suitable prediction model, substantial errors in K_s values may be made. Soil erodibility factor, K_s, can be calculated from the Universal soil Loss Equation (USLE), (see equation 2.1). The equation for the erodibility factor is thus given by

$$K_s = A/RLSCP \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

3 Rate of fall of raindrops should approach terminal velocity.

4 Total energy values of the falling water drops should be comparable to that of natural storms.

A universally applicable prediction equation for K_s values may not exist. Within the limits of the definition, however, accurate K_s value estimates are best obtained from direct measurements on natural runoff plots if a sufficiently long observation period is used and unit conditions are met. Good estimates may be obtained from rainfall simulator studies, provided storm weighting reflects the frequency pattern for the location and unit plot conditions are met. Indirect estimates based on the nomograph, fig 1, or other predictive relationships of soil properties need to be carefully considered in relation to the type of soils for which the relationships were derived. In the absence of suitable prediction model, substantial errors in K_s values may be made. Soil erodibility factor, K_s, can be calculated from the Universal soil Loss Equation (USLE), (see equation 2.1). The equation for the erodibility factor is thus given by

$$K_s = A/RLSCP \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

2.5.0 LENGTH AND STEEPNESS OF SLOPE

Slope steepness is one of the important factors in soil erosion. On level land , water erosion is usually negligible. At slopes over 10 percent it may be the most serious factor encountered in growing cultivated fields. Erosion would normally be expected to increase with increase in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff. Further, whilst on a flat surface raindrops splash soil particles randomly in all directions, on sloping ground, more soil is splashed downslope than upslope, the proportion increasing as the slope steepens. The relationship between erosion and slope can be expressed by the equation:

$$Q_s = \tan^m \theta \, L^n \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

where Q_s is the sediment yield expressed per unit area, θ is the gradient angle and L is the slope length (Morgan, 1986). Zingg (1940), in a study of data from five experimental stations of the United States Soil Conservation Service, found that the relationship had the form :

$$Q_s = \tan^{1.4} \theta \, L^{0.6} \quad \ldots\ldots\ldots\ldots 2.16$$

The values of the exponents have been confirmed in respect of m by Musgrave (1947) and m and n by Kirby (1969). Other studies (Gabriels et al.1975; Horvath and Erodi 1962; Hudson and Jackson 1959) show, however, that the values are sensitive to the interaction of other factors in the erosion-slope relationship.

Working with data from experimental stations in Zimbabwe, Hudson and Jackson (1959) found that m was close to 2.0 in value, indicating that the effect of slope is stronger under tropical conditions where rainfall is heavier.

2.5.1 THE LS FACTOR

The solution of the soil loss equation is made easier by combining the equations for length and percentage slope. The topographic factor **LS** as given by Wischmeir and Smith (1962) adjusts the soil loss from the standard 9% slope and 72ft. The **L** and **S** factors can be calculated from the equations:

$$L = (1/73)^{0.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.17.$$

And

$$S = (0.43 + 0.030s + 043s^2)........2.18.$$

where l is the length of the slope in feet and s is the field slope in percent while **L** and **S** are the length and slope factors respectively. Another such combined equation is given by Morgan, (1986) as :

$$SL = \sqrt{} 1/22 (0.065 + 0.455s + 0.0065s^2)...2.19$$

where s is the percentage slope and l the length of the slope in meters, with **S** and **L** being the slope and length factors respectively. The values used in the equations are ratios of soil loss for any steepness and length of slope with the arbitrarily selected standard, being 9% and 22.1 m in length. The percentage slope factor is known to interact with some conservation practices such as contouring and strip contouring.

2.6 CROPPING AND MANAGEMENT FACTOR (C)

The cropping and management factor (**C**) is the expected ratio of soil loss from land cropped under specific conditions to the corresponding soil loss from continuous fallow. The comparison assumes identical soil, slope and rainfall conditions.

The influence of cropping and cropping practices on erosion is affected by many factors. These include: kind of crop, quantity of cover and root growth, water use by growing plants, quantity of prior-crop residues plowed. It is also significant that these conditions differ within the period from crop planting to harvest.

The importance of plant cover in reducing erosion was demonstrated by experiments at the Henderson Research Station in Zimbabwe, where in the period 1953-56 mean annual soil loss from bare ground was 4.63 kg m^{-2} compared with 0.04 kg m^{-2} from ground with dense cover of Digitaria (Hudson, 1981). The major role of vegetation is in the interception of the raindrops so that their kinetic energy is dissipated by the plants rather than imparted to the soil. In addition to intercepting rainfall, a plant cover dissipates the energy of the running water and wind, by imparting roughness to the flow and thereby reducing its velocity. Plant cover can play an important role in reducing erosion provided that it extends over a sufficient proportion of the soil surface. Overall, forests are the most effective but a densely growth of grass may be as efficient. Agricultural crops vary in their effectiveness depending on their stage of growth and the amount of bare ground exposed to erosion at maturity. For adequate protection at least 70% of the ground must be covered (Fournier, 1972;) Elwell and Stocking, 1976), but reasonable protection can be achieved with 40% cover (Shaxson, 1981).

2.7 CONSERVATION PRACTICES FACTOR (P)

The supporting practice factor reflects the influence of practices like contouring, strip-cropping, terraces, and contour furrows used to support protection provided by crop rotation, canopy cover, and residue mulches. Well constructed and maintained grass buffer strips can trap much sediment in runoff from up slope tilled areas. This trapping is a deposition process that the USLE cannot describe. Unless the buffer strips are periodically alternated with tilled crops, full benefit of the strips will not be realised because soil eroded from the tilled strip is effectively lost from the tilled part of the field.

CHAPTER THREE

MATERIALS AND EXPERIMENTAL METHODS

3.1 SAMPLE COLLECTION

Soil samples used in this study were collected from six areas in the Southern zone of Ghana (see Fig.3.1). These areas were selected because they represent areas with different rainfall erosivity indices (Oduro-Afriyie, 1996) (see Fig. 3.2). The soil samples were collected from the Meteorological stations in the selected towns, since data for the rainfall erosivity values as given by Oduro-Afriyie, (1996) were taken from these stations. This was done in order to relate erodibility values to the rainfall erosivity values for these locations.

Soil materials collected from 0-15 cm depth from six areas in the southern sector of Ghana were sampled. Soil pits 50 cm square were excavated at each sample point. Loose disturbed samples were taken from each pit with a spade and packed into polythene bags.

The soils were of extensive geographic distribution and were associated with a variety of vegetative types and parent materials (see Table 3.1.)

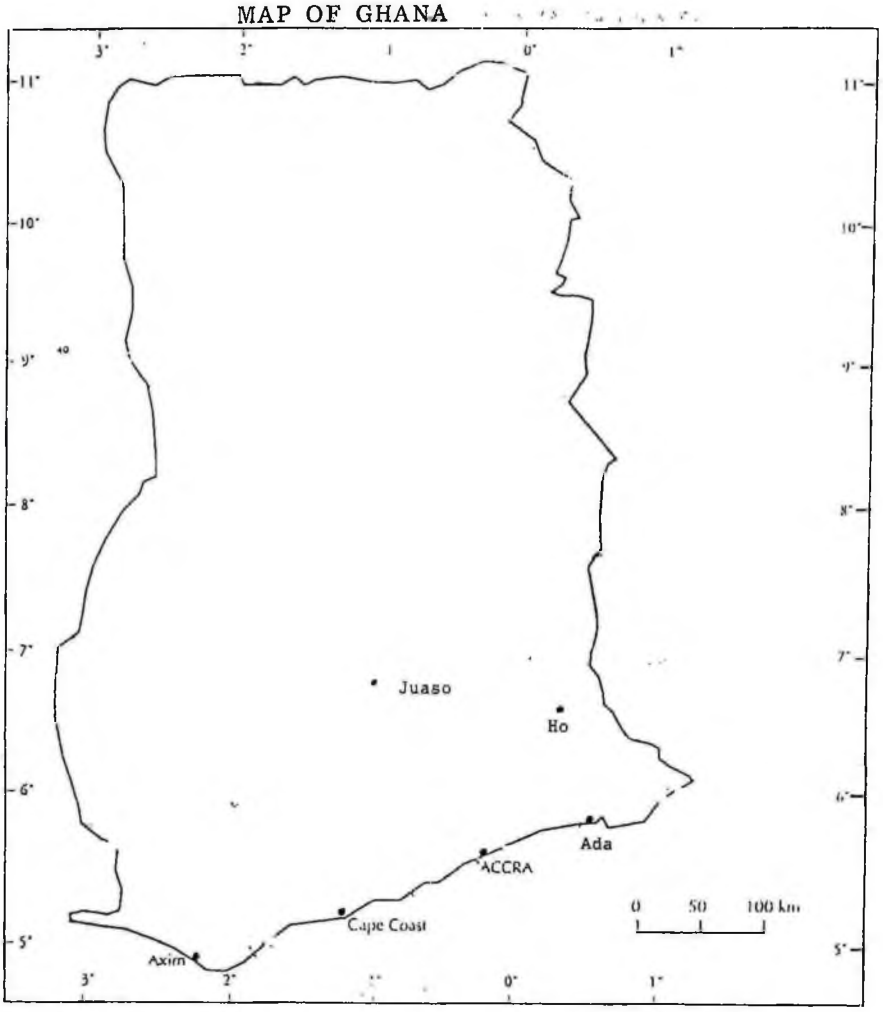
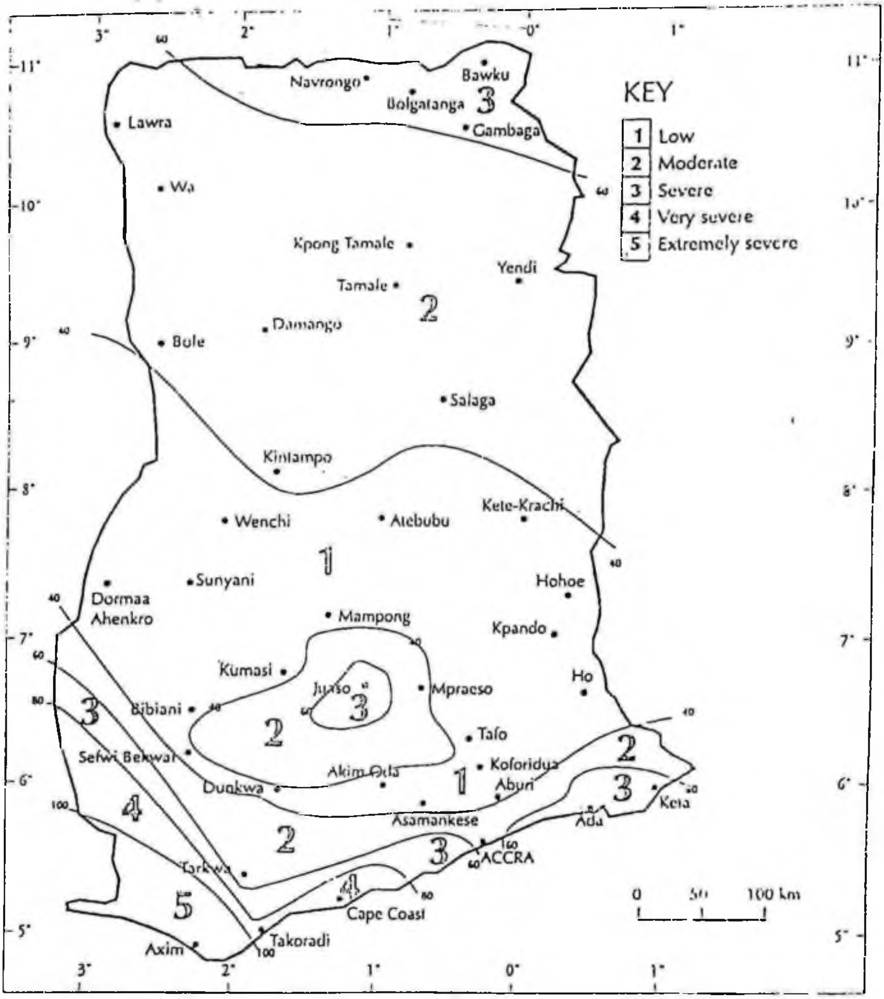


Fig.3.1 Locations of Sampling Sites



Rainfall erosivity map of Ghana showing iso-erosivity lines and various erosion-risk zones.
(based on Fournier's index)

Fig. 3.2. (Oduro - Afriyie, 1996)

Table 3.1 Classification, parent material, vegetative type, and region of soils studied, (Benneh & Dickson, 1970)

Soil Series	Soil Classification	Parent Material	Dorminant Vegetation	Region
ACCRA	Onchrosols	Sandstone	Coastal Scrub & grass	Greater Accra
ADA	Coastal sandy soils	Quartzite	Strand & Mangrove	Greater Accra
AXIM	Coastal Sandy soils	Phylite	Strand & Mangrove	Western
CAPE COAST	Coastal Sandy soil	Granite	Strand & Mangrove	Central
HO	Forest Onchrosols	Quartzite	Guinea Savana	Volta
JUASO	Forest Onchrosols	Sandstone /Shale	Moist semi Deciduous Forest	Ashanti

3.1 Measurement of soil loss

The sampled soils were air dried and crushed to pass through an 8 mm sieve. For each soil sample there were five replicates. The sieved samples were placed in wooden boxes. Each box was 62.0 cm long, 15.2 cm wide and 13.2 cm deep and the front edge of the box was set at 2.5 cm below the level of the other walls, (as indicated by Rubio-Montoya, 1984) (see Fig 3.5a).

To ensure uniform packing in the boxes, they were filled to one third of their depths with the air-dried soil.

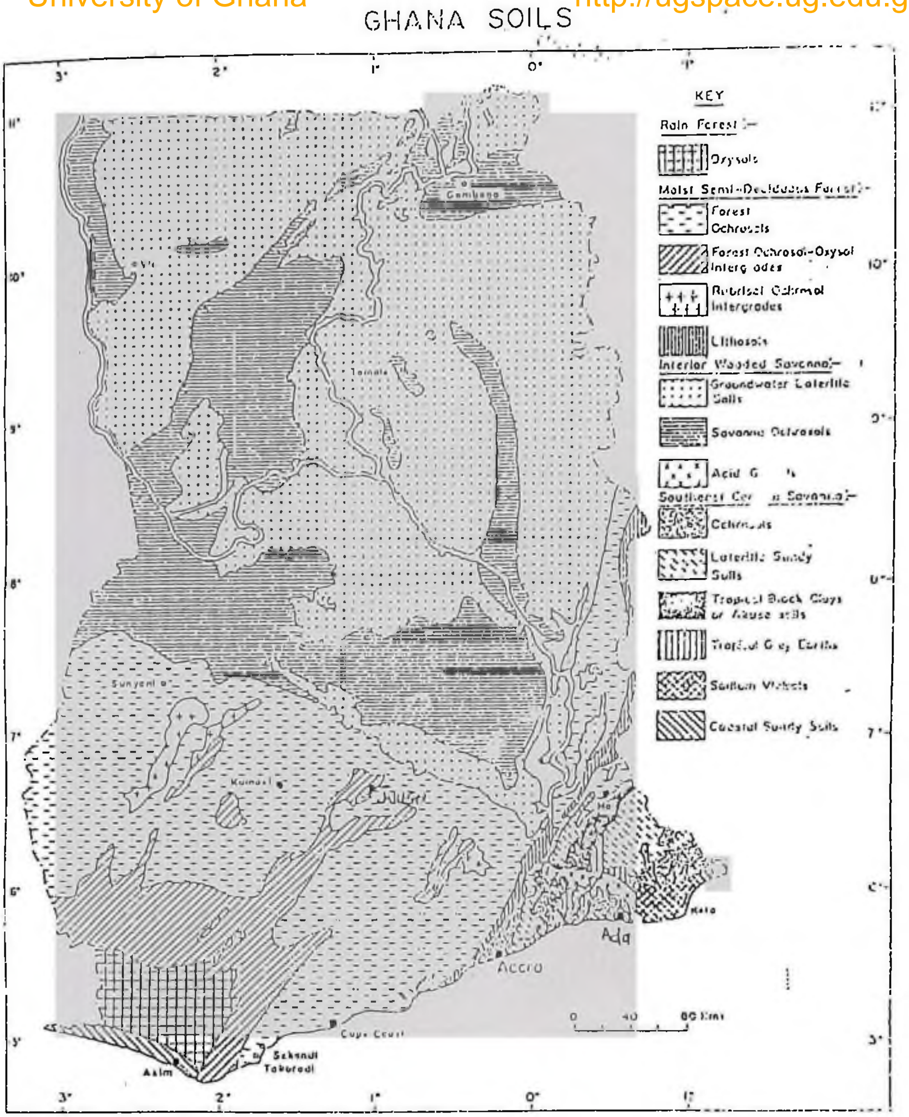


Fig. 3.3 Ghana Soils; (Dickson and Benneh (1988)

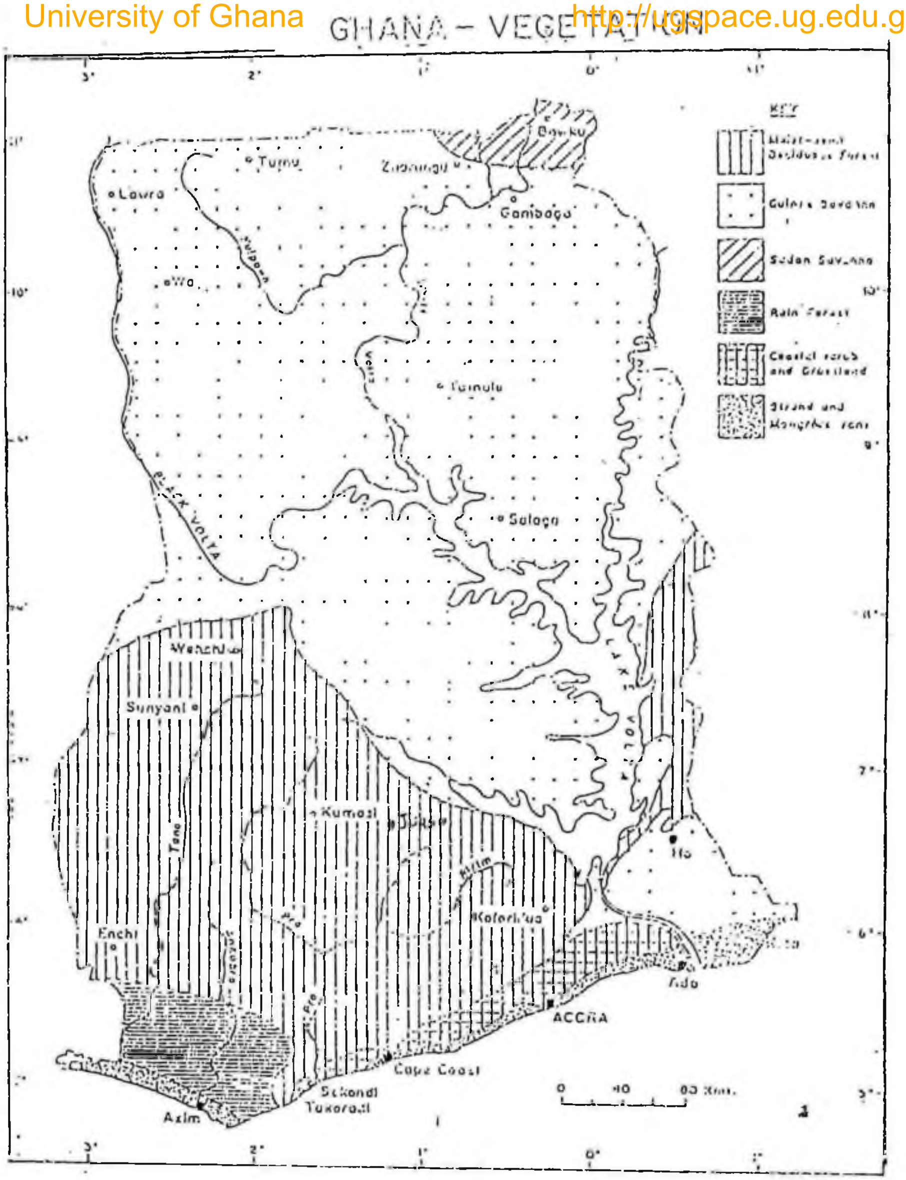
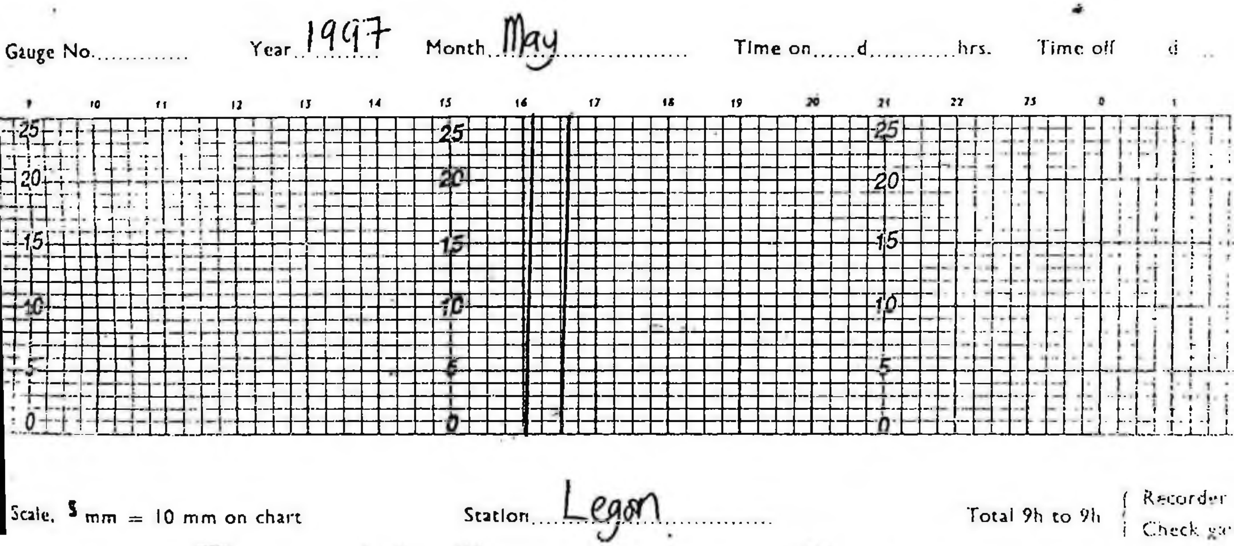


Fig. 3.4 Ghana Vegetation; (Dickson and Benneh(1988)

Each end of the box was then dropped eight times from a height of 10 cm above a table. More soil was added to bring the box to two-thirds full, and the ends of the box dropped as before. The box was then filled and the dropping exercise repeated as described above. The soil was then moistened to saturation with a fine spray of water after which it was allowed to free drain for 2 hours. The soil was then subjected to simulated rainfall of an intensity of 90 mmh^{-1} for a duration of 30 minutes.

3.2 Rainfall Simulation

The rainfall simulator used for this study is as described by El-Asswad and Abufaied (1994). It consists of a PVC pipe, 5 centimeters in diameter unto which four nozzles of 0.68 mm opening were fixed. The nozzles were placed 15.2 cm apart, (see Fig 3.6). A water pressure gauge was connected to the pipe to record the pressure of the water flowing through it. One end of the pipe was sealed and the other end connected to a water source (Fig.3.7). To calibrate the rainfall simulator the tap was opened and the simulated rainfall was allowed to pour onto a rainfall recorder. The intensity of the simulated rainfall was then read from the rainfall chart. The pressure enabled the pressure gauge that induced that



Gauge No. .... Year 1997 Month May .... Time on ......d..........hrs. Time off d

Scale. 5 mm = 10 mm on chart Station Legon .... Total 9h to 9h { Recorder / Check ga

Fig. 3.5 - Rainfall Chart

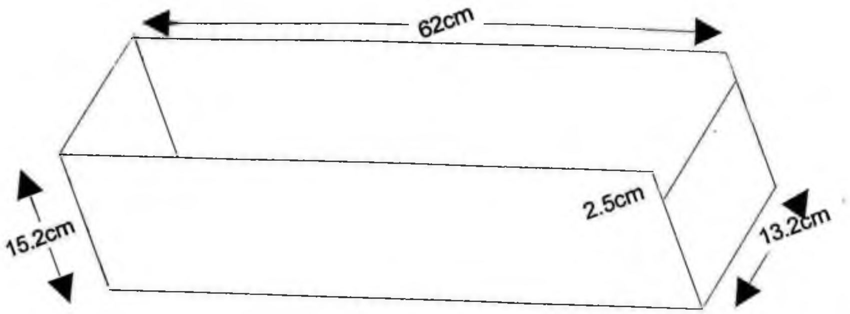


Fig. 3.6a Box for soil sample

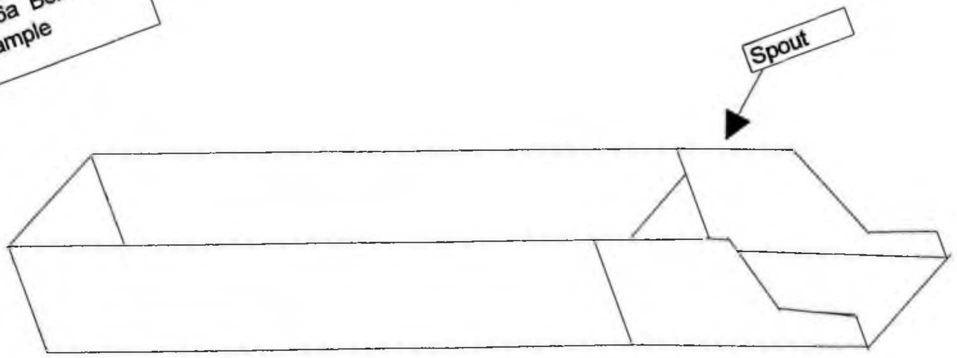


Fig. 3.6 b Box for soil sample with spout attached.

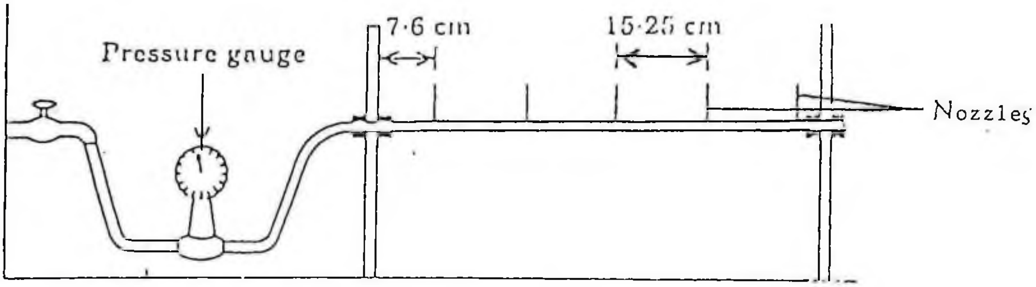


Fig. 3.7. Nozzle arrangement of the rainfall simulator.

intensity to be recorded. By adjusting the pressure of the flowing water and subsequently measuring the 30 minute intensity of the simulated rainfalls the pressure which induced a simulated rainfall of 90 mmh^{-1} was recorded to be 3.05 m head of water. The rainfall simulator was placed in a chamber to prevent the wind from affecting the down pour of the simulated rainfall.

After allowing the saturated soil samples to free drain for 2 hours, they were placed in the area covered by the simulated rainfall. The boxes were arranged to have a 9% slope. A rainfall recorder was used in measuring the intensity of the rainfall storms. A simulated rainfall of intensity 9.0 mmh^{-1} was applied to the boxes for 30 minutes. The runoff water and sediment were collected in a large basin by a spout attached to one end of the box (see Fig. 3.6b). The runoff and sediment in the basin were then thoroughly stirred to a homogeneous mixture and some of it taken to fill a 1-litre measuring cylinder. The mixture was filtered through a Watman's filter paper and the residue dried in an oven at a temperature of 105°C and weighed. Knowing the dry weight of sediment of the runoff in the 1-litre measuring cylinder and also knowing the entire volume of the runoff, the total amount of soil that was eroded was computed.

The erodibility factor, K, of each soil was then calculated using equation 2.15. The erosivity value R for this study was calculated to be 117J/ha from equation (2.6). The kinetic energy per mm of rainfall is given by equation (2.3) as K.E. = 29.8 - 127.5/I where I= 90 mmh^{-1} is the intensity of rainfall. Thus,

K.E = 29.8 - 127.5/90 = 29.6 Jmm^{-1}

Hence for a rainfall of 45 mm, the total kinetic energy of the rainfall is given by

E = 29.6 x 45 = 1302 J

Substituting this value and I_{30} into equation (2.6) gives

R = 117 Jha^{-1}.

The value of the LS factor was found to be 0.166, from equation (2.20). **C** and **P** were each set equal to 1 since there was no plant cover available and no special practices were employed to control erosion.

3.3 Soil analysis

Samples of the soils were taken for analysis. Some of the soil parameters that were measured were, the particle size grading, soil texture, permeability, organic matter content, bulk density, pH, electrical conductivity and some trace elements.

3.4 Particle Size Grading

The USDA classification of soil particles was used in the grading of the particle size. The soil marterials were air dried at ambient temperature and then sieved through a 2mm sieve. The materials that did not pass through the the sieve are stones or gravels. The fine earth fraction was divided into sand, silt and clay as described in Section 3.5. The sand fraction was divided into very fine sand, fine sand, medium sand, coarse sand and very coarse sand as shown by Table 3.1, with value in millimeters.

Table 3.1 Particle size distribution

Clay	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand

0.002 0.002 0.05 0.1 0.25 0.5 1.0 2.0

3.5 Soil Texture: The Bouyoucos Hydrometer Method

A weight of 40g of air-dried soil was put into a dispensing cup. 100ml of calgon solution and 40ml of distilled water were added and the sample allowed to soak for 10 minutes. Another 40g of soil sample was put into a weighed moisture can. This was dried in an oven at 105°C overnight and reweighed and recorded as the the oven-dry weight of the sample. The soil sample and the calgon solution were mixed in a dispensing cup for 5 minutes with a motor mixer. The mixture was transfered to a sedimentation cylinder with the help of distilled water from a wash bottle, and the level of the liquid was brought to the 1000ml mark with distilled water. The cylinder was moved to a constant-temperature room. The temperature of the suspension was recorded when it had become constant. A plunger was inserted and moved up and down to mix the contents thoroughly. A hydrometer was lowered carefully into the suspension and after 5 minutes the scale was read. The second reading was taken 5 hours later. The reading taken after 5 minutes gave the weight of silt and clay while the reading after 5 hours gave the weight of clay. The fraction of silt was calculated by subtracting the weight of clay from the weight of silt and clay

The suspension was then poured from the sedimentation cylinder into a 47 micron sieve, and the effluent discarded. Ordinary tap water was then run on to the sieve. With the fine particles of silt and clay washed through, the sand particles left on the sieve were dried overnight in a oven at 105°C. The oven-dry weight of the sand was then recorded. The percentage sand, silt and clay of soil sample were then calculated.

3.6 Determination of Infiltration rate

Infiltration is the downward entry of water into soil through the soil atmosphere interface. The distribution of water content with depth in the soils, referred to as moisture profile, has the following features: the saturation zone, transmission zone, wetting zone and wetting front. Water moves through the transmission zone of almost constant water content to the wetting zone where it changes markedly with both depth and time.

The infiltration rate is the quantity of water entering the soil per unit area per unit time. This tends to decrease with time until a constant rate, referred to as final infiltration rate is obtained.

A rectangular column made of perspex was filled with air-dried soil sample to bulk density of about 1500Kg/m^3 . A constant head of water was maintained on the surface of the soil in the column using a Mariotte bottle. The rate of water entry into the soil was observed by recording the quantity of water, Q, flowing through the soil at 10 minute intervals. The recording was stopped when the wetting front was about 5cm from the base of the soil column. This was done to prevent the water from collecting at the base of the column, and thereby making it difficult for readings to be taken. A graph of Q/A was plotted against time, where A is the cross sectional area of the column. The slope of the linear portion of the graph gave the final infiltration rate, which gave an indication of the permeability class of the soil.

3.7 Organic Matter Content

Carbon is the chief element of soil organic matter that is readily measured quantitatively. Hence, estimates of organic matter frequently are based on organic - C, which is determined by two methods:

1. those based on qualitative combustion procedures wherein C is determined as CO_2 and

2. those based on the reduction of the $Cr_2\ O_7^{2-}$ ion by organic matter in which case the unreduced $Cr_2\ O_7^{2-}$ is measured by titration. Organic forms of soil - C plus the carbonate forms of this element including HCO_3^- and CO_{3-} of any soluble salts present constitute the total -C present in the soil.

A modification of the wet oxidation procedure based on the reduction of the $Cr_2\ O_7^{2-}$ ion by organic matter which is known as the Warkley and Black procedure was employed in determining the organic matter content.

The soil sample was sieved through a 0.5 mm sieve after which 0.5 g of it was put into a conical flask 10ml of potassium dichromate solution was added to the sample which was followed by 20 ml of conc. H_2S0_4 (Not less than 96%). The flask was swirled such that the solution was in contact with all particles of the soil. The flask with its contents was allowed to stand on an asbestos sheet for 30 minutes. 200 ml of distilled water was added, followed by 10ml of orthophosphoric acid and finally 2 ml of barium diphenylamine sulphonate indicator (0.16% aqueous solution). Ferrous ammonia sulphate solution (0.2N) was poured into a burrette. The soil solution in the flask was titrated with the ferrous ammonia sulphate solution until the colour changed to blue green at the end point.

The percentage of C was calculated using the following formula: (Jackson, 1958)

$$\% \text{ Carbon} = 0.3\ (10 - XN)\ /\ W \quad \ldots\ldots\ldots\ldots 3.1$$

where **X** = ml of ferrous ammonia sulphate solution required for the titration

N = concentration of ferrous ammonia sulphate solution.

W = weight of soil sample

To calculate the percent organic matter, the percentage carbon was multiplied by 1.724. (Jackson, 1958)

3.8 Determination of bulk density

Soil bulk density is defined as the mass per unit volume of dry soil in its undisturbed state. For a soil of a given particle density, bulk density is directly related to total porosity, the space available in the soil for gas and water movement and root development. Less directly, bulk density is also related to soil strength and soil permeability (Daniel,1980).

To determine bulk density, soil samples were taken from the soil pits at each sample point. An iron cylinder of internal diameter 6 cm and height 8 cm was driven into the soil at each sample pit. The buried cylinder was dug out carefully ensuring that the soil core was not disturbed. The entire contents were transferred into a slightly bigger container and placed in an oven to dry overnight at a temperature of 105°C. This was to ensure that the soils were at the same hydrological conditions before applying the simulated rainfall. The soil sample was weighed and recorded. The bulk density of the sample was calculated by dividing the oven dry-weight of the sample by the volume of the sample. Knowing the weight of the empty container, the bulk density was determined using the expression below:

$$\textbf{Bulk Density} = (W_1 - W_2)/V \qquad 3.2$$

Where W_1 is the weight of the container with soil, W_2 the weight of the empty container and V is the volume of the empty cylindrical cutter. The internal volume of the cutter, was determined by measuring its height and the internal diameter.

3.9 Measurement of Electrical Conductivity

The total salt content (the salinity) of the soil is normally determined by measuring its electrical conductivity. The electrical conductivity was determined using a 1:2 extract. This was done by adding 40ml of water to 20g of air dry soil, and shaking the mixture for one hour. The suspension was then allowed to settle for 30 minutes. 20ml of the suspension was poured into a beaker and the electrode of an electrical conductivity meter inserted. The electrical conductivity was recorded from the meter.

3.10 Measurement of pH

The pH of a soil is normally measured by using a suspension of the soil under test. This was done by weighing 10.0 ± 1.0g air dry soil into a bottle with a screw cap. 20ml of water was then added and the suspension shaken for 15 minutes on a shaking machine. The suspension was poured into a beaker and the electrode of a pH meter was inserted into the suspension. The pH was then recorded on the pH meter.

3.11 Estimation of exchangeable Potassium

Available or exchangeable K was determined in a neutral normal ammonium acetate (N NH_4OAc) extract of soil. The shaking and filtration method of Schollenberger and Simon (1945) was used in the determination of available K.

Exactly 5 g of the soil samples were placed in a 150 ml Erlenmeyer flask and 25 ml of neutral N ammonium acetate (pH 7) was placed in it. The flask was placed on a reciprocating shaker (180 + oscillations/ min.) and the contents shaken for 5 minutes. The solution was immediately filtered through Watman No. 1 filter paper, and the volume of the filtrate measured.

CALCULATION:

$$\text{Available K} = \frac{R_p \text{ x volume of extract x } 2.24\text{x}10^6}{\text{wt. of soil taken x } 10^6}$$

where R_p = ppm of K in the extract

= ppm K x 11.2.

3.12 Estimation of exchangeable Calcium and Magnesium

Exchangeable Ca and Mg were determined in ammonium acetate extracts of soils by direct titration with EDTA. This procedure enabled Ca and Mg to be determined in the same solution.

REAGENTS: Standard calcium solution, EDTA solution, Buffer solution, Hydroxylamine - hydrochloride aqueous solution, potassium hexecyanoferrate (II) aqueous solution, potassium cyanide aqueous solution, Triethanolamine, Calcon solution and Eriochrome Black T solution.

PROCEDURE: 5 ml of standard calcium solution was pipetted into a graduated 100 ml beaker. The solution was diluted to 10 ml and 15 ml of ammonium chloride hydroxide buffer solution added. 10 drops each of potassium cyanide, hydoxylamine - hydrochloride, potassium hexacyanoferrate (II), triethanolamine and Eriochrome Black T solution were added. The beaker was placed on a magnetic stirring plate and the solution stirred. A blank solution was prepared in exactly the same manner using 5 ml of water instead of calcium solution. the blank solution had a blue colour. The blank solution was kept alongside the standard calcium solution and the standard solution was titrated with the EDTA solution. The blank was diluted with water to equalise the two volumes of the two solutions as titration proceeded. The determination of the Ca Mg are given in the subsections below.

3.12.1 Determination of Ca in the NH_4OAc

An aliquot of the extract was pipetted into a 100ml beaker and then diluted to 10 ml. To this solution was added 10 drops each of potassium cyanide, hydroxylamine - hydrochloride, and triethanolamine solutons. 2.5 ml NaOH solution and 1 ml of Calcon solution were added. The

3.12.2 mixture was titrated with EDTA until it turned blue.

CALCULATION OF Ca

Ca per 100 g soil =

$$\frac{100}{\text{Soil weight(g)}} \times \frac{\text{Extract volume (ml)}}{1000} \times \text{micron Ca}$$

DETERMINATION OF Ca + Mg

An aliquot of of the extract was pipetted into a beaker. It was diluted to 10 ml and 15 ml of ammonium chloride hydroxide buffer solution was added. 10 drops each of potassium cyanide, hydroxylamine - hydrochloride, potassium hexacyanoferrate(II) and triethanolamine solutions were added while the solution was gently warmed to 45^{0}C on a magnetic stirrer. When all the reagents were added warming continued for 3 minutes. It was then cooled to 25°C and 10 drops of Eriochrome Black T solution was added. It was then titrated with EDTA.

CALCULATON

(Ca + Mg) per 100 g soil =

$$\frac{100}{\text{Soil weight(g)}} \times \frac{\text{Extract volume (ml)}}{1000} \times \text{micron (Ca+Mg)/L}$$

D

A weight of 10 g of air-dried soil was put in a 125 ml conical flask. To this was added 20 ml of DTPA extracting solution. The flask was corked and placed on a horizontal shaker. This was shaken for two hours with a speed of 120 cycles per minute. The suspension was filtered through no. 42 Whatman filter paper. The filtrate was kept in a bottle and analysed for Mn using an atomic absorption spectrophotometer.

To analyse for the Mn the followingmethod was used.

A blank and 3 standards of the cation were used to draw a calibration curve. The blank solution (0 µg/ml) was used to zero the atomic absorption spectrophotometer. The standards were analysed with lowest concentration first, and the blank was run between standards to ensure that the baseline had not changed. A graph of absorbance versus concentration was plotted. After setting the instrument and aspirating the sample the absorbance was read and the concentration, M, was read from the graph.

CONCENTRATION OF Mn in soil = M x 2 ppm (Hesse 1971)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 ERODIBILITY MEASUREMENT

The amount of soil eroded and their respective K_s values are presented in Table 4.1a. Each K_s value represents the mean of 5 values. The results show a variability in the K_s values of the soils studied. Generally, the soils with high K_s values are more erodible than those of low K_s values. The most erodible of the soils is the Juaso soil with a K_s - value of 0.62, which is followed by the Axim soil with K_s value of 0.57. The third most erodible soil is the Ada soil with a K_s value of 0.50. The fourth, fifth and sixth in decreasing order of erodibility are the Cape coast, Accra and Ho with erodibilities of 0.49, 0.47 and 0.36 respectively.

Table 4.1a . Quantity of eroded soil and erodibility data for six Ghanaian soils. (Initial soil mass = 12.5 kg)

Soil Sample	Eroded Soil/g	Eroded Soil/tha^{-1}	Erodibility factor/tJ^{-1}
Accra	85.70	9.22	0.47
Ada	90.40	9.72	0.50
Axim	103.40	11.15	0.57
Cape Coast	88.30	9.49	0.49
Ho	65.56	7.05	0.36
Juaso	112.10	12.04	0.62

Table 4.1b Comparison between measured and estimated K_s values.

Soil Series	Measured Erodibility (rainfall simulation)	Estimated erodibility (nomograph)	Fournier's Rainfall Erosivity (mm) *	Erosion Risk Class
ACCRA	0.47	0.48	53.7	Moderate
ADA	0.50	0.44	75.3	Severe
AXIM	0.57	033	180.9	Extremely Severe
CAPE COAST	0.49	0.37	96.7	Very Severe
HO	0.36	0.36	26.1	Low
JUASO	0.62	0.48	73.1	Severe

*Rainfall Erosivity values obtained from Oduro-Afriyie(1996)

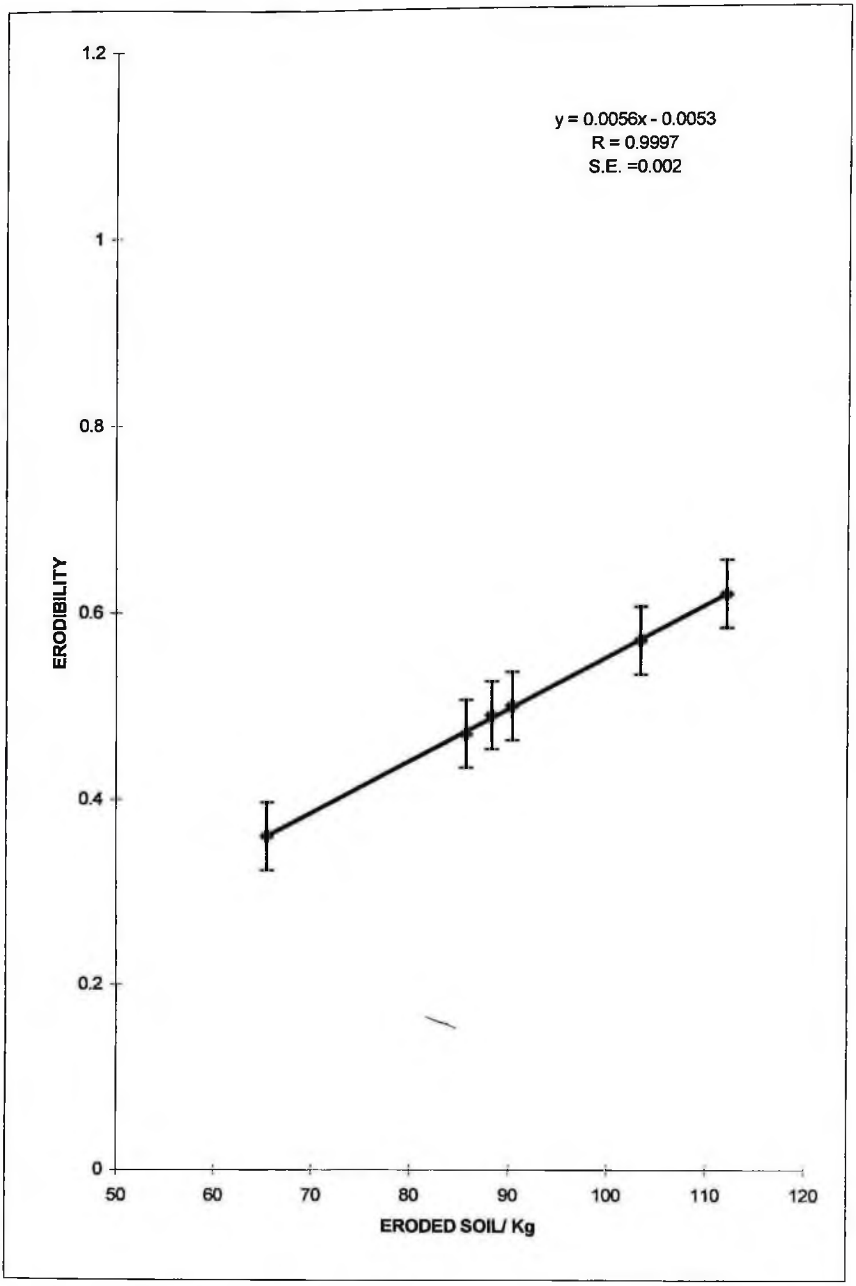


Fig. 4.1 Erodibility versus eroded soil

Table 4.1b illustrates comparison between the erodibilities as determined by the nomograph and by rainfall simulation.

The nomograph K_s values were generally lower than the measured K_s values. The difference may be due to the fact that the nomograph does not consider bulk density or aggregate stability directly, even though these affect detachment and transport of soil. The bulk densities for these soils were higher, for most of the soils than they are under natural conditions. In addition the ranking of soils by bulk density is different for natural soils than for packed densities.

Fig. 4.1 gives the plot of erodibility versus eroded soil. The correlation is significant. The scatter of points shows that other interactive parameters contribute to the prediction of erodibility of the soils studied. These other parameters may include clay mineralogy, cation content and indices of agreggate stability.

4.2 Relation of Erodibility to Soil Structure

The soil ranged in texture from silty clay loam to loamy sand. Organic matter levels varied from 0.3% in Ada to 4.8% in Axim. Except for Axim, the organic matter levels for all the other stations were lower than 4%, which is the upper range of the soils of Wischmeir and Mannering (1969).

Table 4.2a. Selected physical properties of the soil studied.

Soil Series	K_s	Sand (%)	Silt (%)	Clay (%)	Struct Code	B.D. (Kg/m^3	Perm class	O.M. (%)
ACCRA	0.47	71.7	8.30	18.70	1	1519	4	1.1
ADA	0.50	74.8	6.13	18.47	2	1478	4	0.3
AXIM	0.57	70.7	8.45	19.50	3	1492	3	4.8
CAPE COAST	0.49	59.5	12.0	24.75	3	1532	3	3.6
HO	0.36	58.5	6.05	34.15	2	1457	5	1.2
JUASO	0.62	72.7	6.54	19.84	3	1546	1	1.4

B.D. = Bulk Density; O.M. = Organic Matter

Structure Code: 1- very fine granular
2- fine granular
3- Coarse granular
4- blocky or massive

Permeability class: 1- Very Low
2- Low
3- moderate
4-High
5- Very High

Table 4.2b. % Sand (Separate).

Soil Series	Total Sand	V.F.S	F.S	M.S	C.S	K_s
ACCRA	71.7	52.0	14.3	4.3	1.1	0.47
ADA	74.8	56.0	13.8	3.0	2.0	0.50
AXIM	70.7	51.7	13.6	3.2	2.1	0.57
CAPE COAST	59.8	37.0	8.4	8.2	5.9	0.49
HO	58.5	36.0	7.2	6.0	9.3	0.36
JUASO	72.7	54.0	18.3	2.2	3.2	0.62

V.F.S. = Very Fine Sand; F.S.= Fine Sand; M.S. = Medium Sand; C.S. = Coarse Sand;

Generally, soils that are high in silt, low in clay and low in organic matter are the most erodible (Wischmeir & Mannering, 1969). A soil that is low in organic matter does more compact and water easily accumulates on it. This makes it susceptible to detachmemt and transport. Usually a soil type becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction. However, percentages of silt and clay must be considered in relation to existing levels of other physical and chemical properties.

The results suggest that erodibility of the soils decreased as the sum of the percentages of the silt and clay also increased, (see fig. 4.2a).

Table 4.2c Selected chemical properties

Soil series	PH $1:1H_2O$	E.C. $\mu s/cm^2$ $1:2H_2O$	O.M (%)	………….Mc/100g Soil			Ppm……
				K	Ca	Mg	Mn
ACCRA	5.9	108	1.1	0.18	0.09	0.05	0.08
ADA	7.0	90	0.3	0.37	0.16	0.09	0.04
AXIM	5.1	101	4.8	0.34	0.25	0.13	0.05
CAPE COAST	6.0	247	3.6	0.44	0.26	0.24	0.03
HO	7.4	86	1.2	0.28	0.28	0.10	0.04
JUASO	5.2	40	1.4	0.18	0.13	0.11	0.06

The plot of erodibility versus percentage of total sand (see Fig.4.2b) reveals that erodibility of the soils increased with increase in percentage sand. The correlation coefficient, R= 0.67, is significant. Figs. (4.2c) and (4.2d) give the plots of erodibility versus percentages of fine sand and very fine sand respectively. These graphs also show that erodibility increased as the percentage of fine sand and very fine sand increased. Figs. (4.2e) and (4.2f) are graphs of erodibility against percentages of medium sand and coarse sand respectively. These two graphs show that erodibility decreased with increase in the percentages of medium sand and coarse sand. This reflects on the relationship between erodibility and the size of particles. Water transport of large particles is generally more difficult in comparison to smaller ones.

Fig. (4.2g) is a graph of erodibility against bulk density. This plot shows that erodibility increases with increase in bulk density. A high bulk density means that the soil is well compacted, hence the rate of infiltration is low. There is therefore a large runoff which will induce detachment and transfer of surface soil during rains.

A plot of erodibility versus rainfall erosivity (see Fig. 4.2h) reveals that erodibility increased with increase in rainfall erosivity. The rainfall erosivity for Axim has the highest value among the stations considered in this study (Oduro-Afriyie, 1996), and the measured erodibility, $K_s = 0.57$, is relatively high, being the second highest in the series . This shows that Axim is a high erosion risk area and hence adequate conservation practices must be adopted to protect the land from serious erosion effects. The erosivity of Juaso is ranked as severe and from the results (see fig. 4.1b) the Juaso soil has been found to be the most erodible, $K_s = 0.62$. A high erosivity factor combined with a high erodibility factor indicates that Juaso is a very high erosion risk area. It is therefore important that necessary measures are taken to protect the land from rainfall erosion. Ada is a severe erosion risk zone while the measured erodibility value (K_s= 0.50) ranked third highest among the soils studied. Ada is therefore a high erosion risk area. The erodibility of the Cape Coast soil is the fourth highest in the series while its erosivity is ranked as very severe. Soil erosion can hence be a problem in Cape Coast if adequate ground cover is not provided. The erosivity of Accra is ranked as moderate and its measured erodibility value , K_s=0.47, is the fifth highest among the soils studied. The least erodible of the soils is the Ho soil with an erodibility value of K_s=0.36.Its erosivity is also ranked as low. A low erosivity factor and a low erodibility factor indicates that Ho is in the least erosion risk zone.

4.3 MULTIPLE LINEAR REGRESSION ANALYSIS

Regression data for the relationship between the erodibility factor (K_s) and various soil properties are shown in Table 4.3.

Table 4.3 Regression data for relationship between the erodibility factor (K_s) and various soil properties

Equation	**Correlation Coefficient r**
1. $K_s = -0.0674 + 0.06384\mathbf{S}$	0.6606
2. $K_s = 0.1805 + 0.00672\mathbf{VFS}$	0.6685
3. $K_s = 0.2782 + 0.0177\mathbf{FS}$	0.8171
4. $K_s = 0.6097 - 0.0241\mathbf{MS}$	-0.6062
5. $K_s = 0.5751 - 0.0186\mathbf{CS}$	-0.6499
6. $K_s = 0.4766 + 0.0032\mathbf{Sil}$	0.0802
7. $K_s = 0.075 - 0.0110\mathbf{CL}$	-0.7567
8. $K_s = -2.0909 + 0.0017\mathbf{BD}$	0.6684
9. $K_s = 0.4679 + 0.01631\mathbf{OM}$	0.3177
10. $K_s = 0.2843 + 0.0593\mathbf{P}$	-0.9069
11. $K_s = 0.5334 - 2.8333\mathbf{EC}$	-0.2229
12. $K_s = 0.996 - 0.0809\mathbf{pH}$	-0.8465
13. $K_s = 0.5451 + 0.0417\mathbf{P} - 0.0321\mathbf{pH}$	0.9292
14. $K_s = 0.4561 + 0.0305\mathbf{P} - 0.0256\mathbf{pH} + 0.0072\mathbf{FS}$	0.9587
15. $K_s = 0.5289 + 0.0399\mathbf{P} - 0.0114\mathbf{pH} + 2.686E{-}04\mathbf{FS} - 0.005\mathbf{CL}$	0.9761
16. $K_s = 0.0682 + 0.064\mathbf{P} - 0.028\mathbf{pH} - 0.022\mathbf{FS} + 0.0024\mathbf{CL} + 0.012\mathbf{VFS}$	1.000

LEGEND:

S= sand
FS =Fine Sand
VFS =Very Fine Sand
MS =Medium Sand
CS =Coarse Sand
Sil =Silt
Cl =Clay
BD =Bulk Density
OM =Organic Matter
P =Permeability
EC =Electrical Conductivity
pH =pH

Fine sand (R=0.8171), very fine sand (R=0.6685) and bulk density (R= 0.6684) showed relatively high positive correlation coefficients with K_s values. This is in agreement with results of Wischmeir and Mannering (1969), Wischmeir et al. (1971), Romkens et al. (1977) and Wischmeir & Smith (1978). The high correlation for fine sand and very fine sand is attributed to the ease with which these particles are detached and their transferability. The positive correlation coefficient obtained between K_s and bulk density reflects the relationship between rate of infiltration and compaction. Generally, the higher the bulk density the lower the permeability. This results in increased runoff and hence a greater tendency for soil detachment and transfer. Silt showed a positive correlation coefficient with K_s. This is in agreement with findings by Wischmeir et al. (1971), Young & Mutchler (1977), and Romkens et al. (1977)

Permeability showed a high negative correlation with K_s value (R=-0.9069). Parameters such as medium sand and coarse sand showed negative correlation coefficients with K_s. This is a reflection of how the size of particles is related to erodibility. It is more difficult for water to wash off larger particles than smaller particles.

A high negative correlation coefficient r=-0.7567 was obtained between clay and K_s. This negative correlation between clay and the K value is in agreement with the results obtained by Meyer and Harmon (1984), and Barjracharya et al. (1992). This observation indicates that clay soils are easily erodible.

Electric conductivity showed a poor negative correlation with the K value, (K_s=-0.2229). A high negative correlation was obtained between pH and the erodibility value, K_s=-0.8465. Organic matter content of the soils studied showed a poor correlation with erodibility, K_s=0.3177.

Soil parameters which showed high correlation coefficients with K_s-values in decreasing order were permeability K_s=-0.9069; pH K_s=-0.8465; Fine Sand K_s=0.8171; Clay K_s =-0.7567 and Very Fine Sand K_s=0.6685.

Several interactive parameters were tested together against K_s values by multiple regression analysis. Stepwise multiple regression yielded a five term equation that explains 100% of the variation in erodibility of the soils studied, equation (16). The most powerful predictor of erodibility in the model is permeability with a correlation coefficient R= 0.9069. Other workers(El-

Swaify and Dangler 1977 and Young & Mutchler 1977) have also found that permeability is an important factor in the prediction of soil erodibility,

From the results of the multiple linear regression, it can be seen that K_s values for the soils studied can be predicted with reasonable accuracy using permeability, pH fine sand, clay and very fine sand parameters as indicated by equation 16.

Permeability explained 90.6% of the variation in the soil erodibility, (Equation10). Addition of pH explained 92.9%, (Equation 13). Further addition of fine Sand explained a further 95.8% of the variation, (Equation 14). Addition of Clay explained 97.6%, (Equation 15), while addition of Very Fine Sand explained 100% of the variability of the erodibility of the soils studied (Equation 16).

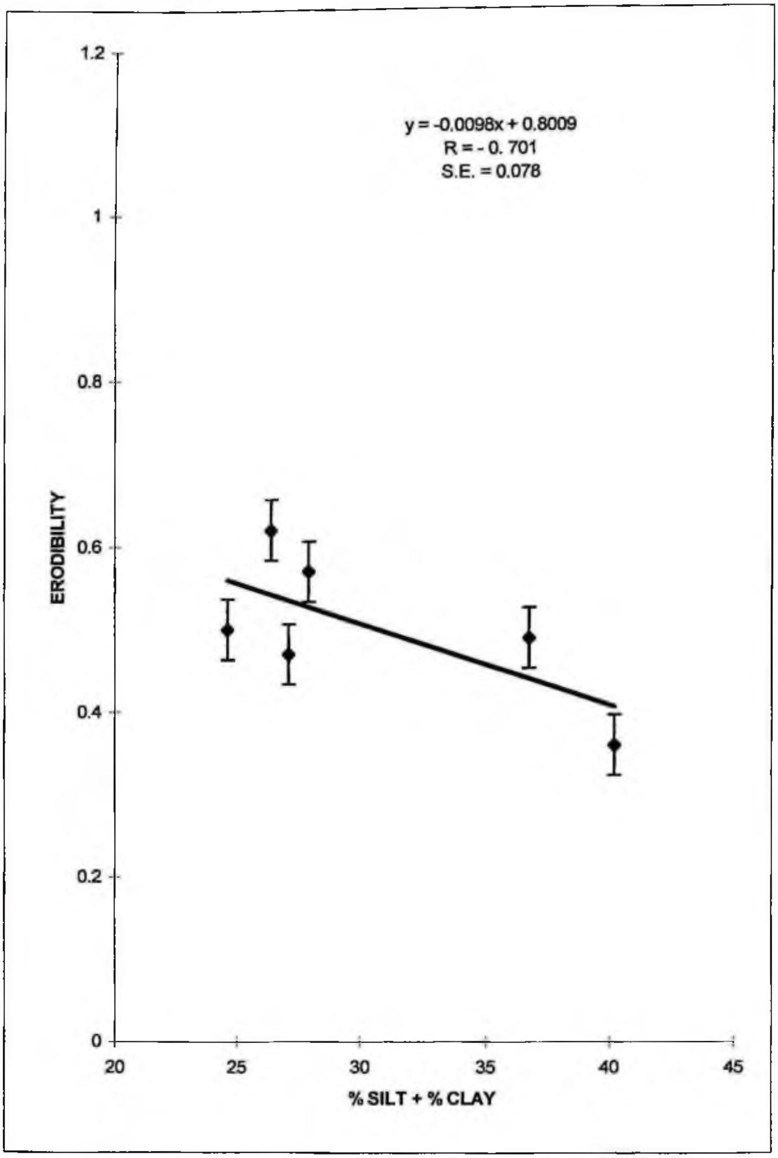


Fig. 4.2a Erodibility versus % Silt + % Clay

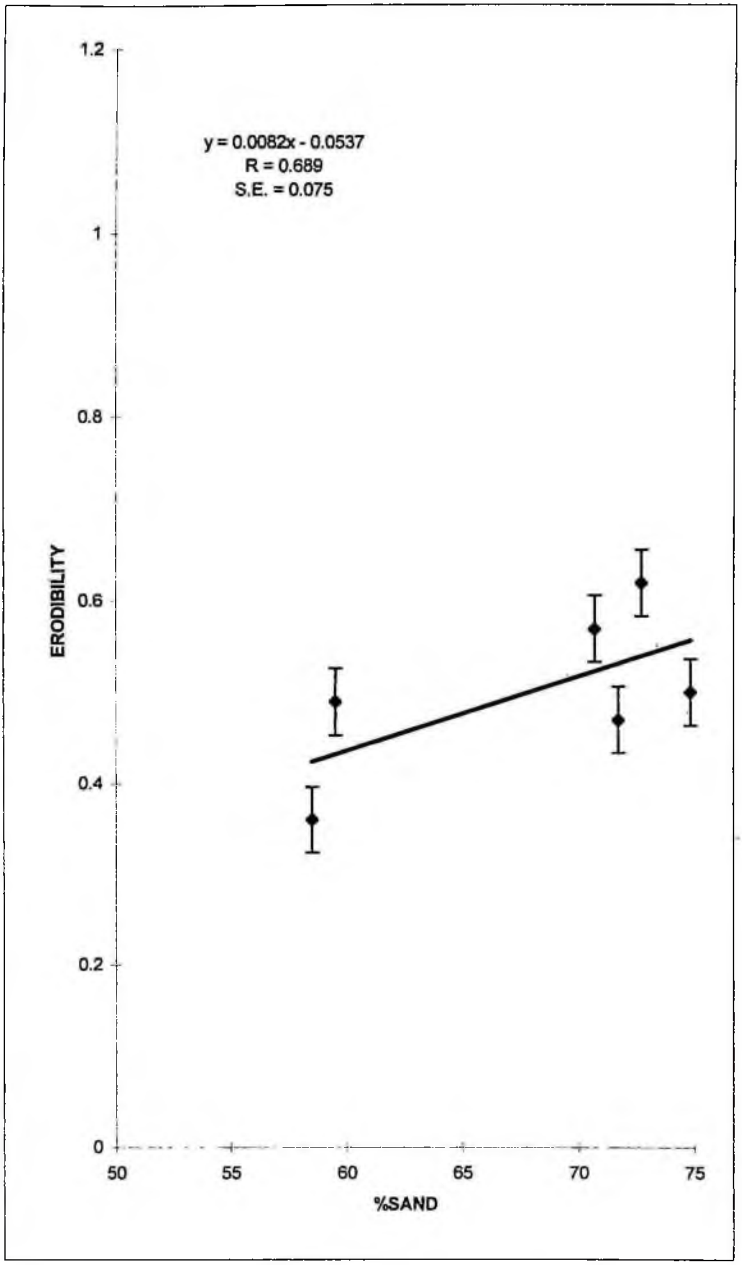


Fig. 4.2b Erodibility versus % Sand

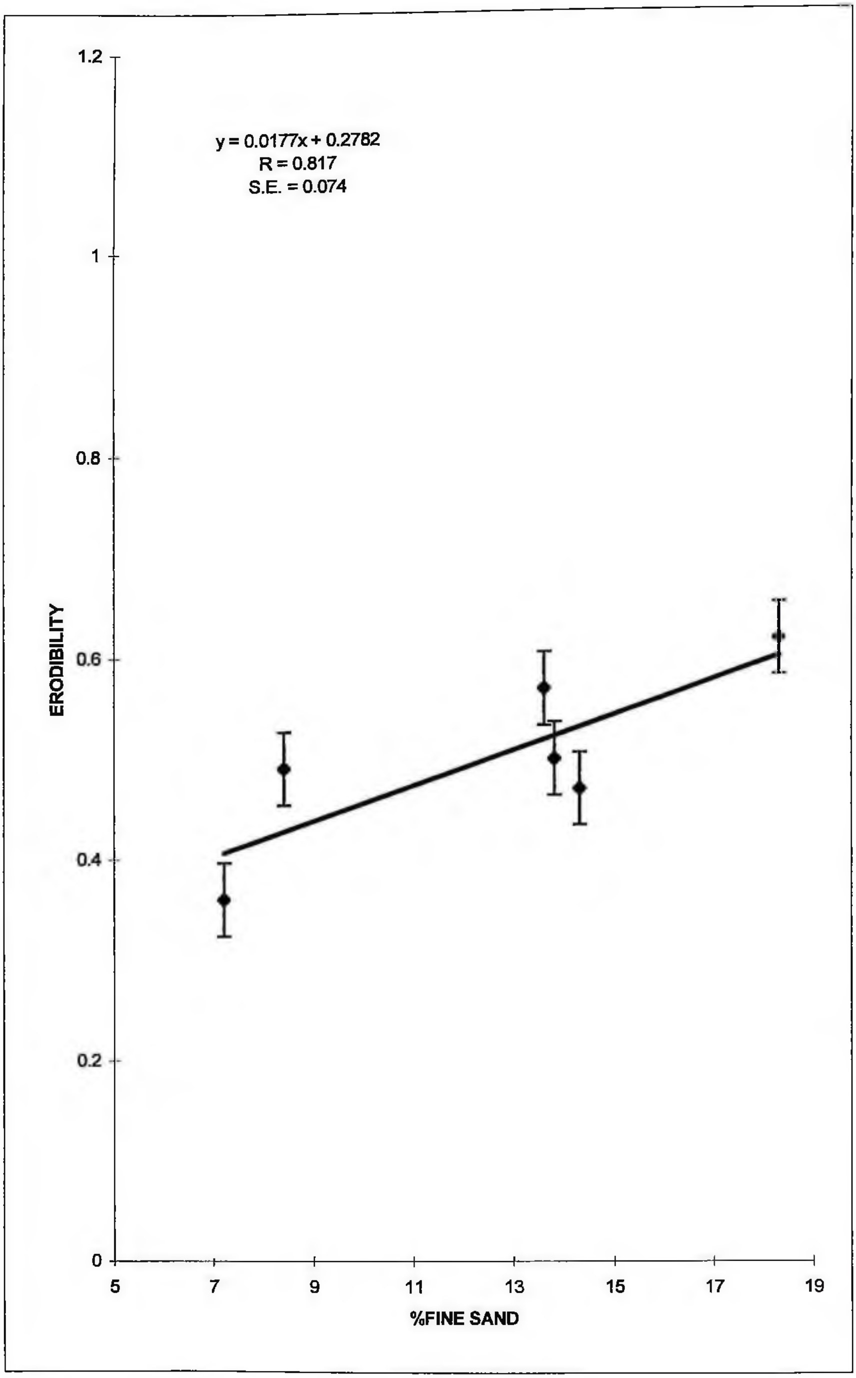


Fig. 4.2c Erodibility versus & Fine Sand

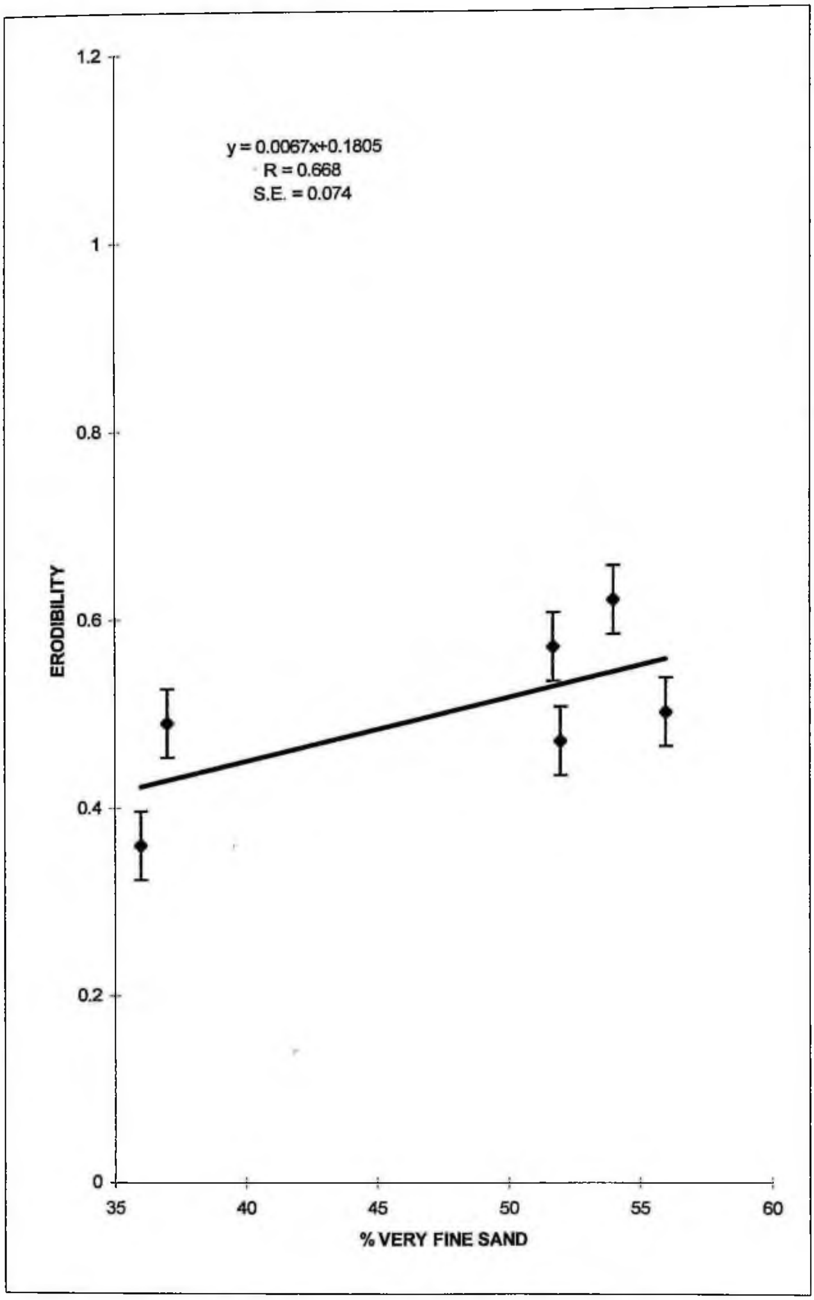


Fig. 4.2d Erodibility versus % Very Fine Sand

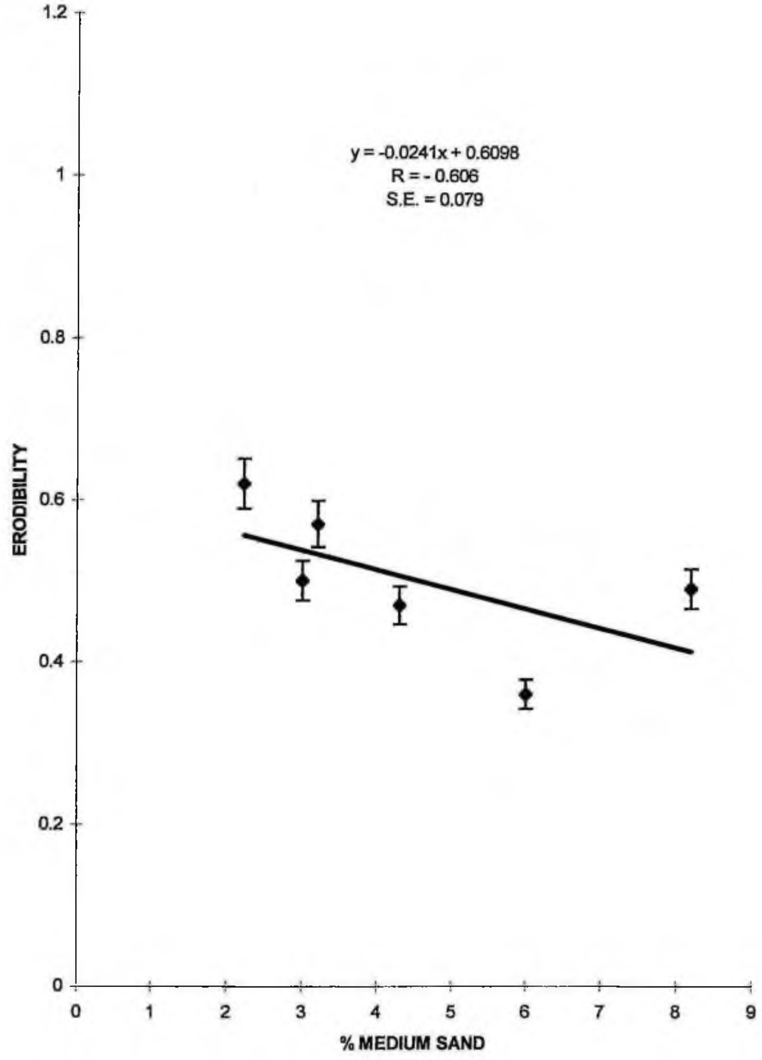


Fig. 4.2e Erodibility versus % Medium Sand

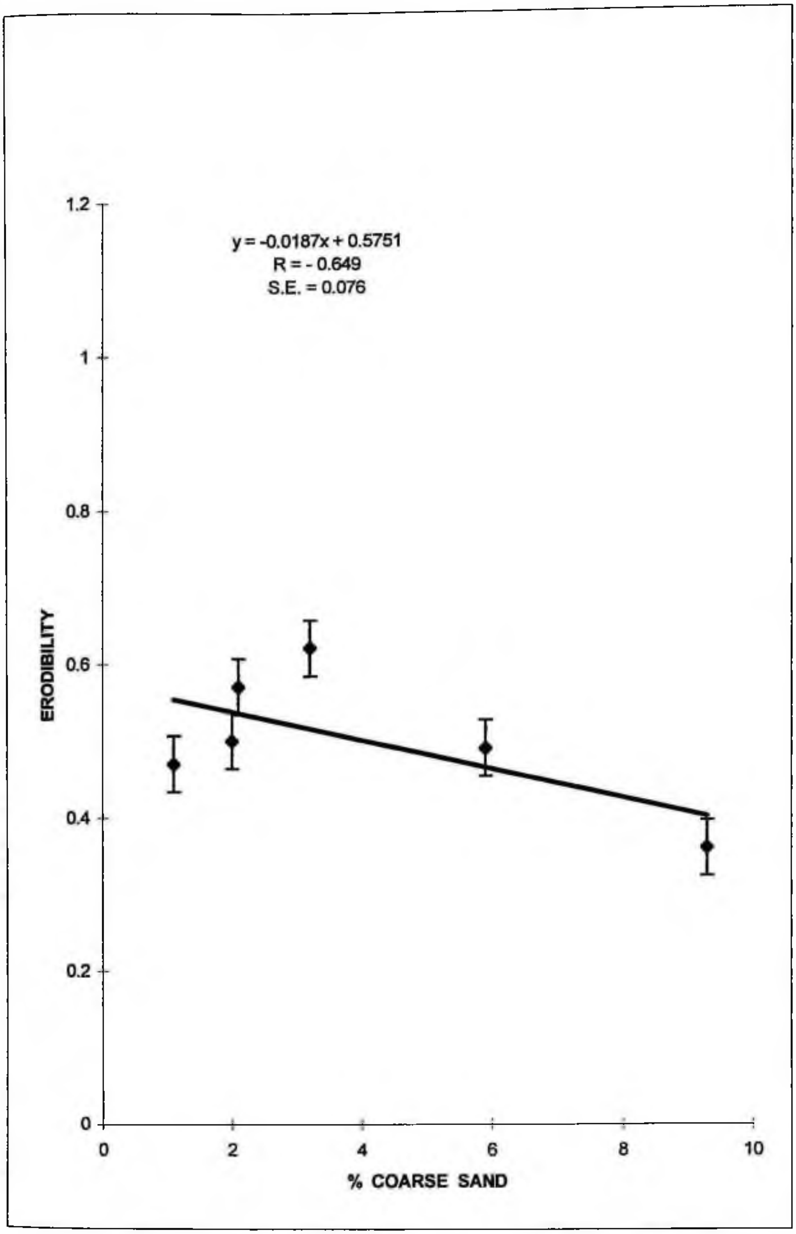


Fig. 4.2f Erodibility versus % Coarse Sand

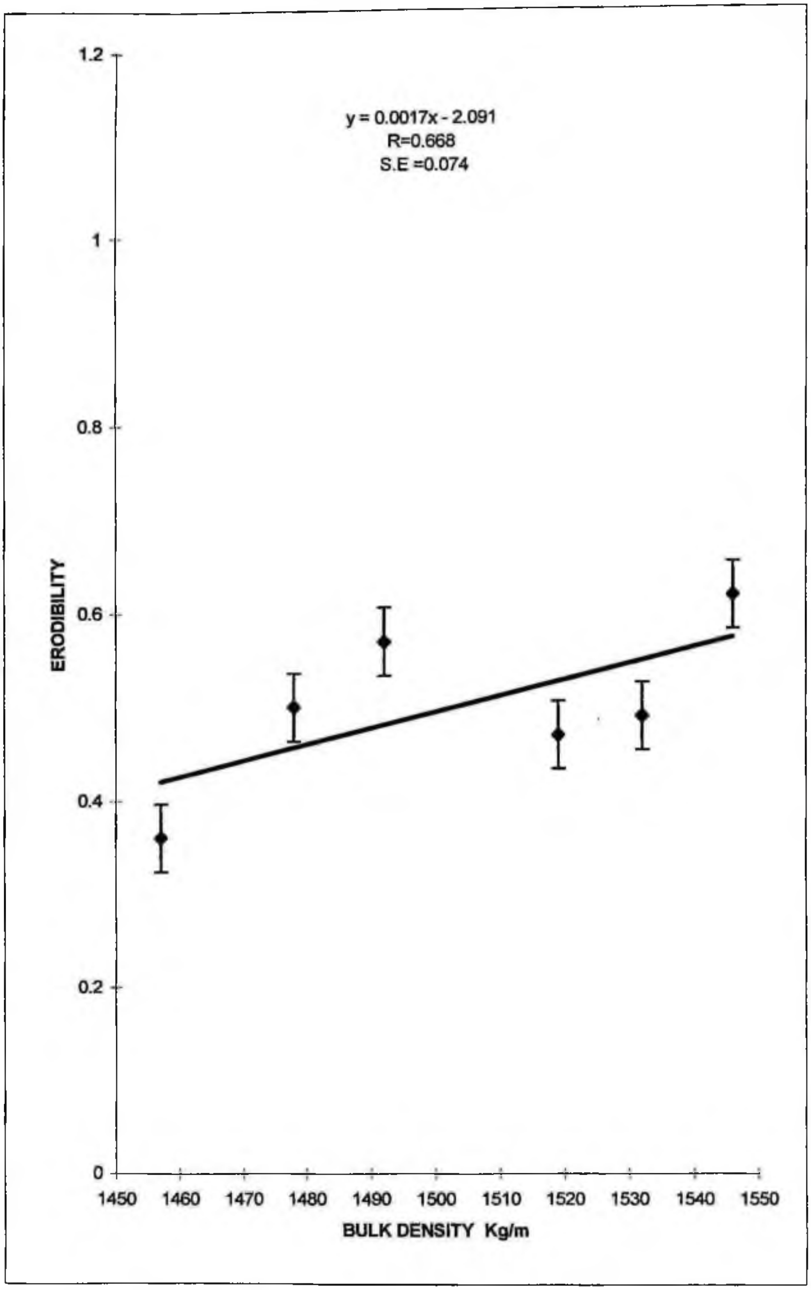


Fig. 4.2g Erodibility versus Bulk Density

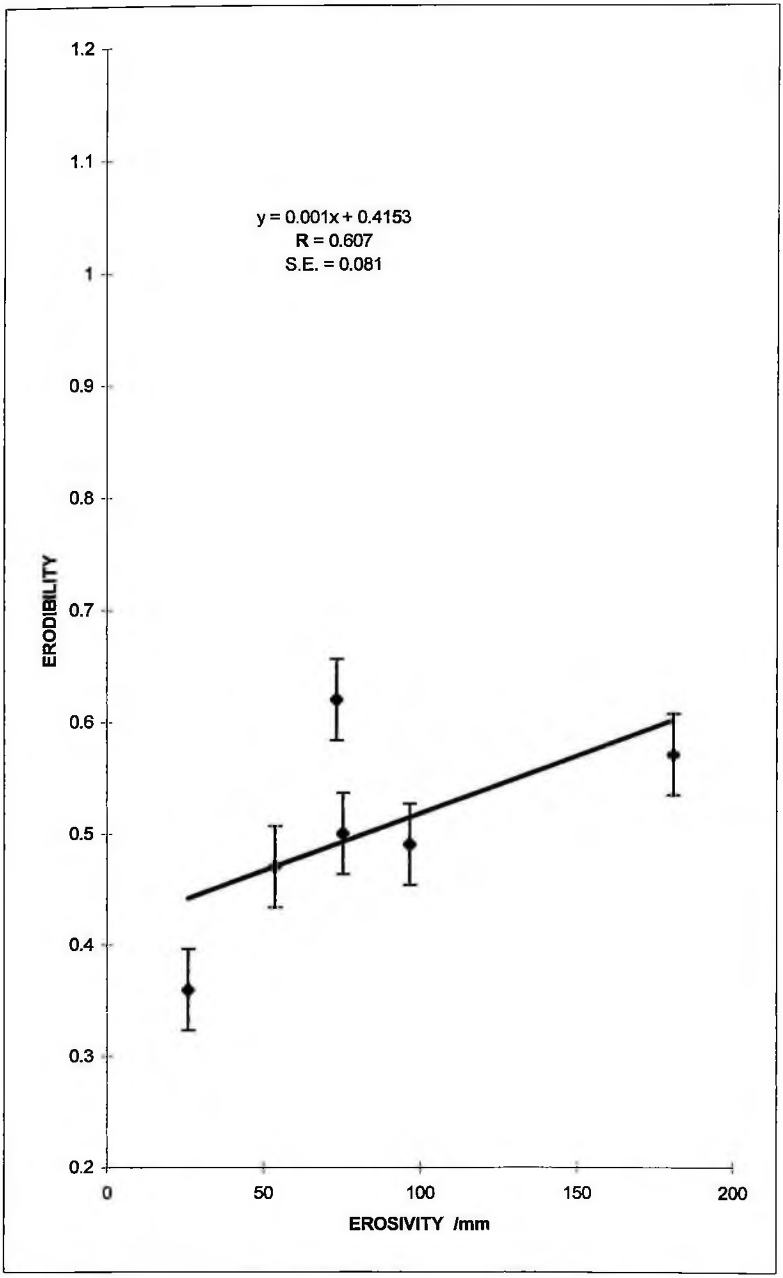


Fig. 4.2h ERODIBILITY VERSUS RAINFALL EROSIVITY

CHAPTER FIVE

CONCLUSION AND SUGGESTION

5.1 CONCLUSION

There was variability in the erodibility of the soils studied. The experimentally obtained erodibility values ranged from 0.62 for Juaso; 0.57 for Axim; 0.50 for Ada; 0.49 for Cape Coast ; 0.47 for Accra and 0.36 for Ho these values were generally higher than those estimated using the erodibility nomograph.

The erosivity values of these locations correlated significantly with their erodibility values. The location which is in the high erosion risk zone is Juaso while the least erosion risk location is Ho.

The most important parameter which predicted the erodibility of the soils considered was permeability with a correlation coeficient of 0.9069 (Table 4.3). Percentages of clay, fine sand and very fine sand also influenced the erodibility values of the soils.

Results from multiple linear regression techniques indicate that the erodibility of the soils is a function of complex interactions of a substantial number of their physical and chemical properties. For the soils studied, the erodibility values can be predicted using permeability, percentage of clay fine sand and very fine sand.

5.2 SUGGESTION

- It is suggested that more research work be carried out to determine the relative erodibilities of soils throughout the country, so that an erosion hazard map can be produced for the entire country. This will go a long way in helping soil conservationists to adopt appropriate management practices to suit any particular area.

REFERENCES

Adams, J.E., D. Kirkham and W.H. Scholtes. 1958. Soil erodibility and other physical properties of some Iowa soils. *J.Sci.* Iowa State Coll. 32: 485-540

Arsov, K., 1963. Studies in the surface water drainage in the djebel region and determining the size of the temporary gutters and furrow to handle it. *Bull. Nst. Tobacco Growing*, Plovdiv vol.3, Sofia Bulgaria.

Ayensu, A., 1987. Estimation of rainfall erosivity values and construction of iso- erodent map. International Agrophysics 3(3) : 113-122

Bajracharya, R.M., W.J. Elliot, R. Lal (1992). Intrill erodibility of some Ohio soils based on field rainfall simulation. *Soil Sci. Soc. of Amer. Journ.*, 56:267-272.

Benneh, G., K. Dickson. 1970. A new Geography for Ghana. Longman Group Limited. Longman Group U.K.

Biolchev, A. 1959.*Eroziya i borbatu s neya* (Soil erosion and soil cons). *Zemizdet*, Sofia Bulgaria.

Browning, G.M., C.I. Parish, and G.A. Clan. 1947. A method for determining the use and limitation of rotation and conservation practices in control of soil erosion in Iowa. *J. Amer. Soc. Of Agron.*, 39:65-73.

Bryan, R.B. 1968. Development of Laboratory Instrumentation for the study of soil erodibility. *Earth Science Journal*, 2: 28-58.

Bryan, R.B., 1970. An improved rainfall simulation for use in erosion research. *Canadian Journal of Earth Sciences,* 7: 1552-1561.

Daniel, H., 1980. Introduction to Soil Physics. Academic Press, Inc. Publishers, Harcourt brace Javanovich, San Diego , California.

Douglas, I 1967. ‘Man, Vegetation and sediment yield of rivers’, *Nature* 215: 925-928.

El-Asswad, R.M., and A.F.Abufaied. 1994. Erodibility of three Libyan soil types in relation to their physical and chemical properties. *Journal of Arid*

Environments.26: 129-134.

El Swaify, S.A., and E.W. Dangler. 1976. Erodibilities of selected tropical soils in relation to structural and hydrologic parameters. p. 105-114. In soil erosion prediction and control. *Spec. Pub. 21 Soil Conserv. Soc. Amer*., Ankeny, Iowa.

Elwell, H.A. and M.A. Stokings. 1976. Vegetal cover to estimate soil erosion hazard in Rhodesia, *Geoderma*. 15, 61-70.

Foster, G.R. and L.D. Meyer. 1972. 'A closed-form soil erosion equation for upland areas', in Shen, H.W.(ed.),*Sedimentation, Dept. Civil Engng*. Colorado State Univ., Fort Collins, Colo., 12-1-12-19.

Foster, G.R., L.D. Meyer and C.A. Onstad 1973. 'Erosion equations derived from modeling principles',ASAE Paper No 7.3-2550, *Am. Soc. agric. Engnrs*, St Joseph, Mich.

Foster, G.R., L.D. Meyer and C.A. Onstad 1977. A runoff erosivity factor and variable slope length for soil loss estimates. *Trans.,* ASAE 20 683-687.

Foster, G.R., O.K. McCool, K.G. Renard and W.C. Moldenhauer. 1981. Conversion of the USLE to SI metric units. J. Soil and water cons. 36: 355-359.

Fournier, F. 1972; Soil conservation, Nature and Environment Series Council of Europe.

Gabriels, O.D., J.M. Pauwels, and M. De Boodt 1975. 'The slope gradient as it affects the amount and size distribution of silt loss material from runoff on silt loam aggregates' Mel. Fac. Landbouw. Rijksuniv. Gent. 40, 1333-1338.

Hesse, W., 1971. Analysis of soils for major nutrients. Soil Sci. Soc. Of Amer. Journ. 23 : 24-27

Horvath, V. and B Erodi. 1962. 'Determination of natural slope category limits functional identity of erosion intensity', *Int. assoc. Scient. Hydrol*. Pub. 59 131-43.

Hudson, N.W. and D.C. Jackson. 1959. 'Results achieved in the measurement of erosion and runoff in southern Rhodesia', Proc. Third Inter-African soils conference Dalaba, 575-83.

Hudson, N.W. 1965. The influence on rainfall on the mechanisms of soil erosion with particular reference to southern Rhodesia, Unpub. MSc thesis, University of Cape Town.

Hudson, N. 1971. Soil Conservation. Cornell Univ. Press Ithaca, N.Y.

Hudson, N., 1972. Soil Cons., Cornel University Press Ithaca, New York.

Hudson, N., 1981. Soil Conservation. Batsford.

Jackson, S.J., 1984. The role of slope form on soil erosion at different scales as a possible link between soil erosion surveys and soil erosion models. Unpub. PhD Thesis. Cranfield Institute of Technology.

Kalcheva, R. 1962. Manual for the rains in the PR of Bulgaria HMS, NIIHM, Sofia Bulgaria.

Kinnel, P.I.A. 1983. The effect of kinetic energy of excess rainfall on soil loss from non-vegetated plots. *Aust. J. Soil Research* 21 (4): 445-453.

Kinnel, P.I.A., 1985. Runoff effects on the efficiency of raindrop kinetic energy in sheet erosion. In Soil Erosion and Cons. S.A. EL-Swaify, W.C. Moldenhauer and A.L. Ankenny. Iowa Soil Cons Soc. Of Amer.

Kinnel, P.I.A., 1993. Sediment concentrations resulting in shallow overland flow. Trans. ASAE 36 (4): 1099-1103.

Kinnel, P.I.A., 1994. The effect of predetached particles on soil erodibilities associated with erosion by rain imparted flow. *Aust. J. Soil Research 32* (1): 127-142.

Kirby, M.J. 1969. 'Erosion by water on hillslopes' in Chorley, R.J. (ed.) , *Water, earth and man*, Methuen, 229-38.

Kubiena, W.L. 1953. The Soils of Europe. Murby, London.

Lal, R. 1976. Soil erosion problems on an alfisol in Western Nigeria and their control. Intenational

Institute of Tropical Agriculture, Mon. No. 1 Ibadan, Nigeria (160 p and appendages)

Lal, R. 1977. Analysis of factors affecting rainfall erosivity and soil sedimentation p.49-56. In D.J. Greenland and R. Lal (ed.) Soil Conservation and management in the humid Tropics. John Wiley and Sons. New York. N.Y.

Lombardi, F. 1977. Rainfall erosivity - Its distribution and relationship with loss at Campinas, Brazil. M.S. Thesis. Perdue University. W. Lafayette IN. 53p

Laws, J.D. and D.A. Parsons. 1943. The relationship of raindrop size to intensity, *Trans. Am. Geophysics* Un. 24: 452-60.

Lazarova, E. 1980. Soil Cons. Effectiveness of some agricultural measures in growing of corn. Thesis. Sofia Bulgaria.

Middleton, H.E.., 1930. Properties of soils which influence soil erosion. United States Department of Agriculture, Technical Bulletin No.178. Washington D.C.: United States Government Printing Office 16pp.

McIntire, D.S. 1958. Permeability measurements of soil crusts formed by rain drops impact. *Soil Science* 85: 185-189.

Morgan, R.P.C. 1986. Soil Erosion and Conservation. (Rev. and enl. ed.). Longman Scientific and Technical. Longman House, Burnt Hill, Harlow.

Moldenhauer, W.C. and D.C. Long. 1964. Influence of rainfall energy on soil loses and infiltration. 1. Effect over a range of texture. *Soil Science Soc. Amer., proc.* 28: 813-817.

Musgrave, G.W. 1947. The quantitative evaluation of factors in water erosion: a first approx. *J. Soil and water Conserv.* 2: 133-138.

Oduro-Afriyie, K 1996. Rainfall erosivity map of Ghana. *Geoderma* 74. pp 161-166.

Olson, T.C. and W.H. Wischmeir, 1963. Soil erodibility evaluations for Soils on runoff and erosion Stations. *Soil Sci. Soc. Amer.,* Proc. 27: 590-592.

Onchev, N., 1977. Prediction of sheet erosion in Bulgaria and optimisation of agrotechnical erosion control and improvement practices. Thesis. Sofia Bulgaria.

Onchev, N., and P. Petrov 1974. Values of erosion factors in predicting soil losses in orchards. *Soil Soc. Agrochem*. 9 (2) Sofia Bulgaria.

Onchev, N. 1978. Universal Index for calculating rainfall erosivity . Soil Sci. and Agrochem. Sofia, Bulgaria.

Onstad, C.A. and G.R. Foster, 1975. Erosion modeling in a watershed. *Trans., ASAE* 18: 288-292.

Ronkens, M.J.M, C.B. Roth and D.M. Nelson 1977. Erodibility of selected clay subsoils in relation to physical and chemical properties. Soil Sci. Soc. of America 41: 954-960.

Rosewell, C.J. 1986. Rainfall kinetic energy in Eastern *Aust., J. Climate and applied Meteor.* 25(7): 1695-1701.

Rubio-Montoya, D. and K.W. Brown. 1984. Erodibility of Stripmine Soils. *Social Science*, 138: 365-373.

Shaxson, T.F., 1981. Reconciling social and technical needs in conservation work on village farmlands; in Morgan, R.P.C. (ed) Soil Conservation, problems and prospects, Wiley, 385-97.

Schollenberger, R. and Simon F., 1945. Methods of soil analysis. (ed) Wiley New York.

Singer, M.J., J. Black, and G.L Huntington. 1980. Plant cover helps control rangeland soil erosion. Calif. *Agric.* 34: 8-10.

Sloneker. L.L., and W.C. Moldenhauer, 1977. Measuring the amounts of crop residue remaining after tillage. *J. Soil and Water Cons.* 32: 231-236.

Tackett, J.L., and R.W. Pearson. 1965. Some characteristics of soil crusts formed by simulated rainfall. *Soil Sci. Soc. Amer.*, proc. 99: 407-413.

Williams, J.R., 1975. Sediment yield predictions with universal equation using runoff energy factor. In present and prospective Technology for predicting sediment yields and sources. ARS-5-40. *Agr. Res. Ser.*, USDA Washingston D.C. pp. 24-252.

Wischmeir, W.H., 1962. A rainfall erosion index for a universal soil *loss equation. Proc. Soil sci. Soc of Amer.*, 23:246-249.

Wischmeir, W.H. and D.D.Smith. 1958. Rainfall energy and its reltionship to soil loss, *Trans. Am. Geophysics* Un. 39: 285-91

Wischmeir, W.H., C.B. Johnson and B. V. Cross 1971. A soil erodibility nomograph for farmland and construction sites. *Journal of Soil Water conservation* Vol. 26: 189-193.

Wischmeir, W.H., 1972. Upland erosion analysis. In H.W. Shen (ed.) Environmental impact on rivers. Water Resources Publictions Chapter 15 Fort Collins. Colo.

Wischmeir, W.H., 1976. Use and misuse of the Universal Soil Loss Equation. *J. Soil Water onserv.* 31(1) 5-9

Wischmeir, W.H., and J.V. Mannering. 1969. Relation of Soil properties to its erodibility. Soil Sci. Soc. Am. proc. 33: 131-137.

Wischmeir, W.H. and D.D. Smith 1962. ' Soil loss estimation as a tool in soil and water management planing', Int. Scient.. Hydrol. Pub. 59, 148-59.

Wischmeir, W.H. and D.D. Smith 1978. Predicting rainfall erosion loss - a guide to conservation and planning. Agricultural handbook No. 537. Washington, D.C. United States Department of Agriculture. 58pp.

Wischmeir, W.H. C.B. Johnson, and B.V. Cross, 1971. A soil erodibility nomograph for farmland and construction sites. *J. Soil Water Conserve.*, 20: 150-152.

Young, R.A. and C.K. Mutchler, 1977. Erodibility of some Minnesota Soils. *Journal of Soil & Water Cons.* 32: 180-182.

Young, R.A., and J.C. Wiersman, 1973. The role of rainfall impact in soil detachment and transport. *Water Resources Res.* 9:1629-1636.

Zanchi, C. and D. Torri. 1980. 'Evaluation of rainfall energy in central Italy', in De Boodt, M. and

Gabriels D. (ed.) Assessment of erosion. Wiley . 133-42.

Zingg A.W. 1940. Degree and length of land slope as it affects Soil loss in runoff, *Agric. Eng*. 21,:59-64.