INFLUENCE OF RAINFALL DIRECTION ON EROSIVITY AND SOIL LOSS

BY

JOHN KWAME BOATENG

B.SC. AGRICULTURE (LEGON)

A THESIS SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN LAND AND WATER MANAGEMENT.
AGRICULTURAL ENGINEERING DEPARTMENT, UNIVERSITY OF NAIROBI,
NAIROBI, KENYA.

MAY 1994.

DEDICATION

Dedicated to Paapa and Maame and to my Brothers and Sisters.

DECLARATION

I solemnly make a declaration that this thesis is my own work and has never been presented as thesis to any University. All sources of information are acknowledged.

Signed...
Mr. John K. Boateng
Date......23/5/94.......................................

This thesis has been submitted for examination with my approval as the University Supervisor.

Signed...
Dr. F. N. Gichuki.
Date.................23/5/94....................

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

thank God the Almighty for keeping me alive and guiding me rough this work. I thank Dr. M. A. Zobisch and Dr. F. N. Gichuki the Department of Agricultural Engineering, University of irobi for supervising the work. I thank as well, Professor D. B. omas, Dr. T. C. Sharma, Mr. P. Klinspor and Mr. A. Oduor, all of e Department of Agricultural Engineering for their useful ntributions.

am very grateful to the following institutions and individuals r their assistance: The Swedish Agency for Research Cooperation h Developing Countries (SAREC), The African Academy of Sciences S) for providing the funds, Mr. E. K. Yego, Mr. B. Muliro, Ms L. ato and all other research assistants stationed at the SAREC earch site and the soil and water laboratories.

ally my most heart-felt gratitude to all and sundry, who might one way or the other assisted me in this work. I pray for God's ssing for all.

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

Rainfall amount in millimetres

Conventional rainfall amount in millimetres

Rainfall amount in millimetres after the effect of gauge inclination has been corrected by multiplying A1 by cosine 30,the angle of gauge inclination.

Percentage.

The product of rainfall amount and intensity (mm^2/h).

Centimetres.

Millimetres.

Metres

Grams.

Kilograms.

Joules.

Kilojoules

Hours

Degrees centigrade

Rainfall intensity(mm/h).

Rainfall kinetic energy($J.m^{-2}$).

Rainfall erosivity.

The product of rainfall kinetic energy and intensity($J.m^{-2}.mmh^{-1}$)

Rainfall kinetic energy computed using Lal's empirical equation($J.m^{-2}$).

Rainfall kinetic energy computed using USDA's empirical equation($J.m^{-2}$)

	Maximum 30-minute intensity(mm/h).
0	The Product of rainfall amount and the storm's maximum 30- minute intensity(mm^2/h).
I_{30}	The product of E_{1al} and I_{30} ($J.m^{-2}.mmh^{-1}$).
I_{30}	The product of E_{usda} and I_{30} ($J.m^{-2}.mmh^{-1}$).
al	And others.
	Figure.
	Coefficient of determination
	Correlation coefficient.
	Probability.
	Level.
	Value obtained in an analysis of variance test to determine the significance level of two or more variables.
	Calculated F value.
	Tabulated F value.
	Degree of freedom.
	Sum of squares.
	Mean square.
	Least significance difference.
	North-West grassed.
	South-West grassed.
	North- East grassed.
	South-East grassed.
	North-West bare.
	South-West bare.

NEb	North-East bare.
SEb	South-East bare.
ad	Direction adjusted.
r/fmm	Rainfall in millimetres
S/Lsg/m2	Soil Loss in gm^{-2}

G. ABSTRACT

A study was carried out to determine the directional impact of rainfall on erosivity and soil loss in the Kabete area of Nairobi. This was done by employing three major fields of data collection : (1) Wind monitoring using a wind recorder. (2) Rainfall monitoring using a rain recorder and three sets of raingauges, each set consisting of five gauges facing different directions and (3) Runoff and soil loss monitoring on twenty-four microplots of size 1x2m and oriented to face four different compass directions. The four compass directions used were NE, SE, NW and SW.

The following erosivity indices: $E_{lal}I_{30}$, $E_{usda}I_{30}$, E_{lal} and AI_{30} were the best indices found to describe runoff erosion in the Kabete area. There was no significant difference in their ability to describe runoff erosion. Hence any of the four can be used for this region. Rainfall dominantly from westerly directions was found to have a significant directional effect over that of easterly and even vertical rainfall. This observation makes inclined gauges really better to use for erosivity prediction than vertical gauges. Slopes facing westerly directions suffered more soil loss, thus were more prone to damage than those facing easterly directions. Conservation planning should focus more attention to westerly facing slopes in this region.

G. ABSTRACT

A study was carried out to determine the directional impact of rainfall on erosivity and soil loss in the Kabete area of Nairobi. This was done by employing three major fields of data collection : (1) Wind monitoring using a wind recorder. (2) Rainfall monitoring using a rain recorder and three sets of raingauges, each set consisting of five gauges facing different directions and (3) Runoff and soil loss monitoring on twenty-four microplots of size 1x2m and oriented to face four different compass directions. The four compass directions used were NE, SE, NW and SW.

The following erosivity indices: $E_{lal}I_{30}$, $E_{usda}I_{30}$, E_{lal} and AI_{30} were the best indices found to describe runoff erosion in the Kabete area. There was no significant difference in their ability to describe runoff erosion. Hence any of the four can be used for this region. Rainfall dominantly from westerly directions was found to have a significant directional effect over that of easterly and even vertical rainfall. This observation makes inclined gauges really better to use for erosivity predictions than vertical gauges. Slopes facing westerly directions suffered more soil loss, thus were more prone to damage than those facing easterly directions. Conservation planning should focus more attention to westerly facing slopes in this region.

CHAPTER 1

1.0 INTRODUCTION

1.1 Rainfall Erosivity

Rainfall Erosivity according to Holy (1980) is the potential ability of rain to cause erosion. It is a function of the physical characteristics of rainfall. The detachment and transportation of soil particles often occurs on a large scale. There have been frequent cases of denudation of subsoil caused by intensive rainfall which washes away the shallow top soil layer. Surveys carried out in the deep soils in the U.S.A. have revealed that the loss of 50.8mm of soil, reduced fertility by 15% ; 101.6mm by 22% ; 152.4mm by 30% ; 203.3mm by 41% ; 252mm by 57% ; and 304.8 by 75% (Stallings, 1984).

The major cause of Erosion is the kinetic energy of raindrop impinging on the soil surface and the mechanical force of surface runoff. Surface runoff is caused by heavy rainfall of long duration and the concentration of water in the natural or artificial hydrographic network. Rainfall erosion from heavily grazed rangelands in eastern Kenya contributes 12 million tons per year of sediment to the eastern Tana river (El-Swaify, Dangler and Armstrong, 1982). Thomas (1974, cited in El-Swaify et al 1982) concluded from air-photo analysis that between 1948 and 1972, in the Machakos district of Kenya, with a bimodal annual rainfall totalling 820mm, the worst erosion occurred not on cultivated cropland, but on the steeper areas denuded by overgrazing and trampling. In a follow up study to Thomas's work, a team from the University of Nairobi, in 1977, noted that lands under both cultivation and grazing were subject to serious erosion problems. While cultivation prevailed in the lower zones, grazing went on, on the higher steeper zones of the district. The lack of adequate crop cover at the beginning of both rainy seasons (ie February and October) is mostly responsible for water erosion in the Machakos and regions of semi-arid climate.

El-Swaify, Dangler and Armstrong (1982) described the situation in Tanzania in similar terms. Based on their field studies and compilation of evidence collected in recent decades by other workers, they gave clear examples of very high erosion rates and rapid loss of water storage capacity in reservoirs. The problem of rainfall erosion in semi-arid Tanzania is therefore as vast and urgent as in Kenya.

Rainfall erosivity depends solely on rainfall properties, and to this extent not dependent of the soil. But according to Hudson (1985), a quantitative measurement of erosivity may only be made when erosion occurs, and this involves the erodibility of the eroded material. The most suitable expression of rainfall erosivity is an index based on the kinetic energy of the rain. Erosivity of a rainstorm is therefore a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops.

Rainfall direction defined as the average inclination and compass direction of falling raindrops of a storm has been perceived as a possible factor influencing soil loss and runoff (Lal,1977). Rainfall acquires its direction from the wind that accompanies the natural rainstorm. The importance of wind in the production of precipitation cannot be over-emphazied. It is only through sustained inflow of moist air into a storm that precipitation can be maintained (Linsley et al, 1988).

Wind has both speed and direction. The wind direction is the direction from which it is blowing. Linsley et al (1988), expressed wind direction in terms of 16 compass points (N, NNE, NE, ENE, etc.) for surface winds, and for winds aloft in degrees or tens of degrees from north, measured clockwise. Wind speed is given in kilometres per hour, miles per hour, metres per second, or knots.

Wind speed varies greatly with height above the ground. On mountain ridges and summits wind speeds at 10 m or more above the ground are higher than in the free air at corresponding elevations because of the convergence of the air forced by the orographic barriers.

On lee slopes and in sheltered valleys wind speeds are light. Wind direction is influenced by the orientation of orographic barriers. With a weak pressure system, diurnal variation of wind direction may occur in mountain regions, the winds blowing upslope in daytime and downslope at night. Wind speeds are reduced and directions deflected in the lower layers of the atmosphere because of friction produced by trees, buildings and other obstacles. These effects is very pronounced in the friction layer (ie below 600 m). Surface wind speed is usually at a minimum about sunrise and increases to a maximum in early afternoon.

Wind speed greatly influence raindrop size and hence raindrop impact and particle detachment. According to Hudson (1985), a great deal of experimental evidence exist which suggest a link between erosive power and the mass and velocity of falling raindrops. The ability of rainfall to cause erosion also varies, both with the orientation of land slope and the value of rainfall erosivity factor in the USLE (Mota Ferreira et al, 1985). Using the range of plot orientation from 104. ° to 207. ° ,at their research station in Vale Fermoso in Portugal, Ferreira and his colleagues established that rainfall seldom or never occurs unless the wind is from a southerly direction. They also observed erosion in the field and this led them to suggest that, practically all the orientation effect occurs within this zone.

In a research catchment in Ethiopia, differences in soil erosion damages have been attributed to uniform directions of rain during several centuries (Hurni 1988). Slopes exposed towards the rain in this catchment are much more damaged than slopes exposed toward the opposite direction. Similarly, a detailed mapping and subsequent analysis of soil erosion damages in the 30 km^2 Jinbar valley in Simen showed significant differences between the eastern and western facing slopes.

This observations led Hurni to recommend the inclusion of rainfall direction measurements for soil erosion process studies as well as for climatic monitoring especially in areas where rainfall direction is uniform over longer periods of time. However, with the exception of the work by Ferreira (1985) and Hurni (1988), not much has been done pertaining to the assessments of the relationship between directional rainfall erosivity,soil loss and runoff. In Kenya, the influence of rainfall direction on soil loss has never been studied intensively.

It has not been established whether inclination of raindrops produce stronger erosivities than vertical ones, nor any of the existing runoff and soil loss models considered a rainfall inclination parameter as an input value. Also not much information is available now on the effective amounts of rainfall on slopes.

The study which was undertaken at the steep-lands research site of the University of Nairobi campus in Kabete attempted to figure out solutions to some of these problems. The steep-lands research site in Kabete was chosen as the site for the study because of its uniqueness for such a study. With an altitude of nearly 2000 m asl; steep slopes and unique river flow system in addition to research facilities, no other place in Kenya qualified better in relation to local conditions i.e. highlands of kenya and the river flow system.

1.2 Objectives

The study has the following objectives :

(i) To determine if dominant wind direction correlates to rainfall direction.

(ii) To establish the energy levels of rainfall from the four compass directions and to determine to what extent they affect erosivity.

(iii) To determine if there exists a better correlation between soil loss and erosivity if rainfall direction were included for erosivity calculations.

(iv) To determine if the orientation of land slope significantly influences runoff and soil loss

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 History of Erosion

The problem of soil erosion, a natural process, was made worse the moment man of the stone age settled down from wandering for food and begun to cultivate the land. The intensive exploitation of the land disturbed the natural soil vegetative cover and exposed the soil surface to the effects of erosive agents. The downfall of many an ancient civilizations such as Syria, China, Egypt and Mesopotamia have often been linked to the devastation of land by erosion.

Following the discovery of the new world by columbus and the subsequent settlement of North and South America led to serious erosion in these virgin lands of the western hemisphere which had hitherto been untouched. The white settlers who came from Western Europe gradually seized Indian land and introduced alien farming methods which were completely unsuitable for the new environment.

Monoculture replaced the natural growth in the prairie land which was burnt down. And farming was gradually mechanised and intensified which in turn accelerated the process of erosion by wind and water. The US soil conservation service survey in 1934, showed that there were in the US more than 20 million hectares of eroded top soil and that this area was gullied to such an extent that it was completely useless for agriculture. Some 112 million hectares of land had been devastated to such an extent that it had become uneconomic for agriculture and cattle breeding. Significant damage had also been done to forest soils, mainly in areas with dense housing construction, highways and mining areas. The situation, however, looked different in areas where ancient culture led to a close relationship between the population and the land.

In the Andes in south America for example, farmers till the steep slopes of the mountains where their ancestors, the Incas lived, and cultivated the land thousands of years ago. The fields were extensively terraced to intercept rainfall and to prevent the occurrence of erosion processes. This enormous work carried out over such a vast period of time indicates what should be done to protect the soil to feed future generations.

2.2 Agents of Erosion

Erosion can be classified according to the agents causing its occurrence and affecting the course of the erosion process into

(i) Erosion by water
(ii) Erosion by wind
(iii) Erosion by glacier and snow

The activities by man accelerates natural processes by wind, water, etc. This type of erosion is called anthropogenic erosion or accelerated erosion. Anthropogenic erosion in not taken for an agent of erosion. The different types of erosion occurs separately or in combination causing erosion of varying intensity. Erosion by glacier and snow is common in the temperate and the cold climate zones of the world. The greatest damage to the economy of the world comes from water and wind erosion whose unfavourable effects are increased by anthropogenic effects.

In this study emphasis is put more on erosion caused by water than by wind.

2.3 Forms of Water induced Erosion

2.3.1 General

Water erosion takes place whenever flowing water passes over a loose soil and carries some of it away (Sopher and Baird, 1982). Water erosion is often classified by form, from the effects of exogenous agents on the soil surface as surface erosion and under the soil as sub-surface erosion.

2.3.2 Surface Water Erosion

Surface water erosion is classified by the effects of water on the soil into splash, sheet, rill, gully and stream erosion. Although all of these types of erosion are important, the splash, sheet and rill type are especially dangerous because they are not

always obvious until all the topsoil is gone. Hence the particular concern given to these three types in this review of literature.
The degree of erosion that will take place is determined by both the amount and duration of a given rainfall event.

Research conducted on stream sediment load has suggested a general relation between erosion by water and rainfall as shown Fig. 2.1. The movement by rain splash and the transport phase of raindrop detached soil by thin-flow surface flow whose erosive capacity is increased by raindrop impact turbulence, has been described as 'interrill' erosion (Meyer 1979). The action of raindrops on soil particles is most easily understood by considering the momentum of a single raindrop falling on a sloping surface (Morgan 1986). Raindrop momentum, a product of mass and velocity of raindrops, is a good indication of pressure exerted by rainfall on the soil.

Several studies on soil detachment by rainsplash have shown that it occurs as a result of rainfall momentum and kinetic energy (Roose 1980; Gregory 1980; and Morgan 1981). In 1981, Lal established a direct relationship between momentum and the amount of soil detached. Rose (1960), observed a more close relationship between the mass of soil detached per unit area and momentum than with kinetic energy of rainfall. However, more recent studies have correlated raindrop energy rather than momentum to splash detachment.

Splash erosion results when raindrops strike the soil surface and break soil aggregates into fine particles that can be carried away. The breaking of soil aggregates into fine particles that can be carried away easily by runoff is referred to as detachment. According to Styczen and Schmidt (1988), detachment by splash is proportional to the sum of squared momentum of each raindrop. Furthermore it is inversely proportional to the average energy required to break the bonds between two micro-aggregates. It is also related to the probability of the event resulting in measurable Splash. Translocation of detached soil particles may be caused by raindrop impact as splash through gravitational force downslope as creep, or by overland flow. It follows, therefore that, detachment precedes transport.

The quantity of material supplied by detachment and the capacity of transport influences remarkably the severity of erosion. The kinetic energy of raindrops, when released on the soil affects it in two distinct ways. First, it compacts the soil creating a thin crust on the surface and hence clogging pores. Secondly it displaces some particles of the soil resulting in splash transport. The soil particles so splashed by the impact of raindrops fall back to the soil surface in a more dispersed manner. This Phenomenon occurs continuously with rainfall and alters many physical properties of the surface soil. Soil susceptibility to erosion by water is subject to change as the thickness of well-developed profiles decreases and underlying horizons contribute increasing amounts of materials to the plough layer (Rhoton et al 1990). Splash transport in the resultant direction of the splash can result in a lot of soil loss. On sloping land, substantial net downslope splash transport has been recorded (Ekern, 1950; Quansah, 1981). During wind-driven storms, net splash transport in the windward direction occurs (Wischmeier and Smith, 1958). Besides losses through direct splash transport, splash erosion also contributes largely to the volume of soil material transported by surface runoff. The finer soil particles resulting from the impact of raindrops on the soil are more susceptible to erosion by runoff. According to Rose (1960) soil loss increases as much as ten times when water is applied as a spray in comparison with same rate of application as surface flow.

The mean splash rate of soils exposed to rainfall of a nearly constant kinetic energy level and impact velocity was influenced by drop size at the lower rate energy levels. As the energy level increased, the influence of drop size decreased (Bubenzer and Jones 1971). Data from the south the South Central States of America show that median raindrop sizes increased with increasing rainfall intensities up to approximately 2.5 in per hour then decreased as rainfall intensities increased further (Carter et al 1974). The decrease in median drop sizes at intensities above 2.5 in per hour was attributed to raindrops breaking into smaller drops as they approached the unstable size of approximately 6.2 mm in diameter.

In a study which calculated rainfall kinetic energy from average drop size distribution measured at 6 locations, median raindrop diameters in North Carolina, New Jersey and the Marshall Islands tended to be less than those observed in Panama, Indonesia, Washinton D.C., and Zimbabwe. Calculated rainfall kinetic energies for Panama and Indonesia were within 10% of that predicted by the USLE rainfall energy equation. Calculated rainfall energies for New Jersey, The Marshall Islands and North Carolina ranged from 5% to 25% less than that predicted by the USLE rainfall energy equation (Mclsaac 1990). Redistribution has important implications for splash erosion (Armstrong and Mitchell 1987). Distribution of drop size with degree of spatial concentration information and estimates of drop velocity enabled estimates of potential splash detachment based on rainfall intensity, momentum and kinetic energy.

The combined effect of splash detachment and transport is a levelling of the surface, and on sloping ground, in a gradual movement of surface particles down the slope. This type of erosion is hardly seen, but greatly influences the amount of soil removed from the land by subsequent runoff.

Sheet or interrill erosion is that characterized by the detachment and removal of soil more or less evenly over the whole affected area. The initial stages of sheet erosion involves selective erosion when surface runoff removes fine soil particles and the chemical substances which they bind. The soil texture changes as does the soil nutrient content. Soils exposed to selective erosion become coarse grained and have a significantly lower nutrient content while the soils enriched by the sediments are fine grained and rich in soil nutrients. Studies have shown that there is no interaction effect of slope on the exponent of the intensity term in an expression relating interrill detachment to rainfall intensity (Watson and Laflen 1986). Interrill soil erodibility was closely related to soil shear strength after rainfall, as measured by a vane shear device. Interrill soil erosion was well estimated by a prediction equation that included rainfall intensity, slope and soil shear strength.

Selective erosion can be going on without people noticing it. It becomes obvious when fine grained material accumulates in the lower parts of slopes normally after heavy downpours. This fine grained material often silts ditches.

Selective sheet erosion causes uneven development of the vegetation which is manifest in its growth, colour and quality on those parts of the slope which have been exposed to the washing of fine grained soil particles and nutrients and in the lower parts of slopes where washed fine-grained soil particles have accumulated. Selective erosion may reliably be ascertained by the texture analysis of the soil and by the measurement of changes in the soil nutrient in different content in different parts of the slope. A laboratory observations with simulated frost layers and rainfall, and the consideration of a theoretically based two-dimensional infiltration model for sloping layered soils, reveal a marked response of runoff characteristics to frost layering. In medium-textured soils, up to a three fold increase in runoff potential and a four fold decrease in time to ponding may be expected with a change in depth to the frost layer from 50mm to 10mm (Rudra et al 1986). Time to ponding and runoff amount were found not sensitive to land slope for short slope lengths.

The removal of soil in this layer by runoff with a higher kinetic energy leads to the unfavourable formation of the soil profile. This type of soil wash is evident either evenly on the whole slope or in broad strips depending on the soil surface relief. It usually results in the total loss of topsoil.

Concentrated surface runoff rills and grooves the soil surface and gradually cuts deep gullies into the soil surface. In the initial stages, small narrow channels are cut into the soil surface which create a dense network on the affected slope or shallow wider channels which are not so dense, continuing erosion and the further concentration of surface runoff cuts deeper channels into the soil surface. These channels or rills and interrills gradually merge and deepen and become gullies. Gully erosion may then gradually develop into dangerous and devastating ravine erosion.

The most susceptible regions are those of intermediate rainfall, where the incidence of rain is seasonal and the vegetative cover is therefore less effective, especially at the end of each dry season. Nonetheless, the erosive power of high rainfall is attested by the broken curve of Fig. 2.1, which applies to humid regions when the natural vegetation is removed.

Soil loss by surface water depends on the potential of rain to erode (rainfall erosivity) and the susceptibility of soil to erosion (soil erodibility). Tropical soils are mostly dominated by oxisols which are highly weathered, strongly structured and well drained with low susceptibility to water erosion. However, erosion hazards in oxisols and other soils of the tropics are high, by virtue of aggressive climates with highly erosive rainfall.

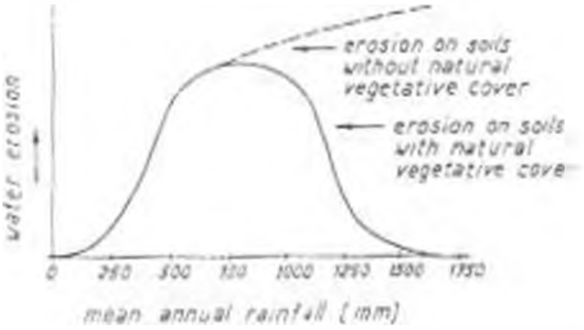

Fig. 2.1. Dependence of water erosion on mean annual rainfall (Source: N. Hudson, 1973).

Erosion usually reduces the productive capacity of soils with an unfavourable subsoil, such as the claypan. If long-term production is to be sustained, methods to improve surface cover for row crops to conserve soil will be necessary. Data from Sanborn Field (Gantzer et al 1990), indicates that long-term productivity will be affected even when using a 6-year rotation. Therefore, development of sustainable systems of row-crop production will be needed to conserve topsoil for future generations.

The design of erosion control measures can be approached by considering protection of the soil against a particular event rather than an annual condition (Styczen and Hogh-Schmidt 1988). The extreme event would probably be too costly for most farmers to consider protecting against while the dominant event would be too small in magnitude to guarantee protection without an unacceptable risk or failure. Hence protecting against the event with a ten-year return period may be suitable compromises. This approach according to Styczen and Hogh-Schmidt would place the design of field-Scale erosion control measures on the same basis as that used in the design of terraces and grass waterways.

2.3.3 Subsurface Water Erosion

This term is sometimes used to describe the transport of soil particles and nutrients from the surface to the lower soil layers with infiltrating precipitation. This process, however, belongs among the normal soil forming processes and should therefore not be classified as erosion.

In soils which are easily exposed to the effects of water erosion, especially loess, groundwater scours the subsoil which it disturbs and accumulates on the impermeable layer. The tunnels which are thus formed reduce the stability of the overburden. In many cases the tunnel erosion is therefore often classified as gully erosion. In karst areas, karst erosion is very frequent and widespread.

2.4 Climatic Factors Influencing Erosion

2.4.1 Atmospheric Precipitation

The climatic and hydrological conditions of an area influence considerably the process of erosion. These climatic and hydrological conditions are characterized by geological position, altitude, atmospheric temperature, precipitation, evaporation, air humidity, direction and force of wind current and surface runoff. Any investigation of erosion processes should therefore include an evaluation of atmospheric precipitation with regard to its direct effect on the soil surface and on the runoff caused thereby.

The erosion effects of heavy rainfall causing high intensity surface runoff are intensified by the effect of kinetic energy of raindrops on the soil surface. The raindrops falling on the soil surface cause a splatter of soil particles in the soil aggregates which are then carried away by surface erosion. Hudson (1964), observed that in the tropical zone the intensity of storm rain can go up to 200mm per hour and duration usually more than 120 minutes.

A number of empirical equations have been developed for expressing the relation between the intensity of heavy rainfall and its duration. The values of theoretical rainfall intensities are given in Table 2.1.

TABLE 2.1 **Theoretical intensities of heavy rainfalls (after J. Haeuser, 1919, and O. Dub, 1963).**

Rainfall duration (min)	5	10	15	20	30	60	90	100
Maximum intensity (mm/min) Haeuser, 1919	7.00	5.40	4.47	3.8	3.07	2.08	1.64	1.4
Maximum intensity (mm/min) Dub, 1963	5.40	3.82	3.06	2.6	1.95	1.20	0.87	0.7

Rain consists of raindrops varying in size. Measurement made by Hudson (1964) and Blanchard (1950) have proved that the biggest raindrops are 5mm in diameter. Rainfall which are >5mm in diameter may split into smaller drops. Regional low intensity precipitation is usually made up of small drops, while high intensity rainfall is usually characterized by drops of much bigger diameter. The intensity of heavy rainfall decreases with the size of the affected area. This inverse relation agrees with what many authors have observed.

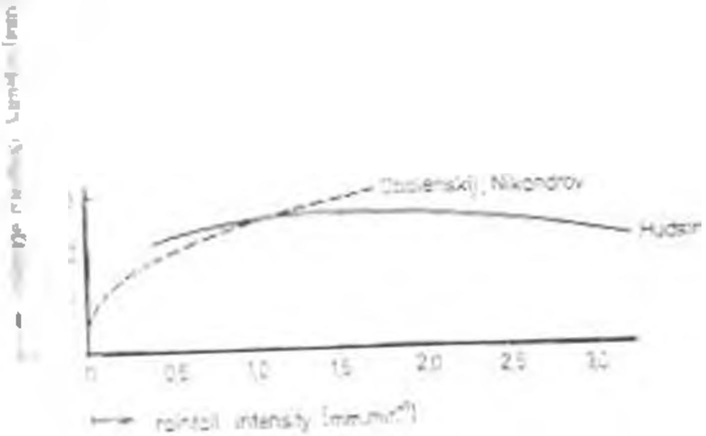

Fig. 2.2. Relation between the average diameter of raindrops and rainfall intensity. (after Holy,1980).

The relation between raindrop size and rainfall intensity is given by Obolenskiy and Nikandrov 1970 and Hudson 1973 (cited in Holy 1980) and is shown in Fig. 2.2. The relation given by Hudson clearly shows that the median volume diameter decreases at very high intensities.

Raindrop distribution is extremely difficult to describe by use of only a single parameter. Hudson (1973) states that probably the best index for drop distribution is the median volume drop diameter D50 which is such that half of the volume of the rain falls in drops with a smaller diameter and the other half as bigger drops.

The index is obtained by plotting a cumulative volume against drop diameter, Fig. 2.3.

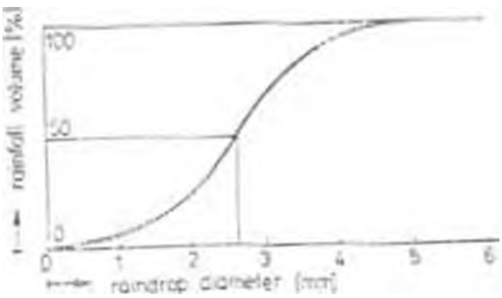

Fig. 2.3. Relation between the size of raindrops and rainfall volume (after Holy, 1980).

The relation between raindrop size and rainfall intensity is given by Obolenskiy and Nikandrov 1970 and Hudson 1973 (cited in Holy 1980) and is shown in Fig. 2.2. The relation given by Hudson clearly shows that the median volume diameter decreases at very high intensities.

Raindrop distribution is extremely difficult to describe by use of only a single parameter. Hudson (1973) states that probably the best index for drop distribution is the median volume drop diameter D50 which is such that half of the volume of the rain falls in drops with a smaller diameter and the other half as bigger drops.

The index is obtained by plotting a cumulative volume against drop diameter, Fig. 2.3.

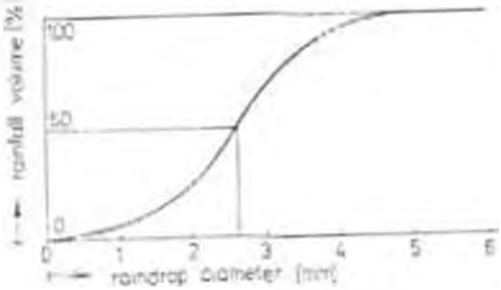

Fig. 2.3. Relation between the size of raindrops and rainfall volume (after Holy, 1980).

2.4.2 Rainfall Characteristics as Influenced by Wind

Wind, often defined as air in motion, is a very influential factor in several hydrometeorological processes. It is important in the production of precipitation, since it is only through sustained inflow of moist air into a storm that precipitation can be maintained (Linsley et al, 1982). For precipitation to occur, some mechanism is required to cool the air sufficiently to bring it to near saturation. The large-scale cooling needed for significant amounts of precipitation is achieved by lifting the air. This is accomplished by convective systems resulting from unequal radiative heating or cooling of the earth's surface and atmosphere or by convergence caused orographic barriers.

Cloud elements must increase in size until their falling speeds exceed the ascensional rate of the air. The cloud element must also be large enough to penetrate the unsaturated air below the cloud base without evaporating completely before reaching the ground. According to Mason (1952), a drop falling out of a cloud base at 1 km in air of 90 percent relative humidity rising at 10 cm/s would require a diameter of about 440 micrometer in order to reach the ground with a diameter of 200 micrometer, which is often considered to mark the boundary between cloud droplet size and precipitation size.

Collision and coalescence of cloud and precipitation elements are considered the most important factors leading to significant precipitation. Collisions between cloud and precipitation particles arise mostly from differences in falling speeds as a result of differences in size. Heavier particles fall faster than smaller particles do. Particles that collide usually coalesce to form larger particles. The process may be repeated a number of times. It has been estimated that in a typical heavy rain seven collisions occur for every kilometre of fall (Gunn, 1965). Raindrops may grow as large as 6mm in diameter. Maximum falling speeds level off as the drops approach maximum size because of increasing air resistance due to flattening. For large diameters, the deformation may be sufficient to break up the drops before they can attain terminal velocity (Table 2.2).

Table 2.2 : Terminal velocity of water drops in still air; (after Gunn and Kinzer, 1949).Pressure 101.33 kilopascals, temperature 20°C, relative humidity 50 percent.

Drop diameter (mm)	Terminal velocity (cm/s)
0.5	204
1.0	403
1.5	541
2.0	649
3.0	806
4.0	883
5.0	909
5.5	915
5.8	917

Speeds of ascending air in vigorous convective systems usually far exceed terminal velocities (Table 2.2) of the largest raindrops. Radar observations have indicated ascensional rates as high as 40 to 50 m/s in cumulonimbus; and aircraft observations have indicated a horizontal diameter of about 1.5 km for updrafts in a thunderstorm cell which usually range from

6 to 10 km in diameter (Linsley et al, 1982). Downdrafts are about the same size as updrafts. The stronger updrafts prevent even the largest raindrops from falling and carry all precipitation elements to the upper portions of the clouds to produce an accumulation of liquid water far exceeding that of the ordinary cloud elements. Theory and radar observations (Hamilton 1966), suggest dependency of accumulation height on updraft speed.

The accumulated water is precipitated as a result of the weakening of the updraft or by horizontal displacement from the supporting updraft to a weaker one or, as often happens, to a downdraft, which possibly may be initiated by the mass of accumulated water (Das, 1964). When suddenly precipitated in a downdraft, the resulting torrential downpour lasts but a few minutes, and point rainfall is usually less than 100 mm. In a thunderstorm there may be several such downpours, or bursts, from a number of cells, and the total point rainfall in 1 hr may exceed 200 mm.

Precipitation is often typed according to the factor mainly responsible for the lifting which causes it. Cyclonic precipitation results from the lifting of air converging into low-pressure area, or cyclone. Cyclonic precipitation may be either frontal or nonfrontal.

Frontal precipitation results from the lifting of warm air on one side of a frontal surface over colder, denser air on the other side. Warm-front precipitation is formed in the warm air advancing upward over a colder air mass. The rate of ascent is relatively slow, since the average slope of the frontal surface is usually between 1/100 and 1/300. Precipitation may extend 300 to 500 km ahead of the surface front and is generally light to moderate and nearly continuous until passage of the front. Cold-front precipitation, on the other hand, is of showery nature and is formed in the warm air forced upward by an advancing mass of cold air, the leading edge of which is the surface cold front.

Convective precipitation is caused by the rising of warmer, lighter air in colder, denser surroundings. The difference in temperature may result from unequal heating at the surface, unequal cooling at the top of the air layer, or mechanical lifting when the air is forced to pass over a denser, colder air mass or over a mountain barrier. Convective precipitation is spotty, and its intensity may range from light showers to cloud bursts.

Orographic precipitation results from mechanical lifting over mountain barriers. In rugged terrain the orographic influence is so marked that storm precipitation patterns tend to resemble that of mean annual precipitation. In nature, the effects of these various types of cooling are often interrelated, and the resulting precipitation cannot be identified as being of any one type.

When rain is accompanied by wind there is the added component of velocity and the resultant vector may be greater than still-air velocity. The effects of wind are more significant in regional rainfall with raindrops of smaller diameters than in torrential rainfall with bigger drops. Laws (1941), observes that even in torrential rainfall accompanied by wind approximately 95% of the raindrops will impinge on the soil surface at the same terminal velocity as in still air. The velocity of falling drops of rain is affected by gravity and by resistance of the air. The raindrop falls freely under the force of gravity and will accelerate until the frictional resistance of the air equals the gravitational force and will then continue to fall at a constant speed. The terminal speed depends on the size and shape of the raindrop(Fig. 2.4).

The vertical acceleration of air forced upward over a gauge imparts an upward acceleration to precipitation about to enter and results in a deficient catch. The deficiency is greater for small raindrops than for large and is thus greater for light than for heavy rain, greater for snow than for rain and larger for dry than for wet snow; hence it is inversely related to air temperature (Struzer, 1969). Reliable evaluation of wind errors is difficult because of problems involved in determining the true or actual precipitation reaching the ground.

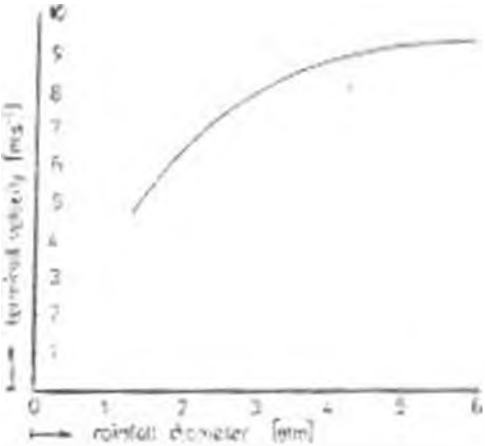

Fig 2.4. Relation between raindrop velocity and raindrop diameter (after Laws 1941)

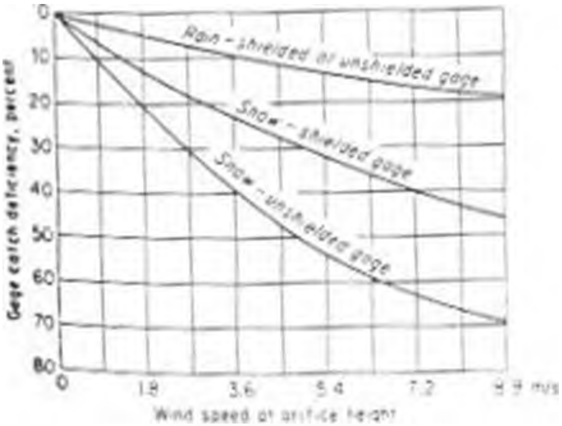

Fig. 2.5. Effect of wind speed on the catch of precipitation gages (after Larson and Peck 1974)

Attempts at assessing wind errors usually consist of comparing gauge measurements with weight changes in nearby lysimeters or by comparing measurements of shielded and unshielded gauges. Fig. 2.5 shows average deficiencies in rain and snow measurements. The curve shown for rain is actually an average of separate curves for shielded and unshielded gauges which showed a spread of only 3 percent at 4.5 m/s and about 5 percent at 8.9 m/s, the curve for unshielded gauges showing the greater deficiencies (Larson and Peck, 1974).

The higher the gauge, the greater the wind error. The best sites have been level grounds with bushes or trees serving as a windbreak, provided that they are not so close that they reduce the gauge catch (Brown & Peck,1962; Weiss, 1963). Trees or other obstacles serving as a windbreak should reach no higher than twice their distance from the gauge and should fairly well surround the gauge to provide protection from all directions. Probably, an ideal site would be a clearing in a coniferous forest.

Various attempts have been made to estimate true or actual precipitation from gauge measurements. One is based on the premise that there is a relationship between the ratio of the unshielded-gauge catch Pug to the actual precipitation Pa and the ratio of the unshielded-gauge catch P_{ug} to the shielded-gauge catch P_{sg},

$$\frac{P_{ug}}{\ln P_a} = \frac{P_{ug}}{b \ln P_{sg}} \ldots\ldots\ldots\ldots\ldots [2.1]$$

where b is a calibration coefficient, which depends on the type of gauge. For weighing gauges (U.S. National Weather Service standard) with an Alter shield, coefficient b was found to be about 1.7. The above is presumably independent of wind and form and type of precipitation (Hamon, 1973). Hanson, Morris and Coon (1979), claimed an equally accurate measurement from the Wyoming shield gauge with two concentric shields 3 and [illegible] diameter. This system has an advantage in that the cost of snow maintenance and data reduction is only about half.

When rain falls vertically, a gauge inclined 10° from the vertical will catch 1.5 percent less than it should. If a gauge on level ground is inclined slightly toward the wind, it will catch more precipitation. Some investigators, namely: Hamilton, (1954); Hoeck, (1952) and Serra, (1953); are of the opinion that gauges should be perpendicular to land slopes. However, the area of a basin is its projection on a horizontal plane, and measurements from tilted gauges must be reduced by multiplying by the cosine of the angle of inclination.

2.4.3 Measurement Techniques for Erosivity from Rainfall [illegible]

2.4.3.1 Erosivity and Kinetic Energy

There has been a great deal of experimental evidence to suggest a link between erosive power and the mass and velocity of falling drops. Ellison (1944), measured in a laboratory experiment splash erosion for various combinations of drop size, velocity and intensity. Analysis of his results yielded the expression

$$S = K V^{4.33} D^{1.07} I^{0.65} \text{..........} [2.2]$$

where K is a constant for the soil type, S is the grams of soil splashed in 30 minutes, V is the drop velocity in feet per second, D is drop diameter in mm, I is rainfall rate in inches per hour. Erosive power was thus linked with combinations of drop mass and drop velocity. It is therefore not surprising that it has also been associated with Kinetic energy. Mihara (1951) found that splash erosion is directly correlated with kinetic energy, and Free (1960) suggests that the relationship which best fits his experimental results was:

for sand,

$$S = K\,E^{0.9} \ldots\ldots\ldots\ldots [2.3]$$

and for soil,

$$S = K\,E^{1.46} \ldots\ldots\ldots\ldots\ldots [2.4]$$

where S is splash erosion, K is a constant and E is kinetic energy.

Several experimental studies have established correlations between soil splash and intensity (Moldenhauer and Long 1964, Bubenzer and Jones 1971, Meyer 1981). The experimental evidence therefore suggests that intensity and energy are likely to be closely linked with erosivity.

Based on the work of laws and Parsons (1943), Wischmeier and Smith (1958) obtained the equation:

$$KE = 11.87 + 8.73\log_{10} I \ldots\ldots\ldots\ldots\ldots [2.5]$$

where I is the rainfall intensity (mm h^{-1}) and KE is the kinetic energy (J m^{-2} mm^{-1}). Zanchi and Torri (1980) carried out similar research in Italy and obtained:

$$KE = 9.81 + 11.25\log_{10}I \quad \text{[2.6]}$$

To compute the kinetic energy of a storm, a trace of the rainfall from an automatically recording rain gauge is analyzed and the storm divided into small time increments of uniform intensity. For each time period, knowing the intensity of the rain, the kinetic energy of rain at that intensity is estimated from one of the above equations and this, multiplied by the amount of rain received, gives the kinetic energy for that time period. The sum of the kinetic energy values for all the time periods gives the total kinetic energy of the storm.

2.4.3.2 The EI Index

Rainfall erosivity factor, EI has been defined as the average annual value of rainfall erosion index (Istok 1986). To be valid as an index of potential erosion, an erosivity index must be significantly correlated with soil loss. Wischmeier and smith (1958) found that soil loss by splash, overland flow and rill erosion is related to a compound index of kinetic energy and the maximum 30-minute rainfall intensity (I30). I30 is computed from recording raingauge charts by locating the greatest amount of rain which falls in any 30 minutes, and then doubling this amount to get the same dimensions as intensity, ie. rainfall per hour (Fig. 2.6).

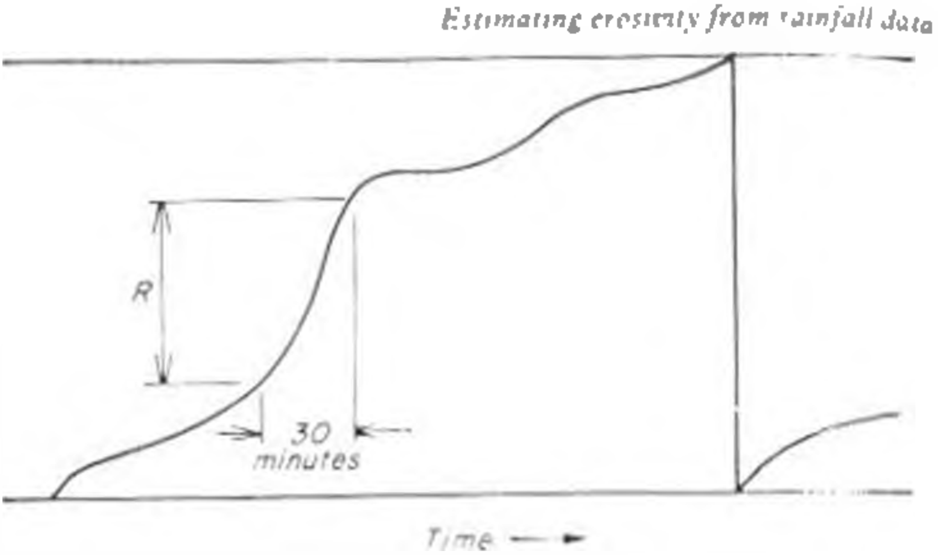

Fig 2.6. Method of obtaining the 30-minute intensity (after Hudson,1985). The 30-minute period with the greatest amount of rain is found from the recording chart. Twice this amount is the 30-minute intensity.

The index, known as EI_{30}, gave an excellent correlation. Wischmeier found that it was in fact possible to improve the relationship even further by taking account of other factors, such as the soil moisture at the beginning of the storm, but these further refinements added so little that they were felt to be not worth the extra complication.

The EI index can be computed for individual storms, and the storm values can be summed over periods of time to give weekly, monthly, or annual values of erosivity. However, a number of scientists have openly criticised this index (Morgan, 1986).

Wischmeier (1976), himself, observes that the use of the EI as index of erosivity and its valuable application in the Universal Soil-Loss Equation have led to over-enthusiastic extension beyond the purpose it was designed for. One hazard, he noted, is that although there is a high degree of correlation in the long term there are large variations. EI values for a particular year can be from 50% to 200% of the long term average. Secondly, he observes, that attempts to apply the original index to tropical rainfall led to some excessively high estimates.

In the revised method (Wischmeier and Smith, 1978) allows a maximum value of energy as shown in Fig. 2.7 (kinetic energy per unit rain calculated using a set maximum values for rainfall intensity of 76.2 mm/h) and a maximum value of 63.5 mm/h for I30.

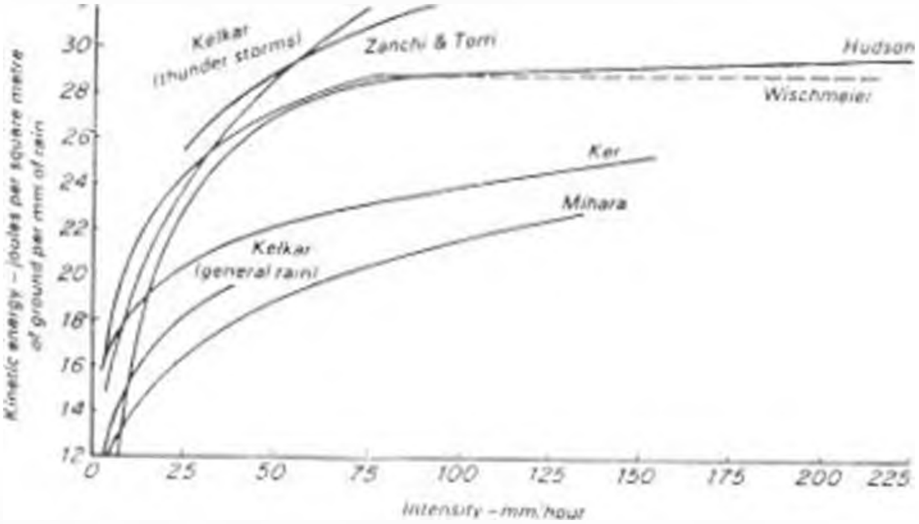

Fig.2.7 The relation between Kinetic energy of rainfall and intensity after Hudson. The full lines extend to the highest intensity recorded. Studies were carried out in different countries. HUDSON-Zimbabwe(1965), KELKAR-India, KER-Trinidad, MIHARA-Japan(1951), WISCHMEIER- U.S.A.(1958), ZANCHI and TORRI-Italy(1981).
(After Hudson 1985).

A model for computing monthly erosion index for the universal soil loss equation (USLE) from daily rainfall records was developed and tested (Thomas et al 1990). The prediction was based on month of year, maximum one-day rainfall during month and extended rainfall expressed as a difference between total rainfall of month and maximum one-day rainfall. Model results were compared with measured data from locations representing wide geographical and climatological differences in order to evaluate the predictive capability.

Patterns portrayed as contours of erosion index were prepared to demonstrate results of smoothing with the prediction model. The patterns were then evaluated to determine the seasonal effects of maximum one day rainfall and extended rainfall on monthly erosion index. Comparisons of the patterns were made to examine the similarities and differences in relationships between rainfall and erosion index among the locations. Cross-sections of the contours were prepared to determine differences in rainfall erosion index relationships for adjacent month.

2.4.3.3 The KE > 25 and the AIm Index

As an alternative erosivity index, Hudson (1965) uses KE > 25 which, to compute for a single storm, means summing the kinetic energy received in those time increments when the rainfall intensity equals 25mm/h or greater. When this index was applied to data from Zimbabwe, a better correlation was obtained for soil loss than between soil loss and EI_{30}. Stocking and Elwel (1973) did rework Hudson's data and incorporating more recent information, suggested that EI_{30} is the better index after all. Since they computed EI_{30} for only storms yielding 12.5mm of rain and with a maximum 5-minute intensity greater than 25mm/h, they removed most of the objections to the original EI_{30} index, but, however, produced an index which is philosophically very close to KE > 25. Hudson's index has the advantages of simplicity and less stringent data requirements.

The concept has been modified for temperate use by Morgan (1977) using a lower threshold value of 10mm/h. The idea of using threshold values for both intensity and amount was also applied by Elwell and Stocking (1975), and it is built into the latest methods of calculating EI by ignoring showers of less than 0.5 inch and separated from other rain periods by more than 6 hours unless 0.25 inch fell in 15 minutes (Wischmeier and Smith, 1978).

For sequenced rainfall events, separated by 24-hour drying periods, Jennings et al (1987) observe that, a series of twelve 5-minute rainfall events on the coarse aggregates produced soil loss rates which were 86% greater than the soil loss rates measured for six 10-minute rainfall events. In a series of storms, each event produces an initial high soil loss rate. When each storm is short, this initial effect repeated many times produces greater soil losses than during longer storms which have fewer initial Precipitation periods.

In Nigeria, Lal tested EI, KE>25, and other possible parameters, and found the best correlation of soil loss from small plots with a new index rather similar to EI. This is AIm, where A is the amount of rain, and Im the maximum intensity over a 7.5 minute period. Like previous studies, the correlation could be improved by the addition of other factors, particularly a measure of wind speed which affects impact velocity and hence energy. For an index intended for a long term predictions, Lal (1976) concluded that, a transient phenomena like wind, cannot be included.

The tendency to use empirical indexes should be treated with reserve. Wischmeier had 10000 plot years of data extending over 22 years and this solid data base was used effectively to generate the empirical index EI. Hudson had 13 years results, giving 2500 plot years to test against KE>25. Lal in Nigeria, and Roose in West Africa had smaller but significant bases (Roose, 1980). However, much time and effort has been spent on trying to generate or test empirical formula against the results of a handful of plots for one or two seasons.

2.5 Topographic Factors

2.5.1 Slope Characteristics

Water erosion is conditional on surface runoff from slopes. With increasing slope gradient and slope length and with continuing rainfall water running off the slopes gains higher velocity and tangential stress and the action of its destructive force on the soil surface increases. The intensity of erosion processes usually decreases with a drop of the slope gradient until soil particles which have been detached and transported over the soil surface begin to sediment. The course of erosion processes shows that areas most affected by water erosion have rugged relief which enhances the concentration of surface runoff and accelerates runoff. Soil erosion measurements on small upland watersheds totalling 229 watershed-years show that most of the total erosion occurring over a long-term period of record comes from a few large storms (Edwards and Owens 1991). Erosion from the contoured watersheds averaged 30% of that from the straight-row treatment.

The morphology of the area also influences wind erosion whose intensity is affected by the exposure of the area to prevailing winds and the relief of the area. Wind direction is greatly influenced by orientation of Orographic barriers (Linsley et al,1982); hence the direction of rainfall during storms accompanied by wind. On mountain ridges and summits wind speeds at 10 meters or more above the ground are higher than in the free air at corresponding elevations because of the convergence of the air forced by the orographic barriers. On lee slopes and in sheltered valleys wind speeds are light. With a weak pressure system, diurnal variation of wind direction may occur in mountain regions, the winds blowing upslope in the daytime and downslope at night.

2.5.2 The Effect of Slope Gradient

Theoretical studies and analysis of the effects of slope gradient on water erosion and numerous field observations and measurements as well as laboratory experiments have shown that slope gradient is one of the major erosion factors (Holy,1980). Its effects on the initiation and course of erosion processes may be reduced by other factors, such as soil properties, the soil vegetative cover, etc. but never fully suppressed.

The interdependence of slope gradient and the erosion intensity as given by various authors shows that the intensity of the erosion process increases with growing tangential stress and velocity of the surface runoff which are prevalently the function of slope gradient. The importance of slope gradient for erosion intensity was proved by Bennet (1939 and 1955, cit Holy 1980). Results of his measurements are given in Table 2.3.

Table 2.3 Effect of slope gradient on soil loss (after Bennet 1955)

Soil & Place	Period of Observation	Rainfall (mm)	Length (m)	Slope (%)	Crop	Soil Loss (t/ha)
Silt Loam	9	965	22.1	8.0	maize	158.8
Muskin-gum	9	965	22.1	12.0	maize	222.4
Ohio	9	965	22.1	20.0	maize	243.7
Fine Sandy-loam	10	1032	22.1	8.7	cotton	50.1
Kirvin	8	1092	22.1	16.5	cotton	136.8
Texas						
Loam	14	1025	27.6	3.7	maize	44.1
Shelby	10	749	22.1	8.0	maize	114.0
Miss-ouri.						

similar conclusions about slope gradient have been arrived at by other authors, namely (Musgrave (1947), Zingg (1940), Neal (1938) and others cit. Holy 1980) who used field measurements and experiments on soil monoliths to derive the empirical relation between soil loss Sp and slope gradient I as:

$$Sp = f\,I^{n} \ldots\ldots\ldots\ldots\ldots [2.7]$$

where n is within the region of 0.8-1.5 and f is a coefficient depending on the soil type.

Wischmeier and smith (1965) Processed a large number of data on the intensity of erosion processes and on the basis of their studies they expressed the effect of slope gradient on soil by the equation:

$$Sp = \frac{f[0.731+0.043I^{2}]}{6.613} \ldots\ldots [2.8]$$

The decisive influence of slope gradient on the orientation and course of erosion processes led to the determination of what is described as the critical slope, i.e., that slope on which a dangerous depletion of the soil surface occurs. It may be assumed that the dangerous depletion of the soil surface begins at that point at which surface sheet runoff changes into concentrated runoff, and sheet erosion changes into rill erosion. Processed data has shown that the critical slope for acute erosion on low resistant soils ranges from 1 - 2°, on medium resistant soils from 3 - 5° and on resistant soils from 6 - 7° (Holy, 1980). The given values are, however, merely informative as they do not consider a number of factors which have a significant effect on soil erodibility.

2.5.3 The Effect of Slope Length

At constant slope gradient and under other constant conditions and providing rainfall duration is longer than the time needed for the water particles to travel from the water divide to the foot of the slope, the runoff, its intensity and tangential stress increases with slope length. The relation between slope length and erosion intensity has been studied by a number of authors. Hydraulic and soil loss variables were measured under simulated rainfall conditions at selected downslope distances on plots with corn residue rates ranging from 0.00 to 6.73 t/ha (Gilley et al 1986).

Application of corn residue produced substantial reductions in runoff rate, runoff velocity, sediment concentration and soil loss rate along the entire slope length. On those plots subject to rilling, runoff rate, sediment concentration and soil loss rate usually increased with downslope distance. Rill and interrill sediment concentration and soil loss rate were also measured at selected slope lengths. Interrill sediment concentration changed little with downslope distance while greater interrill soil loss rates were observed with increasing slope length. Rill sediment concentration and soil loss rate increased rapidly near the bottom of the plots. Kozmenko (1954 cit. Holy 1980) investigated the relation on plots with loamysandy soils and a slope of 5%. Similar conclusions have been arrived at by Bennet (1939, Table 2.4, cited in Holy 1980). In 1965, Wischmeier and Smith made long-term field observations on the basis of which they derived the following expression for the relation between soil loss (Sp) and slope length

$$Sp = fI\frac{L^n}{22.13}I \ldots\ldots\ldots\ldots\ldots (2.9)$$

where L is the slope length measured from the water divide of the slope (m), n is the exponent dependent on the slope gradient and I is the rainfall intensity. For slope gradient less or equal to 10% it is 0.5, for slope gradient greater than 10% it is 0.6.

Table 2.4 Effect of Slope length on Soil loss (after Bennet,1939)

Soil & Location	Period (yrs)	Rain-fall (mm)	Crop	Length (m)	Slope (%)	Soil Loss (t/ha)
Silt loam, Marshall, Iowa	1933-35	684	maize	48.0 96.0 192.0	8.0 8.0 8.0	28.9 40.3 52.6
Fine Sandy Loam, Vernon, Oklahoma	1931-36	800	cotton	11.0 22.1 44.3	7.7 7.7 7.7	42.5 55.6 95.3
Fine Sandy Loam,Kirvin Texas	1931-36	1038	cotton	11.0 22.1 44.3	8.7 8.7 8.7	45.9 68.9 107.7
Silt Loam Clinton Wisconsin	1933-36	820	maize	11.0 22.1 44.3	16.0 16.0 16.0	159.0 248.0 286.6
Silt Loam Shelby Missouri	1934-35	851	maize	20.4 54.9	10.0 10.0	56.8 133.7

Horvath and Erodi (1962) cit. Holy (1980) observed on plots of various lengths with a gradient of between 2-16% that the amount of soil loss doubled with the quadruple increase of slope length. The decrease in the amount of soil loss as related to the increase in slope length was observed by Spiridonov, 1951 and explained by Makayev 1955, who observed that the most significant turbulence of precipitation runoff occurs in the upper part of the slope (cit.Holy 1980). This he said increases the saturation of runoff with detached soil particles which is bigger in the upper part of the slope than in the middle and lower parts where the soil surface is protected from the effect of raindrops by the water mantle. This view seems acceptable only when we assume that there is a continuous sheet surface runoff with increasing depth.

2.5.4 Combined Effects of Slope Length and Gradient

The effects of the slope gradient and slope length on the intensity of the erosion process are significant for suggesting the type and location of erosion control measures. A number of expressions have been derived for calculating the combined effect of the two factors. Musgrave (1947) used the expression :

$$Sp = KpKvI^{1.35}L^{0.35}Z^{1.75} \quad \ldots\ldots\ldots [2.10]$$

where Sp is the erosion process intensity

Kp is the coefficient dependent on soil properties

Kv is the coefficient dependent on vegetative cover

I is slope gradient

L is slope length

Z is rainfall with a 30-minute duration and maximum intensity occurring with a 2-year frequency.

A reliable investigation of the relationship between erosion process intensity, slope gradient and slope length and knowledge of permissible soil loss allows the determination of this limit to be made for slope length.

2.5.5 The Effect of Slope Shape

The intensity of erosion processes and its course is affected by the shapes of slopes, i.e. convex, concave, straight and combined (Fig. 2.8). This kind of classification allows one to observe the different course of erosion processes; because the prevalent erosion factor, the slope gradient, attains maximum values at different distances from the water divide depending on its shape (with the exception of straight slopes where it is constant) and it pertains to catchments of different sizes. The maximum effect of erosion processes will be manifest in those parts of the slope where the relation between the gradient and the distance divide from the water divide is the most propitious.

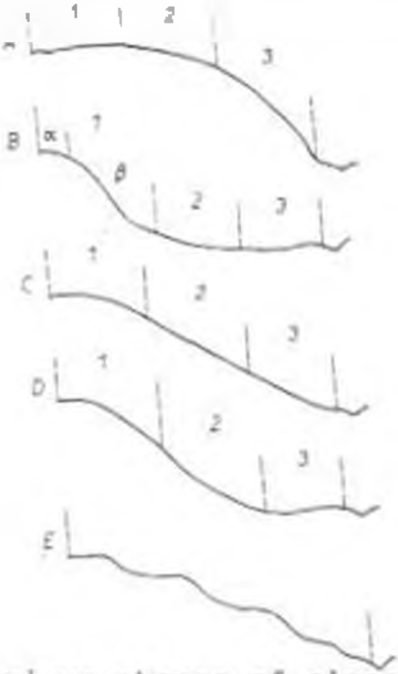

Fig. 2.8 Various shapes of slopes (after Holy 1980)

Convex slope A has in its upper part 1 a relatively small slope gradient and also a small distance from the water divide. As compared with other parts of the slope it is loaded with a small amount of runoff. Neither slope gradient nor slope length allow the full development of erosion processes. In the middle part of slope 2, slope gradient and slope length increase. Slope gradient and slope length reach their highest values in the bottom part of the slope 3 where the intensity of erosion processes reaches its maximum.

In concave slope B, the upper part of the slope may be divided into two sections. The section at the watershed has a relatively small slope gradient which rapidly increases and reaches its maximum in the lower section. The gradient allows the full development of erosion processes. Maximum slope length does not correspond to maximum slope gradient as was the case with convex slope. In the middle part of slope 2 the slope becomes milder while slope length increases. The intensity of erosion processes is determined by the relation between the decrease in steepness and increase in slope length. In the lower part of slope 3, steepness decreases to such an extent that material is deposited at the foot of the slope even in the case of maximum slope length.

The straight slope C has an approximately constant slope gradient throughout. Maximum erosion intensity may be expected at the point where the tangential stress of surface runoff reaches its maximum. Combined slopes have different shapes. Investigators often consider them separately. The most frequent ones are convex-concave and graded slopes.

convex-concave slope D has in its upper part 1 a relatively small gradient which increases in the middle part of the slope 2 where it reaches maximum. Here the convex shape develops into the concave shape and slope gradient decreases with slope length. Maximum erosion intensity may be expected in the middle part of slope 2.

In graded slope E, slope steepness alternately decreases and increases with growing slope length. The assumed course of the erosion process in the individual parts of the slope effect a continuous change in erosion intensity.

Comparisons made of erosion intensity on different slopes have shown that highest intensity is reached on convex slopes, whilst lowest intensity has been observed on concave slopes at the same length and elevation (Holy, 1978 cit. Holy 1980)

1.5.6 The Effect of Slope Exposure

The exposure of the slope is given by its position to the north, south, east and west (Holy, 1980). In cold regions, slope exposure to solar radiation on the southern and western slopes causes the rapid thaw on snow resulting from differences in day and night temperatures. This results in higher surface runoff from the snow thaw, freezing of vegetation and a more intensified depletion of the parental substrate which in turn increases the intensity of the erosion process as compared with shaded slopes.

Runoff from snow thaw is considerable especially from leeward slopes in which a deep layer of snow amasses over the winter. The soil of Sun-exposed slopes dries much more quicker and thus results in a more rapid decomposition of organic substances which in turn reduces consistence and increases the danger of water and wind erosion. Very important for the onset and development of wind erosion is the exposure of the slope to the prevalent direction of the wind . Based on a field survey in 1974 Hurni, observed in a large research catchment in Ethiopia, that differences in soil erosion damages can be attributed to slope exposure and uniform rainfall directions during several centuries.

Slopes which were exposed towards the rain are much more damaged than slopes facing towards the opposite direction (leeward effect). Detailed mapping and subsequent analysis of soil erosion damages in the 30 km^2 Jinbar valley in Simen showed significant differences between eastern and western facing slopes (Hurni 1975; cit. Hurni 1988)

Using about 500 soil depth samples on undisturbed Andosols in the eastern, uncultivated part of the valley, and comparing them with about 300 soil depth samples in the western cultivated and damaged part, it was possible to quantify the differences of soil loss due to different degrees of damage between the two major exposures (Table 2.5). These differences could not be attributed to topography, geomorphology, or soil parameters, and could also not simply be explained by different periods of intensive crop cultivation on the damaged slopes.

Observations made by Hurni and his team during the rainy seasons of 1974 and 1975 of rainfall directions showed very regular rainfall patterns with storms dominantly originating from east-northeastern directions. This led to the hypothesis that rainfall direction may be primarily responsible for the observed differences. A simple set up of four inclined daily raingauges was used during the 1976 rainy seasons to prove the observed general rainfall

pattern (Table 2.6)

Table 2.5 Total soil loss in t/ha (cm soil depth) since the inception of agriculture in the Jinbar Valley,Simen,Ethiopia. Assessment made in 1979 based on survey of 1974 (after H. Hurni 1988)

Location in Valley (age of cultivation)	Slope Exposure	
	E-Facing	W-Facing
Old cultivation north of main river (several centuries)	2,000(16cm)	800(6.4cm)
Recent cultivation south of main river (1-2 centuries)	1,100(8.8cm)	600(4.8cm)

Table 2.6 Amounts and percentage of rainfall and erosivity (metric R; Wischmeier and Smith, 1978) according to compass directions from where the storms originated. Gich Camp climatic station. 3,600m asl; May-November 1976 (after H. Hurni 1988).

Compass direction	Rainfall (mm)	%	Erosivity (metric R)	%
W	12.3	1	3.12	1
SW	26.9	2	4.12	1
S	51.5	4	7.22	3
SE	-	-	-	-
E	268.1	20	163.47	34
NE	601.7	44	216.32	45
N	202.1	15	54.98	11
NW	189.8	14	29.20	5
Total	1,358.4	100	476.55	100

Table 2.6 above shows that the dominant rainfall directions are E to NW which bring adjective storms to the Simen Mountains. 94% of the rainfall and 96% of the respective erosivity originated from these compass directions. It should be noted, the difference in Percentage between rainfall and erosivity for the eastern compass direction as compared to the NE-N-NW directions. Storms originating from eastern directions obviously have stronger erosivities than the ones from northerly directions. There seems, therefore, to be a strong although maybe not direct correlation between the field evidence results presented in Tables 2.5 and 2.6, implying that slopes facing towards major storm directions are more damaged than slopes on the leeward side of the storms.

Based on the field observation in Simen, rainfall direction was brought in direct relationship to soil loss and runoff for differently exposed slopes. The model developed here was based on the assumption that rainfall direction basically affects storm erosivity. Erosivity being primarily, a function of rainfall amounts falling in variable time units used as input values to derive rainfall energy and maximum 30-minute intensity (Wischmeier and Smith 1978), erosivity values obtained this way were linearly correlated to soil loss from a continuous fallow plots of standard size.

Although no clear improvements in correlations between soil loss and erosivity were observed when rainfall amounts inclination was included for erosivity calculation in Simen (Ethiopia), the approach described is worth pursuing. A measuring device for assessing rainfall storm direction, its effects on erosivity and soil loss as well as for including slope exposure for the assessment of true rainfall amounts at the steep lands research site in Kabete is presented in this study.

2.6 Geological and Soil Factors

2.6.1 Geological Conditions

The geological conditions of the area and the soil properties affect soil erodibility and thereby also the intensity of erosion processes.

2.6.2 Geological factors

The effect of geological conditions on the origination and course of erosion processes is manifest directly by the resistance of the denuded bedrock exposed to the flow of water, air and indirectly affected by the character of the parent material whose properties are given by the bedrock. Weathering bedrock often rises to the surface and is denuded by water and wind. In such cases the surface is quickly disturbed and rills, gullies and ravines are formed which spread and deepen very fast.

2.6.3 Soil factors

Soil conditions which are the sum of the individual properties of the soil affect the infiltration of precipitation into the soil and the resistance of soil to the destructive effects of raindrops, surface runoff and wind.

The major factors affecting the infiltration of precipitation into the soil are soil texture, structure, soil moisture and stratification. Next to these factors the most important factors for erosion resistance are the humus content and the saturation of the sorption complex.

Investigations have shown that sandy soils are least susceptible to erosion (Holy 1980), because they are highly permeable. On the other hand clay soils with low permeability have a high content of colloidal particles and show a high level of consistence in a mildly humid state. Clay soils are generally more susceptible to erosion.

2.7 Vegetative Cover

The vegetative cover protects the soil surface from the direct impact of raindrops and from the effects of wind. It enhances the infiltration of rainfall into the soil and slows down surface runoff and thereby improves the physical, chemical and biological properties of the soil. Very important is the binding effect of the root system of the vegetation. The soil surface is protected from the impact of raindrops by the interception of the above ground organs of plants. The plant bodies damp the energy of raindrops, thereby reducing the danger of breaking down soil aggregates. By shading the soil, vegetative cover reduces evaporation and conserves moisture which significantly affects the stability of soil aggregates.

The effects of varying rates of corn residue on runoff and erosion from a loess soil in southwestern Iowa were measured using a rainfall simulator (Gilley et al 1986). Consistent reductions in runoff, sediment concentration and soil loss resulted from increased residue application. Small amounts of surface cover produced substantial reductions in erosion and a regression equation relating surface cover to residue weight was obtained. Equations describing relative runoff, sediment concentration and soil loss as a function of surface cover were also developed using regression analysis.

The favourable effects of the vegetative cover include the mechanical reinforcement of the soil by the root system. The important factor in the binding effect of the roots is the density of the root system and the depth of its penetration into the soil profile. The favourable effects of vegetation on the course and intensity of the erosion process differ according to the type of land-use or vegetation and its condition. Three tillage treatment of cotton (Gossypium hirsutum) in the Tennessee valley of North Alabama has shown that summer cultivation reduced runoff and maintained low sediment concentration (Yoo et al 1987). And in the Mid-Michigan region, long term records of precipitation magnitude and intensity has been used to predict occurrence probabilities of overland flow and potentially erosive flow events, the highest occurrence probabilities for overland flow events coinciding with spring planting and crop emergence when ground cover is obviously low (Gold et al 1986).

Field observations and measurements have made it possible to rank plant cultures by their erosion resistance effectiveness. Ranking highest is the forest, followed by grass, corn and potatoes.

The forest with a dense canopy, good undergrowth and undisturbed litter have the most significant effect on surface runoff and thereby on the intensity and course of erosion (Mracek and Krecmer,1975 cit. Holy 1980). Surface runoff from forest soils hardly exceeds 10% of total precipitation hence forest soils with a good forest cover do not suffer from water erosion (Cablik and

Juva, 1963 cit. Holy 1980). C.R.Hursch (cit. Holy 1980), reported that when some experimental plots were stripped of forest cover and replaced by pasture, maximum surface runoff from the plot increased over 7 years from o.33 to 20.0 m3s-1 km2, soil loss increased 24-fold and after intensive rainfall to 500-fold. Similar observations on the protective effects of forest growths have been made in other catchments where the inter-actions were monitored between meteorological factors and runoff on slopes (Zeleny, 1964 cit. Holy 1980).

The effects of grass cover with a well-developed turf on the value and course of surface runoff and of soil conservation are similar to those of forest growths. Bennet (1955 cit. Holy 1980), found that surface runoff from plots with a good grass cover ranged from 0.3 to 5.5% of total precipitation and soil loss amounted to 0.029-0.132 t/ha while under the same conditions runoff from forest growths was 0.1-3.6% and soil wash was 0.005-0.193 t/ha. There was no marked difference between the efficiency of the forest and of the grass cover.

In a model area (Holy and Vaska 1970 cit. Holy 1980), conducted a comparative investigation of runoffs from a bare plot and from a plot with grass cover. They found that grass cover has a significant effect on surface runoff. In the experimental period from 1960 to 1969, runoff from the plot under grass (44.5% gradient, area 20 x 6 m) was 96% less than runoff from the plot of same gradient and same area but bare of vegetation.

A review of erosion problems in Peru and results from erosion studies in the Sierra and Selva regions shows that the use of cover crops and mulching conserve soil and water efficiently. Contoured rows present both advantages and disadvantages for water erosion control, depending on climate conditions and slope (Alegre et al 1990). National sheet and rill erosion declines were caused primarily by soil loss declines on land that was in crops in both 1982 and 1987 (Linda 1990). And in the Upper Eastern Shore of Maryland it has been shown that cropping adjustments that reduced erosion also reduced field losses of surface nitrogen (Fritz et al 1990).

Land levelling has been recommended for improving crop productivity on dryland on soils such as Pullman clay loam because of its capacity to improve water conservation on dryland (Unger et al 1990). Investigations of the importance of vegetation for erosion control in concrete conditions must be considered with regard to the type and condition of the vegetation in the season during which the soil is most affected by erosion.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental Site

3.1.1 Location

The Experiment was undertaken at the Steep-Lands Research site of the Upper Kabete Campus of the University of Nairobi. The altitude of the site is 2000m above sea level. The location of the site is 1° 15" S and 36° 44" E (Gachene 1989). It is approximately 12 Kilometres West-North-West of the Nairobi city centre.

3.1.2 Climate

The site is in the semi-humid, agro-ecological zone III as described by Sombroek et al (1982), using the Kenya soil survey agro-climatic zonation methodology (cit. Mwaniki 1991).

The rainfall is of a bimodal distribution (long rains from March to May and short rains from October to December). The mean annual rainfall is 1006mm. The average seasonal rainfall for the long rains and short rains is 595.6 mm (50%) and 285.2 mm (28%) respectively. The dry months contribute 215.4 mm. The mean annual temperature is approximately 18°C. Potential evaporation is 1727 mm and potential evapotranspiration is estimated at 1152mm

3.1.3 Soils

Employing the FAO-UNESCO system Sombroek et al (1982) and Gachene (1989), described the soils of the site as:

Eutric nitosol, developed on tertiary trachytic lava (Nairobi trachytes) with a red clay A-horizon, overlying a red B-horizon with a strong Sub-angular blocky structure. Barber et al (1979) established erodibility factor (K) of 0.04 for the soil. Then, Gachene (1989), found that the soils are well drained. He established the chemical fertility status in terms of available nutrients at 0-30 cm as follows (Table 3.1).

Table 3.1 Chemical fertility status of Kabete soils in terms of available nutrients at 0-30cm, (after Gachene, 1989).

pH	5.70
C %	1.99
N %	0.23
P ppm	14.60
Na m.e. %	0.43
Ca m.e. %	9.76
K m.e. %	1.69
Organic matter %	3.44

The soils were found to contain 18% sand, 24% silt, and 58% clay for the top 20 cm depth. The textural class therefore is clay.

3.2 Experimental Design

3.2.1 Data Collection

The experiment was conducted over two rainfall seasons, using only natural rainfall. It employed three major fields of data collection, namely :

(i) Runoff and Soil loss monitoring

(ii) Rainfall monitoring

(iii) Wind monitoring

3.2.2 Runoff and Soil Loss Monitoring

Runoff and Soil loss were monitored from micro-plots in the field.

3.2.2.1 Runoff Equipment Design and Installation

There were 24 micro-plots of size 2m by 1m constructed on 6 mounds (pyramids) of height of 1m above the ground surface. The mounds were formed by heaping up soil scooped out of a plain surface. Seven centimetres depth of soil of the experimental area was scooped out. Each mound or experimental unit consisted of four microplots, oriented towards four compass directions (i.e NE, NW, SE and SW) with a gradient of 30°. The 30° slope was chosen because it was found that the dominant slope in the area around Kabete was around 30°. And the directions NE, NW, SE, and SW were chosen basing on the river flow system in the area; rivers flowing from NW to SE and therefore all major slopes facing either NE or SW.

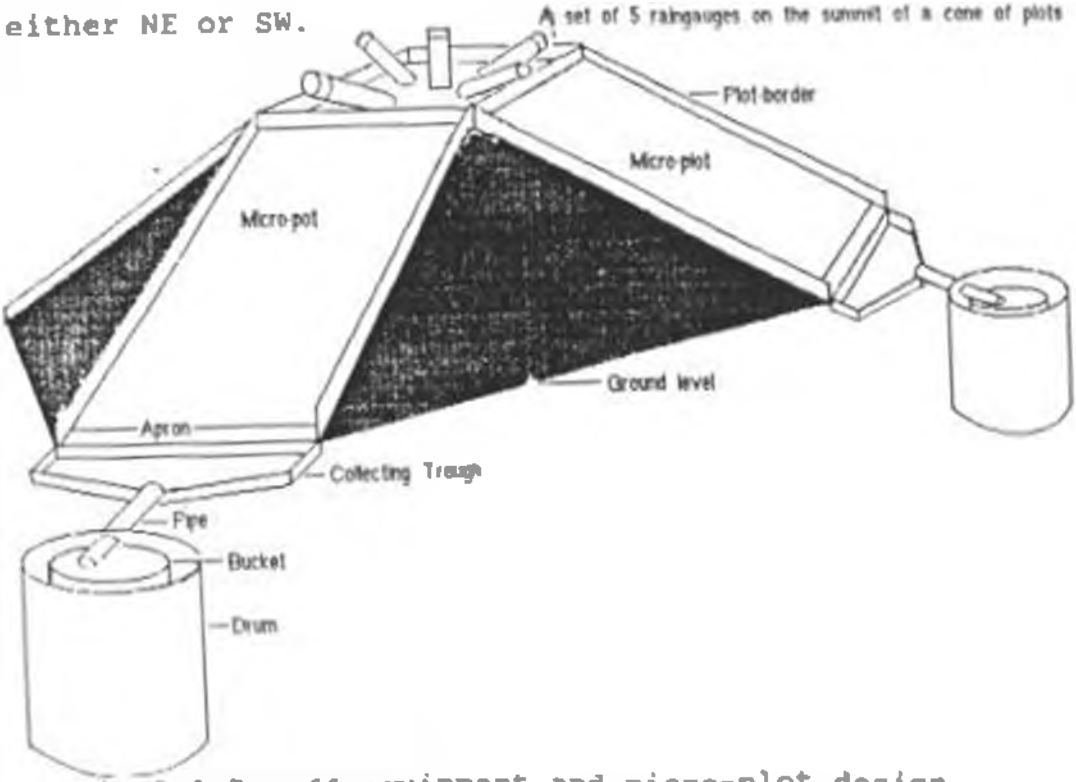

Fig 3.1 Runoff equipment and micro-plot design.

Each micro-plot was designed to have a plot boundary, an apron, collection trough with a cover, a conveyance channel made of a PVC pipe of 10cm diameter and runoff and sediment collectors. Micro-plots designed as shown in Fig. 3.1, discharged into 50 litre plastic buckets placed inside 100 litre metallic drums. The drums were covered with galvanized iron-sheet cap. Design volume of runoff is 100 litres based on the assumption that the maximum expected daily rainfall would be 80 mm with a coefficient of runoff of 0.6. The capacity of the runoff and sediment collectors were then adequate to cater for the maximum expected rainfall event.

3.2.2.2 Experimental Layout

The layout of micro-plots in the field is as shown in Fig. 3.2. Each set of 4 micro-plots occupies an area of 64 m^2. Spaces are left between mounds of plots and to the side boundary. On the whole, the surface area of land accommodating all the plots together with their collection tanks is 504 m^2.

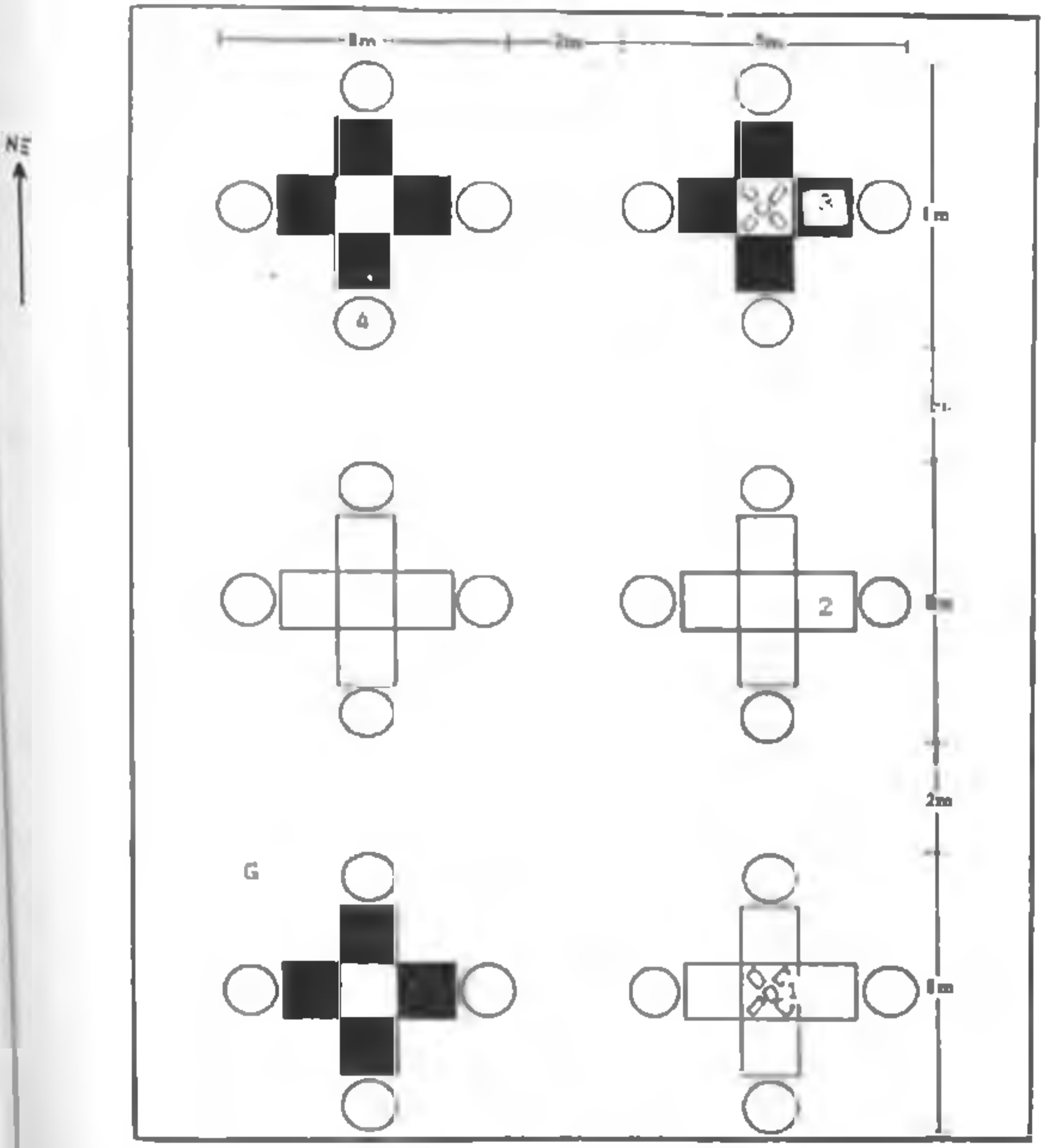

Fig. 3.2 Micro-plot layout

egend:

= A set of 5 raingauges on the summit of a cone of plots
= Bare plot
- Grassed plot
- Collection tank or drum
= Ground level

The approximate volume of soil required to construct the mound was computed using the formula :

$$v=\frac{22}{21}r^2H\ldots\ldots\ldots\ldots\ldots[3.1]$$

where V = Volume of mound

H = Height of mound

r = Radius of mound

If the height of mound is 1m with radius of 4.5 m, the volume of each mound thus becomes:

$$V = \frac{22}{21}4.5^2=5.3m^3\ldots\ldots\ldots\ldots[3.2]$$

For 6 mounds, 5.3 x 6 = 31.8 m^3. Allowing for 10% additional soil for settling,

$$\frac{10}{100}x32+32=35.2m^3\ldots\ldots\ldots[3.3]$$

The total volume of soil heaped up to form the 6 mounds of plots thus came up to 35.2 m^3.

$$D = \frac{V}{A}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[3.4]$$

e depth of soil that was moved in order to obtain the volume dicated above was computed using the formula:

ere D = Depth of soil moved

V = Volume of soil required

A = Area of land occupied

erefore:

$$D = \frac{35.2m^3}{504m^2} = 0.0689m = 7cm$$

3.2.2.3 Experimental Method

e experimental method comprised two treatments and three plicates for each treatment. Three of six experimental units re planted with grass (Tall Guinea Grass). The other three ots were left bare. Brachiaria ruziziensis (Tall signal ass) were planted on the sides of all 6 mounds to ensure their ability. Cover evaluations on plots with grass were done efore the onset of each rainy season and after every 4 week.

.2.2.4 Measurement of Runoff and Soil Loss

unoff was measured from the plastic buckets only. Even for avy rainstorms, runoff never spilled over into the metallic rum. The total volume of runoff that accompanied a particular

The depth of soil that was moved in order to obtain the volume indicated above was computed using the formula:

where D = Depth of soil moved

V = Volume of soil required

A = Area of land occupied

Therefore:

$$D = \frac{35.2m^3}{504m^2} = 0.0689m = 7cm$$

3.2.2.3 <u>Experimental Method</u>

The experimental method comprised two treatments and three replicates for each treatment. Three of six experimental units were planted with grass (Tall Guinea Grass). The other three plots were left bare. <u>Brachiaria</u> <u>ruziziensis</u> (Tall signal grass) were planted on the sides of all 6 mounds to ensure their stability. Cover evaluations on plots with grass were done before the onset of each rainy season and after every 4 week.

3.2.2.4 <u>Measurement of Runoff and Soil Loss</u>

Runoff was measured from the plastic buckets only. Even for heavy rainstorms, runoff never spilled over into the metallic drum. The total volume of runoff that accompanied a particular rainfall event was first recorded either with a measuring cylinder (for small runoff events) or a graduated bucket (for large runoff events). Then a sample of runoff with sediment was taken. The sampling procedure involved thorough mixing of the contents of the bucket until all sediments were evenly suspended, after which samples were immediately taken in a 1 litre plastic sampling bottles. This was done after washing the collector with some of the collected runoff so as to include any eroded sediments that had deposited within the collector. Samples from the various buckets were accordingly labelled and taken to the laboratory for analysis of soil and water loss.

If runoff was accompanied by heavy sediment loss, the sediments or sludge was separated from the runoff and weighed using an electronic precision balance. Total sludge weight thus known, it was thoroughly mixed to attain uniformity. Samples were then taken in labelled sampling bottles for laboratory determination of water content and oven dry weight of sludge.

3.2.2.5 Laboratory Analysis

In the laboratory, the runoff and sediment samples were analyzed using the evaporation method described by Dendy et al (1979). In this method, runoff and sediments were removed from the sampling bottles and their volume and weight determined. For the sludge, only the weight was taken. This was done using an electronic balance with a precision of 0.1g. The samples were then put into evaporation bowls and two drops of aluminium hydrate added to each runoff and sludge samples.

Aluminium hydrate act as a flocculent so as to have most of suspended sediments settled. After 24-48 hours of settling, the clear water was decanted from the samples. The samples were then oven dried at 105°C for 24 hours. The dried sludge and soil sample together with the evaporation bowls were then reweighed for computation of water and soil loss.

3.2.3 **Rainfall Monitoring**

3.2.3.1 **Raingauge Design and Positioning Measurement**

Rainfall was monitored using 3 sets of rain gauges and an automatic rainfall recorder. The rain gauges were intended to determine the average rainfall compass direction whereas the automatic recorder was to determine rainfall duration and intensity. Each set of gauges comprised five raingauges, four of which were inclined at a gradient of 30° to face the four compass directions used for the runoff plots (i.e NE, NW, SE and SW), and a vertical raingauge to measure the standard vertical rainfall.

The inclined gauges were designed in such a manner that the drip holes were off-centred, whereas the vertical gauge had the conventional design in which the drip hole is centrally placed. Two of the three sets of gauges were located on top of two sets of plots (Fig.3.1 & Fig 3.2). The other remaining set of five gauges were mounted on a stand and kept at a distance from the runoff plots.

3.2.3.2 Rainfall Measurements

After every rainfall event, the depth of rainwater in mm collected by each gauge was recorded. For the inclined gauges the true rainfall amount with regard to rain falling vertically was obtained by multiplying the catch amount in mm by the cosine of their inclination (i.e 30^{o}). This was done in accordance with the recommendations by Hoeck (1952), Serra (1953) and Hamilton (1954).

Rainfall duration and intensity was measured using an automatic rainfall recorder.The automatic recorder measured also the total amount of rainfall and the date on which the rainfall event occurred. Rainfall intensity (I) as well as maximum 30-minute intensity values in mm/h were computed from the recording raingauge charts. I30s were computed by locating the greatest amount of rain which falls in any 30 minutes, and then doubling this amount to get the same dimensions as intensity.

3.2.3.3 Computation of Rainfall Energy and Erosivity indices

Two empirical equations were used to compute the kinetic energy of the storms. These equations are:

$$KE = 11.87 + 8.73\log_{10} I \ldots\ldots [3.5]$$

(After Wischmeier and Smith 1958) where I is rainfall intensity in mm/h and KE is the kinetic energy in $J/m^2/mm$.

$$E = 18.2 I_{30} + 18.2 \ldots\ldots\ldots\ldots [3.6]$$

(after Lal, 1981) where I_{30} is the maximum 30-minute intensities of the storms.

To compute the Kinetic energy of the vertical rainfall of a storm, a trace of the rainfall from an automatically recording raingauge was analyzed and the storm divided into small time increments of uniform intensity. For each time period, knowing the intensity of the rain, the kinetic energy of rain at that intensity was estimated from the equation 3.5 above and this multiplied by the amount of rain received gives the kinetic energy values for all the time periods. The sum of the kinetic energy values for all the time periods gives the total kinetic energy of the storm.

Based on the values obtained for the vertical component of rainfall, computations were made for rainfall dominantly originating from NE, NW, SE and SW as follows:

(i) Energy of rain from NE(Ene)

$$Ene = \frac{EV}{RV} \times Rne \ldots\ldots\ldots\ldots\ldots\ldots [3.7]$$

(ii) Energy of rain from NW(Enw)

$$Enw = \frac{EV}{RV} \times Rnw \ldots\ldots\ldots\ldots\ldots\ldots [3.8]$$

(iii) Energy of rain from SE(Ese)

$$Ese = \frac{EV}{RV} \times Rse \ldots\ldots\ldots\ldots\ldots\ldots [3.9]$$

(iv) Energy of rain from SW(Esw)

$$Esw = \frac{EV}{RV} \times Rsw \ldots\ldots\ldots\ldots\ldots [3.10]$$

here EV is energy based on vertical rain, RV is vertical ainfall in mm, Rne, Rnw, Rse and Rsw are rainfall in mm recorded rom gauges facing north-east, north-west, south-east and south-est directions respectively.

aximum 30-minute intensity values computed by locating the reatest amount of rain which falls in any 30 minutes, and then oubling this amount to get the same dimension as intensity, were ubstituted in equation 3.6 to obtain the energy of rainfall; and his multiplied by the amount of rain received from the different mpass directions gives the energy values for rain originating rom the different directions.

e kinetic energy values so obtained were then converted into rtain erosivity indices such as AI_{30} (by multiplying amount of in received from different directions by the I_{30}s), and EI_{30} r the two equations employed for computation of the kinetic ergy of storms. The various erosivity indices (both for rectional and vertical rainfall) were correlated with soil ss.

3.2.4 Wind Monitoring

The dominant wind directions during rainstorms and wind speed were monitored using a wind recorder. The recorder was positioned at 2m above the ground surface. Wind directions were monitored from 8 compass points namely : E, S, SEE, SSE, SSW, NNW, W and NNE. Data from the wind monitoring was brought into direct relationship with rainfall direction and soil loss.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Rainfall Characteristics

4.1.1 Rainfall Amounts

During the data collection period, rainfall data were recorded between 11th october 1992 and 10th June 1993. During this period a mean total of 717 mm of rainfall was recorded for the vertical (V) raingauge. For the raingauges facing north-east(NE), south-east(SE), south-west(SW) and north-west(NW) directions, a mean total of 677, 665, 607, and 622 were recorded respectively. A check gauge situated at the weather station some 10 m away from the experimental site recorded a rainfall amount of 715 mm for the period.

esults given represent that obtained for two rainfall seasons. he second rainfall season was a complete failure in the sense hat rainfall events recordered during the period were not ffective enough to generate runoff and soil loss in the field. nce runoff and soil loss data presented in this report are ose based solely on the first rainfall season. Runoff and soil ss data were collected from November 1992 to February 1993.

ble 4.1 gives the mean monthly distribution of rainfall for the nths October 1992 to June 1993. The wettest month was January d the driest April. This observation is contrary to the normal infall pattern of the Kabete area, where most of the times the rt rains end in December and long rains commence in March or

April hence January, February and March normally remain dry.

Table 4.1 : Distribution of rainfall (mm) from different directions

Mon.	V	NE	SE	SW	NW
Oct.	59.6	58.3	59.2	48.8	43.9
Nov.	107	105	104	86.8	89.5
Dec.	90.9	88.1	86.6	74.0	76.9
Jan.	224	206	193	193	208
Feb.	36.9	31.8	31.2	32.9	34.6
Mar.	56.5	53.8	52.9	46.9	48.1
Apr.	29.1	29.6	29.3	23.9	24.5
May	58.5	55.0	55.8	50.9	50.2
June	54.5	49.4	53.0	49.8	46.3
Tot.	717	677	665	607	622

On the whole, one-hundred and three separate rainfall events were recorded during the period. Thirty-four out of the these events generated runoff. The highest single rainfall event that generated runoff was 47.3 mm for the vertical gauge and 55.6 mm, 42.7 mm, 41.7 mm and 29.6 mm respectively for the NW, SW, NE and SE facing gauges. The smallest rain event that generated runoff as 1.2 mm of rain for the vertical gauge and 1.2 mm, 1.2 mm, 1.1 m and 1.0 mm respectively for the gauges facing NE, NW, SE nd SW directions.

ere were storms of a mean magnitude 25.9 mm for e vertical gauge and 23.7 mm, 23.4 mm, 23.2 mm and 22.8 mm for NE, NW, SE, and SW facing gauges respectively, which did not nerate any runoff. The ability of storms to generate runoff late to the infiltration rate of the soil and the rainfall ensities. In the study certain storms of mean magnitude

25.9mm for the vertical gauge could not generate runoff because of very high infiltration rate of the soil at the time. When the soil is dry infiltration rate is good so rain water infiltrates into the soil apparently nothing left to run over the surface as runoff. However, when the soil is wet and saturated with water, infiltration rate is bad hence rainfall with the least intensity and amount would generate runoff. This is the reason why in this study at certain times, mean rainfall event of 1.2mm generated runoff whilst that of 25.9mm did not.

.1.2 Rainfall Duration and Intensity

he season was characterised by rainfall of generally low ntensities. For the maximum 30-minute intensity, 65 % of the torms had intensities of below 10 mm /hr, 88 % of below 15 mm hr and 94 % of below 25 mm /hr (Table 4.2). The maximum ainfall intensity recorded only on two occasions was 100 mm /hr. he duration ranged from 3 to 5 minutes. Rainfall intensity of 0 mm /hr was also recorded on few occasions for short durations nging from 5 to 8 minutes.

ile the above observations conforms to what other researchers ve observed of the research site (Mati 1991), it contradicts e general expectation of tropical rainstorms. Tropical instorms are normally characterised by short, heavy downpours th rainfall intensities mostly exceeding 25 mm /hr, and even tensities of 50 mm /hr occur quite often (Lal et al 1980).

For the former, the incremental energy amounts were computed by multiplying the energy per mm by the corresponding rainfall amount at that intensities. And for the latter, I_{30} values computed for storms were substituted into the equation to obtain the energies per mm of rain. These were then multiplied by the corresponding rainfall amounts. Rainfall energies were thus computed for rainfall originating from the directions used for the study namely:- Vertical, NE, SE, SW and NW directions.

The equation, KE = 29.8 - 127.5/I (J /m2 /mm), developed by Hudson in 1965 in Zimbabwe was found not suitable, because of the generally low intensities of rainfall of the Kabete area.

Following the computations of rain energy, certain rainfall erosivity indices were deduced for use in the study. These are

(i) Rainfall Amount, conventional (A1)

(ii) Rainfall Amount, with the effect of direction adjusted (A2) The directional effect was adjusted by multiplying A1 by the cosine of 30 (Hamilton 1954). 30° being the inclination of the gauges measuring directional rainfall.

(iii) Maximum 30-minute intensity (I_{30})

iv) Total Rainfall Energy computed using Lal's equation (E Lal for both A1 and A2)

) Total Rainfall Energy computed using the USDA equation (E USDA for both A1 and A2)

i) A1I_{30}

ii) A2I_{30})

iii) Lal's EI_{30} for both A1 and A2 ; and finally

x) USDA's EI_{30} for both A1 and A2.

4.2 Wind Characteristics

4.2.1 Wind Speed

Wind speeds were generally low ranging from as low as 0.3 m/s to 6.0 m/s. Higher wind speeds normally accompanied the severe rainstorms whereas low wind speeds came frequently with light showers and drizzles (Table 4.3).

4.2.2 Wind Direction

The direction from which the wind blows, like the wind speed, also varied from time to time. Eight compass points were observed to be the dominant direction from which the wind blows for all observations during the period of the study. These are as given above under wind characteristics: E, S, SEE, SSE, SSW, NNW, W, and NNE.

were not too frequent. The sample size was 43 representing dominant wind directions during 34 rainstorms which generated runoff and soil loss. Certain rainstorms of particular dates came in two or three separate storms each of which was accompanied by wind dominantly originating from same or different directions. This explains why the sample size for the wind data is 43 and that of runoff and soil loss is 34. Further details on this are given in the appendix 2.7.

Table 4.4 Frequencies of dominant wind direction during rainstorms at kabete

Dominant Wind Direction	Frequency
E	11
S	1
SEE	2
SSE	2
SSW	1
NWW	9
W	4
NEE	13

4.3 Rainfall and Wind

The observed relations existing between dominant wind and rainfall direction is very peculiar. When rainfall direction was brought into directrelationship with wind direction a very regular pattern was observed. A regression analysis done on the two variables yielded an R^2 value of 0.896. There is thus a strong relationship between the dominant wind and rainfall direction. The analysis was made possible by converting values of rain and wind direction in degrees into radians.

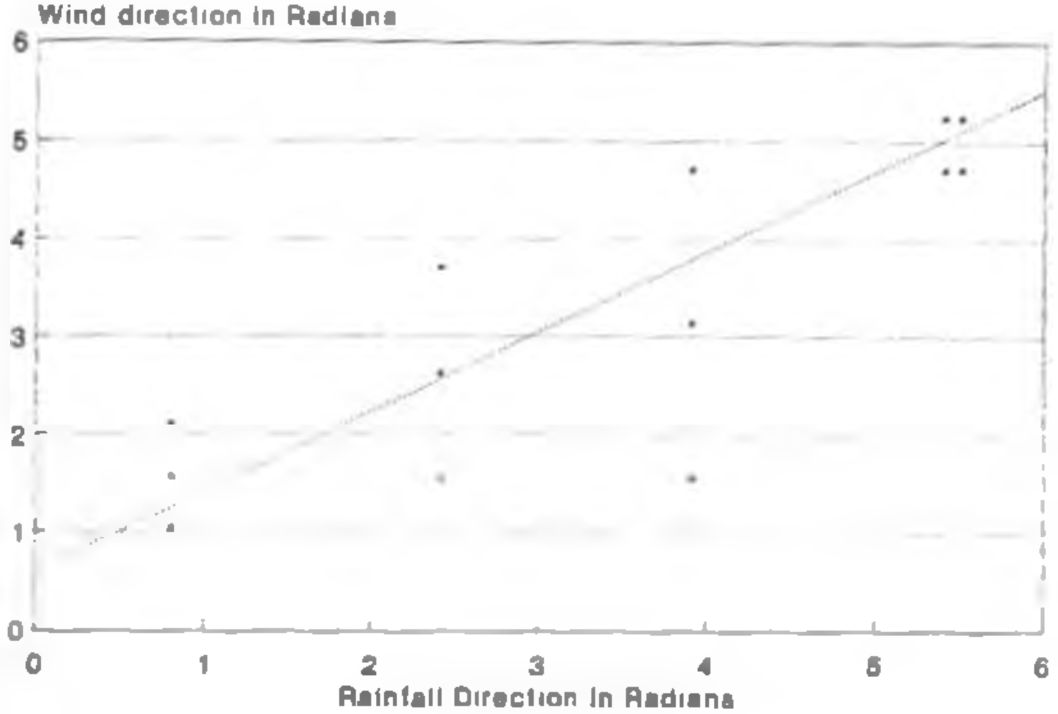

Fig. 4.1. Influence of dominant wind direction on rainfall direction

It is evident from the table 4.3, that when the wind dominantly originates from a particular direction, rainfall tend to come more closely from a related direction. Dominant wind and rainfall directions from easterly directions were much more frequent, having a total frequency of 24 out 43 (i.e E + NEE = 11 + 13 = 24, about 56%), than those from westerly directions which were less frequent (i.e. W + NWW = 4 + 9 = 13, about 30%).

Nonetheless the latter were accompanied by higher intensity storms than the former and caused more damage. Rainstorms accompanied by wind dominantly from westerly directions can then be said of as having stronger erosivity then those from easterly directions.

4.4 **Runoff**

Mean runoff values for bare and grassed treatments observed during the rainy season of November 1992 to February 1993. Though rainfall data were collected up to June 1993, those were not effective enough to generate runoff and soil loss. More runoff were observed on bare plots than on grassed ones. Using the analysis of variance with subsamples for equal subsample numbers (Steel and Torrie 1981), it was observed that significant differences exist between treatments at both 95% and 99% probability levels. The least significant difference (lsd) test established significant differences between NW bare and NW grassed at both probability levels. Significant differences also exist between NE bare and grassed, SW bare and grassed and SE bare and grassed.

significant differences were also observed among plots having different aspects but treated alike (i.e. bare or grassed),thus emphasising the importance of the direction from which the rain generating the runoff originated. The highest runoff was recorded by plots facing NW followed by NE and SW with SE recording the least. The greater runoff produced by bare fallow soil confirms the importance of ground cover in reducing runoff.

Table 4.5 The effect of bare and grassed fallow and of slope orientation on runoff at Kabete during rainy season of November 1992 to February 1993.

Slope Orientation	Mean Runoff(mm) for Bare Tmt	Mean Runoff(mm) for Grassed Tmt	Percentage (%) Reduction in Runoff
NE	19.5	7.8	60
NW	24.0	11.6	52
SE	11.5	3.7	68
SW	15.9	6.2	61

The low mean runoff values is attributed to rainfall and soil characteristics of the research site. According to Gachene (1989), the site is underlain by Nairobi trachytes of tertiary age. The soils are well drained, very deep, highly absorbent dark red friable clay soils. They have an ABC sequence of horizon, with clay cutans and small, soft manganese/iron concretions in the B-horizon. Organic carbon is moderate in the topsoil whilst base saturation is below 50%. Using the FAO system, Soils of the site were classified as humic nitosols. Such soils have very high saturation thresholds and inorder to induce significantly runoff there must be sufficient rainfall exemplified by frequent moderate to extreme rainfall events

(Edwards and Owens 1991). Unfortunately such rainfall events are very rare in the kabete region where rainfall are not so frequent and hardly exceed 20mm. The reduction effect of cover on runoff was not as marked as observed for soil loss, but at least followed a similar trend. Runoff was reduced as a result of cover by 60% on NE oriented plots, NW, SW, and SE oriented plots by 52%, 61% and 68% respectively. Therefore, the higher the percentage cover, the higher the percentage runoff and soil loss reduction and hence less erosion.

4.5 Soil Loss

4.5.1 Effect of Soil Characteristics

The characteristics of soil on the runoff plots were assumed to remain constant through the period of the study. Bulk density test carried out on the plots before data collection begun showed no marked differences in soil on runoff plots and that of the surrounding.

Changes in soil physical structure as a result of surface levelling and compaction during plot construction, continued runoff and soil wash, differences in antecedent soil moisture and the effect by the roots of grass on grassed plots as well as roots of vegetation bordering plots may have had some effect on the amount of runoff and soil loss experienced. But these were difficult to quantify. Texture and nutrient analysis of eroded soil were not carried out as these were a bit off the scope of the study and also because of difficulties involved.

4.5.2 Effect of Plot Orientation

Data for soil loss from bare and grassed fallow for the four compass directions used for the study is shown in Table 4.6. More soil loss were observed from the bare plots than the grassed ones. The highest soil loss for the period was obtained from the NW oriented slopes followed by NE, SW and SE oriented slopes respectively.

The analysis of variance revealed a significant difference between soil loss observed from the bare and grassed plots. Among the bare plots it was found that soil loss observed on NW facing slopes were significantly different from that observed for NE, SW and SE facing slopes at both 95% and 99% probability levels. Soil loss from NE, SW and SE facing plots were not significantly different at both probability levels. No significant difference in soil loss was observed for the grassed plots having different orientation. At 99% probability level soil loss from SE oriented bare plots were found not significantly different from the grassed plots. The coefficient of variability for the soil loss data for the different treatments was established at a 51.2%.

Table 4.6 The Effect of bare and grassed fallow on slope orientation soil loss at Kabete during the rainy season of November 1992 to February 1993.

Slope orientation	Mean Soil Loss (Kg/m^2) for Bare Treatment	Mean Soil Loss (Kg/m^2) for Grassed Treatment	Percentage (%) Reduction in Soil Loss
NE	6.28	0.15	98.0
NW	10.78	0.11	99.0
SE	3.53	0.03	99.2
SW	6.15	0.10	98.4

The above soil loss values give a seasonal sediment concentration of approximately 320g/l. This is probably too high but is explained by slope characteristics of the microplots, soil properties and rainfall characteristics. Mati (1991) established the erodibility of the soil to be 0.23 which is quite high. Then a gradient of 30° for slope length of 2m is very steep. Rates of erosion are greater on steep slopes than on flat slopes(Lingsley et al 1988). The steeper the slope, the more effective splash erosion is in moving soil downslope. Overland-flow velocities are also greater on steep slopes, and mass movements are more likely to occur in steep terrain. Length of slope is also important. For sloping runoff plots, the shorter the length, the sooner the eroded material reaches the collection trough.

Another important factor which has contributed to the high seasonal sediment yield is the influence of a few large storms. Only one rainstorm has contributed more than 70% of the seasonal sediment yield. Recording mean rainfall amount of 55mm, mean runoff of 16.5mm for northwest oriented plots and maximum 30-minute intensity of 60mm/hr, it was the severest rainstorm of the season. Soil loss in kg/m^2 that occurred by this storm of 20th January 1993 on plots facing NW, NE, SW, and SE compass points are respectively 8.8, 3.4, 5.1 and 2.2.

4.5.3 Effect of Grass Cover

Results presented in Table 4.6 indicate the importance of grass cover in reducing soil loss. Grass cover has been very effective in reducing soil loss. This is because of its effect in reducing the soil surface area exposed to the raindrop impact and decreasing runoff flow velocity by imparting roughness. The shear stress of water flow is thus distributed amongst the vegetation and mulch elements provided by the grass cover instead of acting entirely on the soil particles.

Runoff and Soil loss related inversely proportional to the percent grass cover on the grassed plots. It was observed that plots with the highest percentage grass cover (i.e. SE > (SW = NW) > NE) recorded the least runoff and soil loss. On the NE oriented plots, grass cover reduced soil loss by 98%, NW oriented plots by 99% and SW and SE oriented plots by 98.4% and 99.2% respectively.

The average percentage cover observed using the simple sighting [illegible] are as follows: 79.8% for NE, 80% each for SW and NW and [illegible].3% for SE oriented plots.

4.5.4 Effect of Rainfall and Wind Related Variables

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. According to Morgan (1986), The above applies particularly to erosion by overland flow and rills for which intensity is generally considered to be the most important rainfall characteristic.

It is also believed to be influenced significantly by the direction and speed of wind and hence rainfall direction during rainstorms. Other variables believed to enhance soil loss are the ground slope and the aspect or the orientation of land slope. It is in this respect that, in the study, a trial was made to work out a relationship between the contributing erosive agents and soil loss by combining rainfall erosivity index ($E_{1a1}I_{30}$), wind speed, wind direction, Rainfall direction, Maximum 30-minute intensity (I_{30}), runoff, ground slope, plot aspect and wind run seasonal basis. Various combinations were experimented. eeping the ground slope and plot aspect constant, regression uation with R^2 values of 0.995, 0.979 and 0.973 respectively, et explaining the combined effects of the various independent riables on soil loss was obtained as follows:

$$=-43.68+8.84x10^{-4}Er-38.56Ws-97.2Wd+99.43Rd+367.94r-10.3I\,..[4.3]$$

34, R^2=0.995

$$Y=-49.98+2.3x10^{-3}Er+50.8Ws-217.2Wd+209.65Rd\,.....[4.4]$$

4, R^2=0.979

$$Y=-87.9+2.3x10^{-1}Er-32.64Rd .... [4.5]$$

$n=34$, $R^2=0.973$

The value range for the variables, for which the above relationships were derived are as follows:

(i) Wind Speed (Ws) = 0.3m/s - 6m/s

(ii) Erosivity(Er) = 43.7J.m^{-2}.mmh^{-1} - 3, 703, 626J.m^{-2}.mmh^{-1}

(iii) Runoff (r) = 0.1mm - 16.5mm

(iv) I_{30} (I) = 1mm/hr - 60mm/h

(v) Wind Direction(Wd) = 1.05 - 5.24radians

(vi) Rainfall Direction(Rd) = 0.8 - 5.5radians

(vii) Soil Loss (Y) = 0.04g.m^{-2} - 8759.1g.m^{-2}

Where Y is the soil loss in g/m^2, Er is the rainfall erosivity index($E_{1a1}I_{30}$), Ws is wind speed in m/s, Wd is wind direction in radians, Rd is the rainfall direction in radians, I is the maximum 30-minute intensity(I_{30}) in mm/hr and r is runoff in mm. The effects of rainfall erosivity index, rainfall direction, I_{30}, wind speed and wind direction and runoff were highly significant at both 95% and 99% probability levels while the effect of wind run was not significant at all. The above equations were deduced at constant slope orientations. The response of the soil in terms of erosion to the receipt of rainfall may be determined by previous meteorological conditions. In the course of the study between the period October 1992 and June 1993, the initial rains fell on dry ground and no runoff resulted. Most of the water thus went into soaking the soil and after several rainfall events runoff finally resulted. Therefore, the closeness of the soil to saturation which depends on how much rain has fallen in the previous few days, determines the occurence of runoff. Though an important variable, the antecedent soil moisture content could be quantified easily and hence was not represented in the equations.

The question arises of how much rain is required to induce significantly runoff and soil loss. Whilst the importance of extreme events is emphasised by some observers, most workers subscribe to the fact that most erosion occurs with moderate events exemplified by rainstorms yielding 30 to 60 mm. Rather ironically, rainstorms yielding 30 to 60 mm rain were the extreme events in the Kabete region and were responsible for most of runoff and soil loss observed in the field (table 4.7). The pattern of high soil loss in the first and low loss in the second of a series of erosive storms (rainfall events of 6 and 7th January 1993) can be explained by the fact that, weathering and light rainfall loosen the soil surface. Hence most of the loose material is removed during the first runoff event leaving little for erosion in subsequent events. Another way to explain this is the maximum 30-minute intensity and hence erosivity of the two storms.

Sometimes small rainfall events are accompanied by peak I^{30} values which last for only few minutes yet cause significant damage. Figures in Table 4.7 represent all observations for moderate to extreme rainfall events that occurred during the period between October 1992 and June 1993. The figures given are averages for all directions on plots of 2 m^2.

Table 4.7 Effect of antecedent rainfall conditions on soil loss

Date	Rainfall Amount(mm)	Runoff (mm)	Runoff (as % of Rainfall)	Soil Loss (g/m^2)
3/11/92	25.6	0.9	3.5	129.4
16/11/92	25.0	1.6	6.4	498.2
10/12/92	13.8	0.7	5.2	210.4
16/12/92	31.0	1.0	3.2	178.9
1/1/93	11.8	0.4	3.4	34.9
6/1/93	21.2	0.8	3.9	53.8
7/1/93	26.6	0.4	1.3	3.9
15/1/93	17.4	0.6	3.2	288.2
18/1/93	18.6	1.6	8.4	921.5
20/1/93	43.4	10.6	24.5	4840.0

The high runoff and soil loss figures observed for rainfall event of 20-01-93 is attributed to the rainfall intensity and the antecedent soil content of the soil. Having maximum 30-minute intensity of 60mm/hr and mean rainfall amount of 43.4 mm, it was the severest storm of the season. It is very true that the antecedent soil moisture condition could have contributed to the runoff and soil loss observed but its effect could not be more obvious than that of the rainfall intensity.

4.6 Rainfall Erosivity Indices and Soil Loss

The relationship existing between Soil loss and certain rainfall erosivity indices were further studied. For these erosivity indices, the best correlation coefficients with soil loss, are shown in the table 4.8. A complete list of all rainfall erosivity indices, their R^2 values with soil loss as well as their standard errors of estimate are given in appendix 3 and 4.

ne best erosivity indices were found to be EI_{30} using Lal's nergy equation(i.e. 0.972 for NW; 0.978 for SW; 0.936 for V; .843 for SE and 0.764 for NE rains) , EI_{30} using the USDA's quation(i.e. 0.957 for NW; 0.951 for SW; 0.904 for V; 0.797 for E and 0.756 for NE rains), AI_{30} (i.e. 0.958 for NW; 0.948 for W; 0.912 for V; 0.809 for SE and 0.772 for NE rains) and E, al's energy equation (i.e. 0.956 for NW; 0.944 for SW; 0.91 for ; 0.804 for SE and 0.772 for NE rains).

t is of interest to note that the best correlations between the arious erosivity indices and soil loss were observed for slopes ith NW and SW orientation (Figs 4.1 and 4.2), whilst the poorest ere observed for slopes oriented towards NE and SE (Figs 4.3 and .4). The above observation did not reflect very much in the raphs where the relation seems poor in spite of the high R^2 but an be explained by the range of values which were too ivergent. Average soil loss when brought into direct lationship with erosivity indices of rainfall falling rtically, gave correlation coefficients which were intermediate tween those observed for NW/SW and NE/SE originating rainstorms igs 4.5). In effect the directional erosivity indices (with gard to those dominantly originating from westerly directions) rrelate better to soil loss than even vertical rainfall. This velation confirms what has been noted earlier on winds minantly originating from westerly directions. Although not ry frequent as compared with wind from easterly directions, yet me with high intensity rainstorms which were responsible for st of the soil loss observed in the field.

or storms originating from any particular direction, tests were one to compare correlation coefficient estimates (Zar 1984) iven by the rainfall erosivity indices (namely: $E_{lal}I_{30}$, $E_{usda}I_{30}$, $_{lal}$ and AI_{30}). Results showed no significance difference in the ccuracy of the various indices in estimating rainfall erosivity. ence each of the four indices can be used to estimate rainfall rosivities in the Kabete area. However, comparisons of the ccuracy of these indices in estimating directional rainfall rosivity showed a significant directional influence. orrelation coefficients for the rainfall erosivity indices for orms dominantly originating from NW and SW directions were gher and significantly different from those of vertical infall which in turn were higher and significantly different om the erosivity indices of storms dominantly originating from and SE directions. Correlation coefficients for NW and SW iginating storms were not significantly different from each her and so are those for storms dominantly originating from NE d SE directions (Table 4.8).

is discovery seems to make the use of inclined raingauges lly better in directional rainfall erosivity predictions than rtical gauges, especially with regard to storms dominantly ginating from westerly directions.

Table 4.8 Correlation coefficients (r) for rainfall erosivity indices with total soil loss from bare fallow Plots.

Rainfall Direction	$E_{usda}I_{30}$	$E_{lal}I_{30}$	AI_{30}	E_{lal}
V	0.952	0.967	0.954	0.953
NE	0.869	0.874	0.879	0.879
SE	0.893	0.918	0.899	0.897
NW	0.978	0.986	0.979	0.978
SW	0.975	0.989	0.974	0.972

r values in same rows are not significantly different from each other; r values in different rows are significantly different except those of NE and SE, and NW and SW.

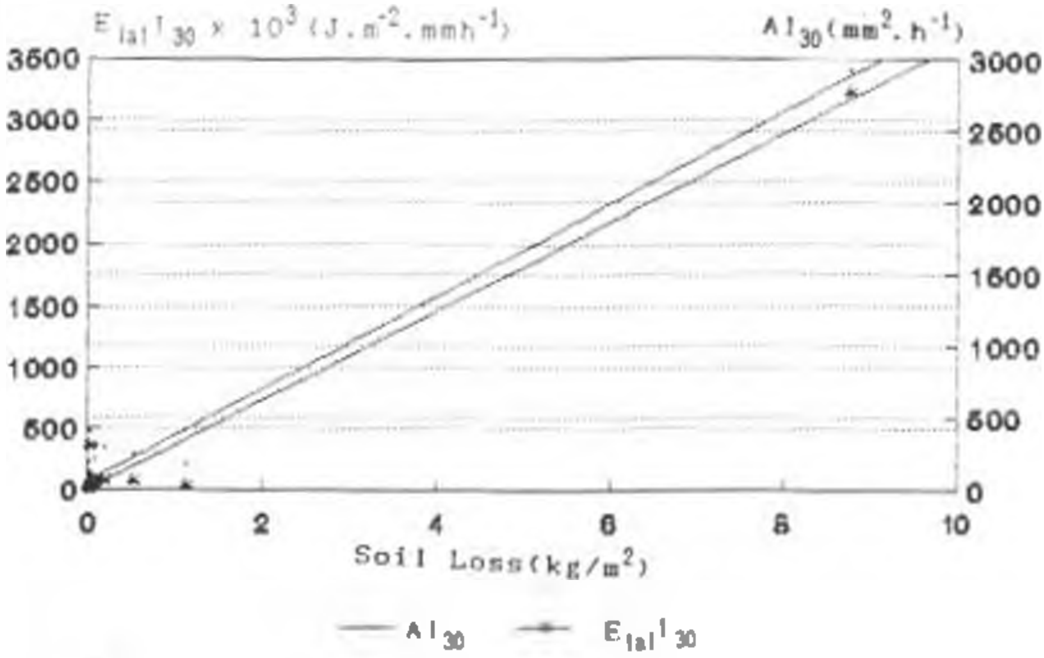

Fig. 4.2 Influence of north-west rainfall on soil loss.
AI_{30}, r=0.979; $E_{(a)}I_{30}$, r=0.986

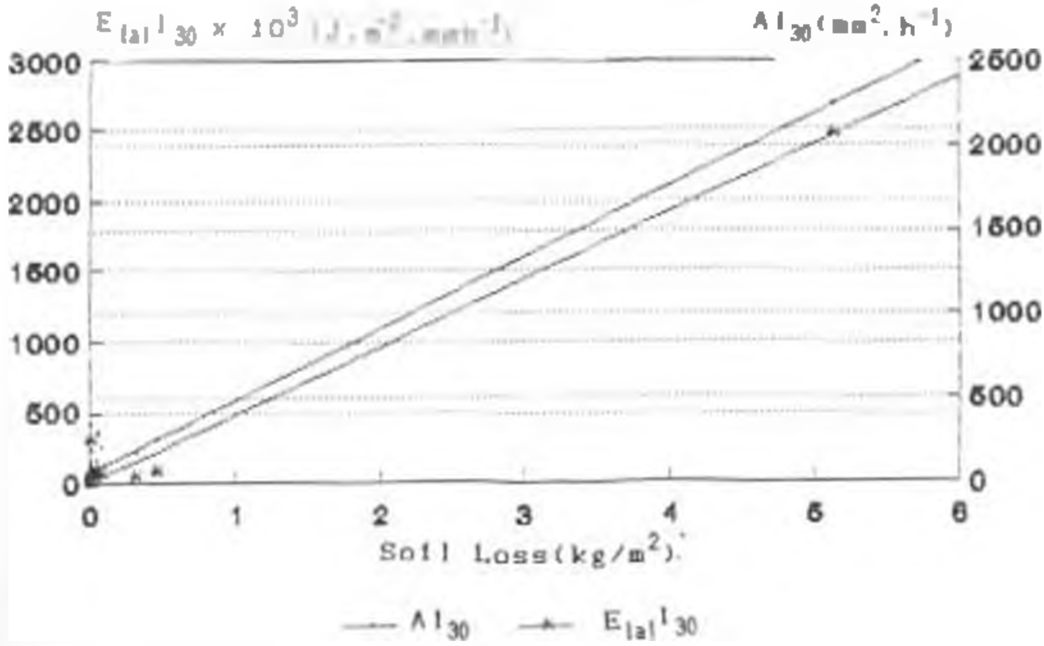

Fig. 4.3 Influence of south-west rainfall on soil loss.
AI_{30}, r=0.974; $E_{(a)}I_{30}$, r=0.989

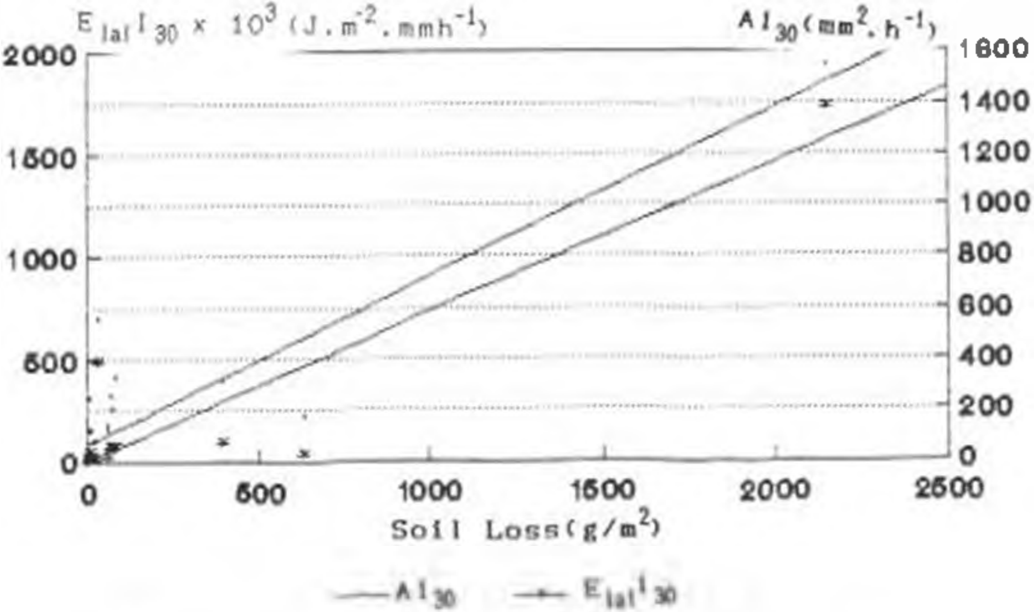

Fig. 4.5 Influence of south-east rainfall on soil loss.
AI_{30}: r=0.899; $E_{lal}I_{30}$: r=0.918

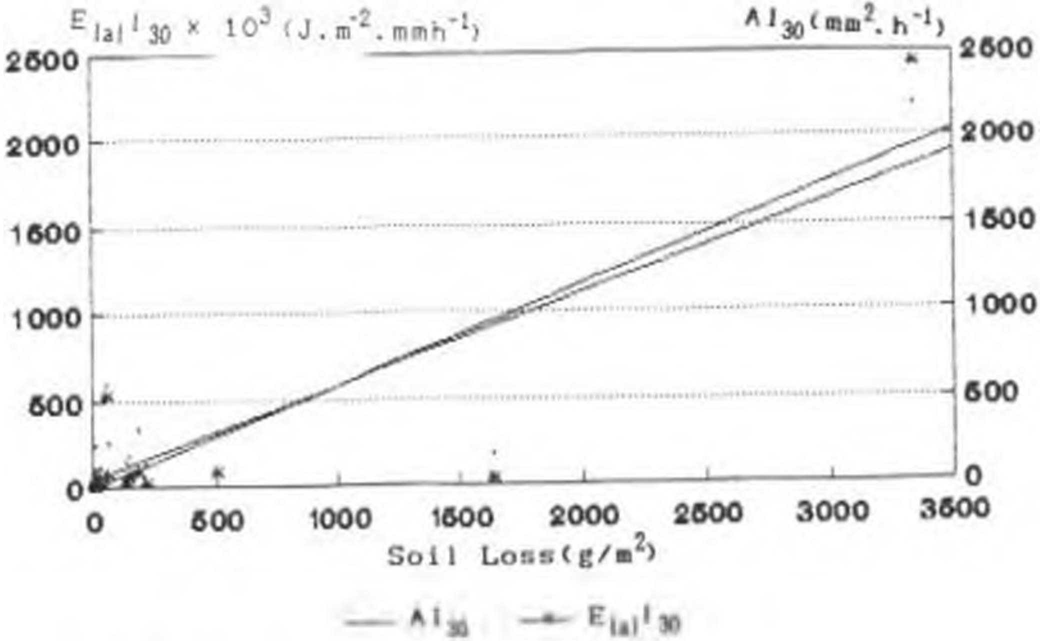

Fig. 4.4 Influence of north-east rainfall on soil loss.
AI_{30}, r=0.879; $E_{|a|}I_{30}$, r=0.874

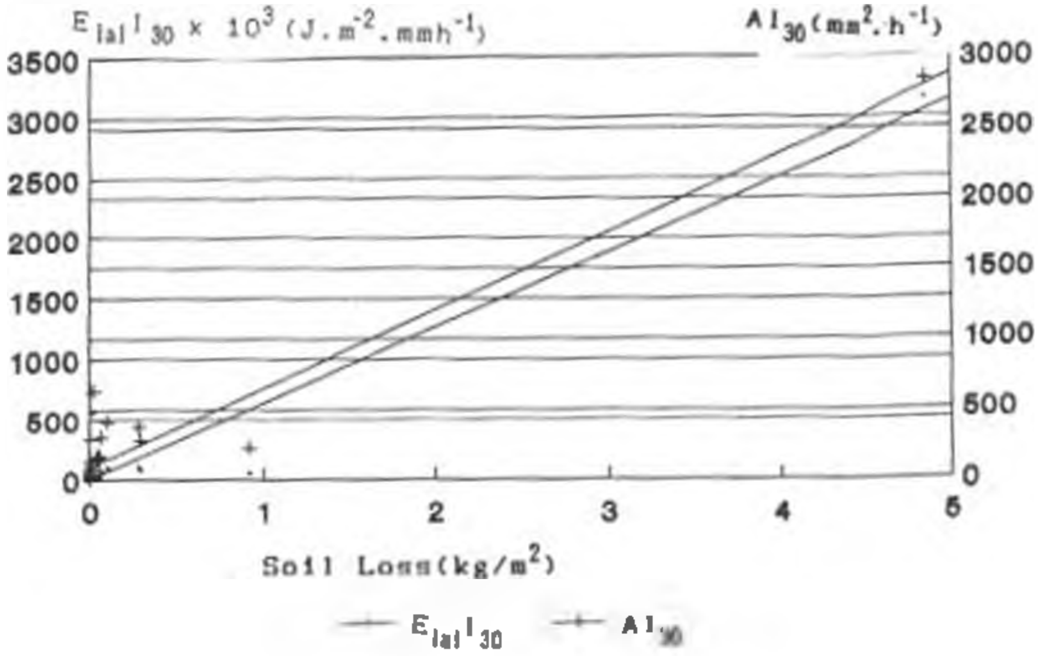

Fig. 4.6 Influence of vertical rainfall on soil loss.
AI_{30}, r=0.954; $E_{|a|}I_{30}$, r=0.967

n table 4.8, only those rainfall factors which correlated best o soil loss on bare fallow plots are given. The number of bservations for each set of data were 34. Computations of R^2 or all other data are presented in the appendix 4. The standard rrors of estimates and statistical t-values for the erosivity ndices are also given in the appendix. Tabulated t-values in ll the cases at 95% probability level is 2.032. Hence, all the rosivity indices are statistically significant.

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Rainfall, wind, runoff and soil loss data were collected over a nine month period, beginning in October 1992 and ending in June 1993. Dominant wind direction during rainstorms correlated well to rainfall directions. Wind speeds were generally low, with the highest average wind speed of 6 m/s and the lowest of 0.3 m/s. There was no significant effect of wind run on soil loss.

Rainfall intensities were generally low. Maximum 30-minute intensities for rainstorms correlated well to soil loss. Extreme rainfall events were rather seldom. Most of the time, the rain came as showers and drizzles, accompanied by virtually no wind, hence rain falling rather vertically. Probably this being the reason why the vertical gauges recorded the highest mean rainfall amount.

lthough the vertical rain gauges recorded the highest mean ainfall amount, it was the rainfall erosivity index computed for ainstorms dominantly originating from south-west and north-west irections that correlated best to soil loss. Storms dominantly riginating from westerly directions were rare but were ccompanied by severe wind and high intensity storms which were sponsible for most of the soil loss observed in the field. ere was a significant rainfall effect for rainstorms dominantly iginating from south-west and north-west directions. This fect was significantly different from vertical rainstorms and oriented toward south-east and north-east directions.

Statistical analysis showed a significant difference in runoff and soil loss observed between north-west oriented plots and all plots with other orientation. Cover significantly reduced runoff and soil loss observed from all plots.

These observations are very relevant for practical purposes. Wind speed and direction affect rainfall direction which in turn acting with the I_{30} of rainstorms influence the rainfall erosivity. Slopes which are thus oriented toward the dominant erosive storm direction get more damaged partly because of the large volume of overland flow which results and also because of their very high potential ability to detach and wash away surface soil particles.

5.2 Recommendations

It is of utmost importance that the observations made be further tested for a few more rainy seasons and at different locations in Kenya to see if they would be sustaining. Future studies should try to identify areas with susceptible slope orientation, as well as dominant wind and rainfall directions for these areas. They should try to find out if dominant wind and rainfall directions changes with differences in locations. Also the rainfall erosivity indices(E_{lal}, $E_{lal}I_{30}$, $E_{usda}I_{30}$ and AI_{30}), identified by this study as the most suitable for this region should be further tested both in time and space to proove their validity.

When such studies have been carried out, conservation planning and land use policies should be developed to focus on the more prone slopes, which are likely to suffer immensely from the directional influence of rainfall. The implementation of such an approach should be aimed at arresting directional rainfall erosion by the integration of various erosion control measures. Various erosion control techniques must be employed concurrently, giving much priority to a more effective and sustainable cover growth on all susceptible slopes.

6.0 References

Alegre, J.C., Felipe-Morales, C., La-Torre, B., (1990): Soil erosion studies in Peru. J. SWC 45(6), 417-420.

Armstrong, C.L., Mitchell, J.K., (1987): Transformation of rainfall by plant canopy. Trans. ASAE 30 (1), 688-696.

Barber, R.G., Moore, T.R., Thomas, D.B., (1979): Erodibility of two soils from Kenya. J. Soil Science. 30: 579-591

Brown, M.J., Peck, E.L., (1962): Reliability of precipitation measurement as related to exposure,.J. Appl. Meteorol., Vol. 1, No.2, 203-207.

Bubenzer, G.D., Jones, B.A., (1971): Drop size and impact velocity effects on the detachment of soils under simulated rainfall. Transactions of American Society of Agricultural Engineers, 14.(4), 625-628.

Carter, C.E., Greer, J.D., Braud, H.J., Floyd, J.M., (1974): Raindrop characteristics in South Central United States. Trans. ASAE 17, 1033-1036.

Chisci, G., Morgan, R.P.C., (1988): Modelling soil erosion by water: Why and how. In: Erosion assessment and modelling, (Report EUR 10860 En) (Eds: Morgan, RPC; Rickson, RS) Commission of the European Community, Luxemburg, 121-146.

Das, P., (1964): Role of condensed water in life cycle of convective cloud. J. Atmos. Sci., Vol. 21, No. 4, 404-418.

Dendy, F.E., Allen, P.D., Piest, R.F., (1979): Sedimentation. In : Brakensiek et al (co-ordinators). Field manual for research in Agricultural Hydrology. US Dept. of Agriculture, Agriculture Handbook No. 224, 239-394.

Edwards, W.M., Owens, L.B., (1991): Large Storm effects on total soil erosion. J. SWC 46(1), 75-78.

Ekern, P.C., (1956): Raindrop impact as the force initiating soil erosion. Soil Sci. Soc. Am. Proc. 15,7-10.

El-Swaify, S.A., Dangler, E.W., Armstrong, C.L., (1982): Soil erosion by water in the tropics. Research extension series 024 Agricultural publication and information office. College of Tropical Agriculture and Human resources, University of Hawaii, Honolulu, 173pp.

Ellison, W.D., (1944): Studies of raindrop Erosion, Agricultural Engineering, 25, 131-136,181-182.

Elwell, H.A., Stocking M.A., (1975): Parameters for estimating annual runoff and soil loss from agricultural lands in Rhodesia, Water Resources Research, 11 (4), 601-605.

Ferreira, I.A.M., (1985): New orientation and erosivity factor added to the USLE makes sense in Alentejo. IVISCO conference. In: Soil conservation and productivity. (Ed: Plasentis,I) Central University of Venezuela, Maracay, 880-899.

Free, G.R., (1960): Erosion characteristics of rainfall, Agricultural Engineering, 41,(7), 447-449, 455.

Frits, M.R., Richard, A.L., Billy, V.L., William, L.M., (1990): Reducing field losses of nitrogen: Is erosion control enough?. J.SWC 45(6), 144-147.

Gachene, C.K.K., (1989): Soils of the erosion research farm. Kabete Campus, Department of Agricultural Engineering, University of Nairobi. Nairobi.

Gantzer, C.J., Anderson, S.H., Thompson, A.L., Brown, S.R., (1990): Estimating soil erosion after 100 years of cropping on Sanborn field. J.SWC 4596), 641-644.

Gilley, JE., Firkner, S.C., Spomer,R.G., NielKe, L.N., (1986): Runoff and erosion as affected by corn residue. Part 1: Total losses. Trans. ASAE 29(1), 157-160.

Gilley, JE., Firkner, S.C., Spomer,R.G., NielKe, L.N., (1986): Runoff and erosion as affected by corn residue. Part 2: Rill and interrill components. Trans. ASAE 29(1), 161-164.

Gold, A.J., Loudon, T.L., Nurnberger, F.V., (1986): Runoff and erosive storm occurrence probabilities. Trans. ASAE 29(1), 119-123.

Gregory, J.M., (1980): Consideration of force components of raindrops in the detachment of soil. In: Assessment of erosion. De Boodt, M., Gabriels (eds). Proceedings of a workshop, Ghent, Belgium. 27th Feb.- 3rd Mar. 1978. John wiley and Sons, 485-494.

Gunn, N., (1965): Collision characteristics of freely falling water drops. Science, Vol 150, No. 3697, 695-791.

Gunn, R., Kinzer, G.D., (1949): The terminal velocity of fall of water droplets in stagnant air. J. Meteorol., Vol 6, 243-248.

Hamilton, P.M., (1966): Vertical profiles of total precipitation in shower situation, Q.J.R. Meteorol. Soc., Vol 92, No. 392, 346-362.

Hamilton, E.L., (1954): Rainfall sampling on rugged terrain U.S. Dept. Agric. Tech. Bull. 1096.

Hamon, W.R., (1973): Computing actual precipitation, in distribution of precipitation in mountainous areas, no. 326, World Meteorological Organization, Geneva, 159-173.

Hanson, C.L., Coon, D.L., (1979): A note on the dual- gage and Wyoming shield precipitation measurements systems, Water Resour. Res., Vol. 15, (4), 956-960.

Hoeck, E., (1952): Report of the committee on the measurement of precipitation, Trans, Int. Assoc. Sci. Hydrol., Vol. 3, 81-93.

Holy, M., (1980): Erosion and environment. Pergamon press, Oxford,225pp.

Hudson, N.W., (1963): Raindrop size distribution in high intensity storms, Rhod. J. Agric. Res. 1, 6-11.

Hudson, N.W., (1965): The influence of rainfall on the mechanics of soil erosion with particular reference to southern Rhodesia, Unpubl. Msc. thesis, University of Cape Town.

Hudson, N., (1973): Soil Conservation. BT Batsford Ltd., London.

Hudson, N., (1985): Soil conservation. Dotesios printers Ltd. Guildford, London and Worcester for BT Batsford Ltd,London, 320pp.

Hurni, H., (1988): Rainfall directions and its relationship to erosivity, soil loss and runoff. In: Land conservation for future generations, Proceedings of the fifth International Soil Conservation Conference, 18-29 Jan.1988. Vol. 1. (Ed. Rimwanich,S). Ministry of Agriculture and cooperation, Bangkok, 329-341.

Istok, J.D., (1986): Effect of rainfall measurement interval on EI calculation. Trans. ASAE 29 (3), 730-734.

Jennings, G.D., Jarrett, A.R., Hoover, J.R., (1987): Simulated rainfall duration and sequencing affect soil loss. Trans. ASAE 30(1),158-161.

Lal,R., (1976): Soil Erosion in Alfisols in Western Nigeria 111. Effects of rainfall characteristics, GcoDrma, 16,389-401.

Lal, R., (1977): Soil erosion problems on an alfisol in western Nigeria and their control. IITA Monograph, IITA, Ibadan.

Lal, R., Lawson, T.L., Anastase, A.N., (1980): Erosivity of tropical rains. In: Assessment of erosion. De Boodt, M. and D. Gabriels (eds). Proceedings of a workshop. Ghent, Belgium. 27th Feb-3rd Mar. 1978. John Wiley and Sons. 143-151.

Lal, R., (1981): Analysis of different processes governing soil erosion by water in the tropics. In: Erosion and sediment transport measurement. Proceedings of a symposium. Florence, Italy. June 22-26,1981. IAHS-AISH Publication no. 133, 351-364.

Larson, L.W., Peck, E.L., (1974): Accuracy of Precipitation measurements for hydrologic modelling, Water Resources Res., Vol 10, no. 4, 857-863.

Laws, J.O., Parsons, D.A., (1943): The relationship of raindrop size to intensity , Trans. Am. Geophys. Un.24, 452-60.

Laws, S.J.O., (1941): Measurement of fall- velocity of water-drops and rain drops. Transaction of the American Geophysical Union 22, 709.

Linda, K.L., (1990): The dynamics of declining soil erosion rates. J.SWC, 45(6), 622-624.

Linsley, R.K. Jr., Kohler, M.A., Paulhus, J.L.H., (1988): Hydrology for Engineers. McGraw-Hill Book Ltd. Singapore. 492pp.

Mason, B.T., (1952): Precipitation of rain and drizzle by coalescence in stratiform clouds, Q.J.R. Meteorol. Soc., V 78, No. 337, 377-386.

Mati, B.M., (1991): The influence of crop cover on soil erosion by splash. M.Sc. thesis, unpublished. Department Agricultural Engineering, University of Nairobi. Nairobi.

Mclsaac, G.F., (1990): Apparent geographic and atmospheric influences on raindrop sizes and rainfall kinetic energy. J. SWC 45, (6), 663-666.

Meyer, L.D., (1979): Water erosion. In: The Encyclopedia of soil science. Part 1. Edited by: Fairbridge, R.W., Finkl, C.W Jnr.,Dowden, Hutchinson and Ross Stroudsburg, P.A.

Meyer, L.D., (1981): How rain intensity affects interrill erosion. Transactions of the American Society of Agricultural Engineers, 24,(6),1472-1475.

Mihara, Y., (1951): Raindrops and soil erosion, Bulletin of the National Institute of Agricultural Science, Series A 1 (Japan).

Moldenhauer, W.C., Long, D.C., (1964): Influence of rainfall energy on soil loss and Infiltration rates, effect over a range of textures. Proceedings of the Soil Science Society of America, 28,(6),813-817.

Morgan, R.P.C., (1977): Soil erosion in the United Kingdom: Field studies in the Ssilsoe area 1973-75, National college of Agricultural Engineering, Occasional Paper No. 4., Silsoe, U.K.

Morgan, R.P.C., (1981): Field measurement of splash erosion. In Erosion and sediment transport measurement. Proceedings of a symposium. Florence, Italy. June 22-26 1981. IAHS-AISH publication no. 133, 373-382.

Morgan, R.P.C., (1986): Soil erosion and conservation. Longman Scientific and Technical publication. John Wiley and Sons Inc.New York. 298pp.

Mwaniki, J.M., (1991): A comparison of different grasses as filter strips for soil and water conservation on crop land. M.Sc. thesis, Unpublished. Department of Agricultural Engineering, University of Nairobi, Nairobi.

Quansah, C., (1981): The effect of soil type, slope, rain intensity and their interactions on splash detachment and transport. J. of Soil Sci. 32, 215-224.

Rhoton, F.E., Meyer, L.D., Tyler, D.D., (1990): Effects of past erosion on the interrill erodibility of a fragipan soil. J. SWC 45, (6), 660-663.

Roose, E.J., (1980): Approach to the definition of rain erosivity in West Africa. In: Assessment of erosion. De Boodt M. and D. Gabriels (eds). Proceedings of a workshop. Ghent, Belgium. Feb. 27th-Mar. 3rd 1978, 154-164.

Rose, C.W., (1960): Soil detachment caused by rainfall. Soil Science. 89, 28-34.

Rudra, R.P., (1986): Runoff response to frost layering. Trans. ASAE 29(3), 735-740.

Serra, L., (1953): The correct measurements of precipitation, Trans Int. Assoc. Sci. Hydrol., Vol. 3, 81-93.

Sombroek, W.G., Braun, H.M.H., Van der Pouw, B.J.A., (1980): Sombroek, W.G., Braun H.M.H., Van der Pouw, B.J.A., (1980) : The exploratory soil map and agro-climatic zone map of Kenya. Report No. E1, Kenya Soil Survey, Nairobi.

Sopher, C.D., Baird, J.V., (1982): Soils and soil management. Second edition . Reston Publishing Company Inc. Reston, Virginia USA. 312pp.

Stallings, J.H., (1964): Soil conservation. Prentice-Hall, Englewood Cliffs, N.J., Prentice-Hall, USA.

Steel, R.G.D., Torrie, J.H., (1981): Principles and procedures of statistics: A biometrical approach. International edition, McGraw-Hill Book Company, Singapore, 633pp.

Stocking, M.A., (1973): Prediction of subtropical storm soil losses from field plot studies. Agric. Met. 12, 193-201.

Struzer, L.R., (1969): Method of measuring the correct value of solid atmospheric precipitation. Sov. Hydrol. Sel . Pap., No. 6, 56-565.

Styczen, M., Schmidt, K.H., (1988): A new description of splash erosion in relation to raindrop sizes and vegetation. In: Erosion assessment and modelling, (Report EUR 10860 En) (Eds: Morgan, RPC; Rickson, RS) Commission of the European Community, Luxemburg, 147-184.

Tefera, F., (1983): The effect of narrow grass strips in controlling soil erosion and runoff on sloping land. M. Sc. Thesis, Unpublished. Department of Agricultural Engineering, University of Nairobi. Nairobi.

Thomas, A.W., Snyder, N.M., Dillard, A.L., (1990): Prediction of monthly erosion index from daily rainfall records. Trans. ASAE, 33(1), 118-126.

Unger, P.W., Fulton, J.L., Jones, O.R., (1990): Land-levelling effects on soil texture, organic matter content, and aggregate stability. J.SWC. 412-415.

Watson, D.A., Laflen, J.M., (1986): Soil strength, slope and rainfall intensity effects on interrill erosion. Transactions of the ASAE, 29(1), 98-102.

Weiss, L.L., (1963): Securing more nearly true precipitation measurements, J. Hydraul. Div. ASCE, Vol. 89, No. HY3, 11-18.

Wischmeier, W.H., Smith, D.D., (1958): Rainfall energy and its relationship to soil loss, Trans. Am. Geophys. Un. 39, 285-91.

Wischmeier, W.H., Smith, D.D., (1965): Predicting rainfall-erosion loss from crop east of the Rocky Mountain Agriculture Handbook 282, Washington.

Wischmeier, W.H., Smith, D.D., (1978): Predicting rainfall erosion losses, United States Dept. of Agriculture, Agricultural Handbook 537.

Wischmeier, W.H., (1976): Use and misuse of the universal soil loss equation. Journal of Soil and Water Conservation, 31,(1), 5-9.

Yoo, K.H., Touchton, J.T., (1987): Effect of tillage on surface runoff and soil loss from cotton. Trans. ASAE 30(1), 166-168.

Zanchi, C., Torri, D., (1980): Evaluation of rainfall energy in central Italy, in De Boodt. M. and Gabriels, D. (eds), Assessment of Erosion,John Wiley, Chichester, 133-42.

Zar, J.H., (1984): Biostatistical Analysis. Prentile-Hill, New Jersey, 311, 31

Appendix 1: Wind Measurements - October 1992 to March 1993.

1.1 : Wind measurement for October 1992.

					Time of day			
Date	1-6 hrs(a.m.)		6-12 hrs		12-18 hrs(p.m.)		18-24 hrs(p.m.)	
	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)
1/11	E	1.0	E	1.2	-	-	-	-
31	NE	1.2	NE	1.8	E	2.0	E	1.8
30	NE	3.0	NE	2.5	E	2.5	E	1.6
29	E	2.0	NE	1.8	E	3.0	E	2.5
28	E	2.0	E	3.0	E	2.0	E	1.0
27	NE	1.0	NE	3.0	E	3.0	E	1.2
26	E	0.8	NE	1.8	E	2.5	E	1.6
25	NE	0.8	E	2.5	E	2.5	E	1.2
24	E	0.8	E	2.5	E	2.5	E	1.8
23	E	1.4	E	2.0	E	4.0	E	2.5
22	E	0.8	E	2.0	E	3.0	E	1.8
21	E	1.4	NE	1.6	E	2.5	E	1.6
20	E	0.8	E	1.6	E	2.5	E	1.6
19	E	0.8	E	1.8	E	2.5	E	1.4
18	E	0.8	NE	1.8	E	4.0	E	3.0
17	W	0.6	N	2.5	SE	2.5	NW	2.0
16	E	1.4	SE	2.5	E	2.0	E	1.2
15	E	1.0	SE	2.0	SE	3.0	E	2.5
14	E	1.2	E	2.0	E	2.5	E	2.5
13	NE	0.6	E	2.0	E	3.0	E	1.8
12	E	1.4	NE	1.8	SE	2.5	SW	1.4
11	W	0.8	SE	2.0	SE	3.0	E	2.5
10	E	0.8	SE	2.0	SE	3.0	E	1.6
9	E	1.2	E	2.0	SE	3.5	E	1.8
8	W	0.8	E	2.0	E	2.5	E	1.8
7	NW	0.8	E	2.5	E	2.5	E	1.6
6	E	1.0	E	1.2	E	3.0	N	0.8
5	SE	1.0	NE	1.8	SE	3.0	E	1.4
4	E	0.8	SE	2.5	SE	2.0	NW	1.2
3	E	0.8	SE	1.6	NE	2.0	S	1.6
2	E	1.2	SE	1.6	SE	2.0	NW	1.0
1	-	-	E	1.8	E	2.0	E	1.6

1.2 : Wind measurement for November 1992.

Date	Time of day							
	1-6 hrs(a.m.)		6-12 hrs		12-18 hrs(p.m.)		18-24 hrs(p.m.)	
	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)
1/12	E	1.4	E	1.2	-	-	-	-
30	E	1.2	E	1.8	NE	3.0	E	1.4
29	E	1.0	E	2.5	E	2.0	E	1.0
28	E	1.0	E	2.0	NE	2.0	E	1.4
27	E	2.0	E	2.5	E	2.5	NE	1.0
26	W	0.8	NE	2.0	E	3.0	NE	0.8
25	NE	1.6	E	3.0	E	3.0	E	1.6
24	NE	1.8	NE	2.5	E	3.0	E	2.5
23	NE	1.4	E	2.5	E	3.0	E	1.4
22	NE	1.0	NE	1.8	E	2.5	E	1.6
21	E	0.6	NE	2.0	E	2.0	E	1.2
20	NE	1.0	NE	2.0	E	2.5	E	1.6
19	NE	1.2	NE	2.0	E	3.0	E	1.8
18	NE	1.8	NE	2.0	E	2.5	E	1.8
17	N	1.0	NE	2.5	E	3.0	E	1.6
16	NW	0.8	SE	2.0	E	2.0	NE	1.2
15	NE	0.8	NE	1.4	E	2.0	NW	0.6
14	E	0.8	NE	1.8	E	2.0	E	1.4
13	E	0.8	E	2.0	NE	2.0	E	1.8
12	E	1.4	NE	2.0	E	2.0	E	1.2
11	E	1.2	E	1.6	E	2.5	E	2.0
10	E	1.0	E	2.0	E	2.5	SE	0.8
9	E	1.2	E	1.8	E	3.0	E	0.8
8	E	1.0	E	2.5	E	2.5	E	1.6
7	E	1.0	E	2.0	E	3.0	E	1.0
6	E	1.2	E	1.6	E	1.8	E	1.0
5	E	1.8	E	1.8	NE	1.8	NE	1.4
4	NE	1.2	E	1.8	E	2.0	E	1.8
3	N	0.8	NE	1.6	NE	1.6	NE	1.4
2	E	1.2	E	1.4	SE	4.0	NE	1.0
1	-	-	NE	2.0	NE	1.6	E	0.8

1.3: Wind measurement for December 1992.

	Time of day							
Date	1-6 hrs(a.m.)		6-12 hrs		12-18 hrs(p.m.)		18-24 hrs(p.m.)	
	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)
1/1	E	1.8	E	2.0	-	-	-	-
31	NE	2.0	E	2.5	E	2.5	E	1.6
30	NE	2.0	NE	2.5	E	3.0	E	2.0
29	NE	1.2	NE	2.5	E	2.5	NE	1.8
28	E	1.0	NE	2.5	E	2.5	NE	1.2
27	NE	1.4	NE	1.8	NE	2.0	NE	1.8
26	NE	1.0	N	2.0	E	3.0	E	2.0
25	NE	0.8	N	2.0	E	2.0	NE	1.4
24	NE	1.0	NE	1.8	E	2.0	NE	1.0
23	NE	0.8	NE	1.6	E	2.0	NE	1.2
22	NW	0.6	NE	1.8	E	2.5	NE	1.2
21	W	0.6	NE	1.6	E	2.0	NE	1.6
20	E	1.0	NE	1.8	E	2.5	NE	1.0
19	W	0.6	NE	2.0	E	2.5	E	1.2
18	NE	1.6	NE	1.6	E	2.0	NE	1.6
17	E	1.0	E	1.0	NE	1.6	NE	1.0
16	NE	0.8	E	1.6	E	2.0	E	1.6
15	E	0.8	NE	2.5	E	2.0	E	1.8
14	E	1.2	NE	2.0	E	2.0	NE	1.2
13	E	1.4	E	2.5	E	3.5	E	2.0
12	NE	1.0	NE	1.6	NE	2.5	NE	1.4
11	E	1.2	NE	2.5	E	2.5	NE	1.4
10	E	1.2	E	1.8	E	2.5	E	1.4
9	E	1.6	E	2.0	E	2.5	E	1.2
8	E	0.8	E	1.8	E	2.5	E	1.4
7	N	1.2	NE	1.8	SE	2.0	N	1.2
6	E	0.6	NE	2.0	SE	2.5	N	1.2
5	NW	0.8	NE	1.6	E	1.2	W	0.6
4	E	1.0	E	1.6	E	2.0	E	1.0
3	E	0.8	NE	1.6	E	3.5	E	1.0
2	E	0.8	E	1.4	E	2.0	E	0.8
1	-	-	E	1.6	E	2.5	E	1.2

..4 : Wind measurement for January 1993.

Date	1-6 hrs(a.m.)		6-12 hrs		12-18 hrs(p.m.)		18-24 hrs(p.m.)	
	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)
1/2	NE	0.8	E	1.0	-	-	-	-
31	NE	1.0	NE	2.5	E	2.5	NE	2.0
30	NE	1.0	E	2.0	NE	2.5	NE	1.6
29	W	0.6	NE	1.8	E	2.5	NE	1.0
28	SE	1.0	E	3.0	E	3.0	E	1.8
27	N	0.8	NE	1.6	E	2.5	NE	1.4
26	NE	1.0	NE	1.8	NE	2.0	NE	1.0
25	NW	0.6	NW	1.6	E	2.0	NE	1.0
24	NW	0.8	NE	1.8	E	2.0	NE	1.0
23	NW	0.8	NE	2.0	E	2.5	NE	1.2
22	NE	0.6	NE	1.6	E	2.5	NE	1.2
21	SE	1.4	SE	1.6	E	2.0	NE	1.6
20	NW	1.8	E	1.6	E	2.0	NE	1.6
19	SE	1.2	SE	2.0	NW	2.0	W	2.5
18	NW	0.6	SE	1.6	W	1.8	NW	0.8
17	NE	0.6	SE	2.0	W	3.0	NW	1.0
16	W	0.8	E	1.4	E	1.8	NE	0.8
15	W	0.8	NE	1.4	NW	2.5	NW	1.2
14	NW	0.6	E	1.4	E	2.0	NW	0.8
13	NW	0.8	NW	1.6	NW	2.5	NW	1.0
12	NE	1.0	SE	1.6	W	4.0	NW	1.6
11	NE	0.8	E	1.4	E	2.0	NE	1.2
10	NE	0.8	E	1.8	E	2.5	NE	1.8
9	W	0.6	NE	2.5	E	2.5	E	1.4
8	NE	1.4	NE	1.4	E	1.8	E	1.0
7	E	1.8	E	1.6	E	2.0	E	2.0
6	NE	1.6	E	2.5	E	2.5	E	2.0
5	E	1.0	NE	2.5	E	2.5	E	1.4
4	NE	0.8	E	2.0	E	2.5	NE	1.2
3	NE	1.4	NE	2.5	E	1.4	NE	1.4
2	E	1.2	NE	1.2	E	1.4	NE	1.6
1	-	-	-	-	E	2.5	E	3.0

1.5 : Wind measurement for February 1993.

	Time of day							
Date	1-6 hrs(a.m.)		6-12 hrs		12-18 hrs(p.m.)		18-24 hrs(p.m.)	
	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)
1/3	NE	1.0	NE	1.0	-	-	-	-
28	NW	0.8	E	2.0	E	2.5	NE	1.8
27	NW	0.6	NE	2.5	E	2.5	E	1.4
26	SE	0.8	N	2.0	E	2.5	E	2.0
25	W	0.6	NW	1.2	E	3.0	E	1.4
24	NW	0.6	E	1.8	E	2.0	NW	1.2
23	NW	1.2	E	1.6	E	2.5	E	1.4
22	W	0.8	NE	1.8	E	2.5	E	1.2
21	NW	0.8	NE	2.0	E	2.0	E	1.6
20	E	1.2	NE	2.0	E	3.0	E	1.8
19	E	1.2	NE	2.0	NE	3.0	E	1.6
18	W	0.6	NE	1.8	E	2.5	E	1.2
17	NW	0.8	NE	1.8	E	2.0	NE	1.4
16	NE	0.6	E	2.0	E	3.0	E	1.4
15	W	0.8	NE	2.0	E	2.5	E	1.4
14	NW	1.0	NE	2.0	E	2.5	NE	1.2
13	NE	0.8	NE	2.0	E	2.5	E	1.4
12	NW	0.6	NE	1.6	E	2.0	NE	1.6
11	NW	2.0	NW	1.4	SE	1.2	NW	0.6
10	W	0.8	NE	1.6	E	2.5	E	1.6
9	NW	0.8	E	2.0	NE	2.5	NE	0.8
8	NE	1.0	NE	1.2	E	2.0	NW	3.0
7	SE	1.2	NE	1.8	E	2.0	NE	1.2
6	W	0.6	NE	1.8	E	2.5	NW	1.8
5	W	0.6	NE	1.2	SE	2.5	NE	1.0
4	E	1.4	NE	1.6	E	2.5	E	1.0
3	NE	1.2	E	2.0	E	2.5	E	1.4
2	E	1.0	NE	2.0	E	2.5	NE	1.8
1	-	-	NE	1.6	E	1.8	E	1.4

1.6 : Wind measurement for March 1993.

Date	Time of day							
	1-6 hrs(a.m.)		6-12 hrs		12-18 hrs(p.m.)		18-24 hrs(p.m.)	
	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)	W.D.	W.S(m/s)
1/4	NE	1.4	NE	1.4	-	-	-	-
31	N	0.8	E	2.0	E	3.0	E	1.6
30	E	1.2	NE	2.0	E	2.5	E	1.8
29	E	1.6	E	3.0	E	2.5	E	1.4
28	E	1.6	NE	2.0	E	2.5	E	1.0
27	E	1.2	E	2.5	E	3.0	E	1.6
26	NW	0.8	NE	2.0	E	3.0	E	1.6
25	E	0.8	NE	2.0	E	2.5	E	1.4
24	E	1.0	E	2.0	E	3.0	E	1.6
23	E	0.8	NE	1.8	E	3.0	E	2.5
22	E	1.0	SE	1.8	E	2.5	E	1.6
21	E	0.8	E	1.8	E	2.0	NE	0.8
20	E	1.4	E	2.5	E	3.0	E	2.0
19	E	1.0	E	3.0	E	3.0	E	1.4
18	E	1.0	E	2.5	E	3.0	NE	0.8
17	E	0.8	N	1.4	E	2.5	E	1.0
16	NW	0.8	E	2.0	E	2.5	E	1.0
15	W	0.6	E	2.5	E	3.0	NE	1.0
14	NW	0.8	N	1.8	E	2.5	NE	1.0
13	NW	1.4	N	1.2	E	2.0	NE	0.6
12	NW	0.6	N	1.6	NW	3.0	NW	1.0
11	NW	1.0	NE	1.6	SE	2.0	NW	0.6
10	W	0.6	E	2.0	E	2.0	NW	0.8
9	E	1.2	E	2.5	E	2.0	E	2.5
8	W	0.6	E	2.0	E	2.0	E	1.0
7	E	1.0	NE	2.5	E	3.0	E	1.2
6	W	0.6	E	2.5	E	2.5	NE	1.2
5	NW	0.8	E	2.5	E	2.5	E	1.4
4	NW	0.8	E	2.5	E	2.5	W	0.6
3	W	0.8	E	1.8	E	3.0	W	0.6
2	NW	0.6	N	1.2	SE	1.6	E	1.2
1	-	-	E	2.5	E	2.5	NE	0.8

<u>Remarks:</u>

W.D. denote wind direction.
W.S denote wind speed.
While the direction of wind varied considerably from time to time, its speeds were relatively higher in the afternoons(i.e.12-18 hrs).

1.7: **Dominant wind and rainfall directions during rainstorms.**

Date	Time of Rainfall	Rain direction		Wind direction		Wind speed (m/s)
1/11/92	9.30pm-10.30pm	NW	315°	NWW	300°	0.60
3/11/92	2.00pm- 7.00pm	NE	45°	NEE	60°	0.76
	11.00pm- 9.00am	NE	45°	NEE	60°	0.53
6/11/92	11.00am- 4.00pm	SE	135°	E	90°	1.52
12/11/92	11.00pm- 1.00am	NE	45°	E	90°	1.70
14/11/92	4.45am- 9.00am	SE	135°	E	90°	0.61
16/11/92	4.00pm- 5.00pm	SW	225°	W	270°	2.75
	10.00pm- 3.30am	SE	135°	SSW	210°	0.30
24/11/92	6.45am- 8.30am	NE	45°	NEE	60°	4.00
30/11/92	11.45am- 2.15pm	NE	45°	E	90°	2.60
	5.45am- 9.00am	NE	45°	E	90°	1.50
7/12/92	4.00pm- 6.15pm	SE	135°	SSE	150°	2.00
8/12/92	4.30am- 9.00am	NE	45°	E	90°	0.44
9/12/92	2.45am- 3.30am	NE	45°	NEE	60°	2.70
10/12/92	9.30pm- 1.00am	NE	45°	NEE	60°	0.88
11/12/92	9.30pm-11.00pm	NE	45°	NEE	60°	0.53
13/12/92	10.00pm-11.00pm	NE	45°	NEE	60°	2.50
	4.00am- 9.00am	NE	45°	E	90°	0.76
16/12/92	6.00pm-10.00pm	NE	45°	SEE	120°	0.95
	2.00am- 9.00am	NE	45°	NEE	60°	0.51
30/12/92	4.30am- 8.00am	NE	45°	NEE	60°	2.10
31/12/92	5.30am- 7.00am	NE	45°	NEE	60°	2.70
1/1/93	8.30pm- 9.00pm	NE	45°	E	90°	3.20
5/1/93	8.00am- 9.00am	NE	45°	NEE	60°	0.50
6/1/93	9.00pm- 9.30pm	NE	45°	E	90°	6.00
	3.00am- 9.00am	NE	45°	NEE	60°	1.20
7/1/93	9.00am- 8.00pm	NE	45°	NEE	90°	1.50
11/1/93	3.00am- 5.00am	NW	315°	NWW	300°	0.30
13/1/93	1.30pm- 7.00pm	NW	315°	NWW	300°	1.50
15/1/93	3.15pm-10.00pm	NW	315°	W	270°	4.00
17/1/93	11.30am-12.30pm	SW	135°	SSE	150°	2.00
18/1/93	12.00nn- 3.45pm	SW	225°	S	180°	4.30
	10.00pm- 5.00am	SW	225°	W	270°	0.50
19/1/93	8.30pm-12.00mn	NW	315°	W	270°	2.73
20/1/93	3.15pm- 9.30pm	NW	315°	NWW	300°	4.90
21/1/93	6.45pm- 8.00pm	NW	315°	NWW	300°	0.64
25/1/93	8.45pm-11.00pm	NW	315°	NWW	300°	0.98
26/1/93	10.15pm-12.15am	NW	315°	NNW	300°	1.00
29/1/93	7.00pm- 9.00am	NE	45°	NEE	60°	1.20
8/2/93	7.15pm-10.45pm	NW	315°	NWW	300°	1.20
10/2/93	10.45pm-12.15am	NE	45°	E	90°	1.40
8/3/93	2.45pm-12.15am	SE	225°	E	90°	0.73
12/3/93	10.45pm- 2.30am	NW	315°	NWW	300°	1.20

Appendix 2:Influence of Rainfall Erosivity Factors on Soil loss

3.1: Characteristics of Vertical Rainfall.

mm A1	I30mm/h	EJ/m2lal	EJ/m2usda	A1I30	EI30lal	EI30usda	S/Lsg/m2
5.80	4.00	127.40	121.50	23.20	509.6	486.00	0.30
28.30	6.00	3605.40	549.30	169.80	21632.4	3295.80	47.00
5.70	4.00	518.70	103.70	22.80	2074.8	414.80	1.30
2.50	3.00	182.00	41.40	7.50	546.0	124.20	0.01
5.30	6.00	675.20	111.70	31.80	4051.2	670.20	0.02
27.10	14.00	7398.30	616.60	379.40	103576.2	8632.40	277.10
4.30	3.00	313.00	72.30	12.90	939.0	216.90	0.11
5.70	5.00	622.40	123.70	28.50	3112.0	618.50	0.33
8.60	8.00	1408.70	160.50	68.80	11269.6	1284.00	0.13
3.80	4.00	345.80	74.10	15.20	1383.2	296.40	0.20
4.40	5.00	480.50	89.90	22.00	2402.5	449.50	0.21
15.00	10.00	3003.00	304.50	150.00	30030.0	3045.00	56.80
1.20	1.00	43.70	18.10	1.20	43.7	18.10	0.10
3.70	4.00	336.70	60.30	14.80	1346.8	241.20	0.03
34.50	12.00	8162.70	610.70	414.00	97952.4	7328.40	99.33
2.80	3.00	203.80	58.60	8.40	611.4	175.80	0.20
8.10	4.00	737.10	146.70	32.40	2948.4	586.80	0.10
13.20	48.00	11771.80	352.80	633.60	565046.4	16934.40	21.00
3.60	4.00	327.60	46.70	14.40	1310.4	186.80	0.13
23.30	13.00	5936.80	402.50	302.90	77178.4	5232.50	62.63
29.10	10.00	5825.80	502.50	291.00	58258.0	5025.00	4.40
6.00	5.00	655.20	102.40	30.00	3276.0	512.00	0.24
7.80	6.00	993.70	114.30	46.80	5962.2	685.80	0.10
18.90	15.00	5503.70	382.00	283.50	82555.5	5730.00	288.20
8.30	17.00	2719.10	222.20	141.10	46224.7	3777.40	4.40
20.70	11.00	4520.90	372.20	227.70	49729.9	4094.20	921.50
4.50	4.00	409.50	62.10	18.00	1638.0	248.40	0.05
47.30	60.00	52512.50	1114.00	2838.00	3150750	66840.00	4840.00
3.90	6.00	497.00	74.40	23.40	2982.0	446.40	1.12
11.20	12.00	2649.90	216.60	134.40	31798.8	2599.20	0.41
6.10	7.00	888.20	120.10	42.70	6217.4	840.70	0.14
5.60	3.00	407.70	98.20	16.80	1223.1	294.60	0.10
16.10	10.00	3223.20	303.80	161.00	32232.0	3038.00	3[illegible].48
19.40	5.00	2118.50	418.00	97.00	10592.5	2090.00	9.14

Remarks:

Refer to page xii - xiv for meaning of abbreviations used for the appendix 3.

2.2: Characteristics of North-Easterly Rainfall.

r/fam A1	r/fam A2 dr. adjt	I30mm/h	EJ/m2ial for A1	EJ/m2ial for A2	EJ/m2Quade for A1	EJ/m2Quade for A2	A1I30	A2I30	EI30ial for A1	EI30ial for A2	EI30Quade for A1	EI30Quade for A2	ErLog/m2
5.70	4.96	4.00	173.00	150.51	119.36	103.84	22.80	19.84	692.00	602.04	477.43	415.37	0.40
28.40	24.71	6.00	3618.20	3147.83	551.24	479.58	170.40	148.25	21709.20	18887.00	3307.46	2877.49	129.40
5.60	4.87	4.00	509.60	443.35	101.81	88.57	22.40	19.49	2038.40	1773.41	407.23	354.29	0.60
2.40	2.09	3.00	174.70	151.99	39.77	34.60	7.20	6.26	524.10	455.97	119.30	103.79	0.02
5.00	4.35	6.00	637.00	554.19	100.10	87.09	30.00	26.10	3822.00	3325.14	600.60	522.52	0.10
25.90	22.53	14.00	7070.70	6151.51	589.23	512.63	362.60	315.46	98989.80	86121.13	8249.15	7176.76	498.20
4.50	3.92	3.00	327.60	285.01	75.73	65.89	13.50	11.75	982.80	855.04	227.20	197.67	0.21
5.90	5.13	5.00	644.30	560.54	128.09	111.44	29.50	25.67	3221.50	2802.71	640.45	557.19	0.50
7.50	6.53	8.00	1228.50	1068.80	139.95	121.76	60.00	52.20	9828.00	8550.36	1119.60	974.05	0.10
3.80	3.31	4.00	345.80	300.85	74.14	64.50	15.20	13.22	1383.20	1203.38	296.55	258.00	0.30
4.60	4.00	5.00	473.30	411.77	93.98	81.76	23.00	20.01	2366.50	2058.86	469.89	408.80	0.12
15.40	13.40	10.00	3083.10	2682.30	312.62	271.98	154.00	133.98	30831.00	26822.97	3126.20	2719.79	210.40
1.10	0.96	1.00	40.00	34.80	16.60	14.44	1.10	0.96	40.00	34.80	16.60	14.44	0.10
4.10	3.57	4.00	373.10	324.60	66.83	58.14	16.40	14.27	1492.40	1298.39	267.32	232.57	0.10
31.70	27.58	12.00	7500.20	6525.17	561.09	488.15	380.40	330.95	90002.40	78302.09	6733.08	5857.78	178.10
4.30	3.74	3.00	313.00	272.31	90.00	78.30	12.90	11.22	939.00	816.93	270.00	234.90	0.10
7.70	6.70	4.00	700.70	609.61	139.52	121.38	30.80	26.80	2802.80	2438.44	558.10	485.54	0.20
14.30	12.44	48.00	12752.70	11094.85	382.24	332.55	686.40	597.17	612129.6	532552.8	18347.47	15962.30	50.40
4.00	3.48	4.00	364.00	316.68	51.80	45.07	16.00	13.92	1456.00	1266.72	207.20	180.26	0.20
23.00	20.01	13.00	5860.40	5098.55	397.21	345.57	299.00	260.13	76185.20	66281.12	5163.73	4492.45	55.30
28.20	24.53	10.00	5645.60	4911.67	487.01	423.70	282.00	245.34	56456.00	49116.72	4870.14	4237.02	2.80
5.80	5.05	5.00	633.40	551.06	99.01	86.14	29.00	25.23	3167.00	2755.29	495.03	430.68	0.24
6.60	5.74	6.00	840.80	731.50	96.62	84.06	39.60	34.45	5044.80	4388.98	579.74	504.38	0.03
14.10	12.27	15.00	4105.90	3572.13	284.96	247.92	211.50	184.01	61588.50	53582.00	4274.42	3718.74	137.00
6.50	5.66	17.00	2129.40	1852.58	174.01	151.39	110.50	96.14	36199.80	31493.83	2958.09	2573.53	8.40
18.50	16.10	11.00	4040.40	3515.15	232.63	202.39	203.50	177.05	44444.40	38666.63	2558.93	2226.27	1632.90
3.70	3.22	4.00	336.70	292.93	51.02	44.39	14.80	12.88	1346.80	1171.72	204.09	177.56	0.06
41.70	36.28	60.00	46295.30	40276.91	982.04	854.37	2502.00	2176.74	2777718	2416615	58922.10	51262.22	3278.30
3.10	2.70	6.00	395.00	343.65	59.18	51.49	18.60	16.18	2370.00	2061.90	355.07	308.91	0.29
10.00	8.70	12.00	2366.00	2058.42	193.40	168.26	120.00	104.40	28392.00	24701.04	2320.80	2019.10	0.34
5.80	5.05	7.00	844.50	734.72	114.14	99.30	40.60	35.32	5911.50	5143.01	799.01	695.14	0.37
5.60	4.87	3.00	407.70	354.70	98.17	85.41	16.80	14.62	1223.10	1064.10	294.50	256.22	0.11
13.40	11.66	10.00	2682.70	2333.95	252.86	219.99	134.00	116.58	26827.00	23339.49	2528.58	2199.86	25.30
17.00	14.79	5.00	1856.40	1615.07	366.35	318.72	85.00	73.95	9282.00	8075.34	1831.75	1593.62	7.00

2.3: Characteristics of South-Easterly Rainfall.

r/mm A1	r/mm A2 gr. adj	I30mm/h	EJ/m2lal for A1	EJ/m2lal for A2	EJ/m2usda for A1	EJ/m2usda for A2	A1I30	A2I30	EI30lal for A1	EI30lal for A2	EI30usda for A1	EI30usda for A2	R/kg/m2
5.00	4.35	4.00	455.00	395.85	104.70	91.09	20.00	17.40	1820.00	1583.40	418.80	364.36	0.00
27.00	23.49	6.00	3439.80	2992.63	524.07	455.94	162.00	140.94	20638.80	17955.76	3144.42	2735.65	33.90
6.00	5.22	4.00	546.00	475.02	109.08	94.90	24.00	20.88	2184.00	1900.08	436.32	379.60	1.50
2.30	2.00	3.00	167.40	145.64	38.11	33.16	6.90	6.00	502.20	436.91	114.33	99.47	0.02
5.10	4.44	6.00	649.70	565.24	102.10	88.83	30.60	26.62	3898.20	3391.43	612.61	532.97	0.03
25.70	22.36	14.00	7016.10	6104.01	584.68	508.67	359.80	313.03	98225.40	85456.10	8185.45	7121.34	387.20
4.10	3.57	3.00	298.50	259.70	69.00	60.03	12.30	10.70	895.50	779.09	207.01	180.10	0.10
5.10	4.44	5.00	131.00	113.97	110.72	96.33	25.50	22.19	655.00	569.85	553.61	481.64	0.00
8.90	7.74	8.00	1457.80	1268.29	166.07	144.48	71.20	61.94	11662.40	10146.29	1329.59	1155.88	[illegible]
3.70	3.22	4.00	336.70	292.93	72.19	62.80	14.80	12.88	1346.80	1171.72	288.75	251.21	0.30
4.20	3.65	5.00	458.60	398.98	85.81	74.65	21.00	18.27	2293.00	1994.91	429.03	373.26	0.01
14.30	12.44	10.00	2862.00	2489.94	290.29	252.55	143.00	124.41	28620.00	24899.40	2902.90	2525.52	[illegible]
1.10	0.96	1.00	40.00	34.80	16.60	14.44	1.10	0.96	40.00	34.80	16.60	14.44	[illegible]
3.70	3.22	4.00	336.70	292.93	60.31	52.47	14.80	12.88	1346.80	1171.72	241.24	209.88	[illegible]
[illegible]	22.49	12.00	7476.60	6504.64	559.32	486.61	279.30	229.90	89719.20	78055.70	6711.84	5839.30	74.40
4.20	3.65	3.00	305.80	266.05	87.91	76.48	12.60	10.96	917.40	798.14	263.72	229.43	0.07
8.20	7.13	4.00	746.20	649.19	148.58	129.27	32.80	28.54	2984.80	2596.78	594.34	517.07	0.04
13.20	11.48	48.00	11771.80	10241.47	352.84	306.97	633.60	551.23	565046.4	491590.4	16936.13	14734.43	25.40
3.70	3.22	4.00	336.70	292.93	47.92	41.69	14.80	12.88	1346.80	1171.72	191.66	166.74	0.03
22.60	19.66	13.00	5758.50	5009.90	390.30	339.56	293.80	255.61	74860.50	65128.64	5073.93	4414.32	46.10
28.30	24.62	10.00	5665.70	4929.16	488.74	425.20	283.00	246.21	56657.00	49291.59	4887.41	4252.05	[illegible]
5.70	4.96	5.00	622.40	541.49	97.30	84.65	28.50	24.80	3112.00	2707.44	486.50	423.25	0.20
5.90	5.13	6.00	751.70	653.98	86.38	75.15	35.40	30.80	4510.20	3923.87	518.26	450.88	0.09
15.50	13.49	15.00	4513.60	3926.83	313.26	272.53	232.50	202.28	67704.00	58902.48	4698.83	4087.70	47.50
8.10	7.05	17.00	2653.60	2308.63	216.84	188.65	137.70	119.80	45111.20	39246.74	3606.23	3207.02	1.52
17.40	15.14	11.00	3800.20	3306.17	312.85	272.18	191.40	166.52	41802.20	36367.91	3441.37	2993.99	[illegible]
3.80	3.31	4.00	345.80	300.85	52.40	45.59	15.20	13.22	1383.20	1203.38	209.61	182.36	0.05
29.60	25.75	60.00	32862.00	28589.94	697.08	606.46	1776.00	1545.12	1971720	1715396	41824.80	36387.58	2141.60
3.20	2.78	6.00	407.70	354.70	61.09	53.15	19.20	16.70	2446.20	2128.19	366.53	318.88	1.28
10.00	8.70	12.00	2366.00	2058.42	193.40	168.26	120.00	104.40	28392.00	24701.04	2320.80	2019.10	1.43
6.50	5.66	7.00	946.40	823.37	127.92	111.29	[illegible]	39.59	6624.80	5763.58	895.44	779.03	0.21
5.50	4.79	3.00	400.40	348.35	96.42	83.88	16.50	14.36	1201.20	1045.04	289.25	251.64	0.04
14.30	12.44	10.00	2862.90	2490.72	269.84	234.76	143.00	124.41	28629.00	24907.23	2698.41	2347.62	[illegible]
18.00	15.66	5.00	1965.60	1710.07	387.90	337.47	90.00	78.30	9828.00	8550.36	1939.50	1687.37	18.92

2.3: Characteristics of South-Easterly Rainfall.

r/fam A1	r/fam A2 dr. adjt	I30mm/h	EJ/m2lal for A1	EJ/m2lal for A2	EJ/m2usda for A1	EJ/m2usda for A2	A1I30	A2I30	EI30lal for A1	EI30lal for A2	EI30usda for A1	EI30usda for A2	B/Lagrm2
5.00	4.35	4.00	455.00	395.85	104.70	91.09	20.00	17.40	1820.00	1583.40	418.80	364.36	0.06
27.00	23.49	6.00	3439.80	2992.63	524.07	455.94	162.00	140.94	20638.80	17955.76	3144.42	2735.65	53.90
6.00	5.22	4.00	546.00	475.02	109.08	94.90	24.00	20.88	2184.00	1900.08	436.32	379.60	1.56
2.30	2.00	3.00	167.40	145.64	38.11	33.16	6.90	6.00	502.20	436.91	114.33	99.47	0.02
5.10	4.44	6.00	649.70	565.24	102.10	88.83	30.60	26.62	3898.20	3391.43	612.61	532.97	0.07
25.70	22.36	14.00	7016.10	6104.01	584.68	508.67	359.80	313.03	98225.40	85456.10	8185.45	7121.34	387.20
6.10	5.31	3.00	298.50	259.70	69.00	60.03	12.30	10.70	895.50	779.09	207.01	180.10	0.10
5.10	4.44	5.00	131.00	113.97	110.72	96.33	25.50	22.18	655.00	569.85	553.61	481.64	0.00
8.90	7.74	8.00	1457.80	1268.29	166.07	144.48	71.20	61.94	11662.40	10146.29	1328.59	1155.88	0.20
3.70	3.22	4.00	336.70	292.93	72.19	62.80	14.80	12.88	1346.80	1171.72	288.75	251.21	0.25
4.20	3.65	5.00	458.60	398.98	85.81	74.65	21.00	18.27	2293.00	1994.91	429.05	373.26	0.01
14.30	12.44	10.00	2862.00	2489.94	290.29	252.55	143.00	124.41	28620.00	24899.40	2902.90	2525.52	6.40
1.10	0.96	1.00	40.00	34.80	16.60	14.44	1.10	0.96	40.00	34.80	16.60	14.44	0.10
3.70	3.22	4.00	336.70	292.93	60.31	52.47	14.80	12.98	1346.80	1171.72	241.24	209.88	0.00
31.60	27.49	12.00	7476.60	6504.64	559.32	486.61	379.20	329.90	89719.20	78055.70	6711.84	5839.70	76.40
4.20	3.65	3.00	305.80	266.05	87.91	76.48	12.60	10.96	917.40	798.14	263.72	229.43	0.03
8.20	7.13	4.00	746.20	649.19	148.58	129.26	32.80	28.54	2984.80	2596.78	594.34	517.07	0.04
13.20	11.48	48.00	11771.80	10241.47	352.84	306.97	633.60	551.23	565046.4	491590.4	16936.13	14734.43	25.80
3.70	3.22	4.00	336.70	292.93	47.92	41.69	14.80	12.88	1346.80	1171.72	191.66	166.74	0.05
22.60	19.66	13.00	5758.50	5009.90	390.30	339.56	293.80	255.61	74860.50	65128.64	5073.93	4414.32	64.10
28.30	24.62	10.00	5665.70	4929.16	488.74	425.20	283.00	246.21	56657.00	49291.59	4887.41	4252.05	2.18
5.70	4.96	5.00	622.40	541.49	97.30	84.65	28.50	24.80	3112.00	2707.44	486.50	423.25	0.20
5.90	5.13	6.00	751.70	653.98	86.38	75.15	35.40	30.80	4510.20	3923.87	518.26	450.88	0.09
15.50	13.49	15.00	4513.60	3926.83	313.26	272.53	232.50	202.28	67704.00	58902.48	4698.83	4087.98	67.50
8.10	7.05	17.00	2653.60	2308.63	216.84	188.65	137.70	119.80	45111.20	39246.74	3686.23	3207.02	1.52
17.40	15.14	11.00	3800.20	3306.17	312.85	272.18	191.40	166.52	41802.20	36367.91	3441.37	2993.99	626.10
3.80	3.31	4.00	345.80	300.85	52.40	45.59	15.20	13.22	1383.20	1203.38	209.61	182.36	0.05
29.60	25.75	60.00	32862.00	28589.94	697.08	606.46	1776.00	1545.12	1971720	1715396	41824.80	36387.58	2141.60
3.20	2.78	6.00	407.70	354.70	61.09	53.15	19.20	16.70	2446.20	2128.19	366.53	318.88	1.26
10.00	8.70	12.00	2366.00	2058.42	193.40	168.26	120.00	104.40	28392.00	24701.04	2320.80	2019.10	1.47
6.50	5.66	7.00	946.40	823.37	127.92	111.29	45.50	39.59	6624.80	5763.59	895.44	779.03	0.21
5.50	4.79	3.00	400.40	348.35	96.42	83.89	16.50	14.36	1201.20	1045.04	289.25	251.64	0.04
14.30	12.44	10.00	2862.90	2490.72	269.84	234.76	143.00	124.41	28629.00	24907.23	2698.41	2347.62	57.30
18.00	15.66	5.00	1965.60	1710.07	387.90	337.47	90.00	78.30	9828.00	8550.36	1939.50	1687.37	18.92

2.4: Characteristics of North-Westerly Rainfall.

r/fmm A1	r/fmm A2 dri adj1	I30mm/h	EJ/m2/al for A1	EJ/m2/al for A2	EJ/m2/usda for A1	EJ/m2/usda for A2	A1I30	A2I30	EI30lal for A1	EI30lal for A2	EI30usda for A1	EI30usda for A2	S/Leq/a2
4.90	4.26	4.00	445.90	387.93	102.61	89.27	19.60	17.05	1783.60	1551.73	410.42	357.07	1.00
23.00	20.04	6.00	2930.20	2549.27	446.43	388.39	138.00	120.06	17581.20	15295.64	2678.58	2330.36	3.70
4.40	3.83	4.00	400.40	348.35	79.99	69.59	17.60	15.31	1601.60	1393.39	319.97	278.37	3.10
2.20	1.91	3.00	160.20	139.37	36.45	31.71	6.60	5.74	480.60	418.12	109.36	95.14	0.10
4.60	4.00	6.00	586.00	509.82	92.09	80.12	27.60	24.01	3516.00	3058.92	552.55	480.72	0.10
23.50	20.45	14.00	6415.50	5581.49	534.63	465.12	329.00	286.27	89817.00	78140.79	7484.75	6511.73	172.30
3.60	3.13	3.00	262.10	228.03	60.59	52.71	10.80	9.40	786.30	684.08	181.76	158.13	0.10
5.20	4.52	5.00	567.80	493.98	112.89	98.22	26.00	22.62	2839.00	2469.93	564.46	491.08	0.70
6.80	5.92	8.00	1113.80	969.01	126.89	110.39	54.40	47.33	8910.40	7752.05	1015.10	883.14	0.22
3.10	2.70	4.00	282.10	245.43	60.48	52.62	12.40	10.79	1128.40	981.71	241.92	210.47	0.10
3.90	3.39	5.00	426.00	370.62	79.68	69.32	19.50	16.97	2130.00	1853.10	398.39	346.59	0.60
13.00	11.31	10.00	2602.60	2264.26	263.90	229.59	130.00	113.10	26026.00	22642.62	2639.00	2295.93	8.91
1.20	1.04	1.00	43.70	38.02	18.11	15.75	1.20	1.04	43.70	38.02	18.11	15.75	0.10
3.10	2.70	4.00	282.10	245.43	50.53	43.96	12.40	10.79	1128.40	981.71	202.12	175.84	0.01
29.10	25.32	12.00	6885.10	5990.04	515.07	448.11	349.20	303.80	82621.20	71880.44	6180.84	5377.32	89.50
3.10	2.70	3.00	225.70	196.36	64.88	56.45	9.30	8.09	677.10	589.08	194.65	169.34	0.20
6.50	5.66	4.00	591.50	514.61	117.78	102.47	26.00	22.62	2366.00	2058.42	471.12	409.87	0.12
9.60	8.35	48.00	8561.30	7448.33	256.61	223.25	460.80	400.90	410942.4	357519.9	12317.18	10715.95	5.30
2.90	2.52	4.00	263.90	229.59	37.56	32.67	11.60	10.09	1055.60	918.37	150.22	130.69	0.17
18.60	16.18	13.00	4739.30	4123.19	321.22	279.46	241.80	210.37	61610.90	53601.48	4175.89	3633.02	60.10
23.20	20.18	10.00	4644.60	4040.80	400.66	348.58	232.00	201.84	46446.00	40408.02	4006.64	3485.78	5.13
5.40	4.70	5.00	589.70	513.04	92.18	80.19	27.00	23.49	2948.50	2565.20	460.89	400.97	0.26
6.80	5.92	6.00	866.30	753.68	99.55	86.61	40.80	35.50	5197.80	4522.09	597.31	519.66	0.10
19.00	16.53	15.00	5532.80	4813.54	383.99	334.07	285.00	247.95	82992.00	72203.04	5759.85	5011.07	503.00
7.30	6.35	17.00	2391.50	2080.61	195.42	170.02	124.10	107.97	40655.50	35370.29	3322.16	2890.28	5.70
18.30	15.92	11.00	3996.70	3477.13	329.03	286.26	201.30	175.13	43963.70	38248.42	3619.37	3148.86	1117.20
4.30	3.74	4.00	391.30	340.43	59.30	51.59	17.20	14.96	1565.20	1361.72	237.19	206.35	0.04
55.60	48.37	60.00	61727.10	53702.58	1309.38	1139.16	3336.00	2902.32	3703626	3222155	78562.80	68349.64	8759.10
3.70	3.22	6.00	471.40	410.12	70.63	61.45	22.20	19.31	2828.40	2460.71	423.80	368.70	0.09
9.40	8.18	12.00	2224.00	1934.88	181.80	158.16	112.80	98.14	26688.00	23218.56	2181.55	1897.95	0.26
5.30	4.61	7.00	771.70	671.38	104.30	90.74	37.10	32.28	5401.90	4699.65	730.13	635.21	0.10
4.90	4.26	3.00	356.70	310.33	85.90	74.71	14.70	12.79	1070.10	930.99	257.69	224.19	0.10
14.50	12.62	10.00	2902.90	2525.52	273.62	238.05	145.00	126.15	29029.00	25255.23	2736.15	2380.45	11.37
17.60	15.31	5.00	1921.90	1672.05	379.28	329.97	88.00	76.56	9609.50	8360.27	1896.40	1649.87	5.95

Appendix 3

Correlation coefficients, Standard errors of Y estimate and Statistical t-values for Rainfall Erosivity Indices(appendix 3) with Soil Loss from bare plots at Kabete.

3.1 : Vertical Rainfall

Rainfall Factor	R Squared	Std. Err of Y Est.	t-value
A1	0.389	8.67	4.516
I_{30}	0.559	8.09	6.365
E_{lal}	0.909	2775.87	17.86
E_{usda}	0.501	167.63	5.664
AI_{30}	0.912	147.01	18.26
$E_{lal}I_{30}$	0.936	139088	21.69
$E_{usda}I_{30}$	0.907	3573.3	17.71

3.2 : North-Easterly Rainfall

Rainfall Factor	R Squared	Std. Err of Y Est.	t-value
A1	0.383	7.976	4.459
A2	0.383	6.939	4.459
I_{30}	0.493	8.684	5.573
E_{lal} for A1	0.772	3913.0	10.40
E_{lal} for A2	0.772	3404.3	10.40
E_{usda} for A1	0.474	156.59	5.374
E_{usda} for A2	0.474	136.24	5.374
$A1I_{30}$	0.772	211.14	10.42
$A2I_{30}$	0.772	183.69	10.42
$E_{lal}I_{30}$ for A1	0.764	237688.3	10.17
$E_{lal}I_{30}$ for A2	0.764	206788.8	10.17
$E_{usda}I_{30}$ for A1	0.756	5180.61	9.957
$E_{usda}I_{30}$ for A2	0.756	4507.13	9.956

3.3 : South-Easterly Rainfall

Rainfall Factor	R Squared	Std. Err of Y Est.	t-value
A1	0.227	8.012	3.063
A2	0.227	6.970	3.063
I_{30}	0.546	8.218	6.199
E_{lal} for A1	0.804	2658.88	11.45
E_{lal} for A2	0.804	2313.23	11.45
E_{usda} for A1	0.319	154.33	3.871
E_{usda} for A2	0.319	134.27	3.871
$A1I_{30}$	0.809	141.30	11.65
$A2I_{30}$	0.809	122.93	11.65
$E_{lal}I_{30}$ for A1	0.843	139022.9	13.13
$E_{lal}I_{30}$ for A2	0.843	120949.9	13.13
$E_{usda}I_{30}$ for A1	0.797	3456.24	11.21
$E_{usda}I_{30}$ for A2	0.797	3006.93	11.21

3.4 : North-Westerly Rainfall

Rainfall Factor	R Squared	Std. Err of Y Est.	t-value
A1	0.565	7.33	6.45
A2	0.565	6.38	6.45
I_{30}	0.557	8.11	6.34
E_{lal} for A1	0.956	2233.0	26.4
E_{lal} for A2	0.956	1942.7	26.4
E_{usda} for A1	0.665	143.22	7.97
E_{usda} for A2	0.665	124.60	7.97
$A1I_{30}$	0.958	118.02	27.05
$A2I_{30}$	0.958	102.68	27.04
$E_{lal}I_{30}$ for A1	0.972	107679.5	33.35
$E_{lal}I_{30}$ for A2	0.972	93681.33	33.35
$E_{usda}I_{30}$ for A1	0.957	2817.87	26.72
$E_{usda}I_{30}$ for A2	0.957	2451.54	26.72

3.5 : South-Westerly Rainfall

Rainfall Factor	R Squared	Std. Err of Y Est.	t-value
A1	0.406	7.424	4.68
A2	0.406	6.458	4.68
I_{30}	0.561	8.073	6.40
E_{lal} for A1	0.944	1950.9	23.16
E_{lal} for A2	0.944	1697.31	23.16
E_{usda} for A1	0.519	144.12	5.88
E_{usda} for A2	0.519	125.39	5.88
$A1I_{30}$	0.948	101.61	24.09
$A2I_{30}$	0.947	88.398	24.09
$E_{lal}I_{30}$ for A1	0.978	73126.99	37.83
$E_{lal}I_{30}$ for A2	0.978	63620.48	37.83
$E_{usda}I_{30}$ for A1	0.951	2318.21	24.93
$E_{usda}I_{30}$ for A2	0.951	2016.84	24.93

Remarks :

The tabulated t-value at 95% probability level is 2.032. Hence all the erosivity indices are statistically significant.

Appendix 4

Summary of the Analysis of Variance Tests.

4.1: Tests done to see if significant difference in soil loss occurred among plots with different orientation and degree of cover.

Source of Variation	df	SS	MS	Fcal.	Ftable	
					5%	1%
Among Plots	23	10,040.720				
Treatments	7	9,998,914.1	1428416.3	546.7**	2.66	4.03
Experimental error	16	41805.9	2612.9	0.006	1.62	1.96
Sampling error	792	354,906,300	448114.02			
Total	815	364,947,020				

4.1.1 : lsd test Results

Lsd at 95% probability level = 86.14

Lsd at 99% probability level = 116.74

Treatments:	NWb	NEb	SWb	SEb	NWg	NEg	SWg	SEg
Means:	317.1	184.8	181.9	103.9	3.4	4.3	2.8	0.8

95% P lvl:

99% P lvl:

Remarks:

b denote bare; g denote grassed; P denote probability and lvl denote level.
Soil loss recorded on NW bare plots were significantly different from others (shown above) at both probability levels.

4.2: Tests done to see if significant difference in runoff occurred among plots with different orientation and degree of cover.

Source of Variation	df	SS	MS	Fcal.	Ftable 5%	Ftable 1%
Among Plots	23	31.1				
Treatments	7	29.57	4.22	43.96**	2.66	4.03
Experimental error	16	1.53	0.096	0.044	1.62	1.96
Sampling error	792	1730.3	2.19			
Total	815	1761.4				

4.2.1 : <u>lsd test results</u>

Lsd at 95% probability level = 0.522
Lsd at 99% probability level = 0.708

Treatments:	NWb	NEb	SWb	SEb	NWg	NEg	SWg	SEg
Means:	24.0	19.5	15.9	11.1	11.6	7.8	6.2	3.7
95% P lvl:				______	______			
99% P lvl:				______	______			

Remarks:

With the exception of runoff from SE bare and NW grassed which were not significantly different from each other, runoff recorded on all other plots with different orientation and degree of cover were significantly different from each other.