RELATING EROSIVITY FACTORS TO SOIL LOSS: A CASE STUDY OF HOMBOLO AND MOROGORO SITES

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURAL ENGINEERING) OF SOKOINE UNIVERSITY OF AGRICULTURE

1996

ABSTRACT

This study was conducted at Morogoro and Hombolo, as part of the ongoing research under the department of Agricultural Engineering and Land Planning. This report acts as interim findings of the research. Ten run off plots were established, four at Hombolo and the rest at Morogoro. Five erosivity factors were regressed to ascertain the best fit on the soil loss. The plots had different treatments of canopy cover for each of the seven rainstorms recorded during the cropping season. EI_{30} compound erosivity factor and runoff proved to have high coefficients of determination of 0.92 and 0.69, respectively. There was a significant difference in soil loss between bare plots and other plots with crop cover. However, the difference in runoff amounts was insignificant.

ACKNOWLEDGEMENTS

First, I am indebted to Prof. B. Kayombo for his tireless guidance throughout the period of study which made this study materialize. Similarly, unrivalled gratitude should go to Mr. M. Mulengera, who whole-heartedly agreed to incorporate my study in his ongoing research at Hombolo and Morogoro. Special thanks should also go to Drs. H.O. Dihenga and N.I. Kihupi for their assistance in the course of study.

My acknowledgements would be incomplete for not thanking Southern African Centre for Co-operation in Agricultural & Natural Resources Research & Training (SACCAR) and Gesellschaft fur Technische Zusammenarbeit (GTZ) for financing the study in the first place.

Also deeply indebted are Catherine Shirima for her encouragement and inspiration during the study period and my son Simon for enduring my absence during the period of study.

Lastly, I wish to express my gratitude and appreciation to my course-mate Mr. M.N.C. Muya, for his brotherly closeness both academically and socially.

DECLARATION

I, Ngalesoni, Gabriel Simon, hereby declare to the senate of the Sokoine University of Agriculture, Morogoro, Tanzania, that the work presented here is my own, and has not been submitted for a higher degree in any other University.

Date: 15. 11. 1996

Signature: 

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DEDICATION

To My Beloved Parents.

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LIST OF ABBREVIATIONS

HADO	Hifadhi Ardhi Dodoma
SECAP	Soil Erosion Control and Agroforestry Projet
FAO	Food and Agriculture Organization of the United Nations
UNESCO	United Nations Education, Scientific and Cultural Organization

1. INTRODUCTION

1.1 Erosion and Rainfall

Soil erosion causes severe and extensive land degradation in the tropics. Ever increasing demand for food and other basic necessities, brought about by increasing population pressure throughout the developing world, necessitates continuous and intensified production even from marginally productive lands (Vaneslande et al., 1984). According to FAO (1986), the doubling of world population and the growth in per capita incomes will triple world food demand by the middle of the 21st century. The prospects of meeting this demand are considered bright but questionable due to over-utilization of natural resources (Repetto, 1990). Soil erosion is intense in many areas of developing countries because of a number of erosive climatic conditions, rugged terrain, and heavy land use, yet little quantitative information is available about the pattern of erosion (Dunne, 1977). This ignorance limits an assessment of real magnitude of erosion problems, or the ranking of the priority regions for most urgent soil conservation programmes. The effects of soil erosion are most apparent on steep mountainous terrain with high population density and intensive farming systems. A dense grass cover can in this respect be as efficient as a forest cover in protecting the soil (Hudson, 1971). Fire and overgrazing contribute appreciably to the erosion hazard in African

semi-arid areas by exposing the soil to the assault by water and wind (Rapp, 1975). In Africa, water erosion is a dominant threat to long term soil productivity and ability of humans to feed themselves (Dregne, 1990).

Tropical and sub-tropical semi-arid areas are thus, in general, zones of great potential erosion hazard due to combination of sparse vegetation at the dry season and periodically very intense rainstorms.Erosion causes losses of productive topsoil, organic matter, nutrients and water. Up to 50% of the annual rainfall can be lost from the eroded slopes due to decreased infiltration and high surface run-off (Rapp, 1975). Research has identified a number of factors which explain much of the spatial variation of the annual soil loss (e.g. Olson and Wischmeier, 1963; Olson et al. 1963). These factors include precipitation, runoff, topography, vegetative cover, biological activity and the inherent ability of a soil to resist erosion, i.e. its erodibility.

Since soil degradation by rainfall is already so wide-spread, there is an urgent need to conserve the productive soil remaining, and to prevent the spread of the soil degradation to areas not yet affected. Only when the seriousness of the problems is recognized, and their causes properly identified, it is possible to develop the agricultural practices and to design and apply conservation measures that will ensure safe use of the land.

In Tanzania, there is a scant specific knowledge on soil detachment by rainfall storms. Soil research in Tanzania has concentrated on simple field measurements of erosion rates, e.g. from tree root exposure or pedestal development; runoff plots to compare erosion on cultivated fields, rangelands and fallows; and stream and reservoir sedimentation studies to assess erosion rates in catchments (Rapp et al., 1973; Christiansson, 1981; Stocking, 1981). A multi-disciplinary research programme on environmental degradation in the semi-arid Kondoa, Babati and Hanang districts is currently being undertaken by the Institute of Resource Assessment, of the University of Dar-es-Salaam. Hombolo and Morogoro in particular, are among areas seriously affected by rainfall erosion (Rapp, 1975). This research on soil detachment by rainfall, conducted at Hombolo and Morogoro areas, aims to provide some knowledge on soil detachment by natural rainfall.

1.2 Objectives

The main objective of this study was to determine the effect of the storm on the detachment and transportation of soil particles at Hombolo and Morogoro areas.
The specific objective were:

(a) To measure various rainfall parameters for each erosive storm during the rain season at both sides;

(b) To measure runoff and sediment transported (soil loss) caused by the storms at both sites;

(c) To determine infiltration and particle size distribution of soil at both sites;

(d) To determine the EI_{30} index value of each storm at both sites;

(e) To establish relationships between soil loss and:

(i) Amount of rainfall, A;

(ii) Energy, E;

(iii) EI_{30};

(iv) Runoff and

(v) AI_{30}.

2. LITERATURE REVIEW

2.1 Quantity and Intensity of Rainfall

Rainfall erosion is the interaction of two items - the rain and the soil. Soil erosion is a two-phase process consisting of the detachment of individual particles of the soil mass and their transport by erosive agents such as running water and wind (Morgan, 1986). Both rainfall and runoff have detachment potential, whereas transport is predominantly by runoff. Since only the detached soil can be carried away, the eroded soil can never exceed the detached soil. Rainsplash is the most important detaching agent. Under some conditions the rate of detachment may be the factor limiting the erosion (Kohnke and Bertrand, 1959). This would be the case where a very cohesive soil lies on a steep slope and a heavy rain causes sheet erosion flow over the area. Sheet erosion is the washing away of a thin surface layer of soil. Therefore, the severity of erosion depends upon the quantity of materials supplied by detachment and the capacity of the eroding agent to transport it.

There is obviously an association between the amount of rainfall and the amount of soil erosion, i.e, more rain goes with more erosion, and less rain with less erosion, but in statistical terms the correlation between the two is poor (Hudson, 1971). The same total quantity of rain can on different occasions result in widely differing amount

of soil erosion. Apart from rainfall amount, intensity is the only feature of which is frequently recorded at conventional meteorological stations. Hudson (1975) pointed out that there is a considerable evidence of a close association between erosion and intensity, and intensity is particularly important as a potential parameter to erosivity.

The transporting agents responsible for the removal of relatively uniform thickness of soil comprise of rainsplash, surface run-off in the form of shallow flows of infinite width, sometimes called sheet erosion flow or overland flow and wind. The splash action and the sheet erosion flow transport many of the detached particles to the runoff concentration (Wischmeier, 1958).

The force causing detachment is that associated with the impact of individual water drop.Rain drop impact has other important effects as well as particle detachment. The detached particles lead to sealing of the soil surface and hence lower the infiltration rate and increased surface run-off. The kinetic energy of rain is the causative factor in initiating detachment and erosion (Wischmeier and Smith, 1958; Greenland and Lal, 1977). The kinetic energy per unit rain is directly related to dropsize, which is roughly proportional to the intensity (Wischmeier and Smith, 1958).

Fournier (1972) reported that average soil loss per rain event increases with the intensity of the storm. The role of intensity is not always obvious. Erosion appears to be related to two types of rain event, short intense storms and the prolonged storms of low intensity (Maene and Harun, 1980). In the first case, the infiltration capacity of the soil may be rapidly exceeded, whereas during the prolonged storm, the soil may be saturated. Morgan (1977) reports that while intense storms, such as the one on July 6, 1973 of 34.9 mm in Bedfordshire, in which 17.7 mm fell at intensities greater than 10 mm h^{-1}, produce erosion so do storms of longer durations and lower intensities, like the one on June 19, 1973 when 39.6 mm of rain fell in over 23 hours. Similarly, in Trier, Germany, a storm of 15.6 mm with a maximum intensity of 50.4 mm h^{-1} was reported by Richter and Negendank (1977) resulting in soil loss from 26^0 slope of 8 m length of 141 gm^{-1} whilst a storm of 19.8 mm and a maximum intensity of 44.4 mm h^{-1} caused a greater loss of 242 g m^{-1}. However, there will obviously be some degree of correlation between erosive power and the amount of rainfall. Morgan (1974) and Elwell and Stocking (1975) obtained some correlation, between erosivity and rainfall in Malaysia and Zimbabwe, respectively. However, their world-wide applications, were limiting due to large

variations in rainfall both temporal and spatial (Hudson, 1971).

Previous meteorological conditions may affect the response of the soil in terms of erosion and runoff to rainfall. Bols (1979), in a multiple linear regression analysis, examined the effect of the antecedent rainfall on run-off for six sites in Java and concluded that the soil moisture content at the onset of rain had a limited effect on the surface run-off. Morgan (1977) also reported that no relationship could be obtained between soil loss and antecedent rainfall in mid-Bedfordshire.

2.1.1 Rainfall Erosivity Indices

Experiments by various researchers have indicated that neither the rainfall amount nor the intensity are very highly correlated with soil loss (Morgan, 1984). Though kinetic energy of the rain is generally accepted to be the driving force, it is a very difficult parameter to monitor (Greenland and Lal, 1977). Attempts therefore were launched to determine a better combination of rainfall parameters which would give a better index of erosivity than either the amount or intensity of rainfall.

An index based on the kinetic energy of the rain is the most suitable expression of the erosivity of rainfall (Morgan, 1986). Consequently, the erosivity of a rainstorm

is a function of its intensity and duration, and of the mass, diameter and velocity of the rain-drops. Because the energy of an individual rain drop is related to its size, the energy of an individual storm is related to its drop-size distribution. Laws and Parsons (1943) reported an increase in median drop size with increase of rain intensity. The relation was found to be:

$$D_{50}=2.23I_o \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where;

I = intensity in inches per hour;

D_{50} = median drop size in millimetres

However, Hudson (1963) pointed out that for tropical rainstorms, a relationship of the type of $D_{50} \propto I^b$ is valid only for low intensities up to 100 mm h^{-1}. At greater intensities, median drop size decreased with increasing intensity, presumably because greater turbulence makes larger drop sizes unstable.

The kinetic energy of a storm is related to the velocity of the rain-drops at the time of impact with the soil. The distance through which a rain drop must fall before attaining its terminal velocity is a function of drop size distribution (Laws, 1941). Recent investigations of rainfall in temperate latitudes reveal that the relationship between median drop-size and drop-size

distribution vary for rains of the same intensity but different origins (Mason and Andrews, 1960; Carter, Greer, Brand and Floyd, 1974). The drop-size characteristics of conventional and frontal rain are different as are those of rain formed at the warm and cold fronts of a temperate depression.

Hudson (1971), reported that there is a great deal of experimental evidence to suggest a link between erosive power and the mass and velocity of falling drops. Ellison (1944), in a laboratory experiment measured splash erosion for various combination of drop-size, velocity and intensity and the results gave the expression:

$$S = k \times V^{4.33} \times D^{1.07} \times I^{0.65} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where;

S = Soil splashed in 30 minutes, in grams;

V = Drop velocity in feet per second;

D = Drop diameter in inches per hour;

I = Rainfall rate in inches per hour; and

k = Constant.

Similarly Bisal (1960) in similar experiments, came with the expression:

$$G = K \times D \times V^{1.4} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where;

G = Weight of soil splashed in grams;

K = Constant for the soil type;

D = Drop diameter in mm; and

V = Impact velocity in meters per second.

However, Mihara (1951) found that splash erosion is directly correlated with kinetic energy and Free (1960) suggested that the relationship which best fits his experimental results was:

For clay

$$Splash\ Erosion = K \times (kinetic\ energy)^{0.9} \quad (4)$$

and for sand

$$Splash\ Erosion = K \times (kinetic\ energy)^{1.46} \quad (5)$$

However, Rose (1960), through detailed experimental work, concluded that the rate of detachment depends more closely on the momentum than energy. However, it has been shown that for natural rain the relationships between intensity and either momentum or kinetic energy are of similar form (Hudson, 1971). The issue of whether momentum can be used instead of energy is, therefore, not important.

Several experimental studies have established correlations between soil splash and intensity (Bubenzer and Jones, 1971; Moldenhauer and Long, 1964 and Meyer, 1981).

Wischmeier and Smith (1958) showed that the factor most closely related to erosion was the kinetic energy of the rain. The equations relating kinetic energy and intensity by Wischmeier and Smith (1958), Hudson (1965) and Zanchi and Torri (1981) are:

(1) Wischmeier and Smith (1958)

$$E=11.9+8.71\log_{10}I \quad \ldots\ldots\ldots\ldots \quad (6)$$

(2) Hudson (1965)

$$E=29.8-\frac{127.5}{I} \quad \ldots\ldots\ldots\ldots \quad (7)$$

(3) Zanchi and Torri (1981)

$$E=9.81+11.25\log_{10}I \quad \ldots\ldots\ldots\ldots \quad (8)$$

where;

I = the rainfall intensity in mmh^{-1};

E = the kinetic energy in $Jm^{-2}mm^{-1}$

The equation (3) by Hudson (1965) based on measurements of rainfall properties in Zimbabwe, was found applicable for tropical rainfall. The equations (2) and (3) show that at intensities greater than 75 mm h^{-1}, the kinetic energy levels off at a value of about 28 m^{-2} mm^{-1}, whereas equation (4) indicates energy values as high as 34 J m^{-2} mm^{-2} when the intensity is 150 mm h^{-1}.

To compute the kinetic energy of a storm, a trace of rainfall from an automatically recording rain gauge is analyzed and the storm divided into small time increments of uniform intensity. For each period, knowing the intensity of the rain, the kinetic energy of rain at that intensity is estimated by 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 energy of the storm.

To be valid as an index of potential erosion, an erosivity index must be significantly correlated with the soil loss (Morgan, 1988). 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, I_{30}. The 30-minute intensity is the greatest average intensity experienced in any 30-minute period during the storm. It is computed from the recording rain gauge charts by locating the greatest amount of rain which falls in any 30-minute period, and then doubling this amount to get the same dimensions as intensity, i.e rainfall per hour. This product term gave an excellent correlation between soil loss and rainfall. In addition Wischmeier found that it was possible to improve the relationship further by taking account of other factors, such as soil moisture at the beginning of the storm, but it was not worth the extra complication. This measure of

erosivity is termed EI index. EI_{30} is a measurement of detachment capacity by rainfall and since **E** is an indication of the amount of runoff and **I** is an indication of the peak runoff rate, it is also a measurement of the runoff detachment and transport potentials.

Wischmeier (1976) reported that the valuable application of the EI index in the Universal Soil Loss Equation have led to over-enthusiastic extension beyond the purpose it was designed for. Although there is high degree of correlation, in the long term, there are large variations (Hudson, 1981). EI values for a particular year can be from 50% to 200% of the long term average. Similarly, attempts to apply the original index to the tropical rainfall led to some excessively high estimates. Consequently, this has led to search for alternative methods for the tropics. Hudson (1965) developed an index based on the fact that little erosion takes place at low intensities. He asserts that, at low intensity, rain is composed mainly of small drops, falling with low velocity, and hence low energy. Even if little splash erosion does occur, there is usually no run-off to carry away the splashed particles. Experiments were carried out to see whether there is a recognizable point below which rain is non-erosive. Tests showed that although there is variation from one storm to another, the intensity of 25 mm per hour can be taken as a practical threshold level separating erosive and non-erosive rain. An erosive index, written as KE > 25, consisting of the total

kinetic energy of all the rain falling at more than 25 mm per hour was found to give an excellent correlation with soil loss.

In Nigeria, Lal (1976) tested EI_{30} by Wischmeier (1958); KE > 25 by Hudson (1965), and other possible parameters and found the best correlation of soil loss from small plots with a new index. This was AI_m, where **A** is the amount of rain, and I_m the maximum intensity over a 7.5 minute period. As with previous studies, the correlation could be improved by the addition of other factors, but wind being a transient phenomena, cannot be included in an index intended for long term predictions (Lal, 1976).

The tendency to use empirical indices should be treated with reserve (Hudson, 1971). Wischmeier (1958) had 10,000 plot years of data extending over 22 years and this solid data base was used effectively to generate the empirical index EI_{30}. Hudson (1965) had 13 years results, giving 2500 plot years to test against KE > 25. Lal (1976) has smaller but significant base (Roose, 1980).

2.2 The Erodibility of Soil

The erodibility of the soil is its vulnerability or susceptibility to erosion, that is the reciprocal of its resistance to erosion. Many factors which affect erodibility of soil fall into three broad groups. First

there are the physical features of the soil, such as the physical composition. Second, there are the topographic features, such as the slope of the land. Third, there is the management of the land, that is, how it is used. Although soil resistance depends in part on topographic position, slope steepness and the amount of disturbance created by man, the properties of the soil are the most determinants (Morgan, 1986). Erodibility varies with the soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content.

2.2.1 Soil Physical Characteristics

2.2.1.1 Soil Texture

Large soil particles are resistant to transport because of the greater force required to entrain them and that fine particles are resistant to detachment because of their cohesiveness (Morgan, 1986). Consequently, soils with a higher silt content are erodible. Richter and Negendank (1977) show that soils with 40 to 60 percent silt content are the most erodible. However, Evans (1980), prefers to examine erodibility in terms of the clay content, indicating that soils with a restricted clay fraction, between 9 to 30 percent, are most susceptible to erosion.

The use of the clay content as an indicator of erodibility is theoretically more satisfying because the clay particles combine with organic matter to form soil aggregates or clods and it is the stability of these which determines the resistance of the soil (Morgan, 1986). Soils with a high content of base minerals are generally more stable as these contribute to the chemical bonding of the aggregates.
In general, aggregate stability depends on the type of the clay mineral present. Illicite and smectite more readily form aggregates but the more open lattice, structure of these minerals and the greater the swelling and shrinkage which occurs on wetting and drying render the aggregates less stable than those formed by kaolinite (Morgan, 1986).

Bouyoucos (1935) suggested that the index of the erodibility to be the ratio:

$$(\%sand + \%silt)/(\%clay) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Similarly, Barnett and Rogers (1966) suggested an index similar to that by Bouyoucos. The index by Wischmeier et al (1971), has for its main variable the (%silt + very fine sand) x (100 - %clay). Wong (1974) based on field observations, classified soils with clay contents exceeding 27% and the sand contents of less than 45% as 'less erodible'. Such soils have surface texture of clay loam, silty clay loam, silty clay and clay. Soils with more than 45% sand and less that 27% clay were classified as more

erodible. Such soils include the textural classes of sandy clay, sandy clay loam, sandy loam, loamy sand, loam and silt loam and silt. The resistance of the soil particles to water erosion is linked with the degree of aggregation of soil particles, and the stability of the particles (Hudson, 1971). Since the aggregate stability is not easily measured, an alternative is to substitute some more easily measured features like organic matter, structure and permeability, which can be expected to have a similar effect.

2.2.1.2 Infiltration Rate

The rate at which water passes into the soil is known as infiltration rate. Philip (1957) described the change in infiltration rate over time mathematically by the equation:

$$I = A + B * t^{(½)} \quad . \; . \; . \; . \; . \; . \; . \quad (10)$$

where;

- **i** = the instantaneous rate of infiltration;
- **A** = the transmission constant or saturated hydraulic conductivity of the soil;
- **B** = sorptivity and
- **t** = the time elapsed since the onset of the rain

Infiltration rates depend on the characteristics of the soil. Generally, coarse-textured soils such as sands and

sandy loams have higher infiltration rates than clay soils because of large spaces between the soil particles. Infiltration capacities may range from more than 200 mm h^{-1} for sands to less than 5 mm h^{-1} for tight clays (Morgan, 1986).

If rainfall intensity is less than the infiltration capacity of the soil, no surface run-off will occur and the infiltration rate equals the rainfall intensity (Horton, 1945). If the rainfall intensity exceed the infiltration capacity, the infiltration will equal the infiltration capacity and the excess rainfall will form surface run-off. However, as a mechanism for generating run-off, this comparison for rainfall intensity and infiltration capacity does not always hold. Morgan (1977), in studies on sandy soil of infiltration capacity of greater than 40 mm h^{-1} in Bedfordshire showed that run-off occurs with rainfall of intensities less than 40 mm h^{-1}.

The important control for run-off production on these soils is not infiltration capacity but a limiting soil moisture content which, when exceeded, results, in a reduction of pore water pressure at the soil surface to zero, allowing ponding of water to take place (Morgan, 1986). This explains why sands which have low levels of capillary storage produce run-off very quickly even though their infiltration capacity is not exceeded by the rainfall

intensity. Since hydraulic conductivity is a flux partly controlled by rainfall intensity, increases in intensity can cause run-off to rise so that, although run-off may have formed rapidly at a relatively low intensities, higher rainfall intensities do not always produce greater run-off. Nassif and Wilson (1985), showed that infiltration rates sometimes increase with rainfall intensity.

2.2.2 Topographic Features (Slope)

Both degree and slope length are important factors influencing soil erosion as a result of increases in velocity and the volume of surface run-off (Morgan, 1986). Whilst on a flat surface raindrops splash soil particles randomly in all directions, on sloping ground more soil is splashed downslope more than upslope, the proportion increasing as the slope steepens (Morgan, 1986). The relationship between erosion and slope can be expressed by the equation:

$$Q_s \propto \tan^m \theta L^n \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where;

Qs = Erosion per unit area;

θ = the gradient angle

L = the slope length

Zingg (1940), in a study of data from five experimental stations of the United States Soil Conservation Service found that the relationship had the form.

$$Q_s \propto \tan^{1.4}\theta L^{0.6} \quad (11)$$

The effect of slope, slope form and angle of slope on soil erosion have not been extensively studied in the humid tropics and most investigations relate to erosion by overland flow (Maene and Farun, 1980). Hudson (1971) reported that erosion generally increases exponentially with increase in slope. For tropical soils, the exponent approaches 2 although values ranging from 1.3 to 2.1 have been reported (Morgan, 1980). Maene et al., (1975) reported an increase in soil loss from 43.5 tonnes ha^{-1} on a slope of 17% to 63.5 tonnes ha^{-1} on the slope of 34% for soil series soil, in Malaysia. These results were obtained from field plot studies whereby the plots were planted with cuttings of *Pennisetum purpureum* (Napier grass) and the losses were recorded during the first 60 days after planting.

2.2.3 Plant Cover

Hudson (1981) demonstrated by experiments at the Henderson Research Station in Zimbabwe where, in the period 1953-56, mean annual soil loss from bare ground was 4.63 kg m^{-2} compared with 0.04 kg m^{-2} from ground with a dense cover of *Digitaria*. The major role of vegetation is in interception

of the raindrops so that their kinetic energy is dissipated by the plants rather than on impact to the soil. Hudson and Jackson (1959) emphasized this role through the mosquito gauze experiment in which soil loss was compared from two identical bare soil plots. Over one plot was suspended a fine wire gauze which had the effect of breaking the force of the raindrops, absorbing their impact and allowing the water to fall to the ground from a lower height as a fine spray. The mean annual soil loss over a ten-year period was 126.6 kg m^{-2} for the open plot and 0.9 kg m^{-2} for the plot covered by gauze.

A vegetative cover as complete as the artificial cover of the wire gauze is only obtained from grass or forage crops (Hudson, 1971). Hudson (1957), through experimental results on comparison of maize grown at two levels of production, reported that small differences in cover can cause big differences in soil loss. The difference in erosion between the two levels was fifteen times.

The effectiveness of a plant cover to erosion protection depends on the type of canopy, the density of the ground cover and the root density. The height of the canopy is important because water drops falling from 7 m may attain over 90 percent of their terminal velocity (Laws, 1941). Further, raindrops intercepted by the canopy may coalesce on the leaves to form larger drops which are more erosive. Shallow (1956) observed that from three hilly catchments in

the Cameroon Highlands, lost 24.5, 488 and 732 m^3 km^{-2} $yr^{-}1$, of soil respectively, under jungle, tea plantation and vegetable farming.

Generally, forests are the most effective in reducing erosion because of their canopy, but a dense undergrowth may be almost as efficient (Hudson, 1971). Fournier (1972) and Elwell and Stocking (1976) reported that for adequate erosion protection, at least 70 percent of the ground surface must be covered. The presence of several tree storeys as well as a dense undergrowth in the rainforest results in a larger interception of precipitation than in cultivated plantation.

Apart from the influence of the canopy on the erosion process, ground surface cover is also an important factor. Maene et al. (1979) reported soil loss values under mature oil palm on a standard slope of 9%, varying from 1.1 tonnes $ha^{-1}yr^{-1}$ and pruned fronds to 14.9 tonnes $ha^{-1}yr^{-1}$ on the harvesting paths. Run-off volumes under these conditions were, respectively, 2.8% and 30.6% of the rainfall whereas the steady state infiltration rate of 0.9 cm h^{-1} was recorded on the harvesting paths against 43.0 cm h^{-1} under the pruned fronds.

2.4 Soil Erosion and Conservation in Tanzania

Reports on soil erosion and conservation measures covering areas of varied climatic, environmental and cultural conditions in Tanzania date as far back as the late 19th century. Soil conservation became a priority for British administrators during the 1930s. Conservation concerns were integrated by the end of that decade with new ideas of developing agriculture and colonial economies overall, rather than simply administering the natives and promoting the settler and metropolitan interests as had previously been the case.

Colonial conservation approach was typified by an interventionist approach to local farming systems and the environment. Emphasis in the early decades of soil conservation in the British colonies was mainly on structural measures for the control of runoff and on tree planting. Contour bunds, diversion channels, earth dams and other structures were built across farm land. Other types of soil erosion and conservation research were pursued by the colonial authorities, for example at Ukiriguru and Lubaga from 1949 (Stocking, 1964).

Tanzania is perhaps the classic case of colonial and post-colonial experience in soil and water conservation, at least in anglophone Africa. Since as early as the 1920s, soil erosion had been known to be a problem particularly on

the wetter, densely populated, and mountainous areas of the Usambara, Pare, Kilimanjaro, Meru, Uluguru and the Southern highlands.

It must have also been developing in menacing proportions elsewhere, for by 1930 serious soil erosion had been reported to be widespread, and occurred even on the drier, less steeply-sloping plateau of central Tanzania. Gillman (1930) reported that Ugogo, Urangi, Unyanturu, Isansu and South east Usukuma were "typical representatives of advanced erosion."

Among the educative measures undertaken by the central government officials during the 1930s was the setting up of a number of demonstration plots in the mountain areas of Kilimanjaro, Usambara the Pares and Mt.Meru. This measures aimed at convincing the native Authorities that soil conservation was necessary to give better yields on steeper slopes and maintain fertility of the soil (Berry and Townshed, 1973).

Other officials aimed at educating the farming community on methods of soil conservation through their publications (e.g Harrison, 1935); Davies, 1935; Gethin -Jones 1936; Ronce, 1949). In addition, during this period research to discover pasture plants which combined soil conservation properties with adequate animal nutrients were undertaken in the central province (French, 1943). The research work

also included experiments to measure soil and water loss on variety of vegetation cover (Staples, 1933, 1935, 1936 and 1938). For example, at Ukiriguru and Lyamungu agricultural research stations research to measure yields of cotton and coffee respectively, on various types of land management was undertaken. Also the gathering of quantitative data on runoff and soil erosion began in Tanganyika in 1933 at Mpwapwa and continued for a period of five years. These data were few and inadequate to provide a general picture of soil erosion even within these limited areas (Kauzeni et al., 1987).

At Mpwapwa, in 1933, experiments were designed to obtain quantitative data on runoff and erosion in semi-arid area of Tanzania. Comparative data for erosion plots differing with regard to plant cover and cultivation treatment were obtained under controlled conditions for at least seven years up to 1939. Data collection from the erosion plots resumed in 1946 under different treatments and further eight years results were published in summary by van Rensburg (1955).

At Lyamungu, near Moshi, experimental plots were designed to measure soil erosion and runoff under young coffee trees using various conservation treatments were established in 1934. The results were reported in the Annual Reports and Quarterly Notes of Coffee Research and Experimental station (1937, 1938 and 1939) and are summarised by Mitchell

(1965). Similarly experimental plots designed to measure runoff and soil erosion under different crops and different cultivation methods were established at Tengeru near Arusha in 1954. The results were reported by Anderson (1962) and Mitchell (1965).

A soil conservation service was set up in Tanganyika in 1945 and an official review of the problem of soil erosion followed later during the period 1951/52. The review outlined the general problems and listed the major schemes where the new direct approach was to be put into operation. This direct approach saw the establishment of Land Usage Schemes. For many reasons, people were discouraged with the schemes. In fact, by 1954, conservation had become a political issue in the vicinity of major schemes many of which were being forced to be abandoned after civil disturbances had stopped any active conservation effort. This is because the schemes had a list of rules attached to them and through which people were convicted and fined if they contravened the rules. Assessments of the Land Usage Schemes further indicate that most of them had been poorly implemented and hence did not improve either agricultural or ecological conditions.

Largely qualitative accounts of the extent of soil erosion problems and schemes have been given by several authors (Temple, 1973; Rapp et al., 1973; Christiansson, 1981; Mbegu and Mlende, 1983). Attempts to deal with soil

erosion, both in the colonial period and since independence have, primarily been sporadic in nature and in response to specific problems.

After independence (1961) therefore, as noted before, there was breakdown of the colonial soil conservation programme (Mbegu and Mlende, 1983). This breakdown of the colonial soil conservation schemes coupled with natural increase in human and livestock populations, accelerated soil and other land degradation processes in the country. As a results of post-independence relaxation of soil conservation measures, land degradation processes had reached advanced stages within the first decade of post-independence (Kauzeni et al., 1987). But accurate assessments on magnitude of the different processes during this period are not available. However most popular example is that of Kondoa District in the central part of the country. According to Mbegu and Mlenge (1984) land degradation in Kondoa District had reached advanced stages by 1968. This prompted the enaction of by-laws to control grazing, cultivation and felling of trees. But typical of many by-laws, laws and directives in Tanzania and in many other developing countries for that matter, they are deficient and their effectiveness is almost negligible. The land degradation processes therefore continued unchecked.

In the second five year plan of 1969-74, the national administration became increasingly aware of the seriousness

of land degradation in Tanzania (Bryceson, 1971; Berry and Townshed, 1973). Similarly, in its annual meeting, TANU, the then ruling party adopted an agricultural policy programme known as *Siasa ni Kilimo*. The policy outlined new agricultural programme on land management through proper agricultural practices. But as usual, the *Siasa ni Kilimo* agricultural policy fell short of follow-up and hence it did not have an impact (Kauzeni et al., 1987).

Parts of Dodoma Region were seen to be experiencing the most severe erosion problems in the country (Kerkhof, 1990). Thus the Dodoma region Soil Conservation Project known as *Hifadhi Ardhi Dodoma* (HADO), was started in 1973. The HADO project in the most comprehensive soil conservation project during the post-independence and it is presently probably the only success story of soil conservation in the country.

The HADO started with the following objectives:-

1. To try to conserve the soils, water and reclaim land already degraded.

2. To make sure that the Dodoma peasants were supplied with sustained forest products through establishment of fuelwood and timber plantations;

3. To encourage and assist villages in tree planting in their respective areas;

4. To educate people through various mass media on the importance of soil conservation and village afforestation.

While the HADO, project was going on, a number of activities were happening. These activities have had direct influence on land degradation. They include the villagization programme and *Kilimo cha Kufa na Kupona* (farm or perish) government's directives. Whereas in the former many people were concentrated in a small area, with many structures hence clearing natural vegetation, in the latter there was indiscriminate vegetation clearing as a result of the directive.

In 1980, the government launched a national campaign mainly in the semi arid regions to raise awareness among people (mainly rural) and stimulate them to plant trees both for environmental conservation and for provision of the forests products. This campaign was in line with the concept of village forestry which had started in 1968. There is no empirical data to evaluate the village forestry campaign. (Kauzeni et al., 1987) pointed out that although communal forestry receive bulk of tree seedlings, they perform poorly compared to seedlings given to schools or individuals. They however assert that the 1982

afforestation campaign definitely raised awareness among rural people on the need and significance of tree planting.

In 1983, the government issued an agricultural policy, which aimed at developing an integrated agricultural sector, using methods of scientific husbandry and technology appropriate to the respective crops, size of operation and national resources. Experience has learnt that policies and directives are useless unless they are followed up (Kauzeni et al., 1987). The assessment of this policy to date is not available.

There are important soil conservation activities which are currently being undertaken in different parts of the country. These are soil conservation programmes in Lushoto, Shinyanga and Iringa.

In Lushoto, the project is under the Tanga Integrated Rural Development Plan . The Soil Erosion Control and Agroforestry Project (SECAP) is an integrated project and is trying to combat land degradation and fall of agricultural productivity both in terms of farming and availability of pasture. Through its activities SECAP is managing to convince local population on appropriate animal husbandry (zero grazing) through introduction of improved breeds, pastures and better farming techniques, including use of contours. People have accepted to plant Guatemala

grass *Leucaena leucocephala*, for example on contours and use them as animal feed.

All in all the SECAP project could be one of the best example in the country of how soil conservation through agroforestry should be undertaken (Kauzeni et al., 1987).

The Shinyanga Soil Conservation is almost similar to the HADO project, starting with the most badly eroded areas. Lessons and experiences from other projects especially from Kondoa gives the project better chances of even better performance.

The Iringa District afforestation programme is a multi-sectoral approach like the SECAP and HADO projects. This involves popular participation. The evaluation of this project is yet to be done.

Unless assessments of a problem are done followed by awareness campaigns, the problem of exaggerating land degradation may be there to stay. The implications of exaggerating may have far reaching implications because the people will not see the problem and the issue will be imposed from above (Kikula, 1986). The failures of the past soil conservation projects were either due to exaggeration of the extent and magnitude of the soil erosion or approaches were not convincing enough to the indigenous people.

Kauzeni et al., (1987), therefore proposed that the following procedure could be followed to improve chances of success of conservation activities:

1. An assessment of the problem, its extent and intensity;

2. Identification of factors attributable to the problem;

3. Assessment of local people's perception of the problem followed by awareness campaigns if need be; and

4. Identification of possible solutions should take into consideration the traditional practices of land management.

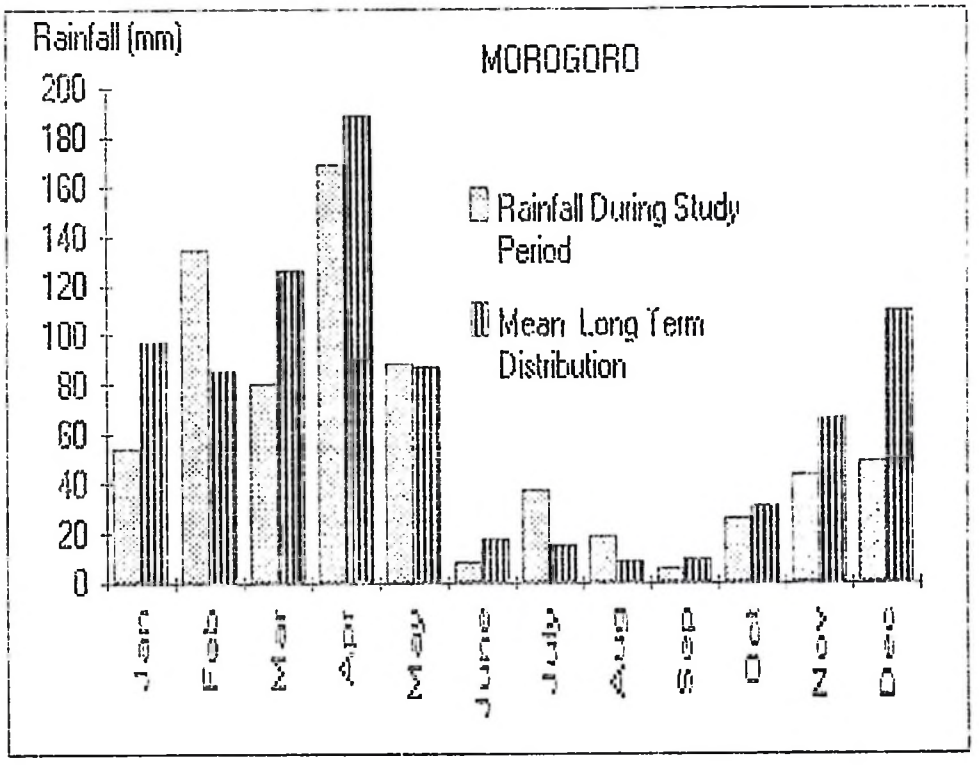
3. MATERIALS AND METHODS

3.1 Location, Climate and Soil

The erosion measurement plots were set at Morogoro and at Hombolo near Dodoma. These sites provide two contrasting types of soil and farming systems which are widely representative of semi-arid Tanzania.

The Morogoro site located 6° 50′ S and 37° 39′ E, has predominantly moderately structured, red, clayey, kaolinitic soils with moderate to low cation exchange capacities developed from deeply weathered precambrian gneisses of intermediate composition under FAO/UNESCO (1977) soil classification. The average annual rainfall is about 800 to 900 mm (Fig 1). The main subsistence crops grown are maize and cowpeas.

The Hombolo site located 5° 55′ S and 35° 50′ E, has predominantly weakly structured, sandy loam clayey, kaolinitic soils with low cation exchange capacities developed from deeply weathered granites of acidic composition under the same soil classification. It is representative of large areas of semi-arid central Tanzania. Average annual rainfall is about 600 mm (Fig 1). The semi-natural vegetation is degraded from of open acacia savannah, and the main subsistence crops grown are sorghum, maize and millet.



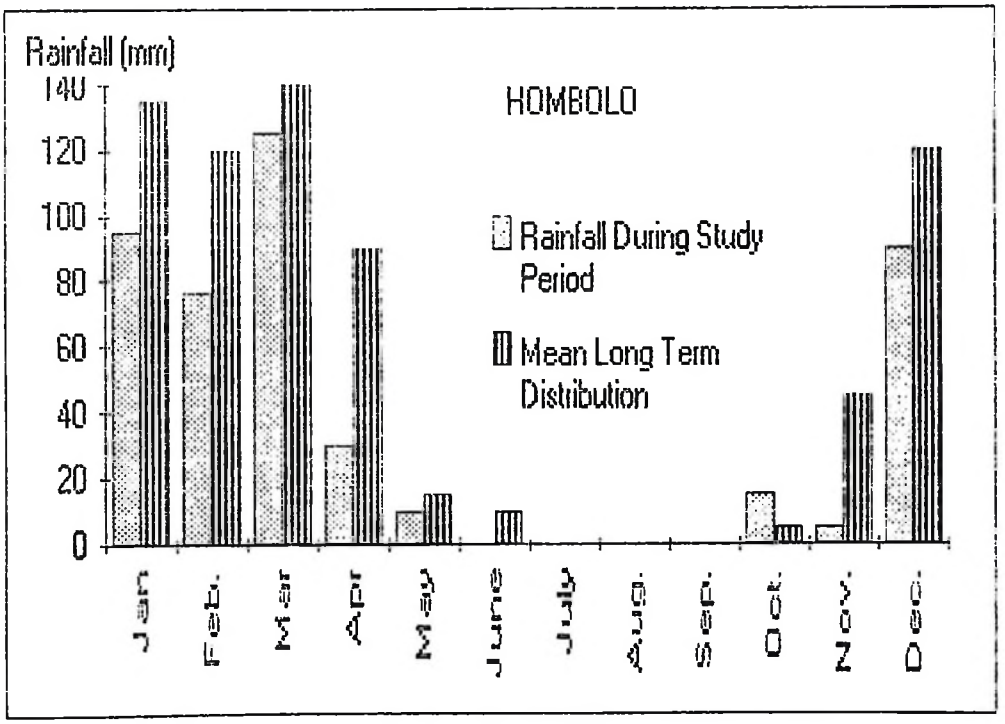


Fig. 1 : Rainfall distribution of Morogoro and Hombolo sites

This study has been conducted for one rainy season at both sites. The period of study had little and poor rainfall distribution compared to the mean rainfall distribution (Fig. 1). This reduced the number of rainstorms studied.

In both areas, the soils occupy long, gentle to moderate mid slopes and form catenary associations with less widespread soil types on the upper and lower slopes.

3.2 Experimental set-up and Data Collection

This study was conducted at Morogoro and Hombolo, near Dodoma as part of the ongoing research under the Department of Agricultural Engineering and Land Planning of the Sokoine University of Agriculture.

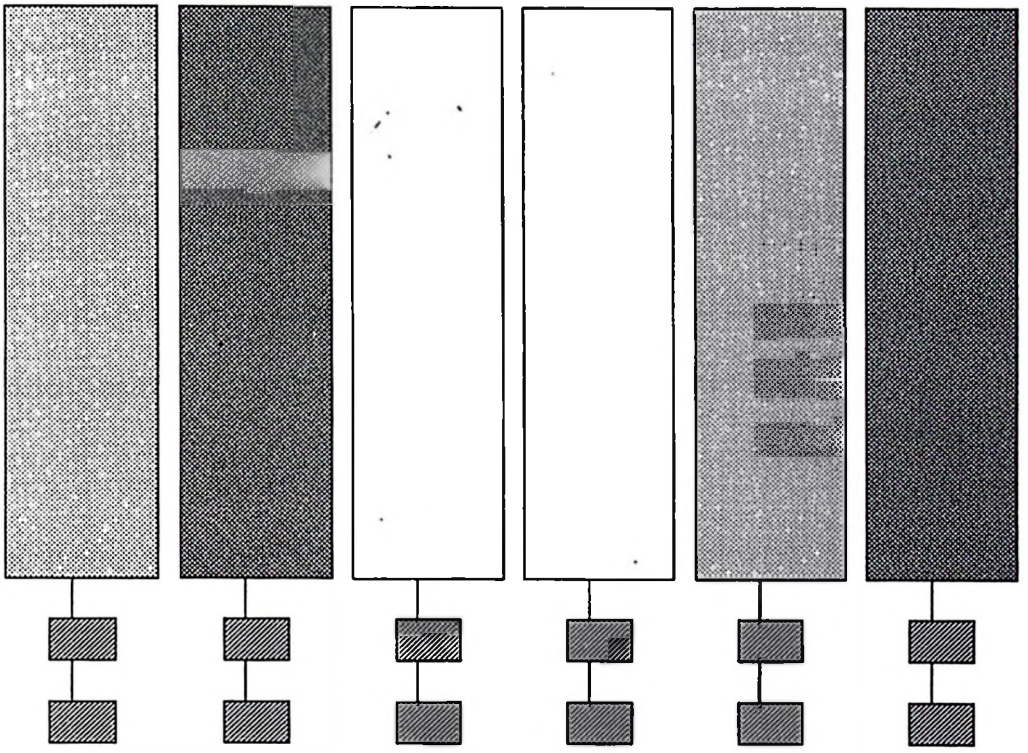
Ten run off plots of the size 22.1 m long by 4.5 m wide, and 9° slope were set up randomly to allow collection of both run-off and soil loss. Six plots were set at Morogoro site and the rest at Hombolo, Dodoma. At Hombolo, two plots were left bare and two plots cropped under sorghum. At Morogoro two plots were left bare; two plots cropped with semi-natural vegetation and two cropped under maize. For both sites, half of the intermediate area next to a plot was cropped and treated in the same manner as the plot itself, and in fact formed part of the plot except for the collection of run-off and measurement of crop yields.

However, measurement of crop yields was outside the scope of this study.

Before selecting the exact locations of plots at both sites, soils were examined at several points using augers to help in selecting ones with typical horizons and other observable features. For determination of soil properties for soil erodibility estimation, soil samples were taken from the tillage depth (up to 200 mm) across the run off plot areas.

The plots consisted of side walls made up of corrugated iron sheets, cement blocks and concrete drainage channels, measuring 20 cm above the ground. Two run-off collection tanks, each of 1.0 m^3 capacity were located at the downstream end of each plot. The layout and section are as shown in Figures 2, 3 and 4.

The tanks were arranged in series such that the first tank had a Geib nine-slot divisor system made up of aluminium sheet which samples one-ninth of the overflow to the second tank. The Geib divisor, designed for this purpose by the United States Conservation Service and consisting of a rectangular metal sheet box with a series of identical vertical slots can accurately divide the flow. To ensure the accurate division of the flow through the divisors, the floating materials were trapped by screens installed before the divisors and that the divisors were accurately



Legend

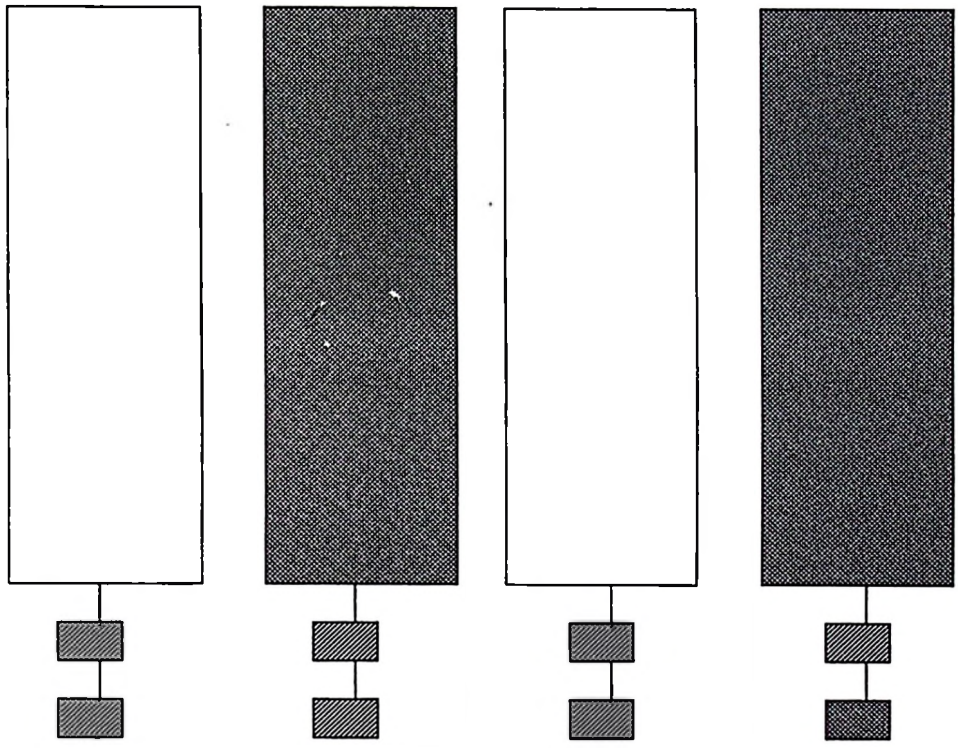
= Cropped with maize

= Left fallow

= Bare plots

= Run-off tanks

Fig.2:Plots layout, Morogoro



Legend:

□ = Bare plots

▩ = Cropped with sorghum

▨ = Run-off tanks

Fig.3 : Plots layout, Hombolo

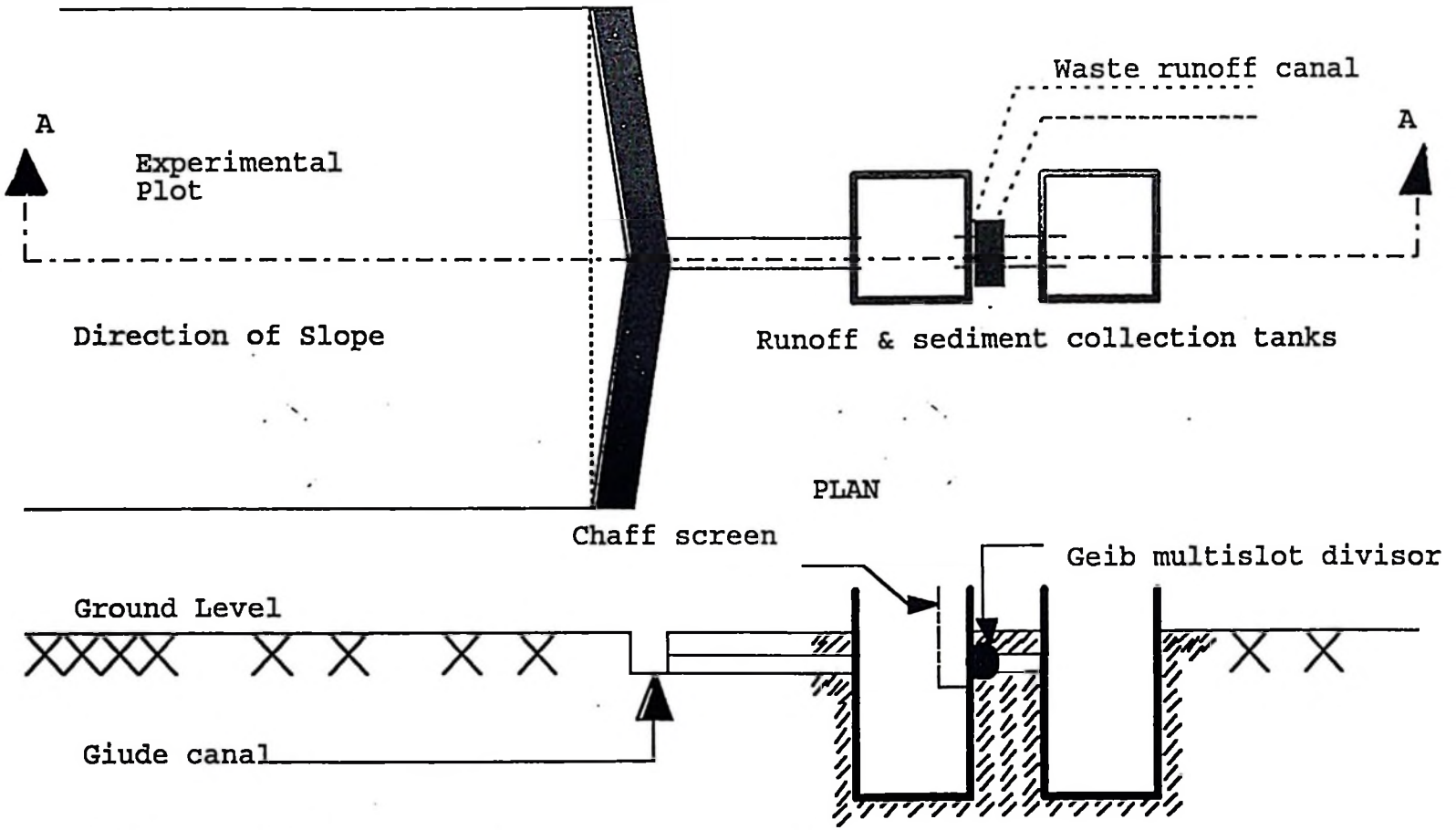


Fig. 4 : Typical Plan and Section of Runoff tank

levelled. In calculating the maximum probable run-off rate, it was assumed that such a storm could occur when the ground was completely saturated and would give 100 per cent run-off, and the collecting tanks, etc. were accordingly designed to take the peak flow. For the Morogoro plots, the rainfall was measured with both the standard and the autographic gauge adjacent to the plots. For the Hombolo plots, the Hombolo Agricultural Sub-station rain gauges was utilised for the measurement of the rainfall. The gauges were standard and autographic.

A flocculating agent was added to the run-off suspension which was collected in each tank to allow it to settle. The soil particles settled at the bottom of the tank and the clear water was drawn off the tank and its quantity measured. The volume of the soil remaining in the tank was determined and taken for drying and weighing. For the tanks below the divisor, the weight of the soil in the tank was adjusted in accordance with the proportion of the total run off and the sediment passing into the tank. Thus, the total soil loss from the plot was the weight found in the first tank plus nine times the weight of the soil found in the second tank. The soil loss was measured for each storm. Therefore, the total weight of the soil loss was the summation of the weights of soil loss from all the storms.

Equation (7) was used to determine storm kinetic energy, E. For the determination of the EI index, the 30-minute maximum intensity was obtained from recording rain gauge charts by locating the greatest amount of rain which falls in any 30-minutes of the storm. To get the rainfall intensity in mm h^{-1}, this amount during the 30-minute period was doubled.

3.3 Data Analysis

Determination of physical and chemical properties of the soil samples collected were done at the Soil Science laboratory of Sokoine University of Agriculture. The properties determined were particle size distribution (texture), pH (H_2O), infiltration capacity and organic carbon. Particle size distribution was determined using pipette method (Gee and Bauder, 1986). Soil pH was determined using electrometric method (Mclean, 1984) and organic matter content using Walkley-Black method (Nelson and Sommers, 1984). Water infiltration rate into the soil was determined using double ring infiltrometer method (Bouwer, 1986). INSTAT statistical programme was used for data analysis. Simple linear regression was used to fit the erosivity factors to soil loss. Before fitting the erosivity factors, graphical techniques were employed to get a preliminary idea of the kind of relationships that might exist. For most of the data, simple linear regression was fitted. This was done after finding that there were high coefficients of correlation. For those data that showed low coefficient of linear correlation, other forms of relations, other than linear, were explored. The data could not reveal other forms of relations possibly due to very few storm data collected during the study period.

4. RESULTS AND DISCUSSION

4.2 Soil Properties

Tables 4.1 and 4.2 show detailed soil properties of Morogoro and Hombolo sites, respectively. The soil for Morogoro site was classified as sandy clayey loam (SCL), while that at Hombolo as loamy sand (LS) according to USDA classification. Using Bouyoucos (1935) erodibility index Hombolo soils have a mean erodibility index of about 9.0 whereas Morogoro soils have an erodibility index of 1.94. Due to its high silt contents, Hombolo soils are therefore more susceptible to erosion than the soils at Morogoro. Infiltration of water into these soils was 150 mm/hr and 100 mm/hr for Hombolo and Morogoro soils, respectively. Tables 4.1 and 4.2 show also that the percentage organic carbon for Morogoro and Hombolo are 0.89 and 0.23, respectively. This indicates that Morogoro soils are less susceptible to erosion than those at Hombolo. The mean pH at the sites was 6.1 and 5.3 for Morogoro and Hombolo, respectively. The difference in pH was insignificant.

Table 4.1: Soil Properties for runoff plot site at Morogoro.

plot no.	Texture								
	Horizon	Depth cm	Sand %	Coarse silt %	Fine silt %	Clay %	Class USDA	pH	Organic Carbon %
Plot 1	Ap	0-20	57	6	4	33	SCL	6.2	0.87
Plot 3	Ap	0-20	52	7	7	34	SCL	5.9	0.85
Plot 4	Ap	0-20	53	6	5	36	SCL	5.8	0.84
Plot 5	Ap	0-20	52	6	6	36	SCL	6.5	0.99
Mean	Ap	0-20	54	6	6	34	SCL	6.1	0.89

Table 4.2: Soil Properties for runoff plots site at Hombolo

plot no.	Texture								
	Horizon	Depth cm	Sand %	Coarse silt %	Fine silt %	Clay %	Class USDA	pH	Organic Carbon %
Plot 1	Ap	0-20	82	3	5	10	LS	5.8	0.24
Plot 3	Ap	0-20	80	4	4	12	LS	5.1	0.25
Plot 4	Ap	0-20	80	3	5	12	LS	5.1	0.24
Plot 5	Ap	0-20	76	6	5	13	LS	5.3	0.28
Mean	Ap	0-20	79	6	5	10	LS	5.3	0.25

4.2 Erosivity factors

The erosivity factors chosen for study included rainfall, runoff, energy, EI_{30} and AI_{30} . The maximum 30-minute intensity, I_{30}, was excluded during the data analysis stage because some rainstorms of varying I_{30} were considered together to be one rainstorm event.

4.2.1 Rainfall amount

This basic variable is related to two major erosive agents, raindrop impact and surface runoff. Simple linear regression was used to fit rainfall amount to the soil loss for each treatment and rainstorm producing runoff. The results are as shown in Tables 4.3 and 4.4. The rainfall amount, A, proved to have contradicting correlations to soil loss at both sites of study. Whereas Hombolo site had a correlation of $r^2 = 0.96$, Morogoro site showed a very poor correlation of $r^2 = 0.01$. Foster et al. (1982) in a similar study of several stations in USA, found that r^2 for rainfall amount ranged from 0.11 to 0.53. Wischmeier and Smith (1958) also found it to be a very poor erosivity factor. Roose (1973), however, in Ivory Coast found the soil loss to be significantly related to rainfall amount. The results in this are also in agreement with those reported by Morgan (1974) in Malaysia and Elwell and Stocking (1975) in Zimbambe.

Table 4.3: Regression equations for Morogoro.

PLOT TREATMENT	EROSIVITY FACTOR	FITTED EQUATION	STANDARD ERROR OF SLOPE	COEFF. OF DETERMINATION (R- Squared)
Cropped with maize	Runoff, R	SL = -233.9 + 51.25 x R	20.42	0.56
	Rainfall, A	SL = 244.1 - 0.27 x A	16.70	.01
	AI_{30}	SL = -7.7 + 0.81 x AI_{30}	0.85	0.15
	Energy, E	SL = 77.6 + 0.60 x E	0.87	0.09
	EI_{30}	SL = -18.9 + 0.05 x EI_{30}	0.02	0.51
Left Fallow	Runoff, R	SL = -125.2 + 46.27 x R	20.45	0.51
	Rainfall, A	SL = 217.4 - 0.96 x A	0.15	0.01
	Intensity, AI_{30}	SL = -3.0 + 0.65 x AI_{30}	0.81	0.11
	Energy, E	SL = -134.2 + 6.23 x E	2.0	0.66
	EI_{30}	SL = -28.3 + 0.05 x EI_{30}	0.02	0.44
Left Bare	Runoff, R	SL = -110.9 + 83.47 x R	23.58	0.71
	Rainfall, A	SL = 289.1 + 9.33 x A	24.48	0.03
	Intensity, AI_{30}	SL = 100.7 + 1.38 x AI_{30}	1.23	0.20
	Energy, E	SL = 64.7+ 0.48 x E	0.82	0.07
	EI_{30}	SL = 166.6 + 0.07 x EI_{30}	0.04	0.44

Table 4.4: Regression equations for Hombolo.

PLOT TREATMENT	EROSIVITY FACTOR	FITTED EQUATION	STANDARD ERROR OF SLOPE	COEFF. OF DETERMINATION (R- Squared)
Left Bare	Runoff, R	SL = 72.2 + 29.99 x R	8.88	0.70
	Rainfall, A	SL = -834.1 + 86.75 x A	7.0	0.97
	AI_{30}	SL = -149.8 + 2.91 x AI_{30}	0.54	0.85
	Energy, E	SL = -888.4 + 5.8 x E	0.69	0.93
	EI_{30}	SL = -184.8 + 0.20 x EI_{30}	0.03	0.92
Cropped with Sorghum	Runoff, R	SL = 350.6 + 8.87 x R	3.85	0.52
	Rainfall, A	SL = 92.9 + 25.01 x A	9.51	0.58
	Intensity, AI_{30}	SL = 377.1 + 0.72 x AI_{30}	0.41	0.38
	Energy, E	SL = 93.7 + 1.6 x E	0.68	0.54
	EI_{30}	SL = 342.6 + 0.05 x EI_{30}	0.03	0.45

4.2.2 Runoff

The rainstorm runoff was found to be one of the best erosivity factors with r^2 ranging from 0.50 to 0.67 (Tables 4.3 and 4.4). The bare plots showed higher correlations than the plots with other treatments. Even though runoff is a good soil loss estimator, it is difficult to use because runoff volumes would also have to be estimated for soil loss prediction purposes.

Simple linear regression was used to fit the erosivity factors to the soil loss data for each treatment and rainstorm(s) producing runoff. The results are as shown in Tables 4.3 and 4.4. Similarly, the correlation coefficients between the soil loss and the erosivity factors are as shown in Tables 4.5 and 4.6.

4.2.3 Energy

The total rainstorm kinetic energy, E gave mixed results. Whereas in Hombolo the coefficient of determination of soil loss to energy was significantly high, ranging from $r^2 = 0.94$ to $r^2 = 0.52$; in Morogoro, the relationship was very poor ranging from $r^2 = 0.05$ to $r^2 = 0.09$

4.2.4 EI_{30}

This compound erosivity factor (Tables 4.7 and 4.8) involving two variables produced good results having r^2 ranging from 0.44 to 0.92. The plots which were bare showed higher coefficients of determination. Foster et al. (1982) in a similar analysis had r^2 ranging from 0.35 to 0.83. Salako et al. (1991) also had a good correlation in a similar study in southern Nigeria.

Table 4.5: Correlation coefficient for soil loss and different erosivity factors at Morogoro.

Plot treatment	Erosivity factors				
	Runoff	Energy, E	EI_{30}	Rainfall, A	AI_{30}
Cropped with maize	0.82	0.30	0.71	0.07	0.39
Left fallow	0.71	0.26	0.66	0.03	0.34
Left bare	0.83	0.22	0.66	0.20	0.45

Table 4.6: Correlation coefficient for soil loss and different erosivity factors at Hombolo.

Plot treatment	Erosivity factors				
	Runoff	Energy, E	EI_{30}	Rainfall, A	AI_{30}
Cropped with sorghum	0.72	0.73	0.67	0.76	0.61
Left bare	0.83	0.97	0.96	0.98	0.92

Table 4.7: Erosivity factors for Morogoro

Day of year*	Rain mm	I_{30} mm/hr	E J/m^2	Total, E	EI_{30}	Total, EI_{30} J/m²·mm/hr	AI_{30}	Total AI_{30} mm^2/hr
97	20.0	33.0	349.2	349.2	11523	11523	415.1	422.9
98	3.8	6.0	-	-	-		7.8	
99	6.0	8.8	36.2	288.2	494.6	2354.6	45.9	235.6
100	5.8	1.6	4.3		6.9		19.9	
101	4.1	9.2	27.0		248.4		18.6	
102	8.8	8.0	200.1		1600.8		151.1	
110	3.8	10.0	40.6	383.2	406.0	8087.1	24.5	461.9
111	5.8	3.5	10.1		33.4		25.6	
113	15.6	23.0	332.4		7645.2		399.8	
115	4.9	9.0	-		-		12.0	
116	5.1	5.0	49.3	54.4	246.5	284.2	24.1	227.4
121	30.2	7.4	5.1		37.7		203.3	
123	13.7	9.8	172.6	491.4	1691.5	8385.6	340.6	491.0
124	11.1	21.0	318.8		6694.8		150.4	
125	7.1	20.2	78.3	78.3	1581.6	1581.6	63.3	63.3
132	6.3	4.0	54.0	219.4	216.0	1637.7	21.5	
133	11.7	9.8	3.1		30.4		154.2	
134	4.9	8.5	162.2		1378.7		21.3	225.2
135	4.1	9.6	-		-		28.3	

* Day no.1 = 1st January

Table 4.8: Erosivity factors for Hombolo

Day of year*	Rain, mm	I_{30} mm/hr	E J/m²	Total E J/m²	EI_{30} J/m²mm/hr	Total EI_{30} J/m²mm/hr	AI_{30} mm²/hr	Total AI_{30} mm²/hr
43	21.0	18.8	296.3	296.3	5571.1	5571.1	384.3	384.3
44	15.5	17.0	245.0		4146.8		263.5	
46	0.9	2.0	-		-		1.8	
49	6.6	5.9	50.8		297.6		38.9	1700.6
50	16.3	6.0	42.8	904.8	256.5	27711.6	97.8	
53	26.7	40.6	566.3		22992.2		1084.0	
54	3.1	5.6	42.6	170.9	238.7	1880.5	17.4	108.6
56	7.1	12.8	128.3		1641.8		90.9	
62	22.6	23.0	472.7	472.7	10871.6	10871.6	519.8	519.8
64	28.6	16.0	266.4	942.2	4262.1	16168.9	457.6	987.6
67	18.7	19.1	371.3		6060.4		357.2	
75	9.0	19.2	304.5		5846.4		172.8	
78	35.3	36.0	604.7	604.7	11549.8	11549.8	1270.8	1270.8
79	11.0	8.5	132.2	132.2	1123.3	1123.3	93.8	93.8

* Day no.1 = 1st January

4.2.5 AI_{30}.

This compound erosivity factor (Tables 4.7 and 4.8) produced results of r^2 ranging from 0.12 to 0.85. In a similar study, Foster et al. (1982) had r^2 ranging from 0.23 to 0.79. In Nigeria, Lal (1976) found that AI_{30} was a better erosivity factor than EI_{30}. Salako et al. (1991), in a similar study in southern Nigeria showed that AI_{30} related well with soil loss.

4.3 Rainfall erosivity parameters and Soil Loss

For Hombolo site, the coefficients for all erosivity factors considered are significantly high. The effect of canopy cover for the plots cropped with sorghum is quite conspicuous compared to the bare plots because its correlation coefficients to soil loss are relatively low. For Morogoro site, rainfall amounts have shown to have very poor correlations with all treatments though bare soil plots have comparatively higher correlation coefficients. The EI_{30} indices indicated to correlate properly with soil loss although it did not show the effect of treatments. The correlation coefficients for EI_{30} index are 0.71, 0.66 and 0.66 for maize, fallow and bare plots, respectively. For both sites, bare plots had a larger cumulative soil loss and runoff compared to other treatments (Fig.5-8). Plots left fallow at Morogoro site have the lowest cumulative soil loss as shown in Figures 5-6; and Tables 4.9 and 4.10.

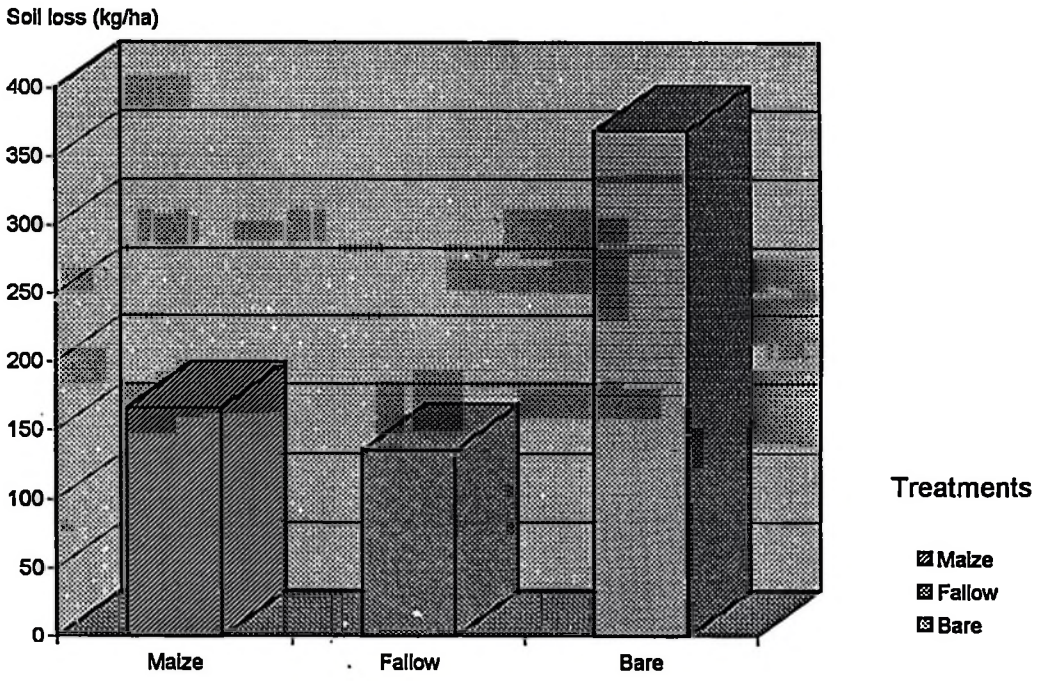


Fig. 5 : Soil loss at Morogoro

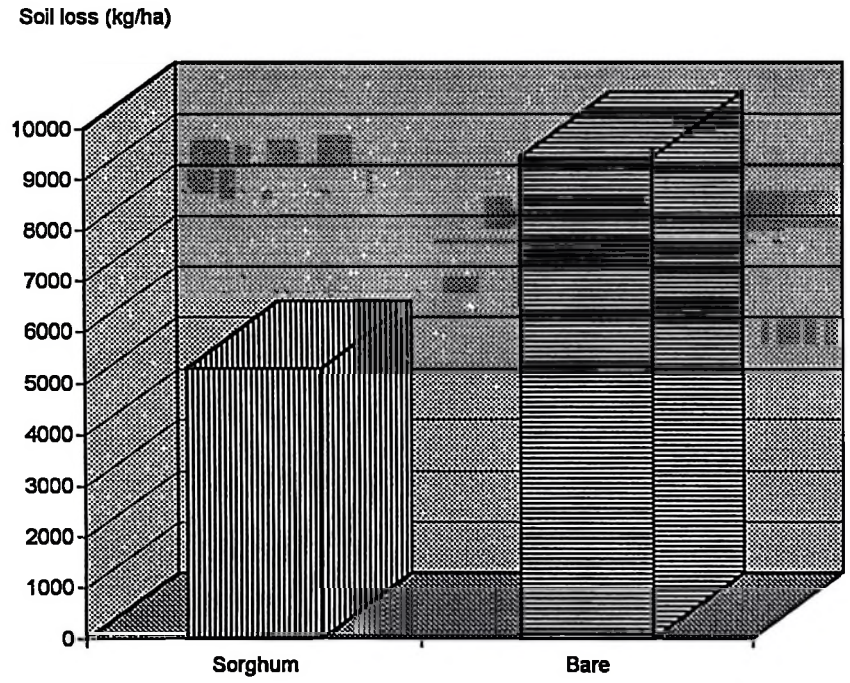


Fig. 6. Soil loss at Hombolo

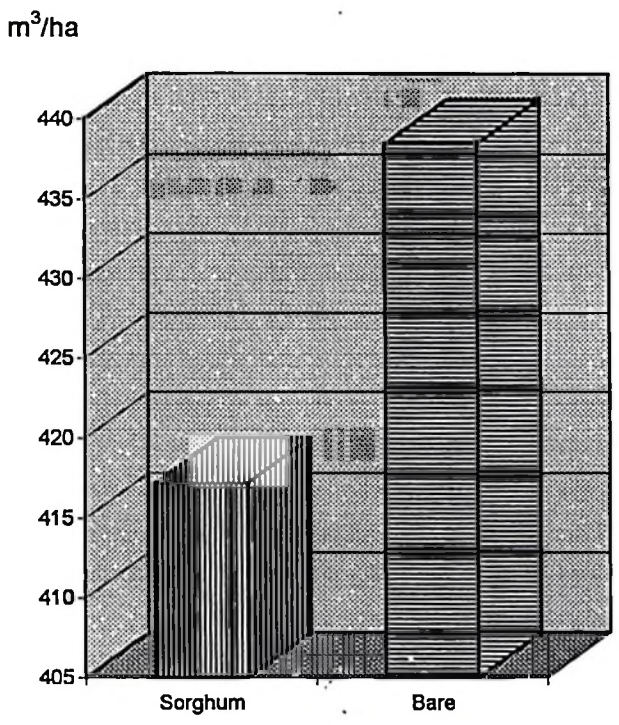


Fig. 7 Plot runoff at Hombolo

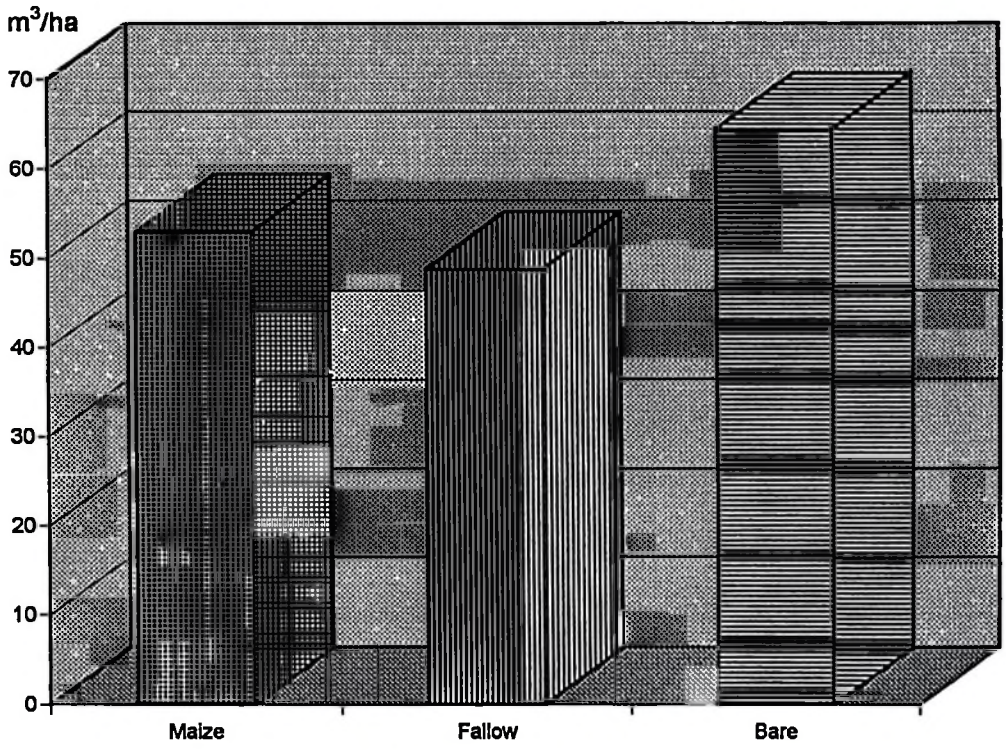


Fig.8 · Plot runoff at Morogoro

Table 4.9: Runoff and soil loss for Hombolo

Day of year	Plot Treatment			
	Left bare		Cropped with Sorghum	
	Runoff m^3/ha	Soil loss kg/ha	Runoff m^3/ha	Soil loss kg/ha
43	10.75	250.5	4.1	81.0
44, 46, 49, 50, 53	91.3	3444.5	89.6	1686.0
54, 56	8.4	65.5	4.9	34.0
63	71.2	950.0	51.4	591.5
64, 67, 75	151.2	2603.0	153.6	1809.0
78	88.8	1777.0	103.7	822.5
79	16.8	353.0	9.9	282.5
Total	438.45	9,443.50	417.20	5,306.50

Table 4.10: Runoff and soil loss for Morogoro site.

DAY OF YEAR	PLOT TREATMENTS					
	CROPPED WITH MAIZE		LEFT FALLOW		LEFT BARE	
	Runoff (m^3/ha)	Soil loss (kg/ha)	Runoff (m^3/ha)	Soil loss (kg/ha)	Runoff (m^3/ha)	Soil loss (kg/ha)
97,98	16.5	96.06	14.75	87.48	17.0	130.83
99,100 101,102	4.0	20.16	3.5	17.84	4.0	31.02
110,111 113,114	10.5	22.37	11.0	8.48	14.0	108.58
116,121	7.75	7.56	6.75	6.62	7.25	49.99
123,124	3.25	7.05	3.0	6.22	7.5	8.11
125	2.63	8.04	2.25	5.26	5.0	30.99
132,133 134	8.25	5.0	7.5	3.74	9.63	9.19
Total	52.88	166.23	48.75	135.64	64.38	368.71

From figures 5 and 6, it is evident that bare plots lost more soil than plots with other crop cover treatments. In Morogoro, there is no significant soil loss difference between plots left fallow and those cropped under maize. The runoffs producing the soil loss are also insignificantly different. However, although there is a significant soil loss difference between the bare plots and plots with other treatments for both sites, the runoffs producing the soil loss are significantly indifferent.

Whereas in Hombolo, a total of 222.4 mm of rainfall produced soil loss of 9443.5 kg/ha and 5306.5 kg/ha for bare and sorghum plots respectively; in Morogoro a total of 172.7 mm of rainfall produced soil loss of 166.22 kg/ha, 135.64 kg/ha and 368.71 kg/ha for plots cropped under maize, fallow and bare, respectively (Tables 4.9 and 4.10). Similarly, whereas in Hombolo soil loss per unit (mm) rainfall is 42.5 kg/ha and 12.9 kg/ha for bare and sorghum plots respectively, the corresponding figures for Morogoro are 0.96 kg/ha, 0.79 kg/ha and 2.13 kg/ha for maize, fallow and bare plots respectively. This indicates that the soils at Hombolo are more erodible than those at Morogoro. This is no surprise as the soils at Hombolo were classified as loamy sand (LS) and those at Morogoro as sandy clay loam (SCL).

Tables 4.11 and 4.12 show amounts of runoff and their percentage to amount of rainfall received. When compared statistically to ascertain whether there is any significant difference in the percentage runoff, the effect of canopy cover was not evident. In Morogoro the significant level that the means of percentage runoff are equal was 77.3% for maize and fallow grass plots, 88.2% for maize and bare plots; and 90.0% for bare and maize plots. In Hombolo, the significant level was 67.3% for bare and sorghum plots for the two-sided t-test.

Whereas in Hombolo, 32.3% reduction in runoff for sorghum plots was attributed to crop cover, only 11.8% and 10.0% was attributed to crop cover for maize and fallow grass plots respectively in Morogoro. Since no erosion can occur without runoff, and Hombolo soils are more erodible than those in Morogoro, establishment of crop cover greatly reduces runoff hence soil loss.

The coefficients of variation for soil loss was 31.8% and 9% for Morogoro and Hombolo sites respectively. This was already evident from figures 5 and 6 respectively. The coefficients of variation for runoff was 6.1% and 11.2% for for Hombolo and Morogoro respectively.

Table 4.11: Rainfall, Runoff and Runoff coefficients for Morogoro.

		Maize		Fallow		Bare	
Day	Rainfall mm	Runoff	% Runoff	Runoff	% Runoff	Runoff	% Runoff
97, 98	23.8	1.68	7.05	1.48	6.2	1.7	7.1
99, 100, 101, 102	24.7	0.4	1.6	0.35	1.4	0.4	1.6
110, 111, 113, 115	30.1	1.05	3.5	1.1	3.7	1.4	4.7
116, 121,	35.3	0.78	2.2	0.68	1.9	0.73	2.1
123, 124	24.7	0.33	1.3	0.3	1.2	0.75	3.03
125	7.1	0.26	3.7	0.23	3.2	0.5	7.0
132, 133, 133, 135	27.0	0.83	3.07	0.75	2.8	0.96	3.6

Table 4.12 Rainfall, Runoff and Runoff coefficients for Hombolo

		Bare		Sorghum	
Day	Rainfall mm	Runoff	% Runoff	Runoff	% Runoff
43	21.0	1.03	4.9	0.41	1.9
44, 46, 49, 50, 53	66.0	9.13	13.8	8.96	13.6
54, 56	10.2	0.84	8.2	0.49	4.8
63	22.6	7.12	31.5	5.14	22.7
64, 67, 75	56.3	15.12	26.9	15.36	27.3
78	35.3	8.88	25.2	10.37	29.4
79	11.0	1.68	15.3	0.99	9.0

5.0 CONCLUSIONS AND RECOMMENDATIONS

This report contains preliminary findings of the on-going research. Although the period of study was relatively short (only one rainy season), some of the results are significant. The erosivity factors, EI_{30} and runoff have shown high correlation with soil loss, with the coefficients of determination being 0.92 and 0.69 respectively.

The other erosivity factors studied namely, AI_{30}, rainfall amount and energy showed poor/lower correlations to soil loss. There is a significant difference in soil loss between bare plots and other plots with canopy cover at both sites. However, there is no significant difference in soil loss between fallow grass plots and plots cropped under maize at Morogoro.

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APPENDICES

Appendix 1: Day numbers of year

Day numbers of year

Mon Day.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366

Appendix 2: **ANOVA TABLE for Soil loss at Morogoro**

Source	DF	SS	MS	F	Prob.
Treatments	2	6131776	3065888	6.1	0.140
Replicates	1	1693891	1693891	3.4	0.207
Error	2	997080	498540		
Total	5	8822747			

Coefficient of Variation 31.8%

MAIN EFFECTS

Treatments		Replicates	
Level	Mean	Level	Mean
Maize	1662	Plot 1	2750
Fallow	1356	Plot 2	1687
Bare	3637		
SE mean	499.3	SE mean	407.7
SE diff	706.1	SE diff	576.5

ANOVA TABLE for Runoff at Morogoro

Source	DF	SS	MS	F	Prob.
Treatments	2	275.77	137.89	3.6	0.217
Replicates	1	1.0417	1.0417	0.0	0.884
Error	2	76.271	38.135		
Total	5	353.08			

Coefficient of Variation 11.2%

MAIN EFFECTS

Treatmen		Replicat	
Level	Mean	Level	Mean
Maize	52.87	1	55.58
Fallow	48.25	2	54.75
Bare	64.37		
SE mean	4.367	SE mean	3.565
SE diff	6.175	SE diff	5.042

Appendix 3: **ANOVA TABLE for Soil loss at Hombolo**

Source	DF	SS	MS	F	Prob.
Replicate	1	2361.7	2361.7	42.4	0.097
Treatments	1	962.4	962.4	17.3	0.150
Error	1	55.689	55.689		
Total	3	3379.8			

Coefficient of Variation 9.0%

MAIN EFFECTS

Replicate Level	Mean	Treatments Level	Mean
Plot 1	107.3	Bare	98.48
Plot 2	58.67	Sorghum	67.46
SE mean	5.277	SE mean	5.277
SE diff	7.462	SE diff	7.462

ANOVA TABLE for Runoff at Hombolo

Source	DF	SS	MS	F	Prob.
Replicate	1	317532	317532	5.4	0.258
Treatments	1	72092	72092	1.2	0.466
Error	1	58322	58322		
Total	3	447947			

Coefficient of Variation 6.1%

MAIN EFFECTS

Replicate Level	Mean	Treatments Level	Mean
Plot 1	4257	Bare	4109
Plot 2	3693	Sorghum	3841
SE mean	170.8	SE mean	170.8
SE diff	241.5	SE diff	241.5