THE EFFECT OF SURFACE STONE COVER ON SOIL LOSS AND RUNOFF

by

NURZEFA SHAFO BUSERE

A thesis submitted to the University of Nairobi for the partial fulfilment of the requirements for the degree of Master of Science in Agricultural Engineering

October 1989.

DECLARATION

I, hereby, declare that this thesis is my original work and has not been presented for a degree in any University.

Date 26/10/89

Nurzefa Shafo Busere

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

D.B. Thomas

Date 26 October 1989

Professor D.B. Thomas

DEDICATION

This thesis is dedicated to my mother Nuria Omar for her encouragement to my education.

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ACKNOWLEDGEMENTS.

I would like to express my sincere thanks to Professor D.B.Thomas, my supervisor, for his encouragement, keen assistance in getting me literature materials and for his constructive criticisms throughout the course of my studies.

I am also indebted to the Community Forest and Soil and Water Conservation Department of the Ministry of Agriculture, Ethiopia, for making all the necessary arrangements for my study.

My special appreciation goes to Food and Agriculture Organization (FAO) for sponsoring my scholarship; and the Swedish Agency for Research Cooperation with Developing Countries (SAREC) for financing my project.

The following also deserve my sincere gratitude:

-Meteorology Department for allowing me to have access to the rainfall record.

-Prof. R.W. Michieka, Department of Crop Science, University of Nairobi, for his valuable advice and letting me to use the spraying equipment for weed control.

My special thanks go to the following persons:

- Mr. E.M. Gachuhi, Soil Science Department; Mr. E. Onyullo, Agric. Engineering Department; Mr. S. Macharia, Agric. Engineering Department; and all technical staffs of the Agric. Engineering Department for their encouragement and/or assistance in matters related to data collection, processing and/or laboratory activities.

Finally, I would like to thank Mr. Mwebi, Baringo District Agricultural Engineering Officer in Ministry of Agriculture and all the farmers interviewed for their assistance and useful information they provided me during the field investigation.

Abstract

The study was carried out on 12 natural runoff plots each being 2 m wide and 11.6 m long installed at Kabete Field Station to assess the effect of surface cover in controlling erosion on an average slope of 8%. Four rates of surface cover (0% cover or control, 10%, 20% and 40% surface cover) with three replications of each rate were tested under the natural rainfall during the short rains of 1988, long rains of 1989 and on the simulated rainfall and overland flow.

Results showed that the different rates of surface cover were significantly affecting the erosion rate. Annual soil loss (total soil loss from October 1988 to August 1989) for the control plot was 318.5 t/ha, while for the 10%, 20% and 40% surface covered plots the annual soil losses were respectively 301.6, 258.4 and 214.8 t/ha. The soil loss was highly reduced by the 40% surface covered plots as compared to the other treatments. The difference between the rates of surface cover was statistically different at 95% confidence in controlling soil loss. The percent surface coverage of the soil by the simulated stones was exponentially related to the soil loss with a coefficient of determination (r^2) of 98%.

The annual runoff was not significantly

influenced by the different rates of the covers. The total rainfall from October 1988 to June 1989 in which the runoff plots were monitored was 1370 mm whereas the total runoff, excluding the runoff from the two heavy storms of 07/05/89 and 18/05/89, was 140 mm from the control plot and 139,138 and 130 from 10% 20% and 40% surface covered plots. Excluding the runoff and the rainfall from the two heavy storms, the runoff as percent of the rainfall was 12% from the 40% surface covered plot and 13%, 12.9% and 12.8% from the bare (0%),10% and 20% surface covered plots respectively. The effect of the four rates of surface cover was not statistically different in controlling runoff.

Soil loss from 79 mm/h simulated rainfall for the one hour initial run, was 31.6, 30.3, 24.4 and 21.1 t/ha from the control, 10%, 20% and 40% surface covered plots respectively. Similarly runoff was 33, 37, 34 and 27 mm from the control, 10%, 20% and 40% surface covered plots respectively.

The ratios of soil loss from the 40% cover to the soil loss from the control plot were 67%, 56%, 57% and 51% respectively from the dry, wet, 1st very wet and 2nd very wet runs. Moreover the ratios of the runoff from the 40% surface covered plots to the control plot were 82%, 77%, 72% and 93% during the dry, wet, 1st very wet and 2nd very wet runs respectively.

The analysis of particle size distribution of

the eroded sediment showed that the proportion of clay sized particles in the eroded sediment was low in the short rains but slowly increased in the long rains as the erosion process continued.

The cover and management C-factor values computed as the ratios of the annual soil loss from the surface covered plots to the control plot was 0.91, 0.81 and 0.65 for 10%, 20% and 40% surface covers respectively.

As a result of the experiment and field investigations it is concluded that increased surface cover reduces erosion whereas removal of stones lead to an increase in runoff and soil loss. However, removal of stones may be desirable in places where the soils are deep and have stones throughout the profile.

1.0 INTRODUCTION

Stony soils make up a substantial part of the land resources of Eastern Africa and their economic importance is an obvious matter as the need for cultivated land is rapidly increasing due to the increasing population.

The need for more food and other agricultural products, as a result of increased population, has resulted in more frequent cultivation of the existing arable lands and cultivation of lands which are considered marginal due to stoniness, less rainfall and irregular landscapes. Clearing of bushes and cultivation of those marginal lands aggravates the extent and amount of soil erosion problems.

Soil loss rates up to 282 tons/ha/y have been recorded from test plots on a 22% slope on cultivated lands planted with wheat, in Gojjam research station, in Ethiopia (SCRP 1986). Hurni (1988) estimated the country's average soil loss on cultivated lands to be 42 ton/ha/y while the highest soil loss rates on single fields to be up to 300 ton/ha/y in the western Ethiopia where the rainfall erosivities are the highest. Such amount of soil loss has a significant impact on crop production.

At present the problem of soil erosion has brought world attention both in research and in implementing and evaluating the soil and water conservation measures. Hurni (1987) reported that the Ethiopian government , between 1978 and 1984, was able to treat 600,000 ha of cultivated lands with contour bunds. However he emphasized that the uniform application of a single conservation measure, in fact structural measures mainly, had led to some problems because the structures were not universally suitable for all agro-ecological conditions. He further stated that high rainfall areas could not be successfully treated with contour bunds, because increased runoff overtopped the bunds during heavy storms, and led to more damage than without conservation. From this we can learn that there is no generally accepted soil and water conservation measure that can be used in all conditions of soil, landuse and climate.

In places where stony soils are common, stones on the surface of cultivated lands are regarded as a nuisance, and are often removed and heaped with a considerable expense. In other places where soil and water conservation activities are taking place, stone bunds are constructed. However, high labour requirement for construction and lack of proper maintenance after construction are some of the common problems (FAO, 1983). Even when the bunds are properly constructed, they will not provide erosion protection unless they are kept in good repairs.

Stones on the surface of the soil are believed to reduce erosion by dissipating rainfall energy and slowing the velocity of runoff. Thomas and Barber (1979) while carrying out trials with a rainfall simulator has observed a reduction of damage to the grass roots from trampling and close grazing by cattle for gravel covered surfaces with 29% steep slope and both soils and runoff were less in plots covered by gravel than bare plots of 11.7% slope. Studies in the Negev, Israel, have shown that removal of stones on the surface of the soil increased the amount of runoff and erosion (Evenari et al. 1971). Therefore, the advantage or disadvantage of removing surface stone covers are matters of great importance to conservation planners and those involved in promoting conservation through food for work programmes.

Although stony soils are a common features of much cultivated lands in the East African Highlands, research findings on the effects of stones on erosion is limited. The effectiveness of surface stone cover of the soil on the East African stony soils may be different from those reported in the Negev and other temperate regions of America due to variations in rainfall characteristics and other climatic conditions.

Therefore, this research was aimed at making preliminary observations on the effects of surface stone cover on erosion on the stony soils of Baringo District and investigating the effect on soil loss and runoff of varying percentages of simulated stone cover on the Kabete nitosols. It would have been desirable to carry out all the work on stony soils in the field but in view of the problems of establishing such trials on farmers field at a great distance from Kabete, it was decided to use simulated stone cover at Kabete as a first step in the investigations.

The study had the following objectives:

1. to evaluate the effects of stone cover on soil loss and runoff,
2. to compute the cover and management C-factor of the Universal Soil Loss Equation and
3. to obtain preliminary information on land use and conservation practices on stony croplands in Baringo District.

To attain the objectives twelve runoff plots were established at Kabete to determine the effect of varying percentages of stone cover on runoff and soil loss. These were monitored from November 1988 to June 1989. The runoff plots were kept bare (without) any vegetation by applying herbicides frequently for the whole period to see the effects of the stone cover on soil loss and runoff at the worst conditions.

A survey of stony croplands in Baringo District was carried out in July 1989. Farmers were interviewed and their farms were visited.

The thesis comprises of a chapter on review of literatures on erosion features on stony soils followed by chapters describing the methodology, the results of the experiment, field investigations, discussion of the results and the last chapter is the conclusion and recommendation.

2. LITERATURE REVIEW

2.1. The Effect of Stone Cover on Runoff, Erosion and Evaporation

Raindrop impact has been shown to be a prime cause of soil erosion and ground cover one of the main methods of controlling it. Hudson (1981) commented that tropical rain storms with high intensities and large drop sizes cause very serious damage due to erosion when there is no protective cover.

The seasonal pattern of erosivity which was analyzed in an assessment of erosion risk in Kenya by Rowntree (1983) taking data from the Katumani research station, Machakos,(mean annual erosivity of 164,325 $J.mm.m^{-2}.h-^{1}$) indicates the severity of rainfall erosion even in the semiarid regions. This value is much higher than the highest value out of 13 stations in Zimbabwe, recorded at Chipenga station, mean annual erosivity of 13,397 $J.mm.m^{-2}.h^{-1}$, (Stocking and Elswell, 1976). This indicates variations of erosivities within tropics since both Rowntree and Stocking and Elwell computed the R-factor values using Hudson's formula i.e. KE > 25.

According to Rowntree (1983) the highest mean monthly erosivity value of 69,668 $J.mm.m^{-2}.h^{-1}$, occurs in April, the beginning of the rainy period immediately after the potential soil moisture deficit is severe and the vegetation cover is poorly established so that there is a need to have some means for protecting the soil from erosion during these periods.

When rain drops strike bare soil, they shatter aggregates and detach particles from the soil mass. Conversely covering bare soils with mulches of various types protects the soil from direct impacts of raindrops and provides shelter for the operation of micro-organisms which improves the soil structure and soil aggregations (plate 1).

Various types of mulching materials have been used to compare the effectiveness of different rates of ground cover in preventing soil erosion. The reduction in erosion from a well-covered soil with a wire gauze was compared with a bare soil under a natural rainfall on a 5% slope (Hudson, 1981) and the soil loss collected for 10 years, (1953-1962), from a bare plot was 100 times more than from the protected plot. Similarly in the studies where wire screens were placed over soil pans to dissipate raindrop impact energy, results showed that interrill flow alone can detach only a small percentage of the particles as compared to bare soils with raindrop impact (Meyer et al., 1975 and Mutchler and Young, 1975).

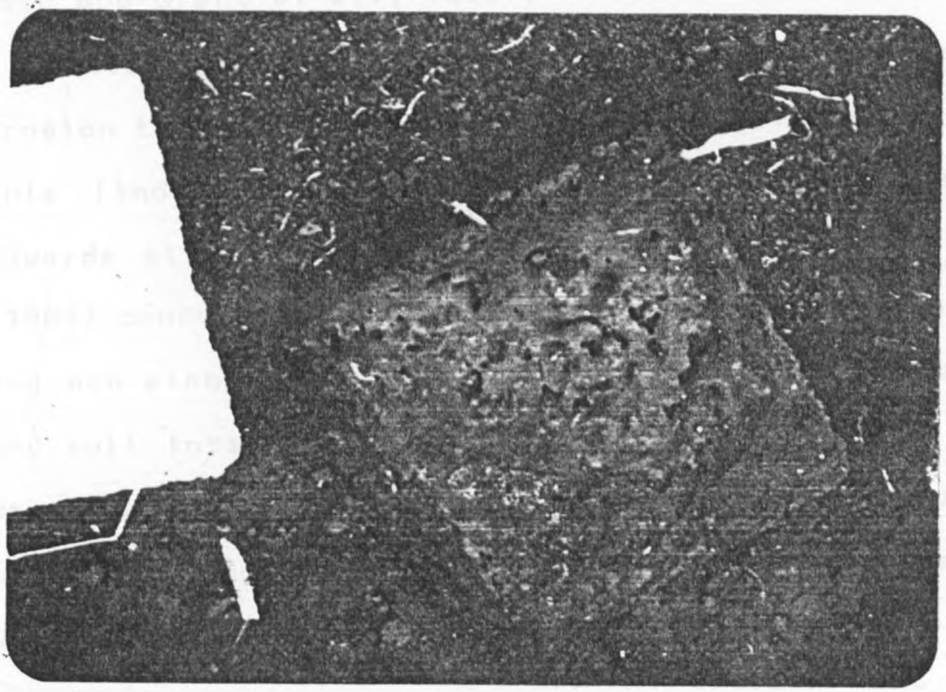


Plate - 1. Small holes made by ants on the soil covered by simulated stones.

(Photo taken on 23/5/89)

2.1.1 Effect on runoff and soil loss

Surface cover of stones acts as a mulch, dissipating an appreciable portion of the impact energy of raindrops, and possibly reducing the extent of compaction and surface sealing. This retarding effect of stones on runoff and reduced sealing leads to greater infiltration (Adams, 1966, Epstein and Grant, 1966 and Grant et al., 1959).

Stony soils were shown to be less liable to erosion than stone free soils (Lamb et al., 1950), and this finding was supported by recent studies of Edwards et al. (1984) in Ohio, U.S.A. Edwards et al. (1984) conducted research on small watersheds of stony and non-stony soils and showed differences in runoff and soil loss. The non-stony watershed which was 0.62 ha with an average slope steepness of 6% produced nearly 40% more runoff than did the adjacent stony watershed of 0.55 ha with average steepness of 9% during 12 years under conventional tillage in a four year rotation. The two watersheds were only about 1 km apart and the top soils in both the watersheds were silty loam developed from residual sedimentary bedrock under humid forest vegetation.

McIntire (1958) indicated that the soil is not only protected by the stones but infiltration is increased as water flows into the soil around the edges of the stones.

Meyer et al. (1972) on their studies in Indiana U.S.A., reported that stone mulches have shown greater potential for erosion control and revegetation than bare plot or plots mulched with straw mulches on steep denuded slopes. Erosion tests were conducted by applying simulated storms to each plot at an intensity of 63.5 mm/h: for one hour duration on the first day, followed by two 30-minutes applications on the next day. Then inflow water was added uniformly across the upper end of each plot to simulate longer slopes and determine mulch stability during increased rates of runoff. For the simulated slope length of 15 m, 30 m and 46 m with 20% $teepness, erosion was successfully controlled by 60% to 100% stone cover.

Jenning and Jarret (1985), in a study conducted in laboratory, compared the effectiveness of various mulching materials and their rates of application in reducing erosion under simulated rainfall of 135 mm/h for 10 minutes on a 2% slope. They reported that 70% surface cover made by limestone rocks with an average thickness of 25 to 100 mm were more effective in controlling erosion than 80% surface cover made by limestone rocks with an average thickness of 10 to 30 mm .Both treatments reduced the soil loss when compared with the bare fallow soil. At 70% stone cover, when compared with the control, the total surface runoff and soil loss were reduced by 4.4 mm and 2.71 t/ha from 16.9 mm and 3.45 t/ha respectively.

According to Box (1981), soil loss was inversely related to the percentage of the soil surface covered by slaty fragments on very slaty silt loam soils in Carolina, U.S.A., with a simulated rainfall at the rate of 63.5 mm/h for two hours on natural runoff plots. The plots were 1.82 m wide and 10.67 m long and the different percentages of surface covers from slaty fragments were made:

1) by removing all the slaty fragments larger than 6 mm upto a depth of 15 cm,
2) by maintaining the slaty fragments in their natural conditions and
3) by adding the slaty fragments removed from the 1st plot to the natural slaty fragments cover.

The relationship between soil loss and percent coverage by slaty fragments was similar to the curve for residue cover with 0% canopy cover given in USDA Handbook 537 pp.19 (Wischmeier and Smith 1978).

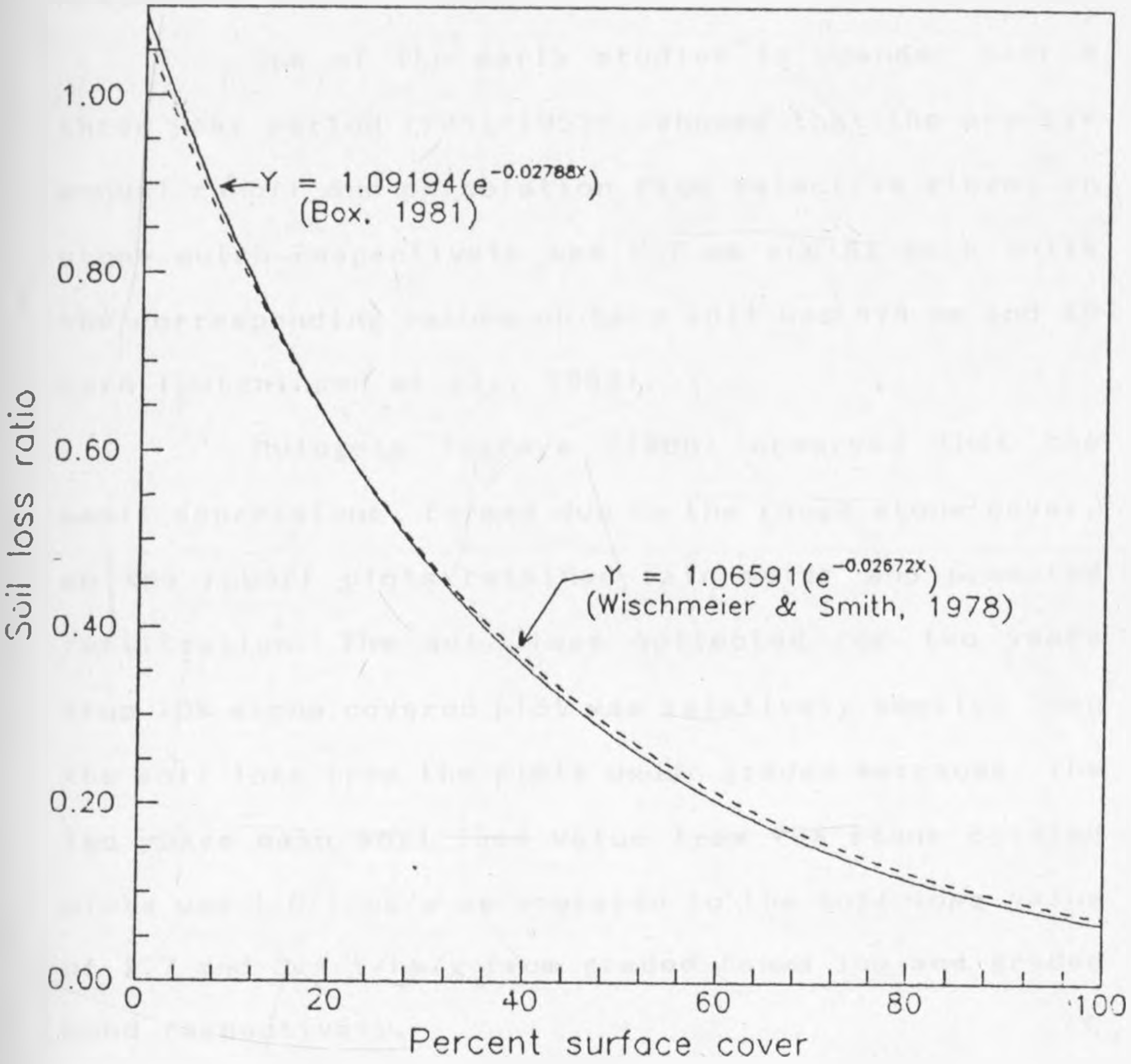


Figure 1. The relationship between soil loss and residue cover.

Source : USDA Handbook 537 and Box. 1981.

The available literature for the East African conditions indicate that soil loss and runoff tends to decrease as the surface coverage by stone increases (SCRP, 1983, Mulugeta Tesfaye, 1988, Smith, 1983 and Hutchinson et al., 1958).

One of the early studies in Uganda, over a three year period (1951-1953), showed that the average annual runoff and percolation from selective storms on stone mulch respectively was 137 mm and 51 mm/h while the corresponding values on bare soil was 474 mm and 25 mm/h (Hutchinson et al., 1958).

Mulugeta Tesfaye (1988) observed that the small depressions, formed due to the rough stone cover, on the runoff plots retained rain water and promoted infiltration. The soil loss collected for two years from 78% stone covered plot was relatively smaller than the soil loss from the plots under graded terraces. The two years mean soil loss value from 78% stone covered plots was 1.6 t/ha/y as compared to the soil loss value of 1.7 and 3.4 t/ha/y from graded fanya juu and graded bund respectively.

The SCRP (1983) report from Ethiopia shows that annual soil loss from Wollo Research Station was less than the tolerable limit and it was explained by the presence of dense stone cover and crop (maize) cover during August in which the highest rainfall erosivity was recorded. The plots were 15 m long and 2 m wide at about 37% slope. The annual soil loss in the plot with dense stone cover was 2 tonnes per hectare in which the soil loss tolerance is estimated to be about 6 tonnes per hectare per year.

The evidence so far presented indicates that stone cover can significantly reduce losses of soil and water. There is also evidence that as well as increasing infiltration, stone cover can reduce losses of water by evaporation from the soil which will be discussed in the next section.

2.1.2. Effects of stone cover on evaporation

In the low rainfall regions of China, where the rainfall is near the minimum for crop production, pebbles mixed with sand are spread over the field in a layer of 10 to 15 cm (Tsiang, 1948). This pebble mulch helps to absorb rain water, to check erosion, to reduce evaporation and to narrow the temperature fluctuation between day and night. Wang Qinghua (1988) reported on the effectiveness of sand or pebble layer above dry fields in combating drought. These pebble mulches enable farmers in the central Gansu regions of China to grow crops such as wheat, melon, and tomatoes which, otherwise, is impossible to have harvest since the annual evaporation is 6.8 times higher than the annual precipitation.

The use of gravel mulch on a fallow surface has high potential for soil and water conservation over a wide range of soil texture in the semi-arid regions of U.S.A. (Adams 1967, Fairbourn 1973).

Large pores of gravel permit rapid infiltration of water to the soil and the less capillary action of these large pores due to this mulching retard evaporation. Fairbourn (1973), reported that crop yield increases for drought seasons were 2 to 4 times higher for gravel mulch than for a bare soil mainly due to more conserved soil water.

Different results with the soil surface covered by gravel were reported by Benoit and Kirkham (1963) and Hanks and Woodruff (1958) for studies conducted in the laboratory. In the study of Benoit and Kirkham (1963), dry soil, gravel and maize cob mulches were placed on the surface of previously wetted soil. Each mulching material reduced water loss compared to the unmulched soil, and gravel mulch was more effective than the soil mulch. Unmulched soil core lost 1.25 to 5 times more water than the mulched cores by the end of 600 hours at room temperature.

On the contrary a gravel mulch was less effective than a soil mulch in the study by Hanks and Woodruff (1958). However in the study the mulches were separated by screens from the saturated soil, and water losses occurred in the vapour phase. The greater water losses from gravel mulch resulted from greater vapour conductivity through the larger pores of the gravel mulch than through the smaller pores of the soil mulch.

In general the discussion so far indicates the importance of stone cover to retain soil moisture for longer periods to be used by crops. On the other hand removing stones increases both soil loss, runoff and evaporation which is dealt in the next section.

2.1.3. The impact of removing stones on erosion and runoff and evaporation.

Stones in agricultural fields are noticed mainly for the problems they pose on agricultural activities specially on mechanized farms. Information in regard to their action on soil and water conservation is of value in small scale farms where the major activities are performed manually. A decrease in infiltration and an increase in runoff and soil loss as a result of removing stones from the fields of stony soils was observed by many investigators (Epstein et al., 1966, Grant and Struchtmeyer, 1959, Lamb and Chapman, 1943, Box, 1981 and SCRP Report, 1986).

According to Epstein et al. (1966), a field study established on gravelly silt loam soil on 8% slope under natural rainfall conditions, removing stones over 3.81 cm in the longest diameter increased soil loss from a four-year period by 47%, 27%, 13% and 30% more than the control plot where stones were not removed. The runoff was shown to have the same trend.

Seginer et al. (1962) as reported by Box (1981) showed that on the average, stone removal from plots with 28% to 62% stone cover increased erosion 12-fold in the Tera Mountain regions of Israel.

Stones from the hillsides were removed and heaped by the ancient settlers of the Negev in order to increase the amount of flood runoff water from the hillsides to be used in the down slope plains for growing crops. Evenari et al. (1971) constructed runoff plots at different percentages of land slopes and stone cover and explained why stone mounds were constructed on the hillsides of the Negev by ancient settlers. They reported that runoff was maximum on the plots, where the surface stones were raked and removed completely than the plots with natural stone cover.

An early study in U.S.A. conducted by Lamb and Chapman (1943) have shown that surface stones increase water intake of soil and reduce evaporation. They demonstrated that removal of stones greater than 5 cm in diameter from a 20% slope with stones covering 18% of the surface almost doubled the water loss and increased the soil loss more than six times. Soil loss and runoff from four rainfall events were respectively 5.5 and 1.4 times less with the 65% stone cover than with 18% stone cover. Similarly soil loss increased greatly in the Wollo Region Research Station, Ethiopia, when stones were removed in the runoff plots to construct stone bunds (SCRP 1986).

The works of researchers quoted in the previous sections give an evidence to draw a conclusion that surface stone covers on agricultural lands influence the erosion process significantly by reducing the amount of soil loss, runoff as well as evaporation. However, the extent of their effect in predicting soil loss using the USLE and to which USLE factor their effect should be incorporated is not clearly defined. Therefore, a very brief explanation of USLE and the different methods suggested by different authors is presented in section 2.2.

2.2. Adjustment of the Universal Soil Loss Equation Factors to Stony Soils.

The most extensively researched and commonly used method of estimating sheet and rill erosion from rainfall and runoff is the Universal Soil Loss Equation. It was developed and refined on the basis of nearly 10,000 plot-year of runoff plot data (Wischmeier and Smith 1978) and it uses empirically derived relationships and, therefore, is expected to give the most reliable estimates of erosion for conditions which closely resemble those from which the model relationships were developed: medium textured agricultural soils with slopes from 3 to 18% and less than 122 metres in length (McIssac et al. 1987).

The factors in the Universal Soil Loss Equation are measures of the effects of climate, soil, topography and landuse on erosion. The factors in the equation are:

$$A = R\ K\ L\ S\ C\ P$$

where

A is the average annual soil loss,

R is the rainfall erosivity factor,

K is the soil erodibility factor,

C is the cover and management factor,

P is the conservation support practice factor and L and S are the topographic factors for slope length and steepness respectively.

The equation was derived in English units and has been subsequently converted into both metric and SI units (Wischmeier and Smith 1978, Mitchell and Bubenzer 1980 and Foster et al. 1981). Foster et al. (1981) converted the Universal Soil Loss Equation factors step by step. Based on these converted factors of the equation to SI units the numeric values of R and K are different from the English (US customary) units so that one should know whether they are in English or SI units before he decides to use.

2.2.1 Rainfall erosivity factor (R).

The rainfall erosivity factor was determined by the energy imparted to the soil surface by raindrop impact (Wischmeier 1959). He found that the product of the kinetic energy of a storm and the 30-minutes maximum intensity (I_{30}) was the most reliable estimates of the rainfall erosion and it is termed as EI_{30}. Annual totals of storm EI_{30} value divided by 100 is referred to as the rainfall erosivity factor (R) in US customary units.

This erosivity index was tested and is still under test in different regions of America and outside America (Bollvinne, 1985, Ulsaker and Onstad, 1984, Lal, 1976, Hudson, 1981, McGregor and Mutchler, 1977, Amezquita and Forsythe, 1985 and Lo et al., 1985).

The R-factor is the sum of individual storm erosivity values, EI_{30}, usually averaged to get the average annual from many years of rainfall data. Storms of less than 12.5 mm and those separated from other rain periods by more than 6 hours are not included in the computations unless as much as 25 mm/h of rainfall occurs in 15 minutes (Foster et al. 1981). Mathematically the values of R is determined as:

$$R = \sum_{j=1}^{n} (EI_{30})_j \tag{1}$$

where

R is the annual rainfall erosivity factor in MJ.mm/ha/h/y,

n is the number of storms in the given year,

I_{30} is the maximum 30-minutes intensity in mm/h for a given storm and

E is the total energy in a given storm in MJ/ha.

E is the sum of all the incremental energies computed from the empirically derived equation of Wischmeier and Smith (1978) such that:

$$e = 916 + 331\mathrm{Log}_{10}I \qquad (2)$$

where

e is energy per unit rainfall in foot-tons per acre-inch and

I is the rainfall intensity in inches per hour.

Later equation (2) was converted to SI units by Foster et al.(1981) and the constants of the equation became as follows:

$e_m = 0.119 + 0.0873\mathrm{Log}_{10}I_m$ for I_m less than 76 mm/h and (3)

$e_m = 0.283$ for I_m greater than 76 mm/h (4)

where

e_m is in MJ/ha/mm and I_m is in mm/h.

2.2.2. Soil erodibility factor (K).

The erodibility of a soil is a quantitative measure of its susceptibility to erosion. A soil with high erodibility will suffer more erosion than a soil with low erodibility if both are exposed to the same rainfall. The soil erodibility depends upon many variables such as soil physical properties, topography, and management of the land which makes its assessment more complicated(Hudson 1981).

However the soil erodibility factor of the Universal Soil Loss Equation for a given locality can be computed using the ratio of the soil loss of a storm to the erosivity index as measured on the standard unit plot (wischmeier and Smith 1978). A standard unit plot is 22.13 m long with a uniform slope steepness of 9% in continuous fallow tilled up and down slope for more than two years.

Wischmeier and Mannering (1969) related soil erodibility to soil properties using data collected from a rainfall simulation studies on 55 soils. The rainfall simulation procedure of Wischmeier and Mannering(1969) were to apply an initial run for 60-minutes, then after 24 hours, to apply two 30-minutes storms of wet and very wet runs separated by about 15 minutes, all at 63.5 mm/h. The erosivity factor, R-values for each 30-minutes of rainfall was 25 US customary units which is equivalent to 425.5 MJ.mm/ha/h in SI units using 17.02 as a conversion factor given by Foster et al. (1981).

Using those soil loss and erosivity data Wischmeier et al. (1971) presented a soil erodibility nomograph. The nomograph was based on the relationship between the soil erodibility factor and soil physical properties (texture, organic matter content, soil structure and permeability).

The measured K-values in West Africa (Roose 1977b) were in a good agreement with those predicted using the nomograph of Wischmeier et al.(1971). Roose (1977b) concluded that the application of the soil erodibility nomograph in evaluating the susceptibility of soils to erosion was satisfactory for the ferrallitic and ferruginous soils studied, with the exception of soils that were gravelly or covered with rocky debris that gave a very low measured K-values. Gerolf Weigel (1986) used the nomograph to derive the erodibility factors for the Maybar areas of Wollo, Ethiopia, and concluded that the nomograph overestimates for the soils with widespread surface stone layers in the survey area.

There is no common agreement among erosion scientists on how to consider the effects of stones or rock fragments on soil loss. Hurni (1987) considered the effects of dense stone cover to be accounted in the conservation support practice factor (P) such that he assigned 0.8 as the value of P for 40% stone cover which is the same as its value from strip cropping.

McCormack et al. (1984) suggested that the effect of rock fragments should be included in the soil erodibility factor since rock fragment content is a soil property. Similarly Wenner (1980) considered the effect of gravel and stones on the soil loss to be accounted in the K-factor and he pointed out that gravel and stones on the ground can reduce the K-factor by half, if the cover of stone is at least 10 - 20 %.

Others suggested the effect of stones to be included in the Cover and Management C-factor of the Universal Soil Loss Equation mainly because their effect on soil loss is due to their mulching effect (Romkens, 1985, Box and Meyer, 1984 and Box, 1981). Box and Meyer (1984) strongly argued that the effect of stones on soil loss is best considered in the C-factor rather than the K-factor because stones or other coarse materials greater than 2 mm are normally excluded in the analysis of soil material for textural classification.

2.2.3 Cover and management factor (C).

C-factor in the Universal Soil Loss Equation is the ratio of soil loss from land cropped under a specific condition to the corresponding soil loss from a standard unit plot. This factor measures the combined effects of all the interrelated cover and management variables (Wischmeier and Smith 1978). This factor of the USLE in relation to stony soils is presented in chapter 2.3 in more details.

2.2.4 Topographic factors (LS).

The effect of the slope length and slope steepness is included to the Universal Soil Loss Equation as a topographic factor. It is defined as the ratio of soil loss from a field slope to the soil loss from the Standard Unit Plot. The standard unit plot is 22.13 m long and 9% steep. The LS factor for a unit plot is 1. For plots other than standard unit plot the LS factor is adjusted using the following equation given by Wischmeier and Smith (1978).

$$L = (l/l_u)^{\blacksquare} \qquad (5)$$

$$S = 65.4\sin^2 B + 4.56B + 0.0654 \qquad (6)$$

where:

L is slope length factor (dimensionless),

l is the slope length of the plot in (m),

l_u is the slope length of the unit plot (22.13m),

S is the slope steepness factor,

B is the slope angle in degrees and

m is an exponent that depends upon local conditions and 0.5 was taken for Katumani (Kilewe 1987) and Wenner (1980) recommended 0.6 for slope more than 10% an average value being 0.5.

2.2.5 Conservation support practice factor (P).

The P-factor is defined as the soil loss from a given conservation practice to the corresponding soil loss from a unit plot under the same conditions of soil and climate (Wischmeier and Smith 1978).

The values of the USLE factors are extensively researched and well documented for agricultural lands and similar conditions with fine to medium textured soils. It is also possible to predict erosion rates in stony soils of agricultural fields by adjusting the USLE factor which is affected by the presence of stones preferably the C-factor. Without such an adjustments of the USLE factor values, the equation is likely to overestimate the amount of soil erosion. In the next section the significance of the C-factor, the different methods used by soil erosion researchers to compute its value from both cropped stony and non-stony soils is briefly reviewed.

2.3 Computing the Cover and Management (C-factor) of the Universal Soil Loss Equation.

The cover and management C-factor of the Universal Soil Loss equation (USLE) is the ratio of soil loss from an area with specific cover and management to that from an identical area of tilled continuous fallow (Wischmeier and Smith 1978). The C-factor indicates the effect of variables related to cover and management on soil erosion.

Using statistical analysis of data from more than 10,000 plot-years of soil loss, Wischmeier (1960) and later Wischmeier and Smith (1978) computed the value of cover and management factors for several crop rotations and crop stage periods. The amount of reduction in soil loss from cropped fields depends on the particular combination of percent cover, crop sequence and management practices. Because of such variations Wischmeier and Smith (1978) presented a procedure for deriving the local values of C-factor on the basis of percent surface cover provided by the growing crop and the erosivity index distribution. Wischmeier and Smith considered five crop stage periods. A crop stage period is defined as a period within which cover and management effects may be considered approximately uniform.

The ratio of soil loss from a given crop stage period to the corresponding soil loss from a clean tilled continuous fallow was multiplied by the rainfall erosion index (erosivity) ratio of that particular period to give the C-factor value of the particular crop stage period. Then the annual value of C-factor for any particular crop and management system on a given field is the sum of all the C-factor values for each of the five crop stage periods and the fallow period (Wischmeier and Smith 1978) or, for Indian conditions, the sum of the three crop- stage Periods (Gurmel Singh et al. 1985).

The average annual value of C-factor for any particular field is computed by summing all the crop stage C-factor values of each year and dividing by the number of years. To determine the annual or seasonal C-factor value of an area using this procedure requires a knowledge of soil loss ratios with bare and fallow plots, otherwise, one will be forced to use tables for the soil loss ratios that are mainly computed for situations relevant to the United States. Moreover the existing values of C-factor for non-agricultural lands such as construction sites published by Wischmeier and Smith (1978) are mainly from studies of the effects of straw, cornstalk and crushed stone mulches on erosion from plots of cropland and construction sites.

Foster (1982) listed the problems of the application of the USLE C-factor to those conditions different from where the model relationships were developed. For West Africa, Roose (1977a) presented the C-factor value for a range of cultural practices and crops considering only the annual soil loss ratios. This procedure may be a good approach in areas where information on the seasonal variation in vegetal cover and erosivity index ratio is lacking.

Foster (1982) considered the various kinds of cover including stones that affect erosion and asked how much do they affect erosion, and how the factor values for stones are related to plant characteristics that are easily measured and classified. Someone can ask whether percent ground cover is an adequate measure for all types of surface cover, or is stone less effective than plant litter and crop residues for the same percent surface cover?

Box (1981) and Box and Meyer (1984) showed that the effects of surface rock fragments were similar to the effects of residue cover. Box (1981) gave three options for adjusting the USLE for the mulching effect of soil surface by slaty fragments on soil erosion. The three possible options were:

1) to adjust the soil erodibility K-factor,
2) to adjust the cover and management C-factor and
3) to develop a new seventh factor as a function of the surface mulching effect of rock fragments which was referred as an "armouring" factor.

However until sufficient data are available to adjust the K-factor or add an armouring factor to the USLE, Box (1981) concluded that the effect of the slaty fragments can be included in the C-factor. The relationship between soil loss ratios and percent surface cover made by slaty fragments was similar to the curve for residue cover with 0% canopy cover as illustrated in figure 1.

Page (1982) suggested that the estimated soil loss values using USLE can far exceed the actual values if surface rock covers are ignored. He tried to estimate soil loss values by incorporating the rock fragments in the USLE in different ways:

1) by adjusting the soil erodibility K-factor,
2) by adjusting the C-factor and
3) by adjusting the K and C-factors.

Soil loss values calculated by incorporating the rock fragments to adjust the K-factor were too high when compared to the actual soil loss values but the soil loss values were quite similar when rock fragments were used to adjust the C-factor or C plus K-factors.

The formulation of a new procedure for estimating the cover and management C-factor to be used in the USLE for several conditions were described (Wischmeier, 1975, Mutchler et al., 1982, and Dissmeyer and Foster, 1981). Wischmeier (1975) showed the determination of the C-factor by considering the effects of the three distinct sub-factors:

1) canopy cover,
2) surface mulch and
3) residual effects of landuse.

Mutchler et al. (1982) computed the C-factor for cotton following the sub-factor approach of Wischmeier (1975). Laflen et al. (1985) developed a procedure to determine the values of the C-factor on daily basis using the sub-factor method and the equation they recommended for computing the C-factor value is:

$$C = (PLU)*(CC)*(RC)*(SR)$$

Where PLU is the prior landuse sub-factor, CC is a crop canopy sub-factor, RC is a residue cover sub-factor and SR is a surface roughness sub-factor.

Israelsen et al. (1980) as reported by Jenning and Jarret (1985) defined and listed a vegetative mechanical factor (VM) for various mulching materials. This factor was designed to replace the C and P-factors of the USLE and its value ranges from 0 to 1 unlike the others described above.

Recent studies have shown that surface cover affects soil loss with an exponentially decaying functions such that the soil loss decreases exponentially with increased percent surface cover. Laflen and Colvin (1981), Cogo et al. (1983), Dicky et al. (1984), Gilley et al. (1986) and many others have shown the relationship between soil loss and percent surface cover was best correlated with the mulch factor expressed as:

$$MF = e^{(b.C)} \tag{7}$$

where:

MF is the mulch factor, ratio of soil loss from a mulched plot to the soil loss from bare plot of similar conditions, and its value ranges from 0 to 1,

C is the percent soil surface covered by residue,

e is the base of the natural logarithm and

b is a regression constant determined in an experiment and its value varies with slope steepness, soil, tillage, cropping system and other factors.

The different methods described above indicate the different approaches people used to establish the effects of surface cover on soil erosion for use in erosion modelling. However some of the above methods, even if they show high correlation between soil loss and surface cover, are still under experiment since the value of their coefficients vary from time to time and from place to place. The USLE is still widely applicable in a large range of situations and the C-factor value for stony soils can be computed by combining the percent surface cover made by stones and growing crops at different crop stages taking care of the overlap made by the stone and crop cover.

The various work of researchers quoted so far indicates the complexity of erosion research to determine the dominant factors affecting erosion and to establish their predictive models. The USLE is still a strong tool for soil erosion researchers and conservation planners aiming at promoting soil conservation.

In places where stones on the surface of the soil are in plenty their effect on soil loss and runoff should be included to the USLE factors so that the predicted soil loss and runoff would be nearer to the actual losses.

It should also be pointed out that the runoff and soil loss data of the present study was generated from simulated stone cover of the soil surface under natural rainfall conditions in which the plots were kept without any vegetation for the study period to see the effect of these simulated stone covers alone. Results obtained from this kind of experimentation are therefore, highly indicative but firm conclusions can not be drawn until experiments are carried out in the field on stony soils under natural conditions.erved in this experiment.

3. MATERIALS AND METHODS

3.1 THE SITE.

The major part of the research was conducted on runoff plots installed at Kabete, Nairobi University Field Station, which lies on 1^0 15' latitude south and 36^0 44' longitude east. The altitude is approximately 1930 metres above sea level.

The soils of the site are deep and well drained with about 18% sand, 58% clay and 24% silt for the soil sample taken from the top 20 cm (Gachene 1989) or 22% sand, 54% clay and 24% silt for the soil sample taken from the top 30 cm (Tefera 1983). Also the proportion of sand, clay and silt was respectively about 32%, 8% and 60% for the soil sample taken from 0-3 cm depth of the surface soil within the plot. The higher silt content and the lower clay content of the surface soil may be due to the surface wash of clay particles aggregated on silt or the selective removal of clay particles by erosion. The soils as described by Sombroek et al. (1982) are a eutric nitosol developed on tertiary trachytic lava with erodibility factor K-factor value of 0.04 (Barber et al. (1979).

The average annual rainfall as computed from 18 years of rainfall data is 1024 mm with a bimodal distribution comprising short rains, from October to December, and long rains, from March to May. The mean monthly distribution of rainfall is presented in fig.2. There was a very heavy storm (183 mm) on 18th of May 1989 with a return period of about 25 to 50 years. The contribution of the short rains and the long rains to the annual rainfall, as computed from the means of the last 18 years using the rainfall data collected in the Agromet Station which is about 500 metres from the runoff plots, was 27% and 51% respectively.

3.2 PAST LANDUSE HISTORY OF THE SITE.

For the past 18 years the land used for the runoff plots was under different crops and pasture. The major past landuse systems of the site is presented in table 1.

Table 1. The landuse history of the research area since 1975.

Period	Landuse System
1975-76	Pasture
1977-80	Maize, Beans and potatoes
1981	Potatoes
1982-83	Bare but grass strips on the lower end of the plots.
1984-87	Maize on long rains and beans on short rains and grass strips on the lower ends.
1988 (long rains)	Maize on six plots and beans on the other six plots.

Source : Tefera, F. (1983) and field assistants.

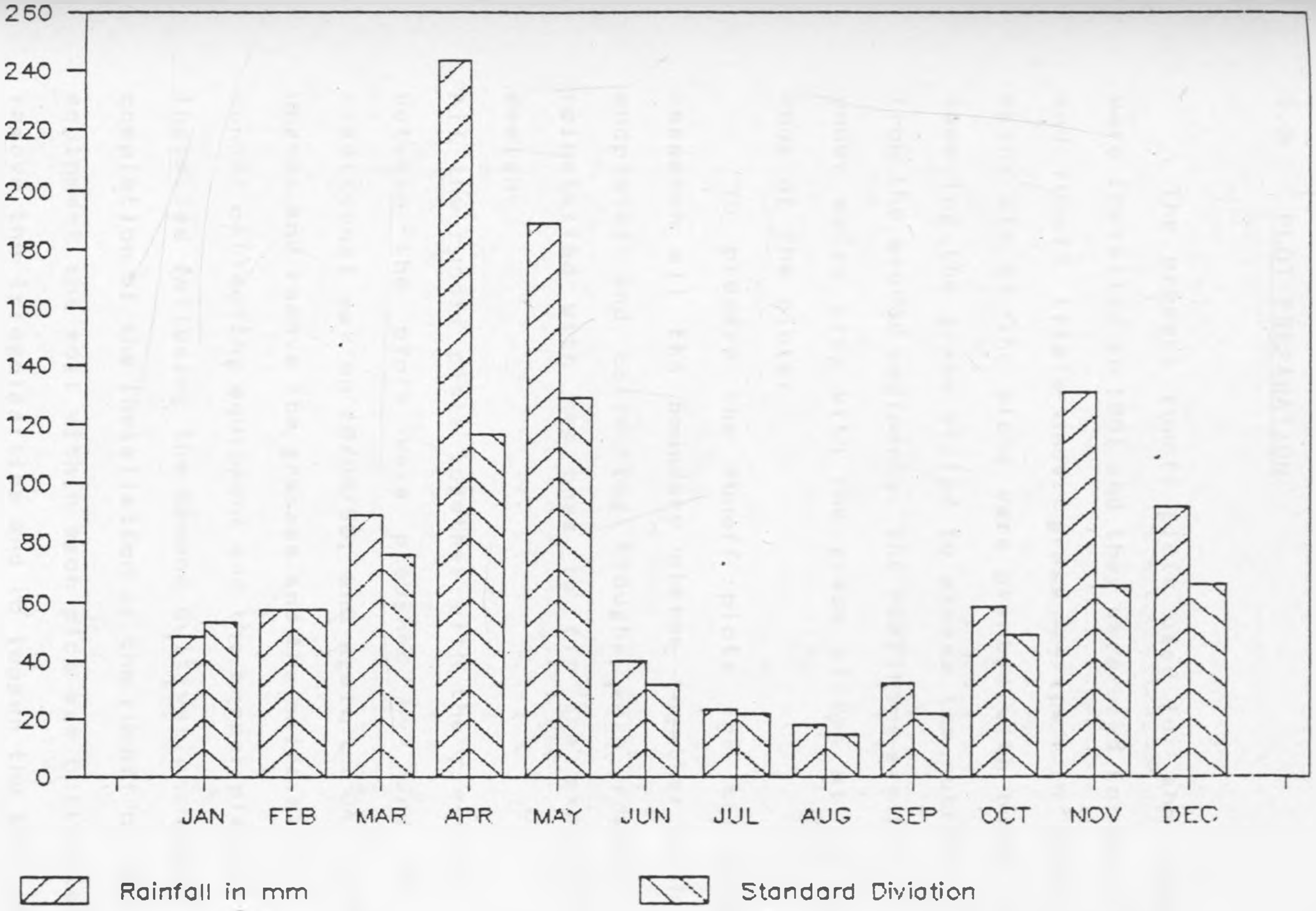


Fig. 2. Monthly Rainfall Distribution at Kabete
(Means of 18 years)

3.3 PLOT PREPARATION.

The present runoff plots used for the research were installed in 1981 and they were used for soil loss and runoff trials under grass strips. In 1986 long rains six of the plots were planted with beans after removing the grass strips to assess the nutrient loss from the eroded sediments. The remaining six plots were under maize crop with the grass strips at the lower ends of the plots.

To prepare the runoff plots for the present research all the boundary plates together with the endplates and collecting troughs were removed and reinstalled with new ones to fit the experimental design.

All the runoff plots together with the piece of land between the plots were ploughed by hand in the traditional way on 18/08/88, and again on 04/10/88 to uproot and remove the grasses and the maize stalks. The runoff collecting equipment and the border plates were installed following the second cultivation. After the completion of the installation of the runoff collecting equipment the soil within each plot was cultivated to remove the irregularities and to loosen the soil which had been compacted by stepping during the installation of the border plates and runoff collecting equipment.

The plots were ready on October 1988 and were used to measure runoff and soil loss during the natural rainfall in the short rains of 1988, in the long rains of 1989 and during the simulated rainfall on March 1989.

3.4 PLOT SIZE AND LAYOUT.

The size of each plot was 11.6 metres long and 2 metres wide, the longest side running up and down the slope. The plots within each replication were separated by a 50 cm buffer space and the distance between replications was 3 m wide. Every plot was enclosed by a galvanized sheet metal strips to define the boundaries, and collecting equipment at the lower end of the plots to collect runoff and eroded soil.
The dimensions and the general orientation of the runoff plots used for the experiment is shown in figure 3.

3.5 RUNOFF COLLECTING EQUIPMENT.

The runoff collecting equipment consists of the border plates and end plates,collecting troughs, channelling pipes and storage tanks.

3.5.1 Border-plates.

Plots for each treatment are separated and bounded by a 24 gauge galvanized sheet-metal of size 25 cm wide in which 15 cm was driven into the ground so that any runoff was not allowed to get into or out of the plots.

The sheet metals are supported by a rounded iron rods of 8 mm in diameter at every one metre along the length of the plots. The iron rods were folded to hold the boundary plates at the joints tightly in both sides.

3.5.2 End-plates and Collecting troughs.

The runoff collecting troughs are connected to the lower ends of the plots firmly by the end plates to prevent any runoff water passing under the troughs as seepage.

Sediment deposition in the collecting troughs used by Tefera (1983) on the same site reduced the capacity to discharge runoff. Therefore, the collecting troughs were designed and fabricated with a 10% gradient towards the centre from both ends to let the runoff with the eroded soil be easily conveyed into the conveyer pipe as shown in Figure 4. Details are also given in appendix-10.

The design runoff rate was based on 120 mm/h, the expected 5 minutes maximum rainfall intensity, with 100% runoff coefficient as recommended by Mutchler et al. (1988).

All the troughs and end-plates were covered with a 24 gauge galvanized sheet-metal to prevent any rain and splash outside the plots entering into the troughs.

3.5.3 Storage Tanks and Conveyer Pipes.

The runoff and sediment collected into the troughs was channelled into the storage tank by a 7.5 cm diameter PVC pipe at a minimum slope of 12%. Small containers (dustbins) of 60 litres capacity were placed inside the tanks to hold eroded sediment and runoff of small storms for easier handling and sampling of the sediments and runoff.

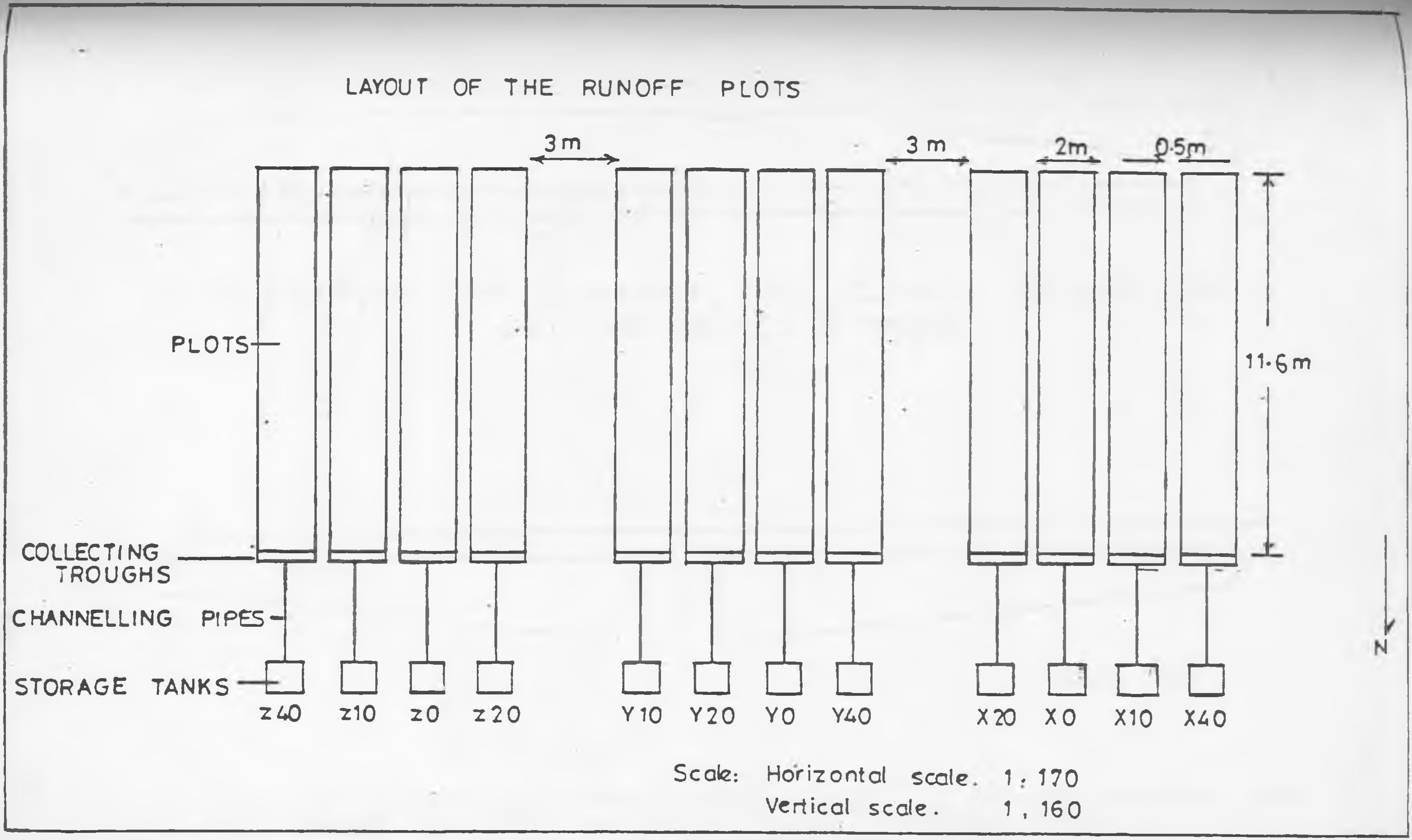
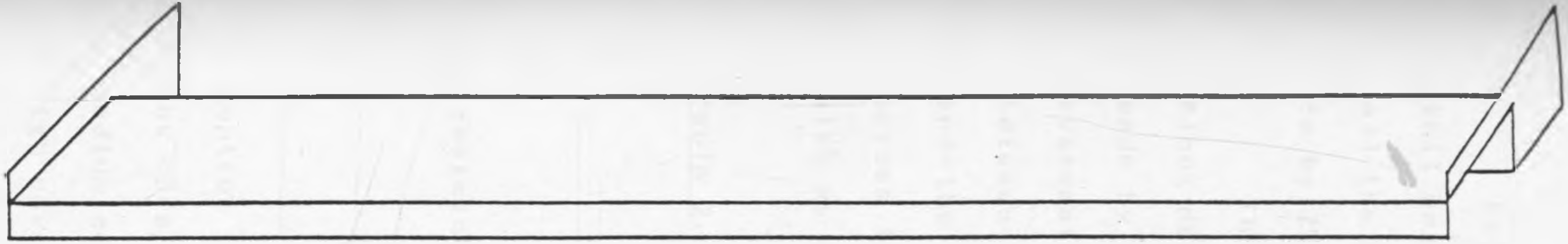
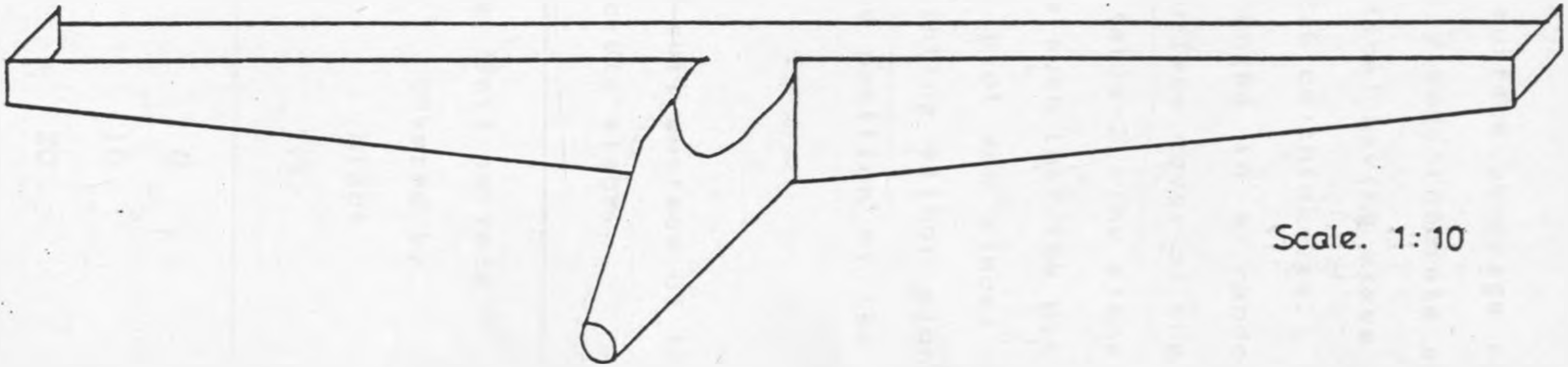


Fig. 3. LAYOUT AND DIMENSIONS OF THE RUNOFF PLOTS USED FOR THE EXPERIMENT



4a. END PLATE USED TO MAKE A FIRM CONTACT BETWEEN THE SOIL AND COLLECTING TROUGH.



4b. THE RUNOFF COLLECTING TROUGH USED TO CHANNEL RUNOFF AND ERODED SOIL FROM THE PLOTS TO THE STORAGE TANKS.

Fig.4. THE END-PLATE AND THE RUNOFF COLLECTING TROUGH USED IN THE EXPERIMENT

3.6 TREATMENTS.

Four different rates of surface coverage of the soil were tested using specially made concrete slabs. All the slabs were almost identical having sizes of 20 cm by 20 cm surface area and 2.5 cm thickness.

The treatments were arranged in a randomized block design and the percent surface cover of the soil made by the slabs is shown in table-2. The slabs were systematically put on the plots such that the distance between the slabs within each plot was almost equal and the corner edges were pointing either along or across the length based on the position of the next slab as shown in plate 2.

Table 2. The percentage of the soil surface of the plots covered by concrete slabs.

Treatment	No. of Slabs	Surface area covered by Slabs (m^2)	Soil surface covered by Slabs (%)
Control	0	0	0
Low cover	60	2.4	10
Medium cover	120	4.8	20
High cover	240	9.6	40

3.7 SIMULATION OF RAINFALL AND RUNOFF.

3.7.1 Simulation of rainfall.

Rainfall was simulated using a simple portable rainfall simulator, described by Moges Worku (unpublished M.Sc. thesis), on all the twelve plots in March 1989 before the long rains had started. The length of the plots was reduced to 5 m instead of 11.6 m to match the size of the simulator. The average rainfall intensities applied were:

1) 79 mm/h for 60 minutes initial run with the existing soil moisture content,
2) 84 mm/h wet-run for 20 minutes after 24 hours interval following the dry-run
3) 82 mm/h 1st very wet-run for 20 minutes after 20 minutes interval following the wet-run and
4) 81 mm/h 2nd very wet-run together with three rates of inflow water for 50 minutes after 5 minute interval of the 1st very wet-run.

The amount of rainfall applied to each plot was recorded using nine catch cans of identical opening diameter and the intensity was determined using the recorded rainfall amount for each run. The catch cans were put as shown in figure 5 and plate 3 to minimize the splash water coming from the frames of the simulator.

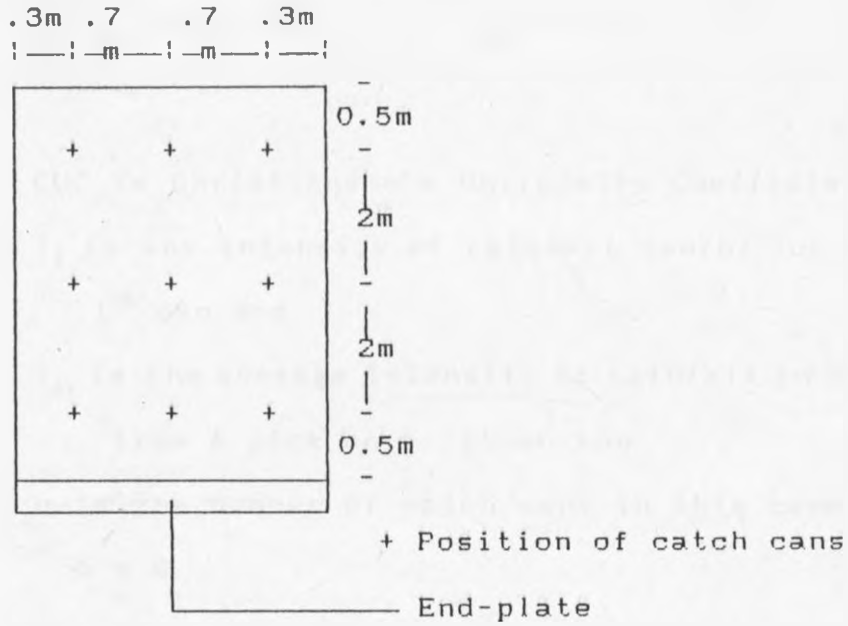


Figure 5. Position of catch cans used to collect water for intensity measurement during the simulated rainfall.

The design intensities for each of the dry-run, wet-run, 1^{st} very wet-run and the 2^{nd} very wet-run were determined by taking the average of all the intensities from every plot for the particular run because the intensities from different plots were not exactly the same even if much effort was given to regulate the variation.

The actual intensities of rainfall and the coefficient of uniformity calculated using Christianson's formula is shown in appendix 11.

$$CUC = 100* \{1-[\quad |I_i - I_{av}|/(n * I_{av})]\} \qquad (1)$$

where

CUC is Christianson's Uniformity Coefficient,

I_i is the intensity of rainfall (mm/h) for the i^{th} can and

i_{av} is the average intensity of rainfall in mm/h from a plot on a given run

n is the number of catch cans in this case $n = 9$

I_i was computed as

$$I_i = V_i/[(22/7/4)*d^2]*(60/t) \qquad . \quad . \quad . \; (2)$$

where:

V_i volume in ml, d is the diameter of the opening in mm and

t is the time of rainfall application in minutes.

The soil loss and the runoff for each run was adjusted to the design intensities as suggested by Meyer (1988) as follows:

$$SL_{adj} = SL_{\blacksquare} * (RI_d/RI_{\blacksquare})^2 \qquad (3)$$

$$RO_{adj} = RO_{\blacksquare} + (RI_d - RI_{\blacksquare}) \qquad (4)$$

where

SL_{adj} is adjusted soil loss in t/ha,

SL_m is the actual measured soil loss in t/ha,

RI_d is the design rainfall intensity in mm/h,

RO_{adj} is the adjusted runoff in mm and

RO_m is the actual measured runoff in mm

3.7.2 Simulation of runoff.

Three different rates of inflow water was applied as overland flow across the upper end of each plot in the two replications coded as block Y and block Z in figure 3, to see their effects on longer slopes since the runoff plots used for simulated rainfall were only 5 metres long and the runoff produced was not as it was expected from such high intensity storms.

To evaluate the retarding effects of the treatments on runoff velocity an attempt was made to simulate the slope length by adding different rates of water as a runoff. Therefore water was added into the plots uniformly from the upper end of the plots in which a continuous flow of runoff was maintained.

The simulated slope length was computed as suggested by Laflen (1982) as follows:

$$X = L * (1 + (Q_a/Q_m) \qquad (5)$$

where

X is the new slope length in metres,

L is the actual length of the plot in this case 5m,

Q_a is the added flow rate (l/min) and

Q_m is the measured runoff rate in the 1st very wet-run after constant rate was maintained (l/min)

The rate of added water to each plot was regulated with a constant head method where the water level in the supply tank was kept constant. Two tanks connected by hose pipes to the main water line each having 0.75 m^2 surface area and 0.45 m^3 capacity were used as a supply tank. Three hose pipes of identical size connected to one of the supply tank in which the water level was regulated were supplying water to a trough. The trough supplied water uniformly as overland flow to the upper end of a plot with small perforations on one of the sides as shown in plate-4 and figure 6.

After 5 minutes following the 1st very wet-run the following rates of inflow water together with 81 mm/h rainfall were applied for 50 minutes.

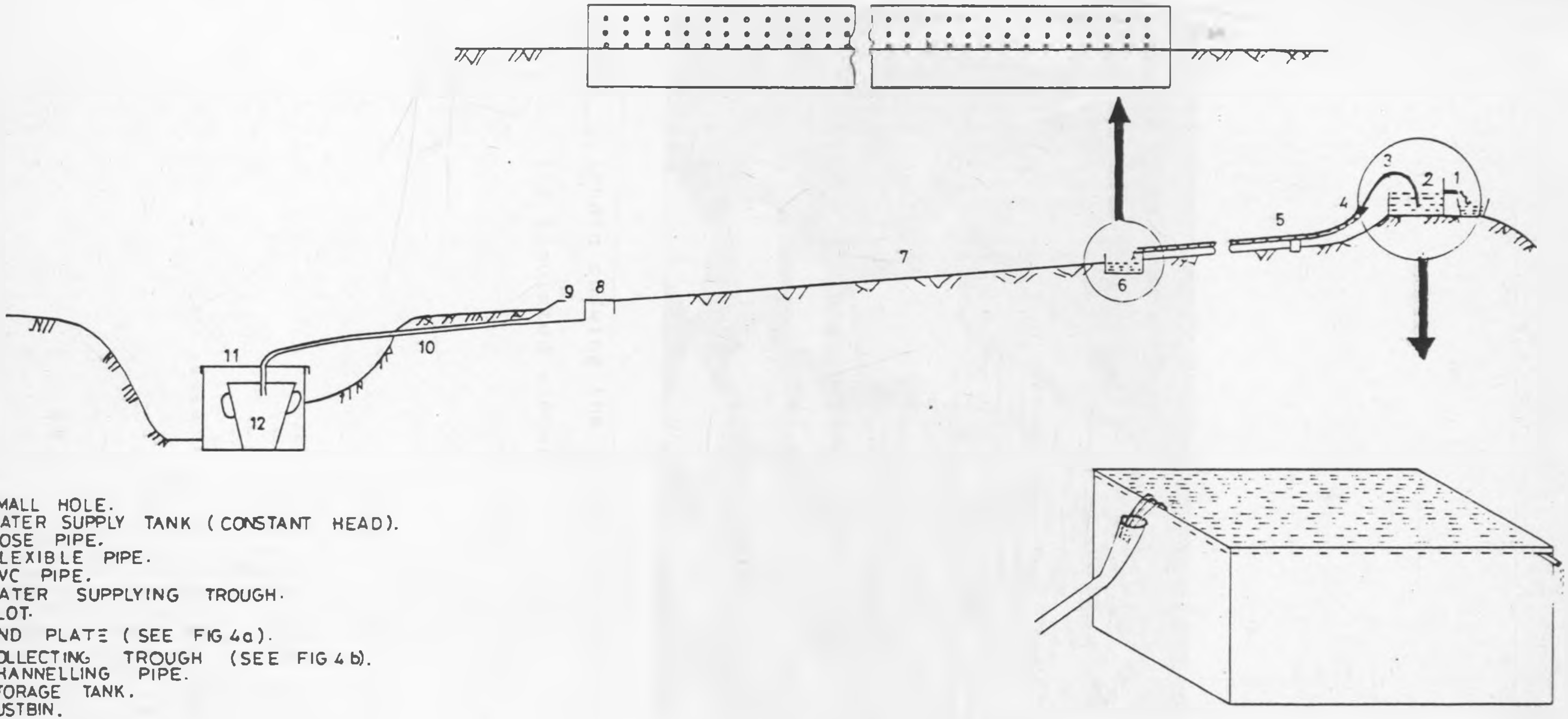
a) 0 l/min. for 5 minutes

b) 8 l/min. for 15 minutes

c) 16 l/min. for 15 minutes

d) 24 l/min. for 15 minutes.

FIG-6 SECTION VIEW OF THE RUNOFF PLOTS.
ALL THE ITEMS FROM 1-6 WERE USED ON RUNOFF SIMULATION ONLY.



1 SMALL HOLE.
2 WATER SUPPLY TANK (CONSTANT HEAD).
3 HOSE PIPE.
4 FLEXIBLE PIPE.
5 PVC PIPE.
6 WATER SUPPLYING TROUGH.
7 PLOT.
8 END PLATE (SEE FIG 4a).
9 COLLECTING TROUGH (SEE FIG 4 b).
10 CHANNELLING PIPE.
11 STORAGE TANK.
12 DUSTBIN.

Plate 2. Photo showing the staggering arrangement of the simulated stones.

Plate 3. Arrangement of catch cans during the rainfall simulation

Plate 4. The trough used to supply water uniformly as overland flow (Photo was taken after the experiment was completed)

3.8 COLLECTION OF DATA.

3.8.1 Measurement of Rainfall.

The daily amount and intensities of rainfall were obtained for each storm using a recording rain gauge installed on site between plots (plate-5). A non-recording rain gauge was also installed near the recording rain gauge to collect the amount of daily rainfall to be used as a check and to avoid losses of data if the recording gauge malfunctions. The recorded rainfall data was used to compute the rainfall and runoff erosivity factor (R) of the Universal Soil Loss Equation.

The rainfall erosivity factor (R) is the product of the total energy of a storm and the maximum 30 minutes intensity of that particular storm.

The rainfall energy of each storm was computed using the formula:

$$e_i = [0.119 + (0.0873 * \text{Log}_{10} I_i)] A_i \qquad (6)$$

$$E = \sum (e_i) \qquad (7)$$

$$R = E * I_{30} \qquad (8)$$

where

e_i is the rainfall energy for a uniform increment i.e. a period of constant intensity during a storm (MJ/ha/h),

I_i is the rainfall intensity (mm/h) for the i^{th} increment,

A_i is the rainfall amount for the increment (mm),

E is the total rainfall energy for an individual storm (MJ/ha) and

R is the rainfall erosivity factor of the Universal Soil Loss Equation for a storm (MJ.mm/ha/h) and the sum of all the R values divided by the number of years will be the annual erosivity factor value in MJ.mm/ha/h/y.

3.8.2 <u>Measurement of Runoff</u>.

The data from the runoff plots were collected after every storm. A storm was considered as an erosive event when one of the plots had produced more than 5 litres of runoff. Before the runoff was measured all the troughs were checked for any sign that runoff had flowed out of the troughs but there was no sign of runoff overflowing.

The next step was washing all the endplates and collecting troughs with the runoff water from the respective storage tanks so that any soil that reached up to the end-plate was taken into account for soil loss measurement.

The total runoff collected in the storage tanks was measured with a graduated bucket of 20 litres capacity.

3.8.3 Measurement of Soil Loss.

After stirring the runoff from every full bucket completely two litres samples from each full bucket were taken and all the samples were mixed so that one litre representative sample was taken from the mixture to determine the sediment concentration of the runoff. A further one litre more sample was taken when the remaining runoff did not comprise a full bucket.

After removing the runoff and the suspended sediment, about 200 grams of sediment was taken from different points to determine the particle size distribution of the eroded sediment before disturbing it to compare with the particle size distribution of the soil samples taken from the surface of the plots at 0-3 cm depth. The sediment samples were taken in such a way that for small storms when the sediment was only in the dustbins in the tanks runoff was removed and then sediment samples at the top and the bottom were taken and mixed together. For large storms when the runoff overflowed, all the runoff from the dustbin and the big tanks was removed and then sediment samples at the top and bottom of both the dustbin and big tanks were taken and mixed together for each plot.

The sediment deposited in the tanks was scooped into a bucket and weighed with a spring balance of 0.1 kg precision. Then the sediment was thoroughly mixed until a uniform consistency was made and samples of about 0.6 kg were taken so that the water content of the sediment was determined by weighing the samples before and after oven-drying for 24 hours at 105 °C.

The suspended soil in the runoff samples was made to settle using alum ($AlK(SO_4)_2.12H_2O$) as a flocculant. After decanting the clear water the samples were dried in an oven at a temperature of 105 °C. for 24 hours to determine the sediment concentration of the runoff.

3.8.4 Determination of Actual Soil Loss and Runoff.

The total soil loss for each storm is the sum of the oven-dried soil from deposited sediment and from the suspended sediment. The amount of soil loss (t/ha) was computed using a computer as follows:

$$SL = 10/A(\sum(DS_i/WS_i*TS_i) + \sum(SC_i/1000*TR_i)) \qquad (9)$$

where

SL is the total soil loss from a storm in t/ha,

DS_i is the weight of oven-dried soil sample taken from deposited sediment in kg,

WS_i is the wet weight of soil sample taken from the deposited sediment in kg,

TS_i is the total wet weight of the deposited sediment from which the i^{th} sample was taken in kg,

A is the area of the plot (m^2) in this case 23.2 m^2,

SC_i is the sediment concentration of the runoff sample (g/l) determined by oven-dried weight of soil from one litre runoff sample and

TR_i is the total volume of runoff (litres) from which the i^{th} runoff sample was taken.

Similarly the total water loss was computed by summing the water loss from the deposited sediment and runoff. It was computed by assuming 1 kg/l and 2.35 kg/l respectively for the density of water and the sediment as suggested by Hamlett et al. (1987). Thus:

$$WL1 = \{ \sum [(1-DS_i/WS_i)*TS_i] + \sum [(V_{si}-D_i/1000*1/2.35)/V_{si}*TR_i] \} \qquad (10)$$

$$WL2 = WL1/23.2 \qquad (11)$$

where

WL1 is the total water loss in litres,

WL2 is the total water loss in millimetres,

V_{si} is volume of runoff sample in litres,

D_i is the dry weight of the soil from runoff as suspension and

WS_i, TS_i, and TR_i are as described above.

3.8.5 Measurement of Erosion Rate under Simulated Rainfall.

To determine the rate of erosion at different duration during simulated rainfall of almost constant intensity, runoff samples were taken at every 5 minutes interval. The time taken to fill a 1.25 litre capacity container was recorded using a stop watch, and later in the laboratory, the exact volume of the collected runoff samples with the sediment was measured and oven-dried to determine the sediment concentration. This measurement was important because the containers were not standardized.

3.8.6 Measurement of Profile Changes of the Plots.

The profile of each plot was surveyed using a quick set level at 0.5 metre interval at the beginning and end of each of the short and long rainy seasons. The data was also used to compute the average slope steepness of each plot.

3.8.7 Particle Size Distribution Analysis.

The soil samples for particle size distribution analysis were taken from the eroded sediment deposited in the tanks. The sediment samples were air-dried and sieved with a 2.0 mm sieve to remove gravel size particles. 51.0 grams of the less than 2.0 mm soil sample (IITA, 1979) was used for mechanical analysis to determine the proportions of sand silt and clay.

Then each of the soil samples were treated and measurements were made in the following sequence.

1. Each sample was wetted with distilled water and after the soil was completely wetted hydrogen peroxide (6% H_2O_2) was added to oxidise the organic matter in the sample until frothing ceased.
2. 25 mm of calgon, prepared by mixing 33 grams of sodium hexametaphosphate and 7 grams of sodium carbonate to make one litre of solution, was added as a dispersing agent.
3. Each sample was transferred to a shaking cup and shaken for 7 minutes using an electrical shaker and then immediately was transferred to a sedimentation cylinder.
4. Distilled water was added into the cylinder until it reached 1000 ml level.

5. The soil suspension in the cylinder was stirred thoroughly with a stirrer and immediately the hydrometer was inserted and the first hydrometer and temperature readings were taken at 40 seconds after the stirrer was removed.
6. The suspension in the cylinder was kept undisturbed for 3 hours and exactly after 3 hours the second hydrometer and temperature readings were recorded.
7. After taking the second readings the sedimentation cylinders were emptied to make them ready for the next samples.

3.6.8 Measurement of Changes in Soil Depth.

The soil under the slabs were protected from detachment and the soil which was not covered was removed as shown in plate 6. The difference in depth of the soil as a result of erosion from the long rains only was measured as described below.

1. Measurements were taken at a maximum of 100 points and a minimum of 60 points for each plot.
2. The measurements were taken at 0.5m, 3.0 m, 6.0 m, 9.0 m and 11.0 m from the end-plates along the length and from 3 to 5 places alcng the width.
3. A vernier cailiper was used to measure the depth of soil removed by taking the surface of the slabs as a reference.

4. At 4 points (2 in opposite corners and 2 in opposite edges of a slab) the depth of soil removed was measured and an average value was taken along the width of each plot.
5. The depth was converted into volume and the volume occupied by the soil under the slabs was subtracted. Then using a bulk density of 0.61 g/cc (Tefera, 1983), it was converted into t/ha.

Plate 5. The location of the rain gauges and partial view of the runoff plots.

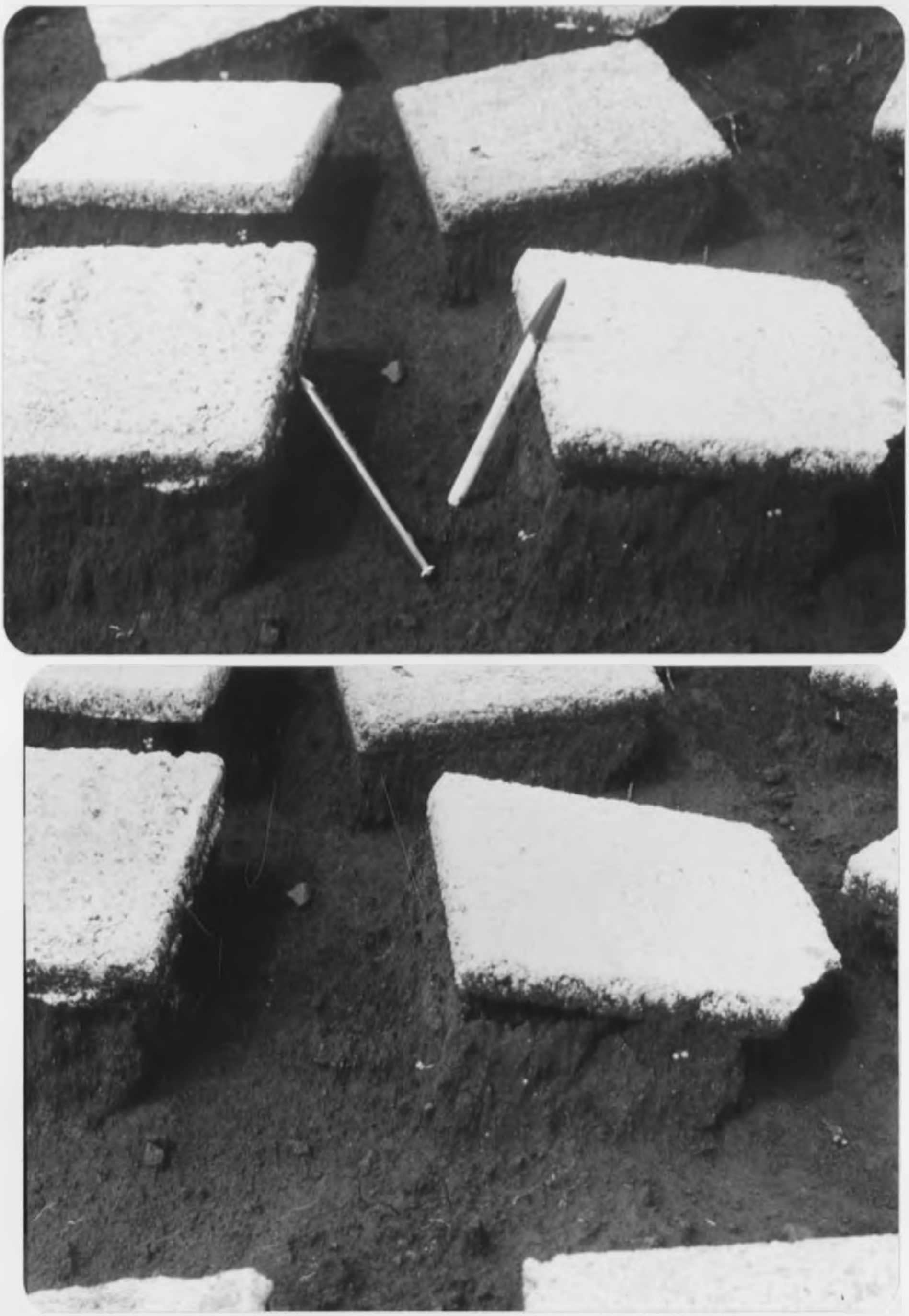


Plate 6. Photo showing the importance of surface cover to protect soil from rain drop impact

Plate 7. Measurement of the soil depth removed by the long rains

4. RESULTS

Data collected on the runoff plots for the total soil loss and runoff from the natural and simulated rainfall were analyzed to see the effects of different percentage of surface cover.

4.1 DATA FROM NATURAL RAINFALL

Runoff and soil loss data from natural rainfall was collected and analyzed for all the storms of the year that caused runoff. Since the rainfall characteristics were different for the short rains as compared to the long rains, the resulting soil loss and runoff data are summarized separately for each season.

4.1.1 Short Rainy Season

4.1.1.1 Rainfall and Erosivity

The total rainfall and rainfall erosivity during the short rains of October 1988 to January 1989 was 409.2 mm and 1148 MJ.mm/ha/hr respectively. In this analysis the January rains and the resulting erosion data are included in the short rains since an exceptional rain that caused much erosion fell in

January. In the other months of the short rainy season there were small and frequent showers of rains which did not cause significant erosion. The total monthly rainfall amount and erosivity is shown in figure 7 and table 3.

4.1.1.2 Soil Loss and Runoff

The amount of soil loss and water loss for each storm was determined using data from the sediment deposited in tanks and the runoff for that particular storm.

During this short rainy season, only four storms (table 4) caused erosion and among those storms the maximum soil loss and runoff was recorded on 06/01/89 storm in which the total rainfall amount and erosivity was 48 mm and 699 MJ.mm/ha/hr respectively.

The whole season maximum soil loss, 26.4 t/ha, and the minimum soil loss, 15.3 t/ha, were recorded respectively on the bare plot and plots with 40% surface cover as shown in table 4.

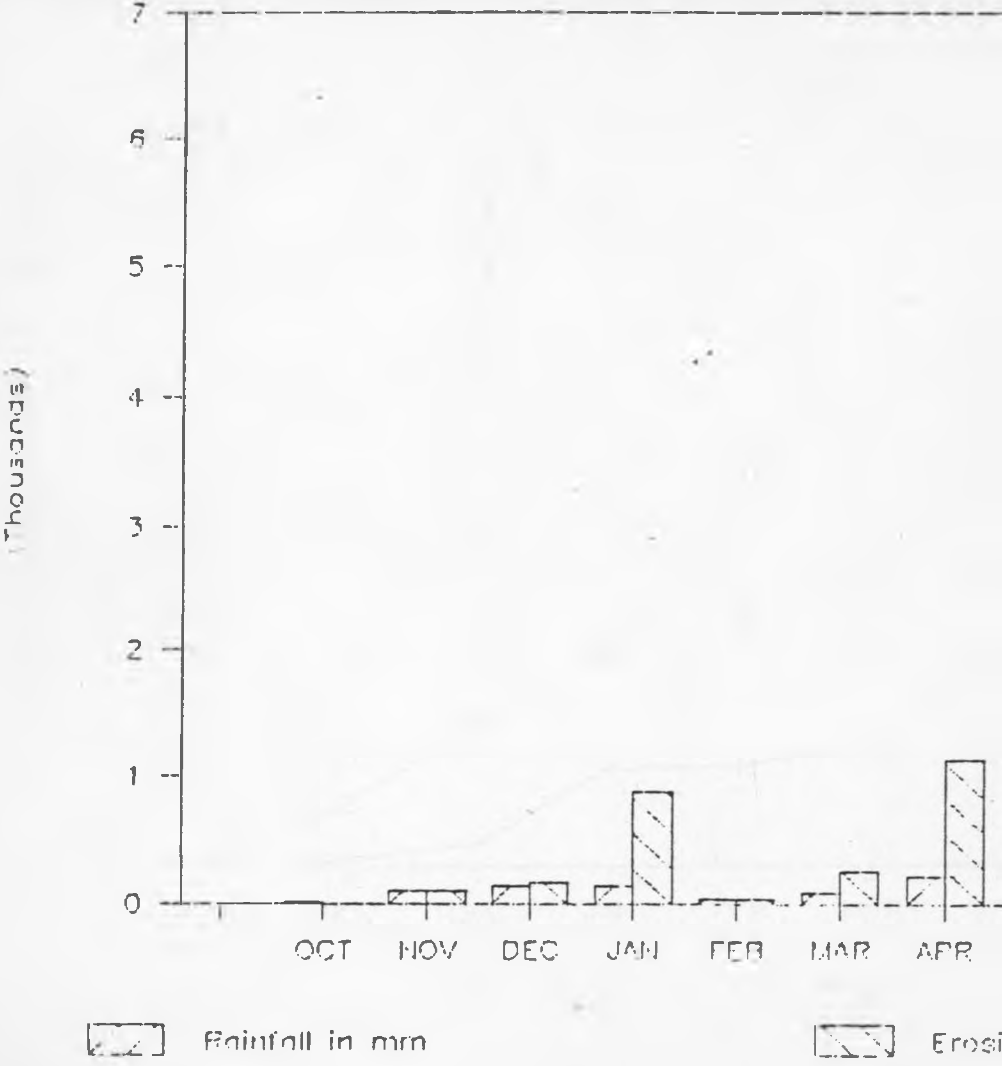
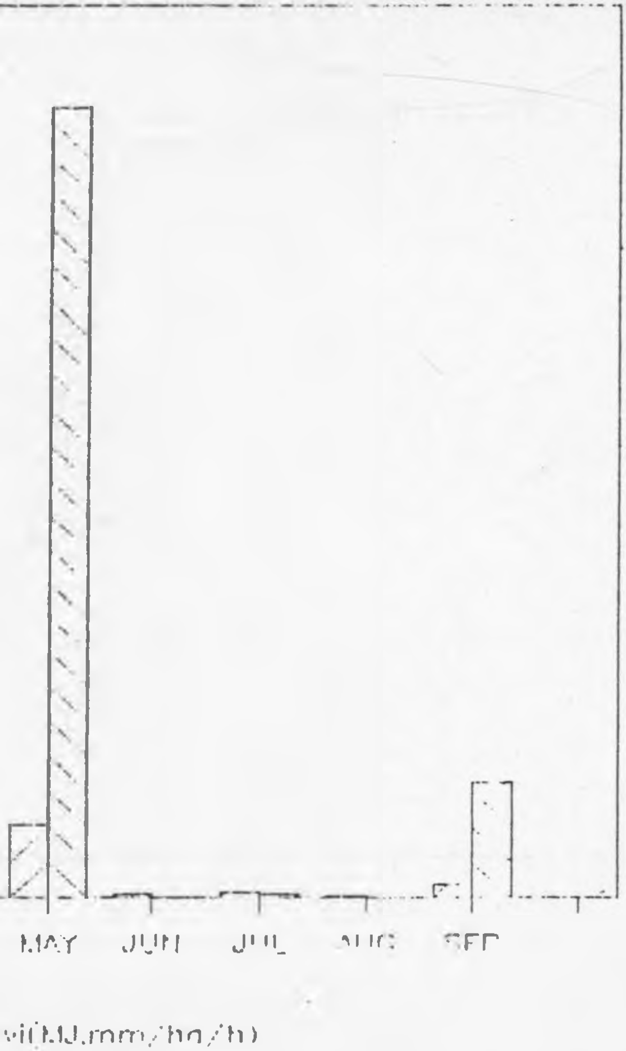


Fig.7. Monthly Total Rainfall

(from Oct. 1987 to Sep.



& Erosivity.

1989)

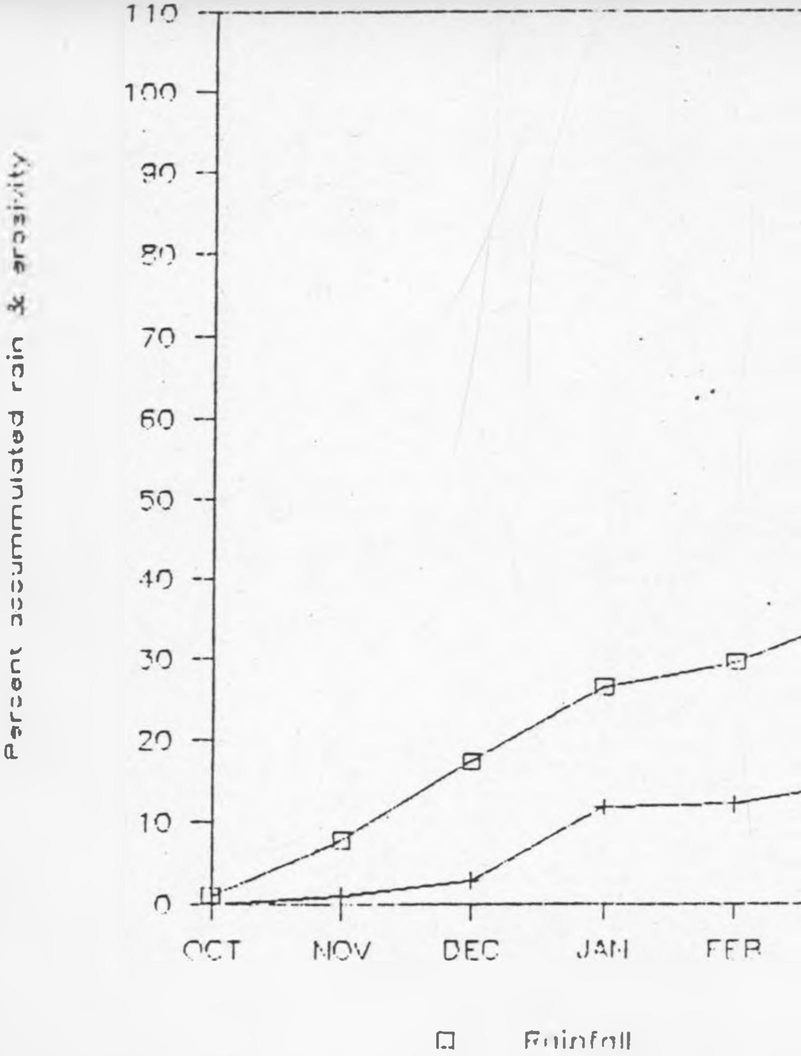
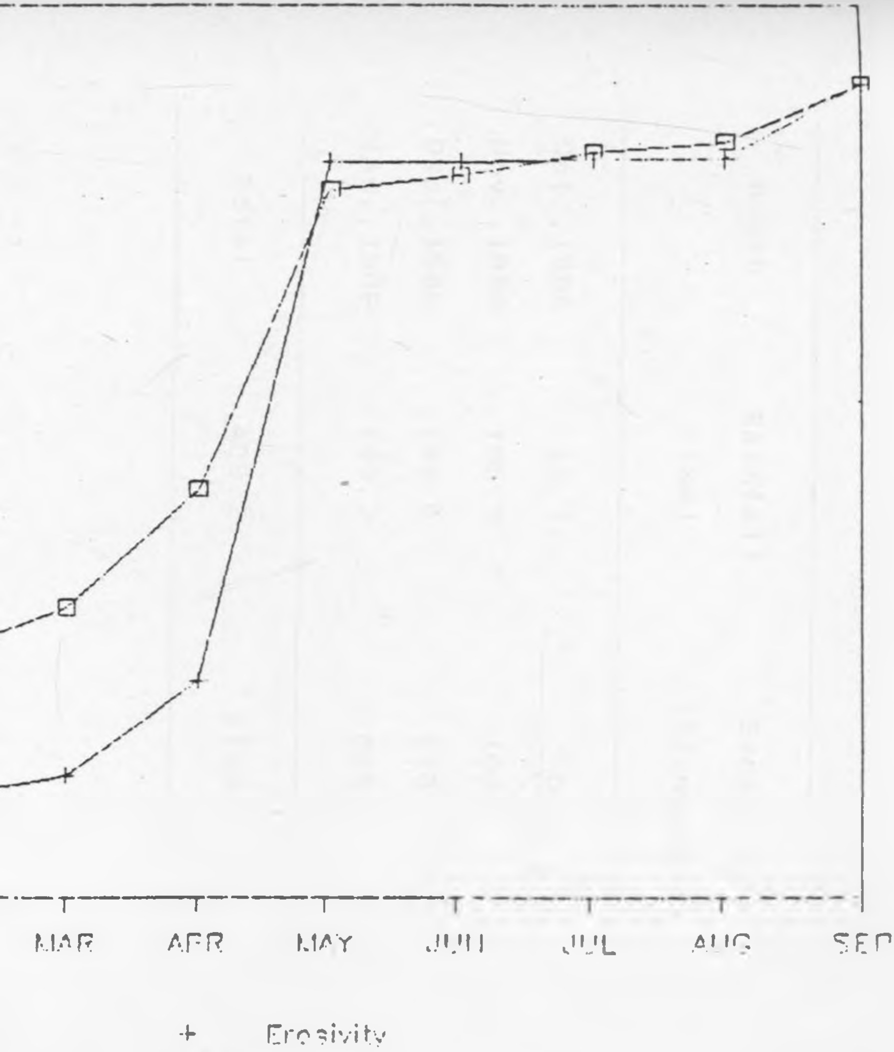


Fig.7. Monthly Total

(from Oct



Rainfall & Erosivity.

1988 to Sep. 1989)

Table 3. Monthly total rainfall (mm) and erosivity (MJ.mm/ha/h) during the short rainy season.

Month	Rainfall (mm)	Erosivity (MJ.mm/ha/h)
Oct.,1988	16.7	0
Nov.,1988	105.3	107
Dec.,1988	146.5	173
Jan.,1989	140.7	868
Total	409.2	1148

Table 4. Effect of surface cover on soil loss and runoff during the short rains.

(Figures are means of three replications)

Date of storm	Surface cover (%)	Soil loss (t/ha)	Runoff (mm)
21/11/88	0	0.2	0.4
	10	0.2	0.3
	20	0.2	0.2
	40	0.1	0.2
21/12/88	0	0.2	0.1
	10	0.2	0.2
	20	0.2	0.1
	40	0.2	0.2
25/12/88	0	2.8	4.2
	10	2.4	4.1
	20	1.7	2.8
	40	1.4	2.5
06/01/89	0	23.2	21.3
	10	23.4	20.8
	20	18.5	19.5
	40	13.5	16.2
Total	0	26.4	26.0
	10	26.2	25.4
	20	20.6	22.6
	40	15.3	19.1

The effects of the different rate of surface cover was significantly different at 0.05 level of significance in controlling erosion (Appendix 1) and variations in soil loss for each replication block is shown in figure 8a.

Similarly the maximum runoff over the short rainy season, 25.9 mm, and the minimum runoff, 19.1 mm, was recorded on the bare plot and plots with 40% surface cover respectively. Analysis of variance shows that there was a significant difference between treatments in controlling water loss (Appendix 2). There was much variation between the replication blocks for each treatment as shown in figure 8b which suggests the use of randomized block design to be correct.

4.1.1.3. Particle Size Distribution of Eroded Sediment

Eroded sediment sample from the storm on 6/1/89 was analyzed for the distribution of particles. In the analysis the eroded sediment contained more sand than clay or silt as shown in figure 9. The analysis was made with samples taken from the deposited sediment only which possibly has reduced the percentages of silt and clay particles since suspended sediment is rich in silt and clay particles. But when the amount of soil suspended in the runoff was compared to the amount of the soil deposited in the tanks the variation is negligible since more than 90% of the soil loss was from the deposited sediment.

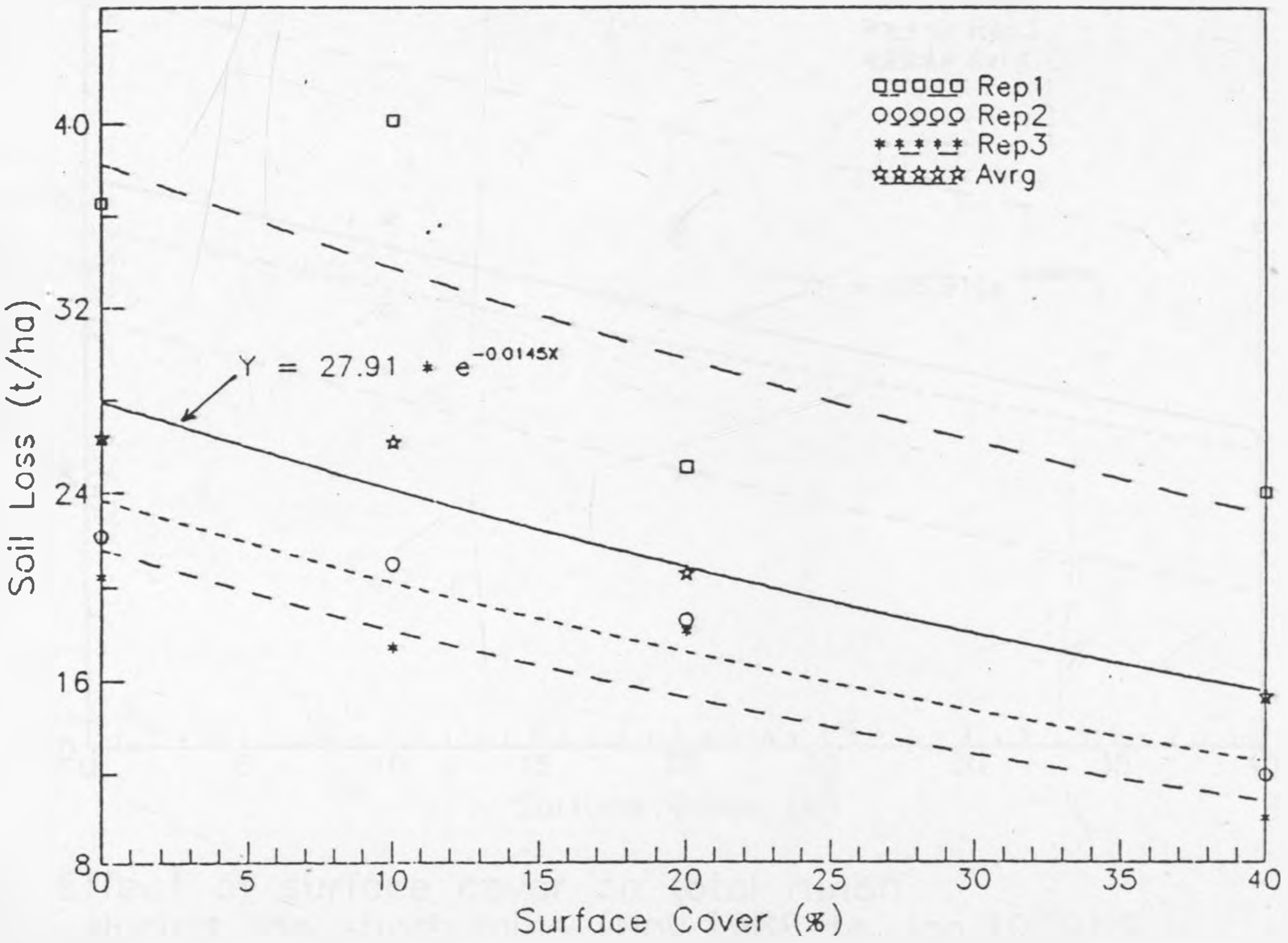


Fig.8a. Effect of surface cover on total soil loss during the short rains (Nov.1988 to Jan.1989)

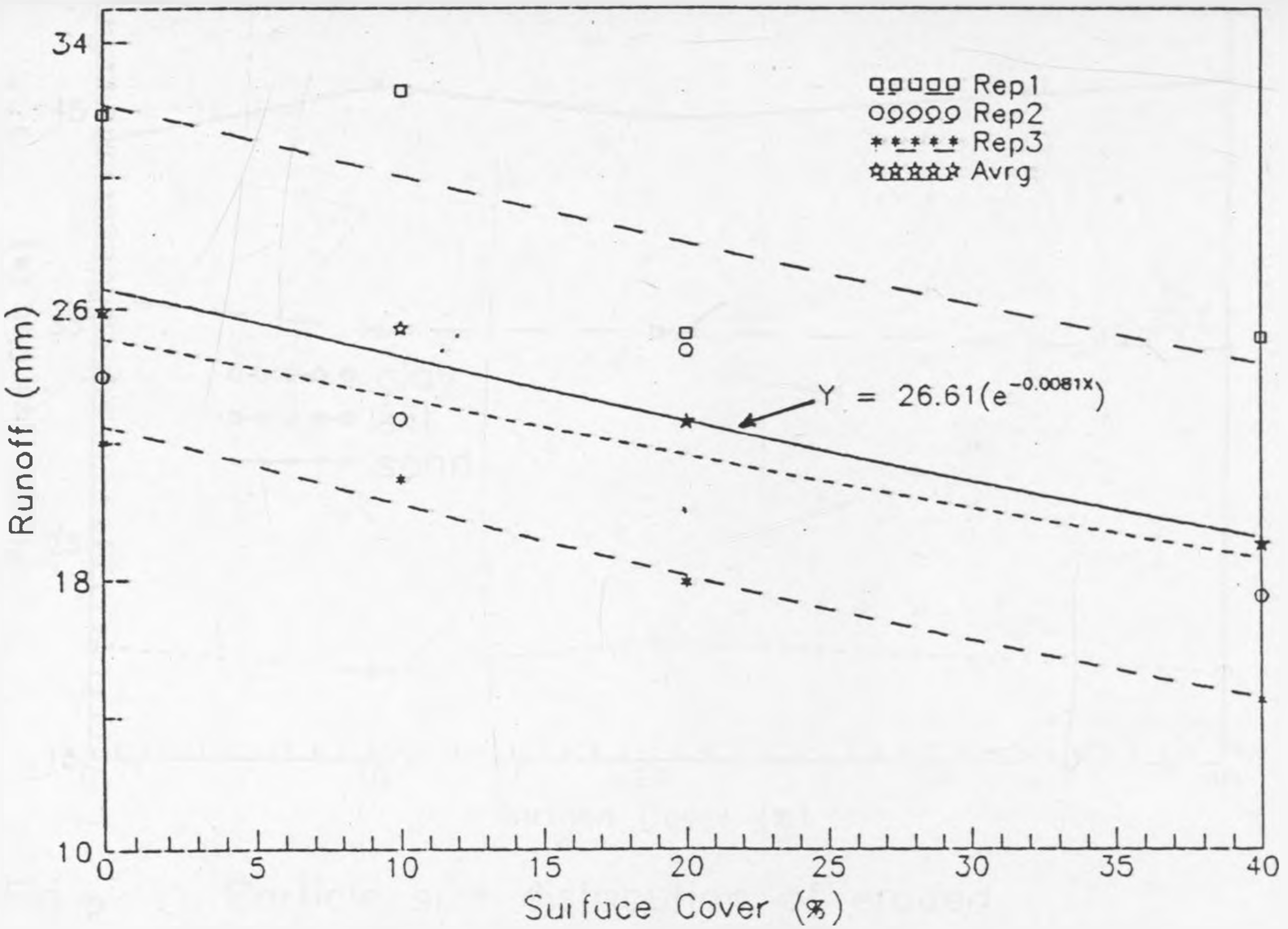


Fig.8b. Effect of surface cover on total runoff during the short rains (Nov.1988 to Jan.1989)

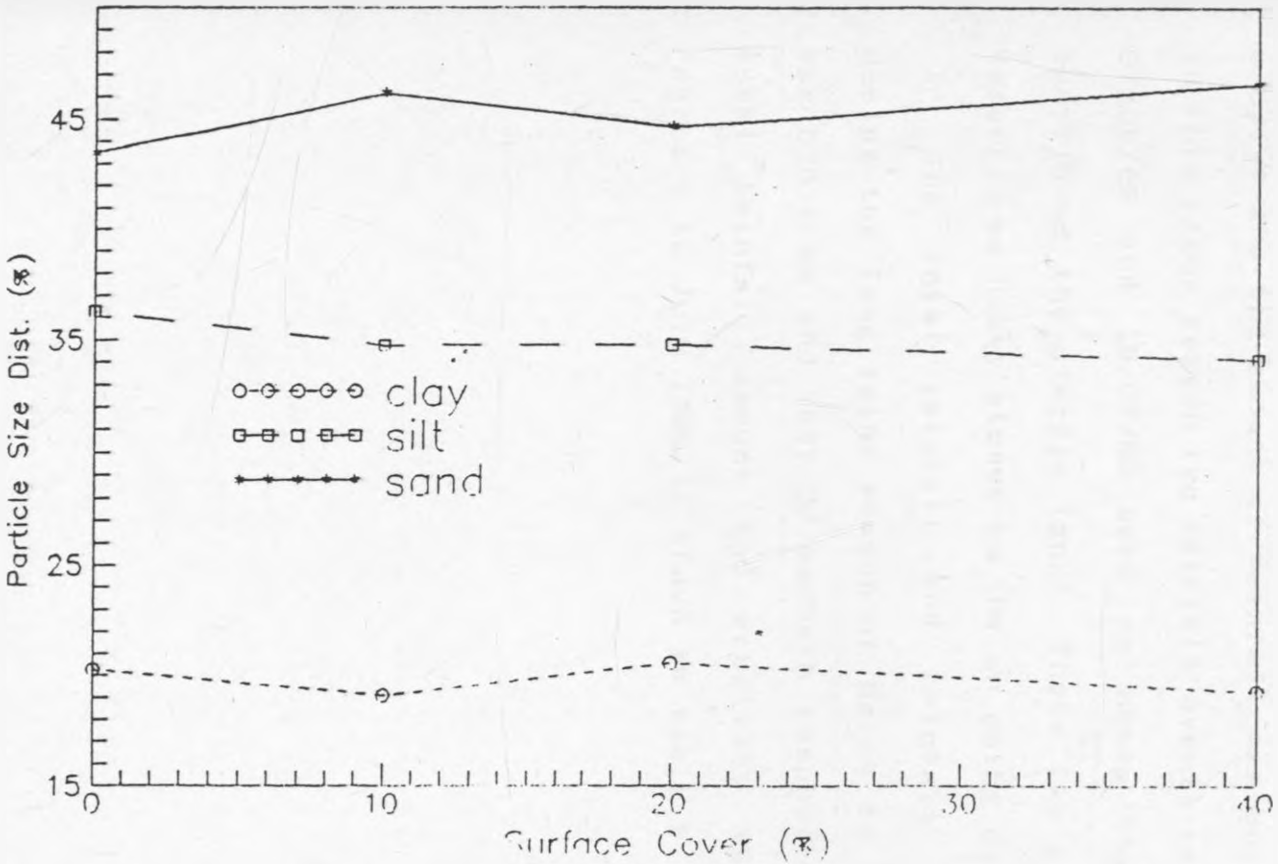


Fig-9³ . Particle size distribution of eroded sediments from 06/01/89 storm.

4.1.2 Long Rainy Season

4.1.2.1 Rainfall and Erosivity

Unlike the short rains the long rains were more erosive and the amount of rainfall was much higher. In this rainy season two rainfall events recorded on 07/05/89 and 18/05/89 were so heavy that runoff overflowed the storage tanks. These two storms are referred as heavy storms in the on going discussion.

The total rainfall and rainfall erosivity during the long rainy season of March to June 1989 was 828.1 mm and 7581 MJ.mm/ha/h respectively. The total rainfall amount and erosivity (EI_{30}) from February to July 1989 is shown in table 5.

Table 5. Monthly total rainfall (mm) and erosivity (MJ.mm/ha/h) from February to September 1989.

Month	Rainfall (mm)	Erosivity (MJ.mm/ha/h)
Feb.,1989	47.8	38
Mar.,1989	94.2	265
Apr.,1989	230.0	1127
May, 1989	561.3	6190
Jun.,1989	27.5	*
Jul.,1989	44.2	32
Aug.,1989	19.1	0
Sep.,1989	110.6	901
Total	1134.7	8553

*Rainfall chart for 3/6/89 was missing but the daily rainfall, 26.7mm, was recorded from the non-recording rain gauge.

Table 6. Comparison of effectiveness of increased surface cover on soil loss from 2 heavy storms of 07/05 and 18/05/1989 and 12 light storms of 1989 long rains.

Storm		Surface cover			
		0%	10%	20%	40%
Light	*R	2514	2514	2514	2514
	*SL	107.9	101.8	91.1	84.8
	*(%)	100	94	84	79
Heavy	*R	4634	4634	4634	4634
	*SL	184.2	173.5	146.7	114.7
	*(%)	100	94	80	62
Total	*R	7148	7148	7148	7148
	*SL	292.1	275.4	237.8	199.5
	*(%)	100	94	81	68

*R = Rainfall erosivity (MJ.mm/ha/h)

*SL = Soil loss (t/ha)

*(%) = Percentage of soil loss from covered plot to the control plot.

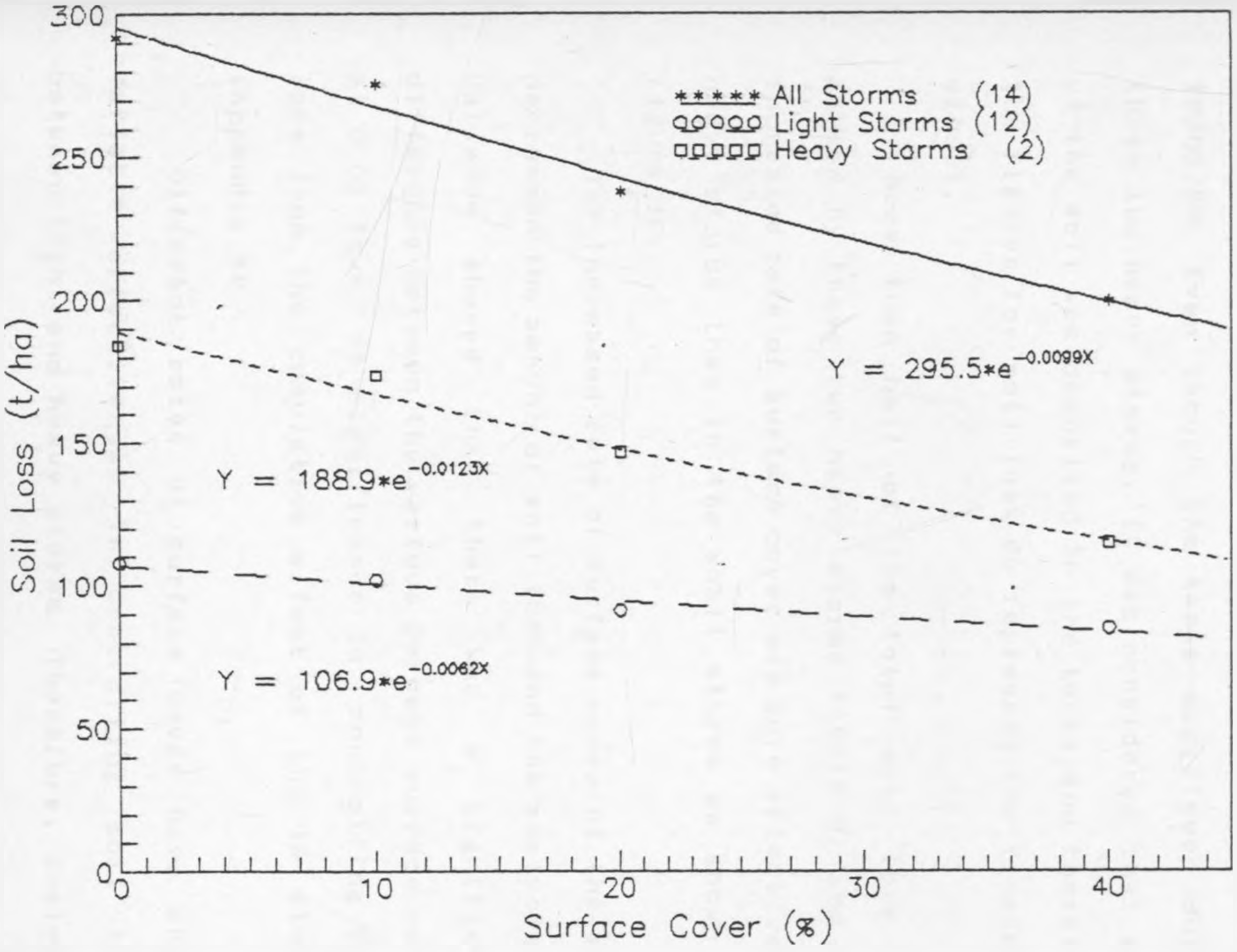


Fig.10. Effect of surface cover on soil loss from light and heavy storms of 1989 long rains.

4.1.2.2 Soil loss and Runoff.

The soil and water loss for each storm were computed in the same procedure as for the short rains. During the long rainy season 14 rainfall storms caused erosion. Among the 14 storms the maximum soil loss was recorded on 07/05/89 and 18/05/89. Even though the tanks overflowed during these two heavy storms, it was considered that most of the soil was deposited in the tanks and therefore the figures for soil loss do represent the treatment effect.

More than half of the total soil loss was caused by these two heavy storms (table 6) and the increased rate of surface cover was more effective in heavy storms than in the small storms as shown in figure 10.

The increased rate of surface cover of the soil decreased the amount of soil loss and the analysis of variance showed that there was a significant difference between the various percent surface cover at 0.05 level of significance in controlling soil loss from the cumulative effect of the 14 storms (Appendix 3)

Different rates of surface cover have shown variable effectiveness in controlling soil loss between light and heavy storms. Therefore, analysis of variance was made separately for the two situations (i.e. for the two heavy storms and for the remaining 12 light storms).

There was a significant difference between treatments at 0.01 level of significance for the heavy storms (Appendix 4a), but there was no statistical difference between treatments for the light storms even at 0.05 level of significance (Appendix 4b). However there was reduction in amount of soil loss as the percent surface cover was increased as shown in table 6 and figure 10.

The total amount of runoff and the Analysis of Variance Table for the light storms of the long rains of 1989 are given in table 7 and Appendix 5 respectively. The tables do not include runoff figures for the two heavy storms since all the storage tanks have overtopped.

The increased rate of surface cover was not directly related to the amount of runoff. The maximum runoff was recorded on plots with 20% surface cover and the minimum on plots with 40% surface cover. As shown in Appendix 5 increased surface coverage has not reduced the amount of runoff significantly at 0.05 level of significance.

4.1.2.3. Particle size distribution of eroded sediments.

Eroded sediment samples taken from the deposited sediment were analyzed separately for the

Table 7. Total runoff (mm) from 12 light storms of 1989 long rainy season.

Surface Cover (%)	Runoff (mm)	 (%)
0	114.2	100
10	114.0	100
20	116.1	102
40	111.3	97

two heavy storms of 07/05/89 and 18/05/90 and for the light storms of 24/04/89, 25/04/89 and 27/04/89 after mixing together.

The proportions of sand, silt and clay size particles is given in table 6, and fig.11 for various rainfall events and from the natural soil sample taken from the top 0 to 3 cm on the surface of the plots. The figures suggest that the proportion of clay size particles is slightly greater and silt size particles is slightly less from the heavy storms.

It can also be seen that the particle size distribution of the eroded sediments in all rainfall events is very different from that of the original soil.

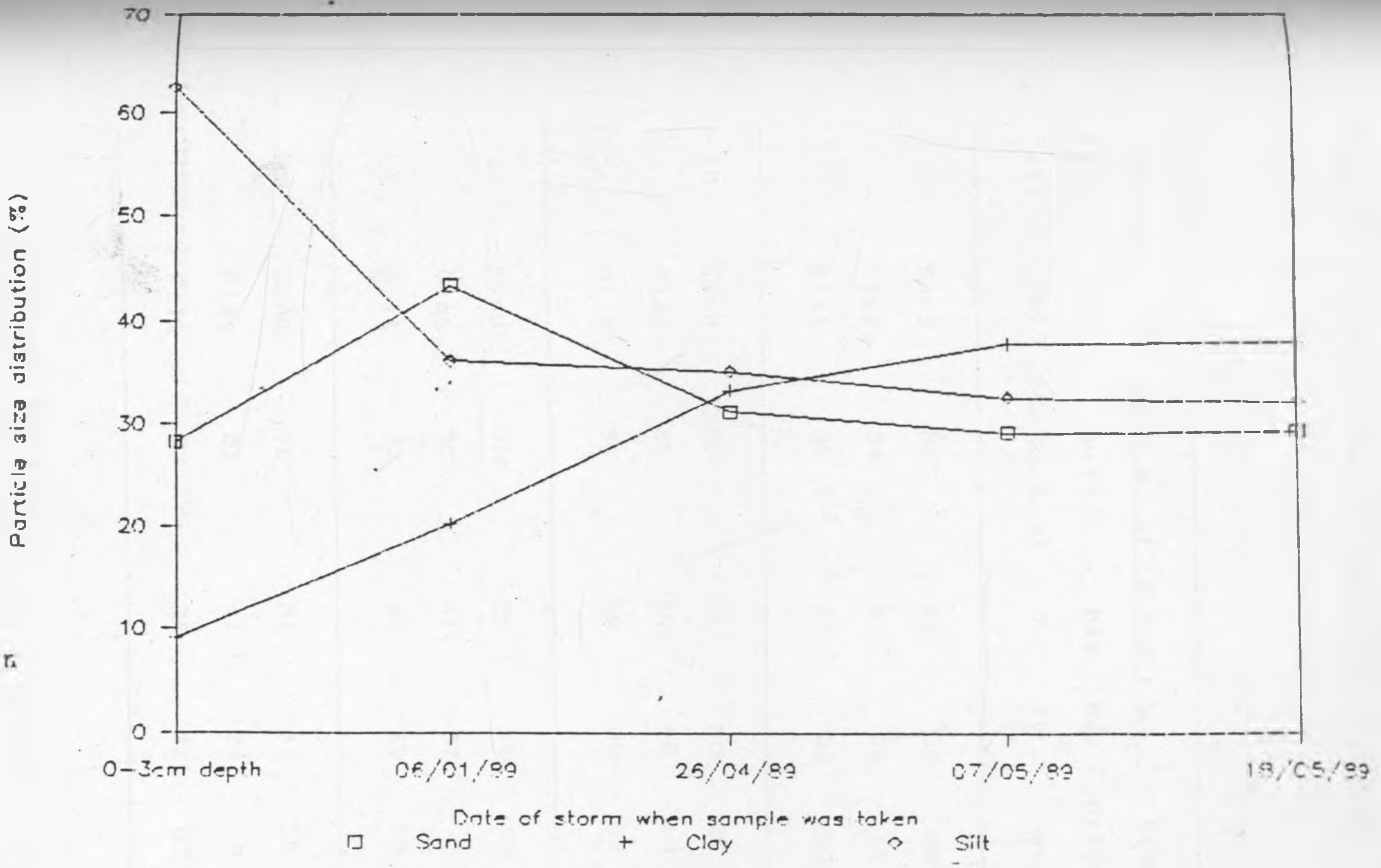


Fig. 11. Particle size distribution.
(from 0% Surface covered plots)

Table 8. Particle Size Distribution of Eroded Sediments of Individual Storms.

Surface Cover (%)	PSD (%)	Date of Storm April 24, 25 & 27	May 7	May 18	From Original soil
0	Sand	31	29	30	29
	Clay	34	38	38	11
	Silt	35	33	32	60
10	Sand	30	31	30	28
	Clay	35	40	40	10
	Silt	35	29	30	62
20	Sand	31	30	34	33
	Clay	37	41	37	7
	Silt	32	29	29	59
40	Sand	32	31	34	28
	Clay	31	41	34	9
	Silt	37	28	32	63

4.2 DATA FROM SIMULATED RAINFALL

To evaluate the effect of surface cover on erosion rate, sediment concentration and sediment amount under heavy storms, rainfall was simulated on all the plots and runoff was simulated on eight plots (2 replications). In all the plots, a one hour storm at a rate of 79 mm/h (dry-run), a 20 minutes storm at 84 mm/h (wet-run) after 24 hours interval from the dry-run, and a 20 minutes storm at 82 mm/h (very wet-run) after 20 minutes interval from the wet-run were applied.

In addition water as runoff (overland flow) was applied for 45 minutes together with the simulated rainfall of 81 mm/h after 5 minutes from the start of the 2nd very wet-run and after 10 minutes from the end of the 1st very wet-run on the plots of blocks Y and Z. The rate of applied overland flow was 0 l/min for 5 minutes, 8 l/min for 15 minutes, 16 l/min for 15 minutes and 24 l/min for 15 minutes.

The total amount of soil loss and runoff from each run is given in tables 9 and 10 respectively. Both soil loss and runoff were maximum in the second very wet-run but the 40% surface cover reduced the soil loss almost by half.

Table 9. Soil Loss (t/ha) from Simulated Rainfall

Surface	Dry-run		Wet-run		1st Very Wet-run		2nd Very Wet-run	
Cover	SL[*]		SL		SL		SL	
(%)	(t/ha)	(%)[*]	(t/ha)	(%)	(t/ha)	(%)	(t/ha)	(%)
0	31.6	0	11.9	0	11.7	0	50.2	0
10	30.3	4	9.4	21	9.2	21	55.2	-10
20	24.4	23	10.1	15	9.0	23	52.4	-4
40	21.1	33	6.7	44	6.7	43	25.6	49

SL[*] = soil loss

(%)[*] = soil reduction from covered plots when compared to the control plot.

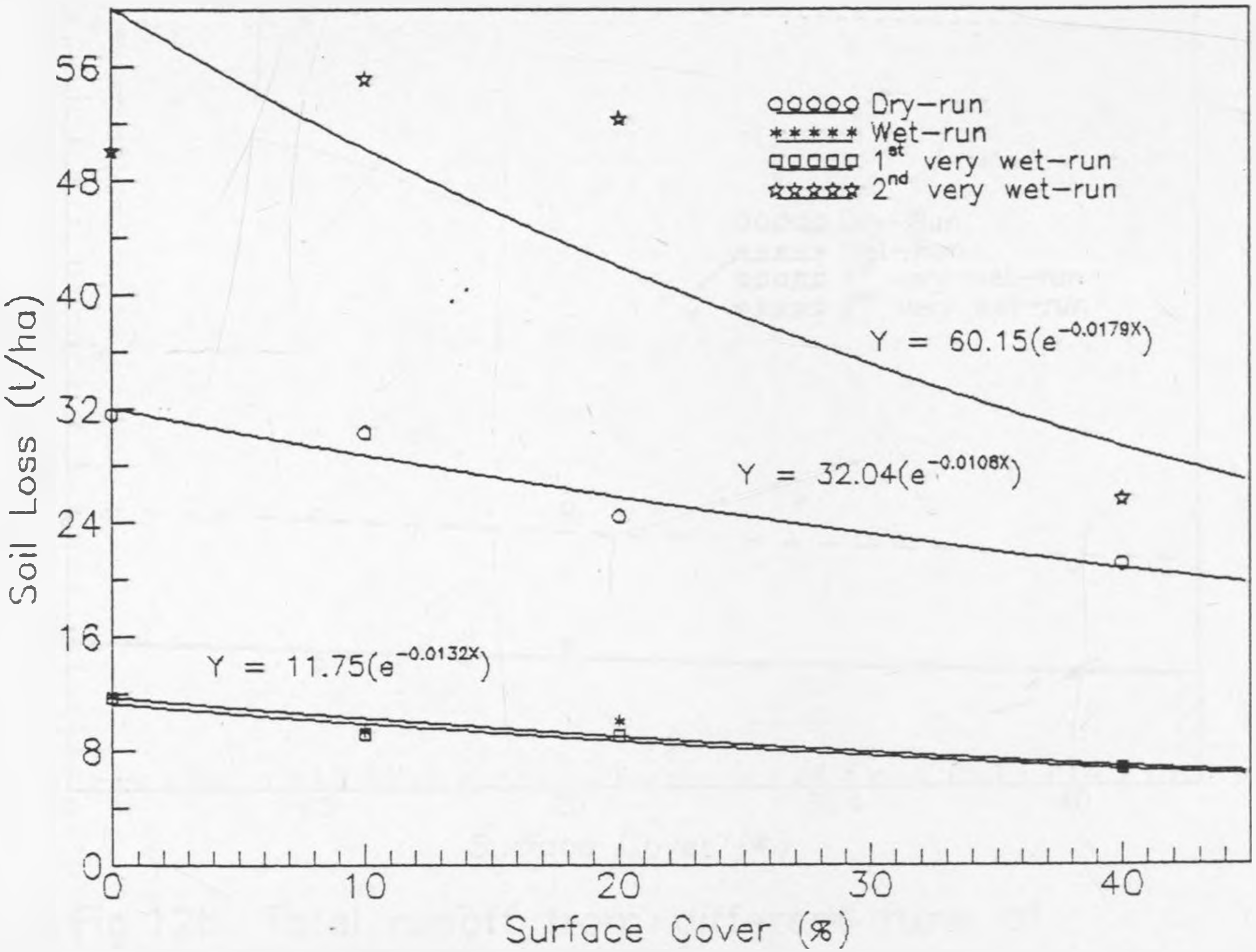


Fig.12a. Total soil loss from different runs of simulated rainfall

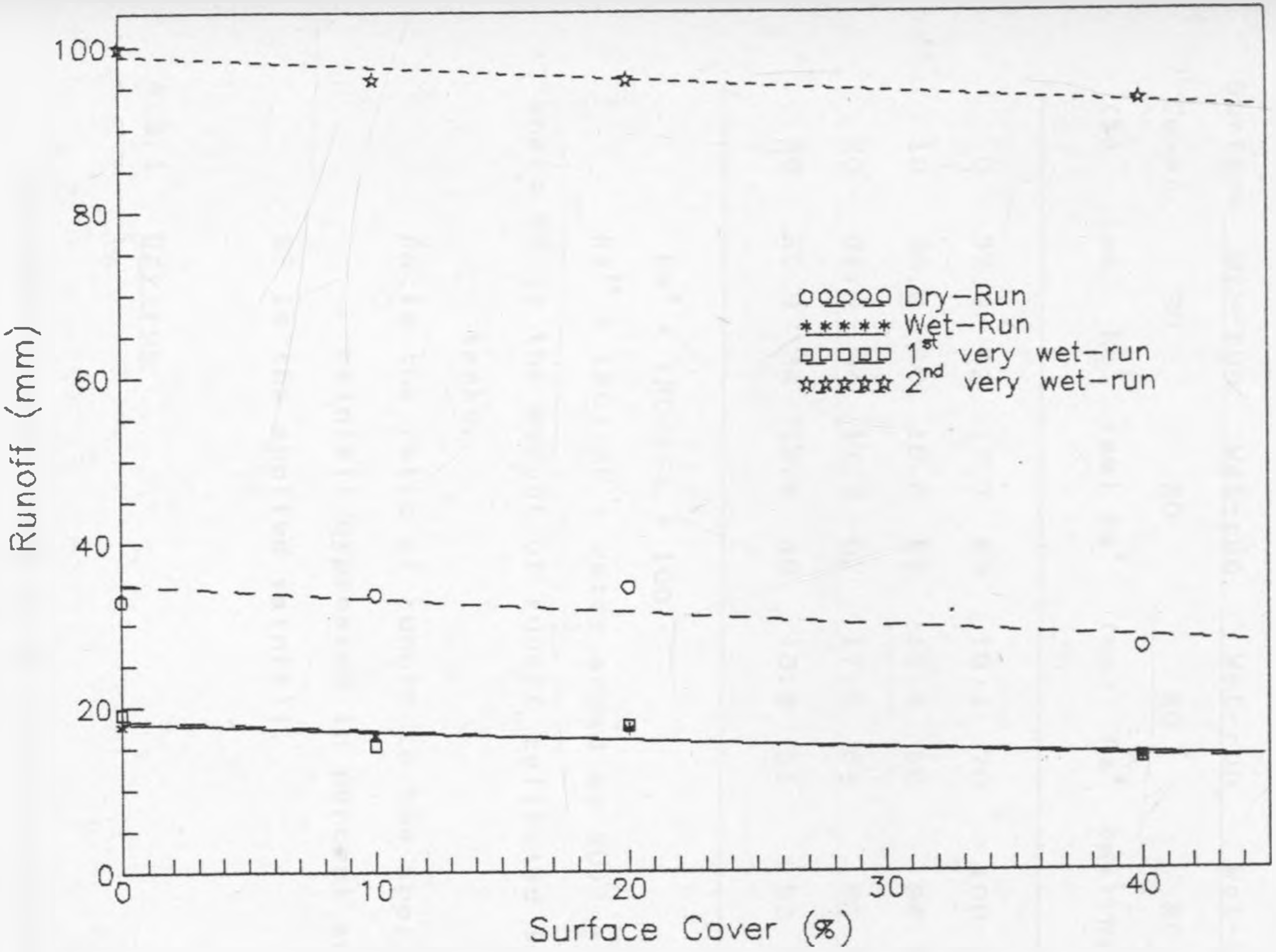


Fig.12b. Total runoff from different runs of simulated rainfall

Table 10. Total runoff (mm) and ratios of runoff to rainfall expressed in percent from simulated rainfall

Surface	Dry-run		Wet-run		1st Very Wet-run		2nd Very Wet-run	
Cover	RO		RO		RO		RO	
(%)	(mm)	Ra'	(mm)	Ra'	(mm)	Ra'	(mm)	Ra''
0	32.9	42	17.7	63	19.1	70	100	72
10	36.6	46	16.6	59	15.4	56	96	69
20	34.4	44	17.3	62	17.6	64	96	69
40	26.9	34	13.6	49	13.8	51	93	67

$Ra' = (RO/RF) * 100$

$Ra'' = (RO/(RF + \text{water added as RO})) * 100$

Where RO is the amount of runoff collected in the tanks,

Ra is the ratio of runoff to the applied rainfall expressed in percent and

RF is the applied rainfall.

4.2.1 Dry-run

The rate of soil loss at different durations of simulated rainfall is shown in figure 13a. The change in sediment concentration as the application of rainfall was continued is given in figure 13b.

The total amount of soil loss and runoff is shown in table 9 and table 10b respectively. Although the amount of soil loss was reduced as the percentage surface cover was increased, there was no significant difference between different rates of surface cover in controlling erosion at 0.05 level of significance. There was greater reduction in soil loss from 20% and 40% surface cover when compared to the 10% surface cover as shown in table 9 and figure 12a. The maximum soil loss, 31.6 t/ha, was on bare plot and the minimum, 21.1 t/ha, was on 40% surface covered plots.

Runoff was not related to the percent surface cover as it was for soil loss. Runoff in 10% and 20% surface cover was higher than the control. However at 40% cover the total runoff was the least of all.

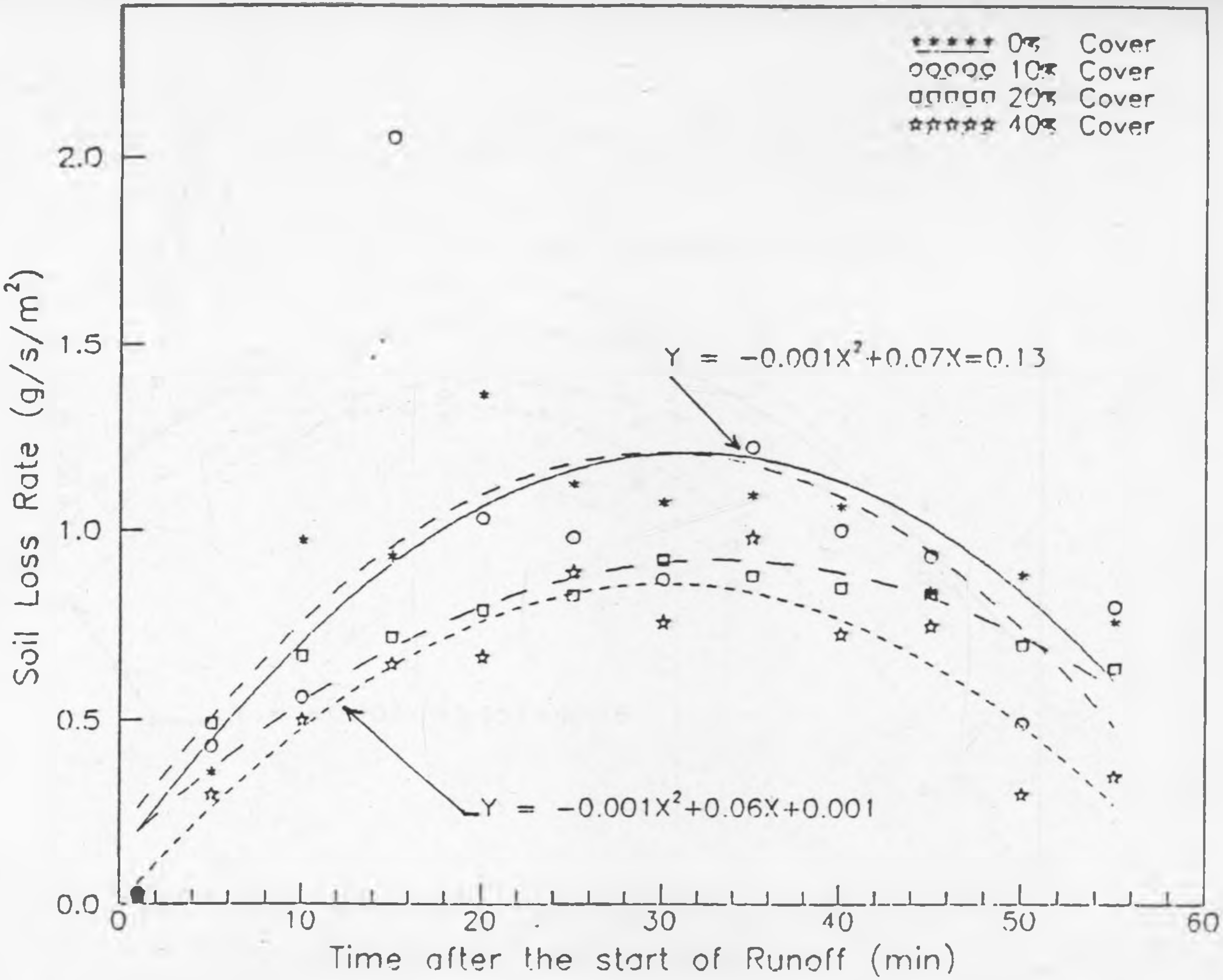


Fig.13a. The Rate of Soil Loss from Dry-run

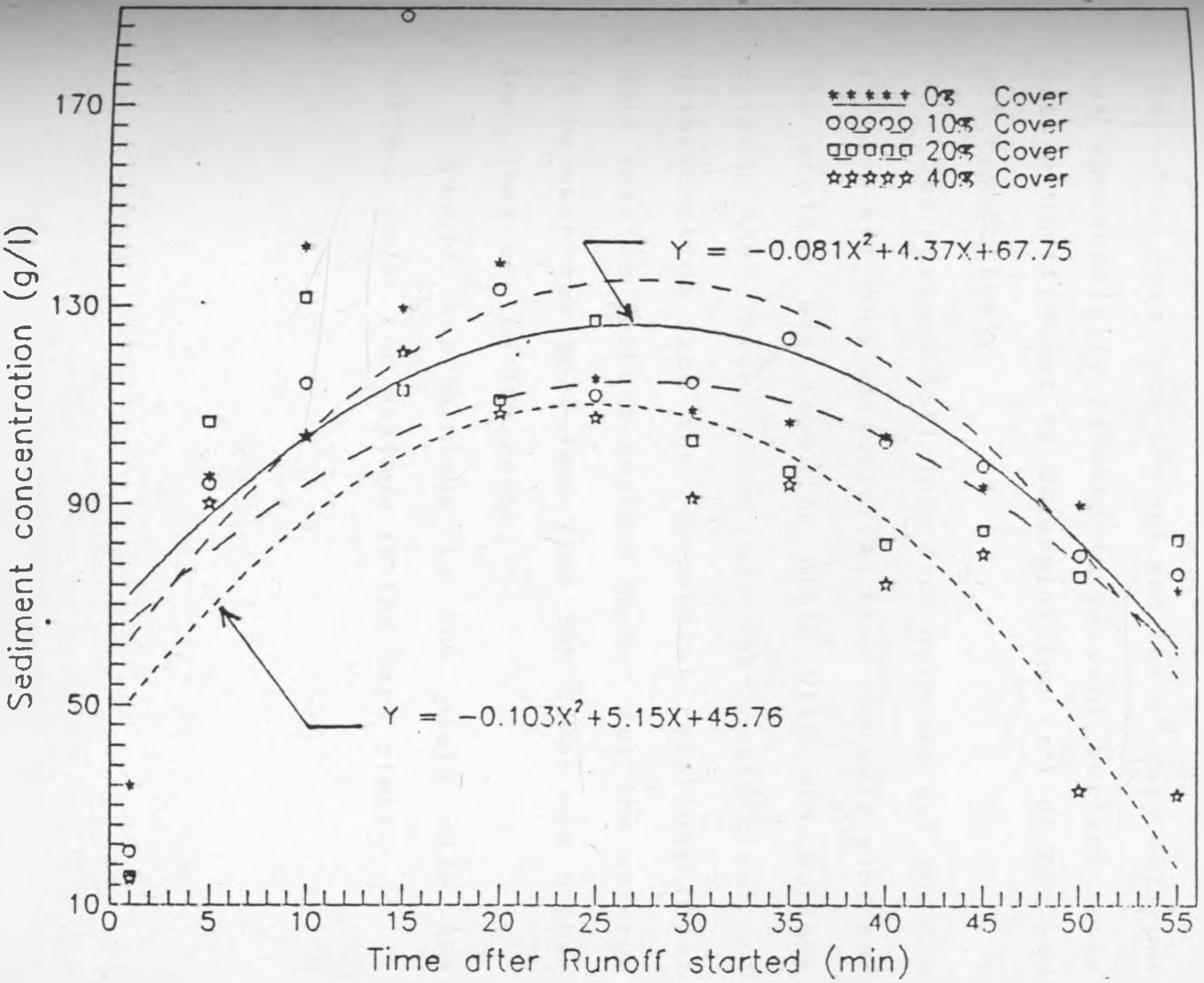


Fig.13b. Sediment concentration (g/l) from the dry-run.

4.2.2 Wet and 1st Very Wet-runs.

The total amount of soil loss and runoff is shown in table 9 and table 10 respectively for both the wet and the 1st very wet-runs. The respective erosion rate values are also shown in figures 14a and 15a. Soil loss from the wet and the 1st very wet-runs was exponentially related to percent surface cover with a coefficient of determination (r^2) of 88% and 95% respectively.

The maximum soil loss from both the wet and the 1st very wet runs was observed from the bare plot and the minimum was from the plots with 40% surface cover. The lower value of the coefficient of determination from the exponential relationship of soil loss to percent surface cover for the wet-run is because the soil loss from 20% cover was higher than that of the 10% cover.

Runoff was minimum in the plots with 40% surface cover and maximum in the bare plots.

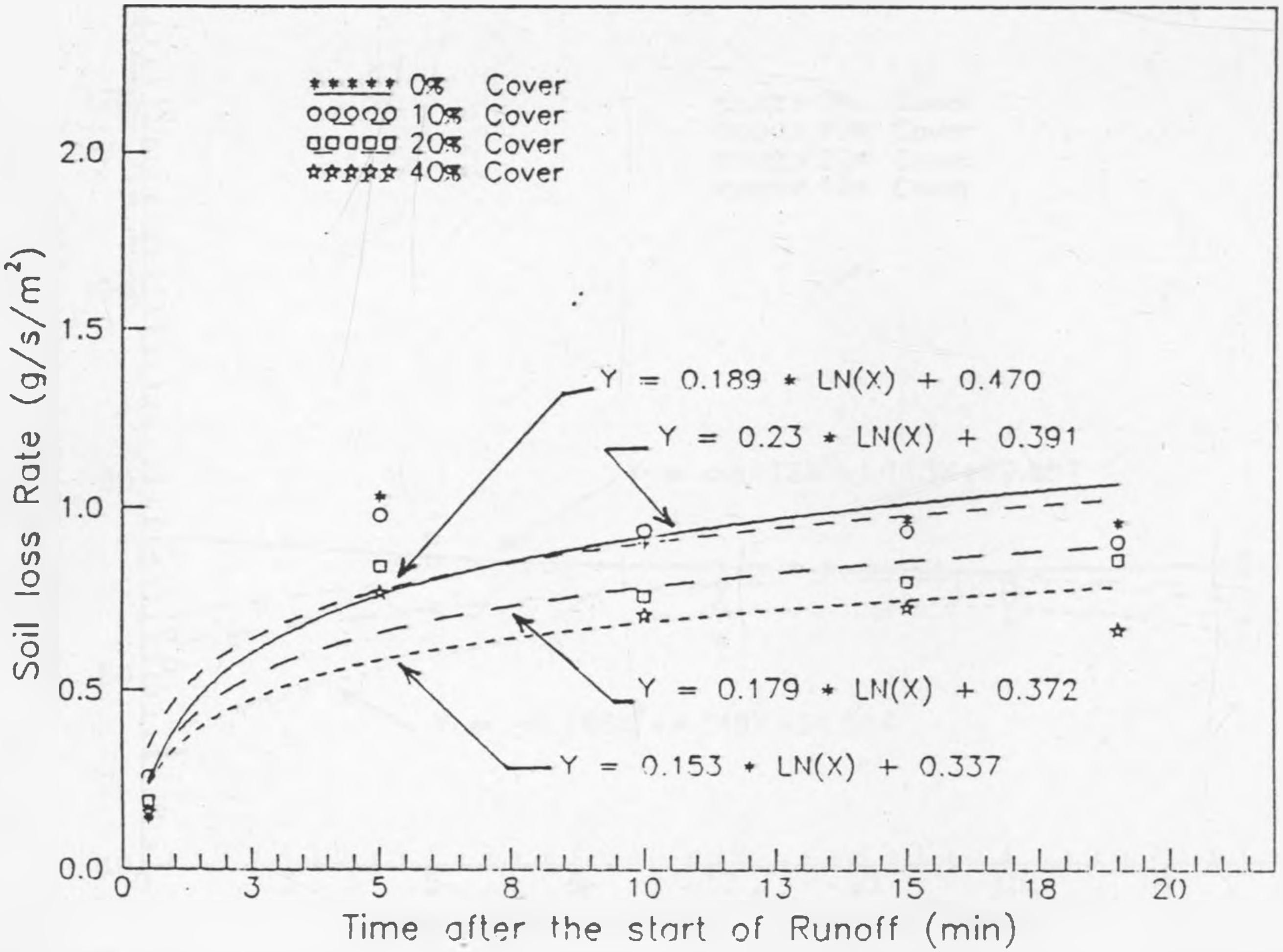


Fig.14a. The rate of soil loss from 20 min. wet--run.

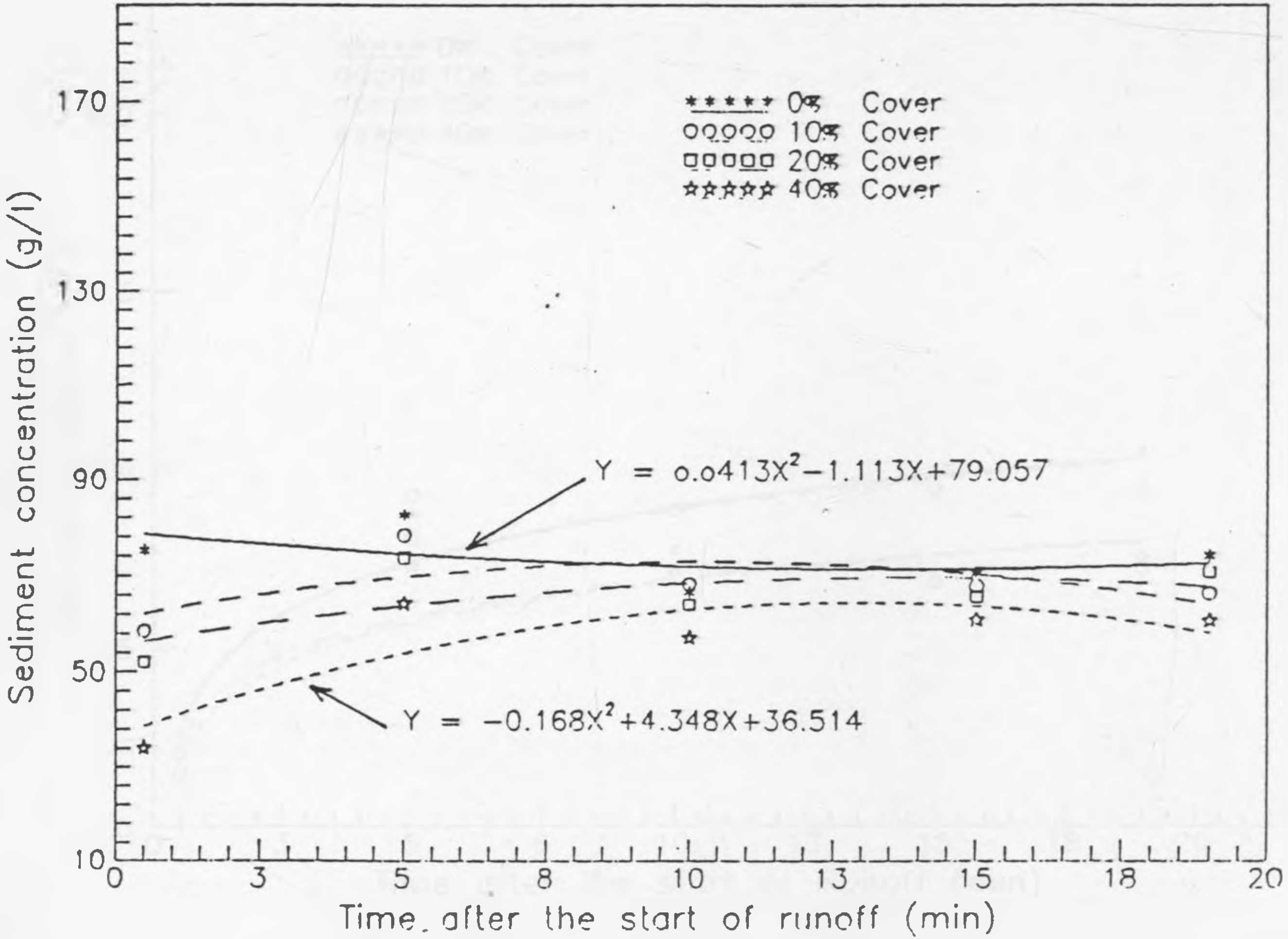


Fig.14$_b$. Sediment concentration (g/l)from the wet-run.

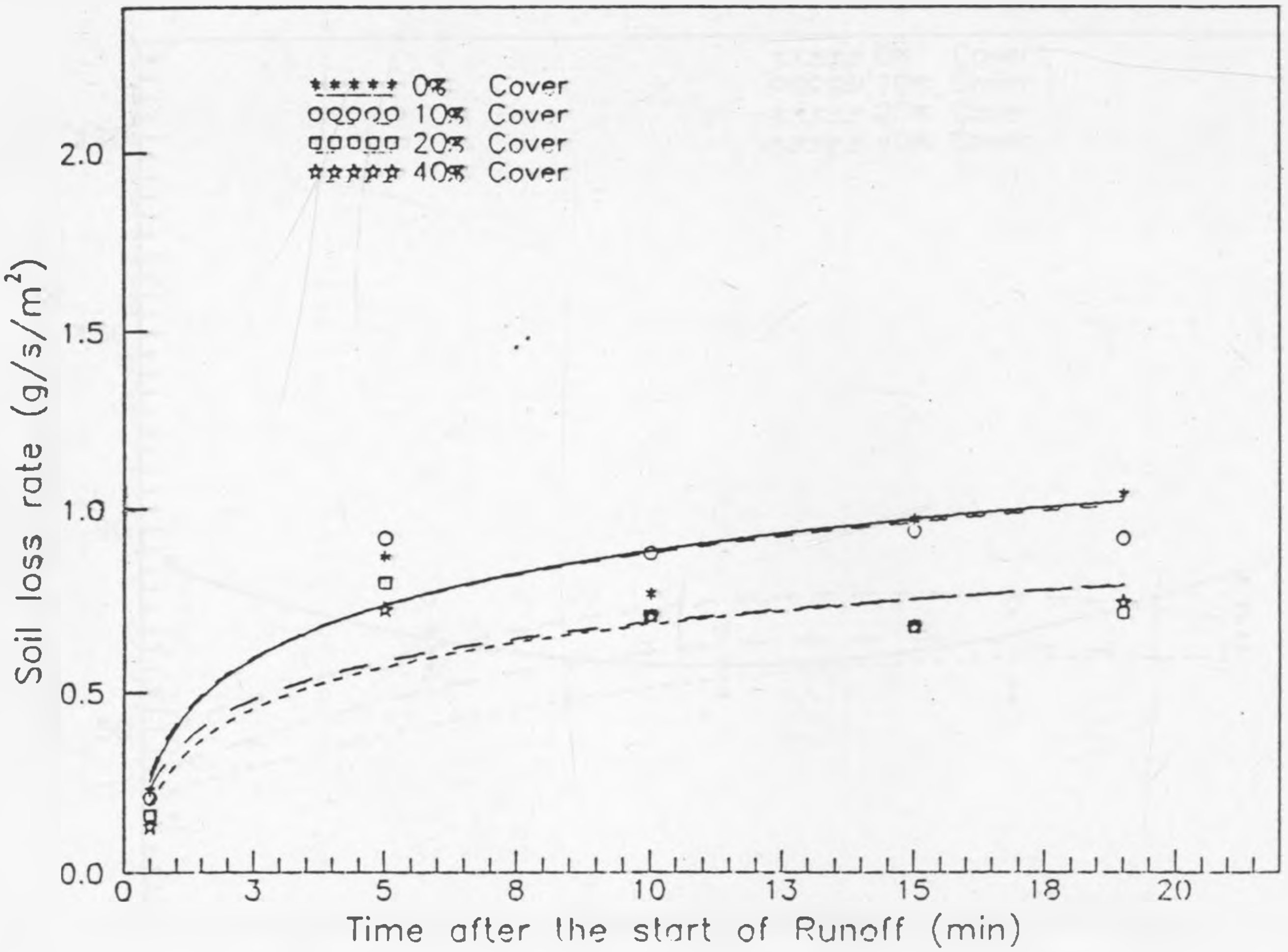


Fig.15a. The rate of soil loss from the 1st 20 min. very wet-run.

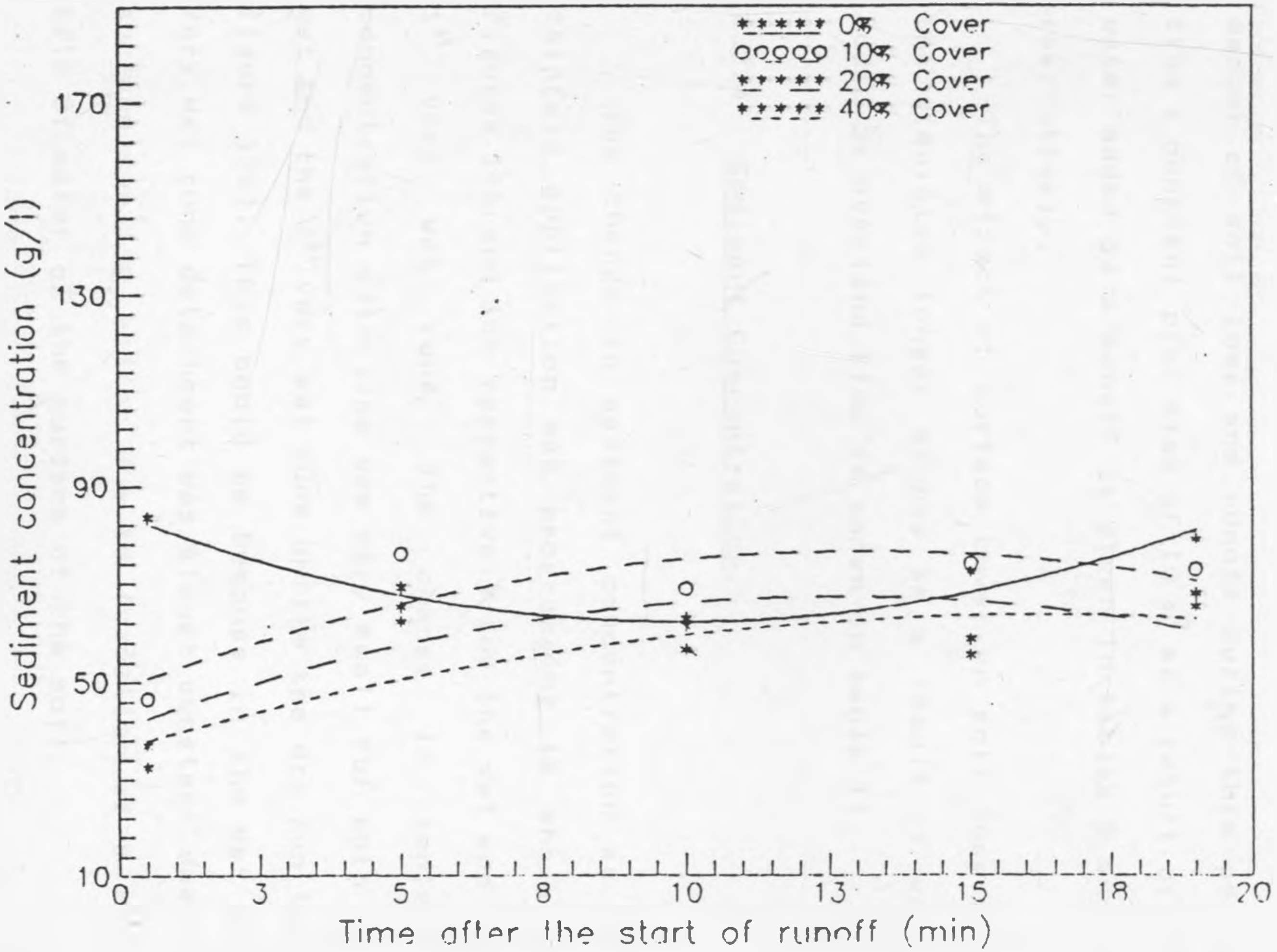


Fig.15b. Sediment concentration (g/l) from the 1^{st} 20 minnutes very wet-run

4.2.3 2nd Very Wet-run with Added Overland Flow.

Rainfall application was continued for 50 minutes with different rates of water added uniformly as runoff at the upper ends of the plots. The total amount of soil loss and runoff during this period from a constant plot area of 10 m^2 as a result of the water added as a runoff is given in tables 9 and 10 respectively.

The effect of surface cover on soil loss from the simulated longer slopes as a result of water added as overland flow is shown in table 11.

4.2.4 Sediment Concentration.

The change in sediment concentration as the rainfall application was progressing is shown in figures 14b and 15b respectively for the wet and the 1st very wet runs. The change in sediment concentration with time was very small for both the wet and the 1st very wet runs unlike the dry run (see figure 13b). This could be because in the wet and very wet runs detachment was almost constant due to surface sealing and/or due to formation of a thin film of water on the surface of the soil.

Table 11. The effect of surface cover on soil loss (t/ha/15minutes) from longer slopes.

	Slope length (m)			
Treatment	5.0	9.9	14.7	19.6
0% Cover	8.8	5.4	6.0	5.0
10% Cover	6.9	6.2	6.7	5.6
20% Cover	6.8	6.9	5.8	5.1
40% Cover	5.0	3.3	2.9	2.4

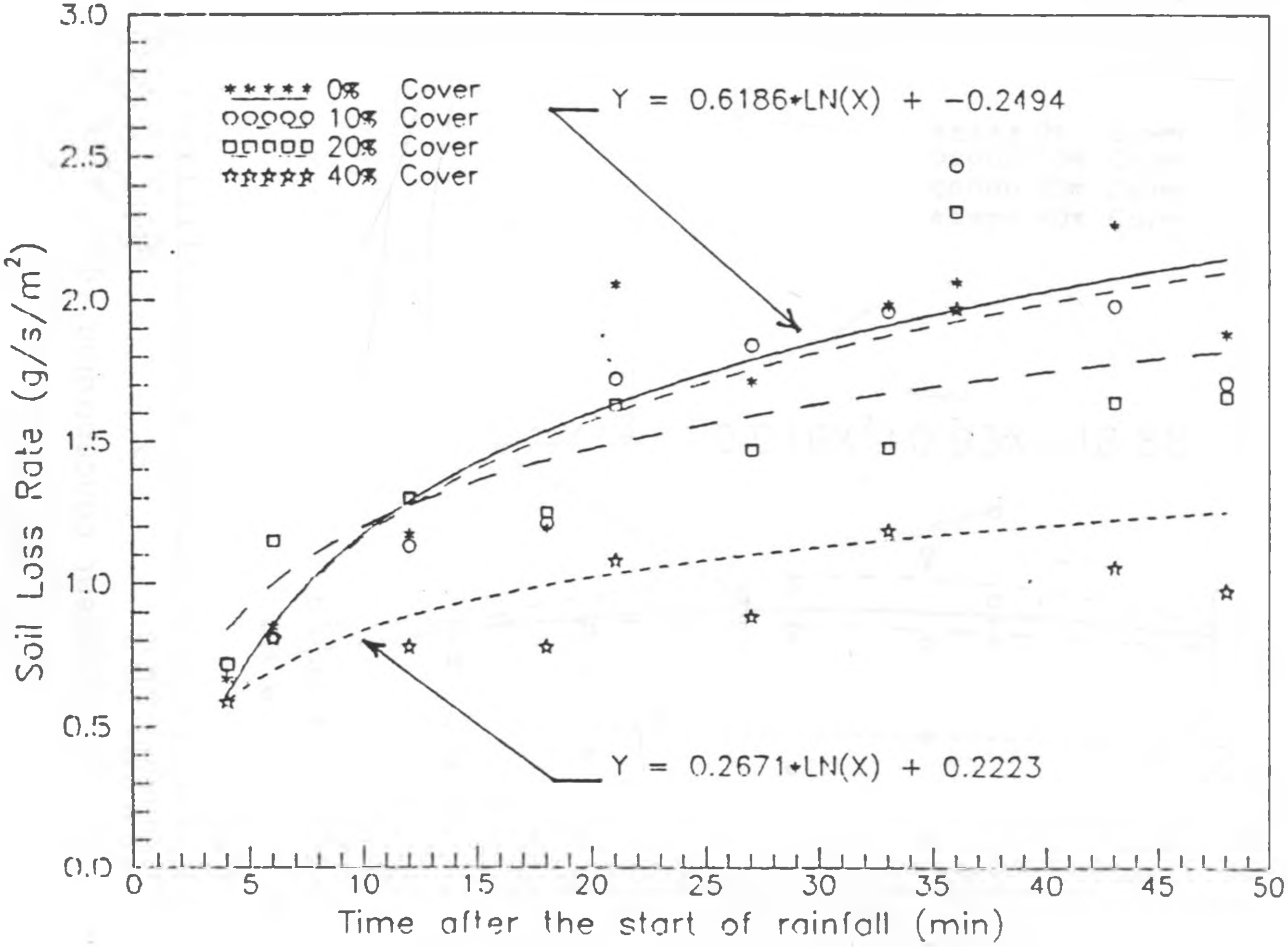


Fig. 16a. The rate of soil loss ($g/s/m^2$) from the 2nd very wet-run and added runoff

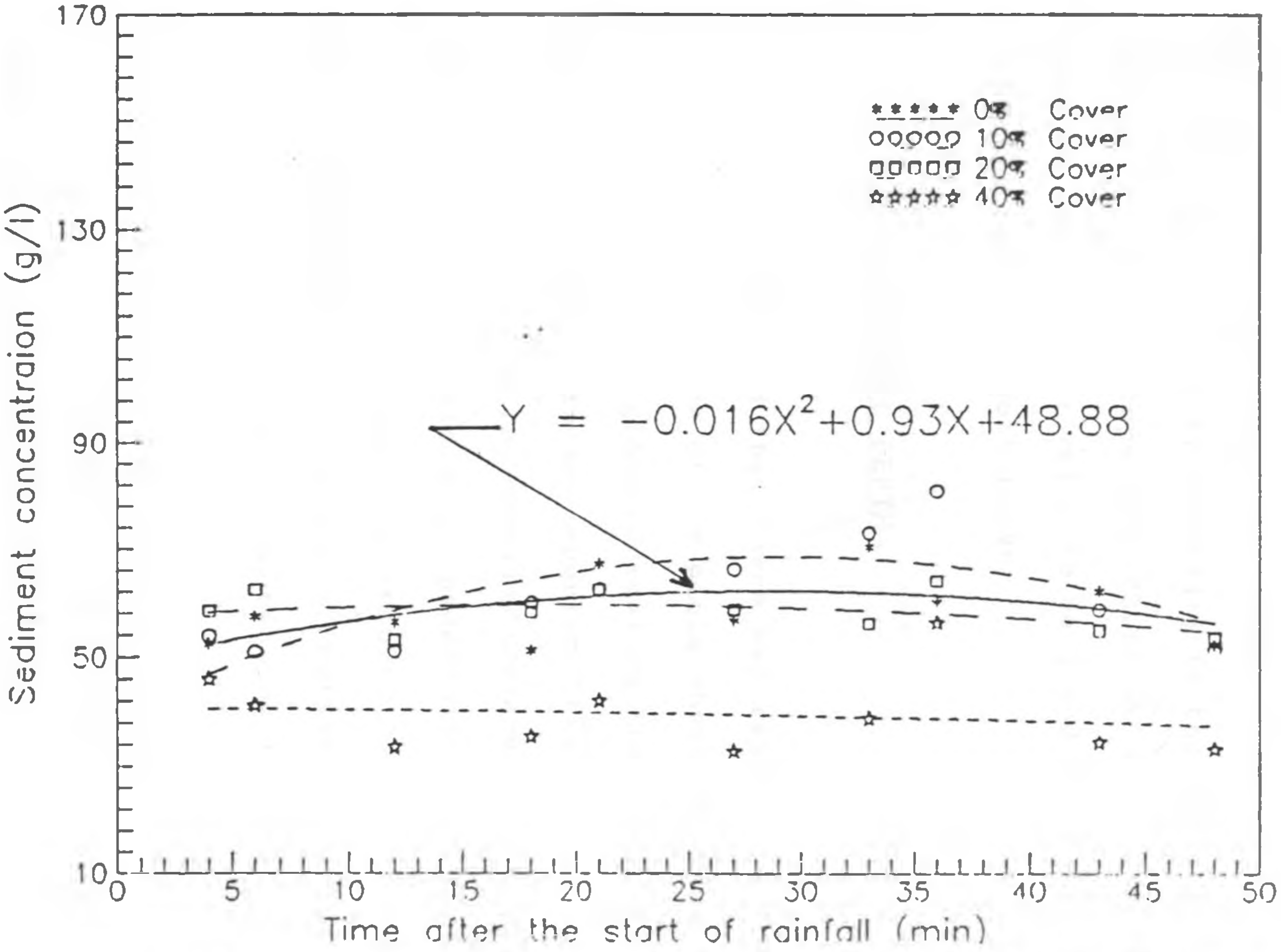


Fig.16b. Sediment concentration (g/l) from 50 minutes 2nd very wet-run and added runoff

4.3 COVER & MANAGEMENT FACTOR (C) VALUE.

Table 12 shows the cover and management C-factor values of the USLE for the simulated stone cover. The C-factor value of the surface cover made by simulated stones was computed as a ratio of annual soil loss from a given percent cover to the soil loss from the bare plot after adjusting to the topographic factors of a 9% slope and 22.13 m slope length assuming the P-factor value to be 1 and the K-factor to be the same for both plots.

4.4 CHANGE IN SOIL DEPTH

It was observed that there was removal of soil even on the upper ends of the plots where scouring by runoff would be negligible indicating that detachment by raindrop impact is an important factor for soil erosion. When riling had occurred adjacent to or near the covers soil pillars or pedestals were formed below the covers as soil was removed by splash into the rills which indicate the effectiveness of such covers including stones in protecting the soil from raindrop impact.

Based on such observations the depth of the soil removed only from the long rains was measured systematically (see section 3.8.8 in methodology). In all the plots at predetermined sampling sections and points the soil depth removed was measured taking the surface of the stones as a reference surface. Along the width of each plot for each of the five distances from the end-plate 3 to 5 stones were taken and at four 4 sides of each stone the depth of soil removed was measured and then the average was taken.

Table-13 shows the depth of soil removed in the long rainy season only. The depth of eroded soil from the bare plot was not measured because there was no reference surface for measurement.

The calculated soil loss value from this procedure was very much less than the actual soil loss that was collected in the storage tanks from each storm. In addition the soil loss calculated from the change in soil depth was not consistent. For example the soil loss from 40% surface cover was greater than that from the 20% surface covered plots which is very different from what was in the actual case. One of the reasons for this difference may be the displacement of the stones at the lower parts of the plots specially near the end-plates. As the soil under the stones was removed the stones did not stay in their position instead the stones inclined to rest on a new position. However, there is one fact that the depth of soil removed was progressively increasing from the upper end to the lower end of the plots, although the soil loss when converted to t/ha was lower than the actual soil loss.

Therefore, predicting the erosion rate by the depth of soil removed from some sample points may be misleading unless it is used for rough estimations.

Table 12. The computed C-factor values of the surface cover made by simulated stones (concrete slabs) and the adjusted soil loss values to a topographic factor of 9% and 22.13 m.

Surface cover (%)	0	10	20	40
Annual soil loss (t/ha)	467.7	427.3	379.1	303.9
C-factor value	1.00	0.91	0.81	0.65

Table 13. Depth of soil removed (in mm) at different points along the length of the plots.

	Distance from end-plate (m)					Volume	Weight
Plots	0.5	3.0	6.0	9.0	11.0	(m^3/ha)	(t/ha)
Z40	26	19	20	18	11	113	69
Y40	59	43	39	41	26	238	145
X40	62	58	57	45	45	320	195
Z20	45	34	37	28	18	259	158
Y20	44	32	45	37	21	286	174
X20	38	23	22	17	8	173	106
Z10	54	35	39	30	19	318	194
Y10	24	9	20	9	8	126	77
X10	59	48	47	39	25	393	240
40%	42	29	32	25	16	220	134
20%	39	28	35	29	18	210	128
10%	53	43	42	34	26	300	183

* Weight (t/ha) = Vol (m^3/ha) * 0.61t/m^3.

5. CURRENT LANDUSE AND SOIL CONSERVATION METHODS ON STONY SOILS IN BARINGO DISTRICT

Field investigations on stony soils in Baringo District were carried out to observe the present landuse systems, crops that are grown and the existing soil and water conservation measures.

5.1 BACKGROUND STUDY

Baringo district is in the central part of Rift Valley province of Kenya. It lies between 35^0 30' and 36^0 30' east and 0^0 50' and 1^0 5' north. The elevation of the district ranges from 900 to 2700 metres above sea level. The annual rainfall varies from 600 mm in the semi-arid areas to 1500 mm in the highland areas (Biamah, 1989 and Smith, 1983).

The soils on the hills and lower slopes are mostly of volcanic origin with dense stone cover on the surface and throughout the profile. The vegetation consists of natural and planted forests in the highlands; and bushes, shrubs and acacia trees in the lowlands.

The study reported in this thesis was carried out in the farmlands owned by individual farmers. The farms were selected from five locations for which the details are shown in Appendix 13 and 14.

5.2 LANDUSE

Twenty farmers were interviewed and their farms were visited. Most of the farms were on recently cleared lands and all the farms visited were owned by small holding farmers. For tilling and cultivating the land they use different types of jembes (fork, plain and traditional jembes) so that the stones do not restrict cultivation.

On the performance of crop growth it can be concluded that perennial crops grow better than annual crops due to the fact that the root system of the perennial crops can penetrate deep into the soil to absorb water and nutrients (see plate 8a and 8b). These perennial crops are also important in stabilizing the bunds by minimizing the removal of the soil at the lower edges of the bunds due to the binding effect of their root system.

Although the stony soils are believed to be more suitable for orchard trees (Magier and Ravina, 1984), in the visited farms they are not well adapted. In general cereals are the most abundant crops grown in the majority of the farms (see appendix 13).

On a farm where cattle were allowed to graze, the bunds were easily damaged facilitating gulley formation (see plate 9). This may lead to more soil erosion by forming gullies and greater costs than the expenditure of labour and money for the construction and maintenance. On grazing lands, there is no advantage in removing stones from the surface to make terraces, provided that overgrazing is avoided.

Plate 8a. Growth of bananas and sugarcane indicates the potential of stony soils for perennial crops

Plate 8b. Planting sugarcane at both edges of bunds helps the bund to steblize.

Plate 9. Stone bunds are easily damaged when cattle are allowed to graze

5.3 SOIL AND WATER CONSERVATION

Most of the crop lands that are terraced with stone bunds is due to the fact that farmers are supposed to construct bunds before they plant crops on the newly opened fields. In many farms especially those which were cleared and under crops for several years, it was observed that crop stands were better near the upper edges of bunds than the immediate lower edges of the bunds. This clearly indicates that there was much deposition of the top fertile soil above the bunds and erosion immediately below the lower edges of the bunds (see plate 10).

Based on visual observation a conclusion can be made that the soil and water conservation measures are very essential to protect the soil from erosion where the soils are deep and the stones are throughout the profile. The stoniness of the soils were variable at different farms. In the majority of the farms surface stones were dense comprising about 60 to 80% of the soil surface (see plate 11 and Appendix 14).

The distribution of stones along the profile was not properly investigated, although the proportion of the stones was decreasing down the profile on road cuts and pits near the farms (see plate 12). Some farmers described that when the surface stones are removed the soil becomes free of stones implying that stones are dense on the surface.

The higher deposition on the upper edges of the terraces (bunds) and soil removal on the lower edges of the bunds is most likely accelerated by removing the stones for bunding (see plate 13).

Plate 10a. Deposition of soil on the upper edges of bunds resulted in a good crop stand

Plate - 10b. Properly constructed and maintained bunds let the water to infiltrate so that crops grow better near the upper edges of bunds.

Plate - 11a. When surface stones are numerous removal of big stones may be desirable.

Plate - 11b. When stones are throughout the profile, stones come to the surface by cultivation.

Plate - 12a. Random distribution of stones down the soil profile.

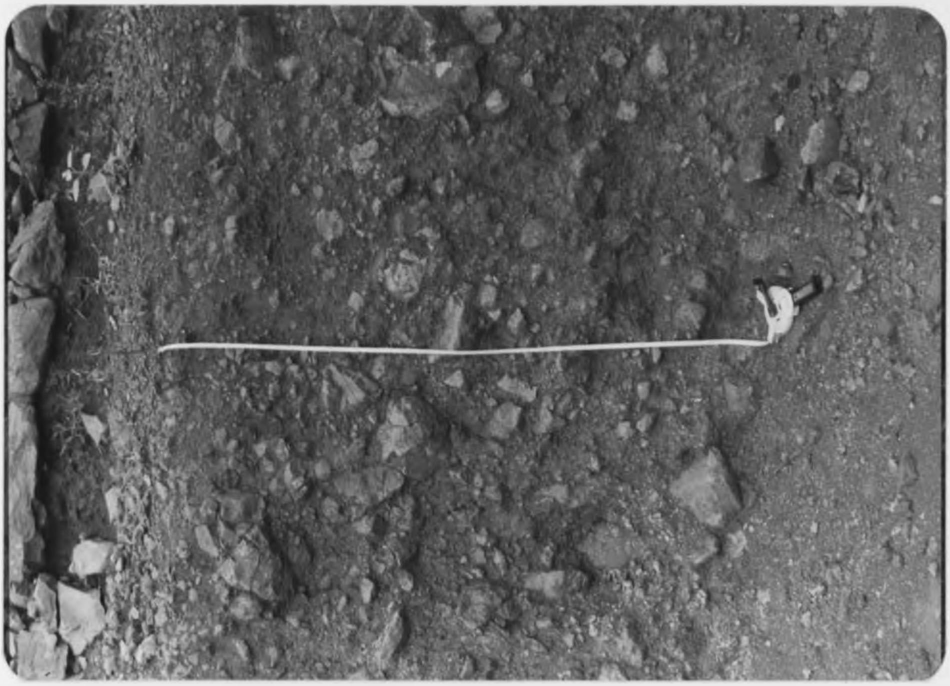


Plate - 12b. Stones are concentrated on the top few centimetres of the profile.

Plate 13. Removal of stones for bunding may accelerate erosion at the lower edges of bunds.

6.0 DISCUSSION

This section follows the pattern of the result section. First the effects of the simulated surface stone cover on soil loss and runoff from the natural rainfall is discussed. Then follows the discussion of the results of the simulated rainfall and runoff, sediment concentration and the cover and management C-factor values of the surface stone covers. The last part of this section deals with the importance of stones on soil loss and runoff from the natural stony soils.

6.1 SOIL LOSS AND RUNOFF FROM NATURAL RAINFALL

The total annual soil loss during the trial period on the bare plot was 318 t/ha while in 1982/83 annual soil loss from bare plots in the same site was 97 t/ha (Fisiha Tefera, 1983) which is mainly because of the variations in rainfall erosivity.

6.1.1 Short Rains.

During the short rainy season of 1988, the total soil loss and runoff was light. This was mainly due to the occurrence of low rainfall with low erosivity values. Both soil loss and runoff were highly correlated with the rainfall erosivity for which the coefficient of determination (r^2) was 97% and 96% respectively on the bare plot. This shows the importance of climatic factors for soil erosion.

The effects of different percentages of surface cover was statistically different at 0.05 level of significance in controlling erosion, although the difference in soil loss between 0 % surface cover and 10 % surface cover was negligible. For the small storms on 21/11/88 and 21/12/88 the influence of surface cover on soil loss as well as runoff was negligible but there was a visible treatment effect for the relatively more erosive storms of 25/12/88 and 06/01/89.

6.1.2 Long Rains.

The rains, in this long rainy season of 1989, were more erosive and frequent. The maximum monthly soil loss which was recorded in May 1989 was mainly due to more frequent rains with higher erosivity. More than 75% of the annual soil loss on the bare plots was observed within nine consecutive days and more than 57% of the annual soil loss was by two heavy storms.

When there was rainfall every day even a storm with 7 MJ.mm/ha/h, observed on 08/05/89 caused erosion unlike other storms with a greater erosivity values which occurred after a dry period. For example, a rainfall with an erosivity of 102 MJ.mm/ha/h, on 05/01/89 raining after 11 non-rainy days did not cause any erosion. This could be attributed to the existing soil moisture conditions which influence the infiltration rate of the soil.

The results show the enormous erosion potential of one or two heavy storms taking place when the ground is already wet. Therefore conservation plans should include arrangements to deal with such heavy storms which can occur when a crop is just becoming established and there is little ground cover.

The effect of different percent surface cover was statistically different at 0.05 level of significance for the whole of the long rainy season of 1989. But when the data from the heavy and light storms was analyzed separately the cover effect on soil loss was different.

6.1.3 Effect of Surface Cover on Annual Soil Loss.

The total annual soil loss and runoff was influenced by the percentage of the surface covered by the simulated stones. The data on soil loss versus percent surface cover were analyzed using a non-linear curve fitting technique and soil loss was highly correlated with cover according to the following equation:

$$SL = a * e^{bC}$$

where SL is the soil loss in ton/ha, a and b are constants and C is the percent surface cover and e is the base of the natural logarithm whose value is

2.71828. The values of the constants in the fitted equation for different rainfall events are shown in table 14.

The percent surface cover was more effective for the heavy storms than the light storms. The soil loss from different percent surface cover was statistically significant at 0.01 level of significance for the heavy storms.

The increased effectiveness of the higher percent surface cover to control soil loss on higher intensities and heavy storms is different from what was observed in other places. In Israel on natural stony soils, Evenari et al. (1971) found that stone cover was more effective to reduce runoff from the lower intensities of rainfall than from the higher intensities of rainfall. Such variations may be attributed to the soil type, the nature of the cover, the slope steepness and/or the surface conditions.

Evenari et al. (1971) reported that the better effectiveness of the stone cover on stony soils from low intensities of rainfall was because of the presence of fissures between the stones and the soil which promoted higher infiltration. But in the research reported in this paper, there were no such fissures since the simulated stones (concrete slabs) were only put on the surface of the soil so that their effect on soil loss and runoff was mainly due to their effect on dissipating the rain drop impact and retarding the velocity of the runoff.

The greater effect of increased surface cover made by the simulated stones on soil loss from high intensities and heavy storms of rainfall is interesting because the reverse might be expected due to decreased surface area of the soil per plot for infiltration. It was unfortunate that it was not possible to compare the treatments effect on runoff during the two heavy storms in May 1989 since all the storage tanks overflowed. If the assumption that the total amount of soil loss is linearly correlated to the total amount of runoff for all the treatments is valid for such storms, the increased surface cover of the soil is an important aspect for conservation under tropical conditions where the rains can fall at high intensities.

The annual soil loss on bare plots was linearly correlated with the runoff from all the storms, excluding the two exceptionally heavy storms, with a coefficient of determination (r^2) of 95% (see Appendix 7). Such correlation was in agreement with others published in Ethiopia (Werner 1986). Although the slope of the regression lines from different percent surface cover is different, such correlation of soil loss with runoff is important because the soil loss can be estimated when only the runoff data is available.

6.2 SIMULATED RAINFALL

6.2.1 Soil loss and runoff

The amount of soil loss was slightly reduced from both dry-run, wet-run and very wet-run as the percent surface cover by concrete slabs was increased. The increased surface cover was more effective in wet and very wet runs than the 60 minutes duration dry-run.

The soil loss from the 40% surface covered plots when expressed as the percent of the soil loss from the bare plots was 67%, 56% and 57% respectively for dry, wet and very wet runs.

This shows the slightly greater effectiveness of higher surface stone cover in controlling erosion when the soil moisture is high. Such tendencies of increased effectiveness of 40% surface cover in high rainfall intensities and frequencies was observed even in the natural rains.

Although there was reduction on the total amount of soil loss as the percentage of the surface cover was increased, an F-test has shown that there was no significant difference between treatments in reducing erosion from the dry and very wet-runs at 0.05 level of significance.

The reduction of soil loss as the percent surface cover was increased is in agreement with studies carried out under the natural and artificial rock fragment cover (Meyer et al. 1972 and Box 1981). Using a rainfall simulator, Meyer et al. (1972) found that the total soil loss was negligible on 100% stone cover as compared to 5.1 tons/ha and 17.7 ton/ha on 60% stone cover and bare plot respectively. Similarly Box (1981), using a rainfall simulator on natural rock fragment cover, found that removing the stone fragments from the plots increased the amount of soil loss and adding rock fragments reduced the total soil loss from the plots.

At Kabete the soil loss per unit area tended to decrease as the slope length was increased (see table-11). In the previous studies it was shown and is generally accepted that the amount of soil loss increases as the slope length increases (Meyer et al., 1972, Wischmeier and Smith, 1978). Meyer et al. (1972) found that the rate of soil loss per unit area increased for longer simulated slope length at 20% slope.

However, in this study, using a similar method, soil loss decreased as the simulated slope length was increased. This may be due to one, or all, of the following reasons:

1) it may be because of the differences in slope steepness in which the average slope steepness in this case was about 8%.
2) it may be because of soil parameters that

affect infiltration and resistance to the shear stress of the runoff.

3) it may be because of the assumption that "doubling the runoff added doubles the slope length" is not valid in all conditions.

The other major reason may be the formation of rills. In the study the contribution of rills to soil loss was relatively minor when compared to sheet erosion unlike in the experiment reported by Meyer et al. (1972).

At Kabete runoff on 10% and 20% covered plots was not significantly different from the bare plot and it was reduced only by 40% covered plots. Such different effects of surface cover on runoff when compared to soil loss may be due to some unexplained factors. However, some of the reasons for the variation may be due to the simulated rainfall effects such as wind and simulation time which could affect the drop impact energy as well as the infiltration rate. In addition the ratio of runoff to the applied rainfall progressively increased from dry-run to the 2nd very wet-run. This observation emphasises the importance of the antecedent soil moisture to the amount of runoff and rate of infiltration.

The low value of the ratio of runoff to rainfall for the 40% surface cover indicates not only the effects of the stones on sealing and crusting, it also shows the effects of the roughnesses created by those stones on retarding runoff velocity. Visually it was observed that the runoff was not concentrated to flow in one or two specific paths on the 40% surface stone cover unlike the control and 10% surface covered plots. Rather the runoff was flowing in a staggering path between the stones and was distributed all over the plots.

In this view there would be a threshold point from which both soil loss and runoff starts to decrease rapidly and a further research would be important to determine this threshold point for the surface stone cover.

6.2.2 Sediment Concentration.

Estimates of soil loss from a catchment is made by sampling the sediment concentration of the flowing rivers and measuring the flow rates at various intervals of time. A similar procedure is also used in the runoff plots to determine the amount of soil loss from a particular rainfall event.

Therefore, the concentration of sediment at a regular intervals of 5 minutes was determined for each of the runs with the simulated rainfall. In general, the concentration of sediment tended to increase until it reached the peak and then started to decrease for all runs. Such a change in sediment concentration was significantly higher during the dry run. This could be attributed to the decrease in the infiltration rate and increase in runoff once the soil became saturated.

A comparison can be made about the effect of the varying surface stone cover at different durations of the rainfall on sediment concentration and erosion rates at different soil moisture conditions. If the dry-run is considered the sediment concentration started from low value, reached a peak and then started to decline (see figure 13a and 13b).

The erosion rate was computed from the same samples that were used to determine the sediment concentration and it reached to the maximum rate within 10 minutes after the runoff had start.

In both varying surface covered plots the sediment concentration attained maximum value within 25 minutes after the runoff had started and then tended to decline, during the one hour dry-run.

The increasing sediment concentration at the beginning may be due to high infiltration rate and high detaching effect of the raindrops. As the ground became saturated and the infiltration rate declined, the surface water formed a layer cushioning the raindrop impact and reducing its detaching force.

Table 14. The values of the coefficient of determination (r^2) and the constants a and b in the statistically fitted equation of soil loss versus percent surface cover[*].

Type of Rain	a	b	r^2
Natural Rainfall			
Short rains	27.91	-0.015	0.95
Long rains	295.6	-0.010	0.99
Heavy storms	188.9	-0.012	0.98
Light storms	106.9	-0.006	0.95
Simulated Rainfall			
Dry-run	32.0	-0.011	0.94
Wet-run	11.8	-0.013	0.88
1st Very wet-run	11.3	-0.013	0.95
2nd very wet-run	60.1	-0.018	0.72

[*] The equation of the best fit curve was in the form of:

$$Y = a * e^{bX}$$

where:

Y = soil loss,

X = percent surface cover

e = the base of the natural logarithm

a and b are coefficients whose values are given in the above table.

6.3 COVER AND CROP MANAGEMENT C-FACTOR

Figure 17 shows the relationship between the percent surface cover and erosion ratios of the annual soil loss. The erosion ratio for each treatment was obtained by dividing the total annual soil loss from the given treatment to the soil loss from the control or bare plot after adjusting the other factor values to their corresponding values on a standard unit plot.

The graph suggests an almost linear relationship between erosion ratio and the percent surface cover. This inverse relation between the erosion ratio and the percent surface cover confirms the benefit of stone cover but there are several processes that brought about differences from the observations reported by Box and Meyer (1984).

Box and Meyer (1984), comparing the soil loss ratio from natural coarse fragment and surface mulches of crushed stones to the no canopy curve of Wischmeier and Smith (1978), showed that the data collected from the stone cover satisfactorily fitted the no canopy curve.

Whereas at Kabete with simulated stones, there was not an abrupt reduction in soil loss as the percent surface coverage was increasing. For example, the soil loss ratio for the 40% cover was 0.68, which is very high unlike the previous studies reported by Box (1981) in which the soil loss ratio for the same percentage of cove made by stone fragments was less than 0.4.

The values of the soil loss ratio in figure 17 is the value of the C-factor from the corresponding percent surface cover made solely by simulated stones since the plots were kept without any vegetation because the aim was to see the effect of the surface cover made by concrete slabs. However the control plots do not satisfy the requirements of the bare fallow conditions of Wischmeier and Smith (1978) because they were under crop for the previous seasons as described in the methodology section. This may decrease the values of the soil loss from the control plots due to the binding action of the roots and the presence of more soil organic matter than would be found if it was kept fallow, tilled up and down, for more than two years.

Therefore the figures for the C-factor value are only a comparison that could be made between different rates of surface cover in controlling soil loss.

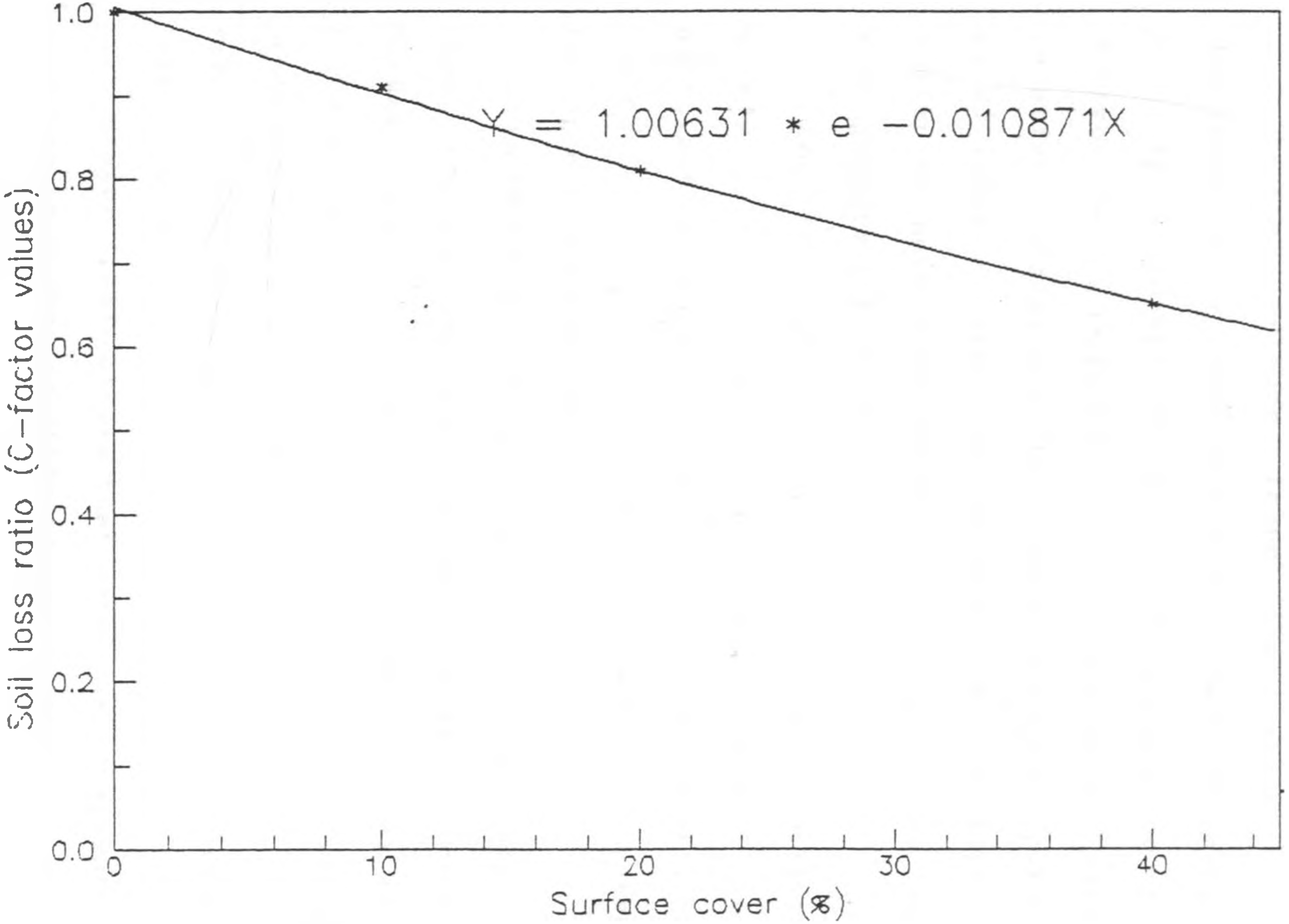


Fig.17 The C-factor value of the USLE for stone cover as computed from one year data

6.4 IMPORTANCE OF STONES ON NATURAL STONY SOILS

Several authors found that stone cover decreases runoff yield on a slope because the stones intercept raindrops dissipating their energy so that surface sealing is impeded and infiltration increases relatively (Grant and Struchtmeyer,1959 and Epstein et al.,1966). Many insects and burrowing animals prefer to nest under stones, and this nesting may also promote infiltration.

The effect of stones on soil loss and runoff is widely variable due to their nature and distribution. In some places stones are dominantly on the surface and in other places they are distributed throughout the profile.

In Kenya, for instance, soils with fragments of quartz representing an erosion pavement are common in Machakos and Kitui Districts. In areas such as the Tugen hills, stones are distributed throughout the profile which have little or no history of accelerated erosion (D.B.Thomas personal communication).

Poesen (1987) showed that small rock fragments, upto 9 cm intermediate diameter can be transported to a considerable distance by rill flow. The displacement of the rock fragments was negatively correlated to their diameter. Therefore, the transportability of stones greater than 9 cm by rill flow is negligible compared to the finer soil particles under normal rainfall conditions.

In those places like in Machakos and Kitui districts, where there are dense stone fragments on the surface of the soil, it can be pointed out that the dense surface stone cover might be due to the selective removal of the soil by erosion. As the erosion process continues for decades or centuries the finer soil particles are selectively removed, the stones remaining in place. The soils in such areas are shallow with slow weathering processes due to the presence of none or few vegetation.

Therefore, it would be advisable to a soil and water conservation planner to consider biological measures that enhance the growth of vegetation which are the major factors for weathering and improving the soil structure.

At specific situations, even where there are stones heavy storms as we had at Kabete in May can cause heavy soil losses if the soil between the stones is exposed to direct raindrop impact. Even though such circumstances arise complications in deciding whether or not removal of stones is desirable, there are several techniques to be adapted in stony soils to protect the soil from erosion without removing the stones. Planting narrow grass strips may effectively control erosion on stony soils. The grass strips can act as a filter to trap the sediments and provide organic matter to the soil to improve the soil structure.

In addition, when the soils have stones throughout the profile, stones may be removed to make bunds since other stones might come to the surface during cultivation.

According to the available evidence, mentioned in the literature review, it is clear that such stony soils reduce the runoff and soil loss by increasing infiltration and dissipating the raindrop impact energy. The increased infiltration is due to two major reasons:

1) the pore space between the stones and the soil results in high permeability.
2) reduced sealing and crusting on the surface of the soil prevents the decrease in infiltration rate.

In general it can be concluded that removal of surface stones will lead to an increase in runoff and soil loss . However, removal of stones to make bunds may be desirable in the following conditions:

1. <u>When the soils are deep and have stones throughout the profile</u>. As it was observed with simulated stones at Kabete, a substantial amount of soil loss is caused by two or more heavy storms. The soil loss could be more than the tolerable limit in

the natural stony soils having similar heavy storms so that some erosion control measures are required to minimize the soil loss.

Forming bunds may be one of the measures because bunding shortens the slope length and deposition occurs at the upper edges of bunds so that the net soil loss from the field will be reduced. Even if some stones are removed to make bunds, others will come to the surface during cultivation when the stones are throughout the profile.

2. When the surface stones are too numerous and or boulders restrict cultivation. Small stones provide space for crops to be supported by the soil even if 80% of the total volume is occupied by stones (Ashby et al.1984). But boulders should be removed since they restrict cultivation and occupy space so that crop growth is limited only to the space between the boulders since crops can not be supported on the surface of the boulders.

On the contrary, removal of stones to make bunds may be disadvantageous in the view of soil and water conservation:

1. When the soils are shallow. The effect of erosion is always noticed easily in shallow soils than in deep soils. The removal of a few millimetres

of soil from shallow soils cause a substantial reduction in crop growth and yield. Poor crop growth, in turn causes more erosion due to the lower organic matter added and cover provided to the soil.

Even if bunds are constructed by removing the stones, the bunds need to be spaced closer in which a significant amount of land is taken by the bunds, otherwise soils from the lower edges of the bunds will be removed completely until unproductive infertile soil layer is reached or the bedrock is exposed.

2. <u>If the stones are only on the surface</u>. The observations in the Kabete trial had proved that the raindrop impact energy is the major cause of erosion and surface cover the most effective preventive measure (see Plate 6).

3. <u>If the land is very steep</u>. The soil loss rate increases progressively as the steepness of the land is increased. In steep slopes if bunds are to be made they must be spaced closer and this, in addition to the reduction of the land size taken by bunds, interferes cultivation specially in places where the land is cultivated by oxen.

4. <u>If the land is under grazing</u>. Cattle destroy bunds and introduce more erosion even if they are

properly constructed. Stones scattered on the surface prevent sealing and provide protection to some useful plants.

7 CONCLUSION AND RECOMMENDATION.

7.1 CONCLUSION.

The annual soil loss results (presented in sections 4.1 and discussed in section 6.1) were extremely high which was mainly due to the erosive rainfall events observed in the long rains in May 1989. Therefore, a few major erosive events have been found to be the most important factors in determining soil loss, and increased surface coverage of the soil was superior in controlling erosion from such rainfall events than from relatively lower intensity storms.

Out of the 18 rainfall storms that caused soil loss and runoff about 56% and 53% of the annual soil loss occurred with two exceptionally heavy storms on the bare (control) plot and the 40% surface covered plots respectively.

In May when there were no crops to provide surface cover, the soil loss in tonnes per hectare was 242 and 162 on the bare and 40% surface covered plots respectively. The contribution of the soil loss in May 1989 to the annual soil loss on bare plots was 76%.

Heavy storms as we have at Kabete in May can cause heavy soil losses if the soil between the stones exposed to direct raindrop impact, if there is no crop cover and if the ground is saturated. In such situations, it would appear necessary to have grass strips or stone bunds to reduce the losses of soil off the field. There is good reason to argue that it would be best to leave the stones in situ and plant narrow grass strips to trap any soil that might be carried off the field.

The 40% surface cover has shown superiority in controlling soil loss and runoff. The reduction of soil loss from the increased surface coverage implies the importance of surface stone cover in reducing erosion since more than 50% of the soil surface is covered by stones in most areas where the soil is stony.

It can be concluded that removal of surface stones will lead to an increase in runoff and soil loss. However, removal of stones to make bunds may be desirable in the following conditions:

1. when the soils are deep with high infiltration rate and have stones throughout the profile and
2. when the surface stones are too numerous and/or boulders restrict cultivation.

On the contrary, removal of stones to make bunds may be disadvantageous in the view of soil and water conservation:

1. when the soils specially in the A-horizon are shallow,
2. if the stones are only on the surface
3. if the land is very steep and
4. if the land is under grazing.

7.2 RECOMMENDATION.

1. Removing the stones from the soil surface accelerates erosion since surface stone cover protects the soil from raindrop impact energy which is the major cause of erosion. Therefore in places where bunding is feasible smaller stones should be kept in situ and removal of larger stones, which might interfere with cultivation, would be justified provided that stones occur throughout the profile.

2. On steep slopes with shallow soils leaving stones in situ and letting the natural vegetation grow is a better form of land use than trying to cultivate and grow crops. If cropping is unavoidable stone terraces can be constructed but the terraces must be close and the amount of land left for cultivation will be small and cropping uneconomical.

3. Trials carried out by others in the arid and semi-arid regions, where the rainfall is

scarce, have shown that stones on the surface of the soil are useful to reduce evaporation, to increase surface detention and infiltration so that crops grow better than on stone free soils. Further trial is needed to investigate the effect of removing stones on water losses by evaporation and crop growth in the low rainfall areas where water is the limiting factor for crop production.

4. There is a need for more information on the losses of soil and water from stony soils under normal cropping practices; the relationship between soil loss and percent surface cover made by crops and stone; and the use of grass strips on stony soils.

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9. APPENDICES

Appendix-1. ANOVA table of soil loss from the short rainy season.

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	251.48	83.6	7.0'	4.76	9.7
Rep.	2	531.27	265.6	22.3''		
Error	6	71.53	11.92			
Total	11	854.28				

' significant at 0.05 level of significance

'' significant at 0.01 level of significance

^{ns} not significant at 0.05 level of significance

Appendix-2. ANOVA table of Runoff from the short rainy season.

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	89.38	29.8	6.98'	4.76	9.7
Rep.	2	199.89	99.9	23.4''		
Error	6	25.60	4.32			
Total	11	314.88				

Appendix-3. ANOVA table of Soil loss from the long rainy season of 1989.

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	15325	5108	8.21'	4.76	9.7
Rep.	2	22057	11028	17.72"	5.14	10.9
Error	6	3734	622			
Total	11	41115	3738			

Appendix-4a. ANOVA table of Soil loss from the two heavy storms of 1989 long rains.

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	8675	2892	16.09"	4.76	9.7
Rep.	2	5233	2617	14.56"		
Error	6	1078	179			
Total	11	14987	1362			

Appendix-4b. ANOVA table of Soil loss from the 12 light storms of 1989 long rains.

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	970	323	1.9^{ns}	4.76	9.7
Rep.	2	5820	2910	$17.3^{''}$		
Error	6	1011	168			
Total	11	7801	709			

Appendix-5. ANOVA table of Runoff from the 12 light storms of 1989 long rains.

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	41	14	0.08^{ns}	4.76	9.7
Rep.	2	824	412	2.44^{ns}		
Error	6	1011	169			
Total	11	1875	170			

Appendix-6. ANOVA table of Soil loss from the simulated rainfall.

a) for dry-run

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	223	74	1.94^{ns}	4.76	9.7
Rep.	2	261	131	3.42^{ns}	5.14	10.9
Error	6	229	38			
Total	11	714	65			

b) for wet-run

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	42	14	12.61^{**}	4.76	9.7
Rep.	2	90	46	40.8^{**}	5.14	10.9
Error	6	7	1			
Total	11	139				

c) for the first very wet-run

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	38	13	2.38^{ns}	4.76	9.7
Rep.	2	107	53	$10.16^{'}$	5.14	10.9
Error	6	32	5			
Total	11	176				

d) for the second very wet-run

Source	df	SS	MS	F_{cal}	$F_{.05}$	$F_{.01}$
Cover	3	1115	372	5.06^{ns}	4.76	9.7
Rep.	2	617	617	8.4^{ns}	5.14	10.9
Error	6	220	73			
Total	11	1952				

Appendix -7

Table showing the constants from the regression equation and their coefficient of determinations (r^2) for different rainfall conditions.

Correlation Variables	Constants	Coefficient of X	r^2 (%)	n	df
X Y					
RF & EROS	-299	17.40	91	35	33
RF & SL_0	-12	0.66	90	36	34
RF & RO_0	-5.4	0.36	54	34	32
EROS & SL_0	-0.9	0.03	96	35	33
EROS & RO_0	-0.8	0.03	83	33	31
RO & SL_0	-0.00	0.98	95	16	14
RO & SL_{10}	0.05	0.90	90	16	14
RO & SL_{20}	0.41	0.70	83	16	14
RO & SL_{40}	0.13	0.73	92	16	14

APPENDIX - 8.

a) Summary of Annual soil loss Results (t/ha).

	REPLICATIONS			
% COVER	X	Y	Z	AVG
	Short Rains			
0	36.6	22.1	20.4	26.4
10	40.1	21.0	17.4	26.2
20	25.1	18.6	18.1	20.6
40	24.0	11.9	10.0	15.3
	Long Rains			
0	357.8	265.2	253.3	292.1
10	366.0	231.9	228.2	275.4
20	277.8	233.6	202.1	273.8
40	237.6	210.8	150.1	199.5
	Annual			
0	394.4	287.3	237.7	318.5
10	406.1	252.9	245.6	301.6
20	302.9	252.2	220.2	258.4
40	261.6	222.7	160.1	214.8

b) Soil loss (t/ha) from individual rainfall storms that cuased erosion. (Figures are means of 3 replications)

Date	Rainfall (mm)	Erosivity (MJ.mm/ha/h)	Soil loss (t/ha) 0%	10%	20%	40%
21/11/88	30.6	54	0.21	0.22	0.17	0.14
21/12/88	23.5	32	0.23	0.20	0.19	0.22
25/12/88	36.5	83	2.8	2.4	1.7	1.4
06/01/89	48.0	699	23.2	23.4	18.5	13.6
06/04/89	45.1	138	2.7	2.5	2.2	1.4
24/04/89	35.4	470	11.2	9.8	7.2	7.0
25/04/89	36.7	289	9.2	8.8	6.9	6.2
27/04/89	22.9	107	4.6	5	4.1	4.4
07/05/89	112.4	1240	65.7	62.8	53.6	45.8
08/05/89	18.2	6	0.9	0.9	0.8	0.9
09/05/89	50.0	298	10.9	10.4	10.5	10.8
11/05/89	49.7	438	9	8.3	7.3	6.5
12/05/89	56.0	584	25.3	21.1	20.4	17.6
13/05/89	19.4	33	2.5	2.2	2.0	1.7
15/05/89	8.1	19	4.4	4.6	4.2	3.8
17/05/89	17.7	132	4.5	5.8	5.6	6.1
18/05/89	182.5	3394	118.5	110.7	93.1	68.9
03/06/89	26.7	-	22.5	22.3	19.9	18.5

APPENDIX - 9.

a) Summary of Annual Runoff Results (mm).

% COVER	X	Y	Z	AVG
		REPLICATIONS		
		Short Rains		
0	31.9	24.0	22.0	25.9
10	32.5	22.5	20.9	25.4
20	25.2	24.7	17.9	22.6
40	25.1	17.5	14.5	19.1
		Long Rains[*]		
0	128.1	113.0	101.4	114.2
10	116.2	108.2	117.6	114.0
20	119.3	138.3	90.8	116.1
40	117.6	·110.1	106.2	111.3
		Annual[*]		
0	160	137	123.4	140.1
10	148.7	130.9	138.5	139.4
20	144.5	163.0	108.7	138.7
40	142.7	127.6	120.7	130.7

[*] These figures do not include the runoff from 07/05/89 and 18/05/89.

b) The ratio of monthly runoff to rainfall expressed in percent (from October, 1988 to August, 1989 and figures are means of 3 replications)

Month	Rainfall	RUNOFF RATIO			
	(mm)	0%	10%	20%	40%
Oct	16.7	0	0	0	0
Nov	105.3	0.4	0.3	0.2	0.1
Dec	146.5	2.9	2.9	2.0	1.8
Jan	140.7	15.1	14.8	13.9	11.5
Feb	47.0	0	0	0	0
Mar	94.2	0	0	0	0
Apr	230.0	11.1	10.1	9.0	8.7
May1	561.3*	-	-	-	-
May2	266.4**	26.5	27.5	31.0	27.9
Jun	27.5	66.2	63.3	45.8	61.8
Jul	44.2	0	0	0	0
Aug	19.1	0	0	0	0

* Total rainfall in May 1989

** The rainfall in May 1989 excluding the two heavy storms of 7th and 18th of May.

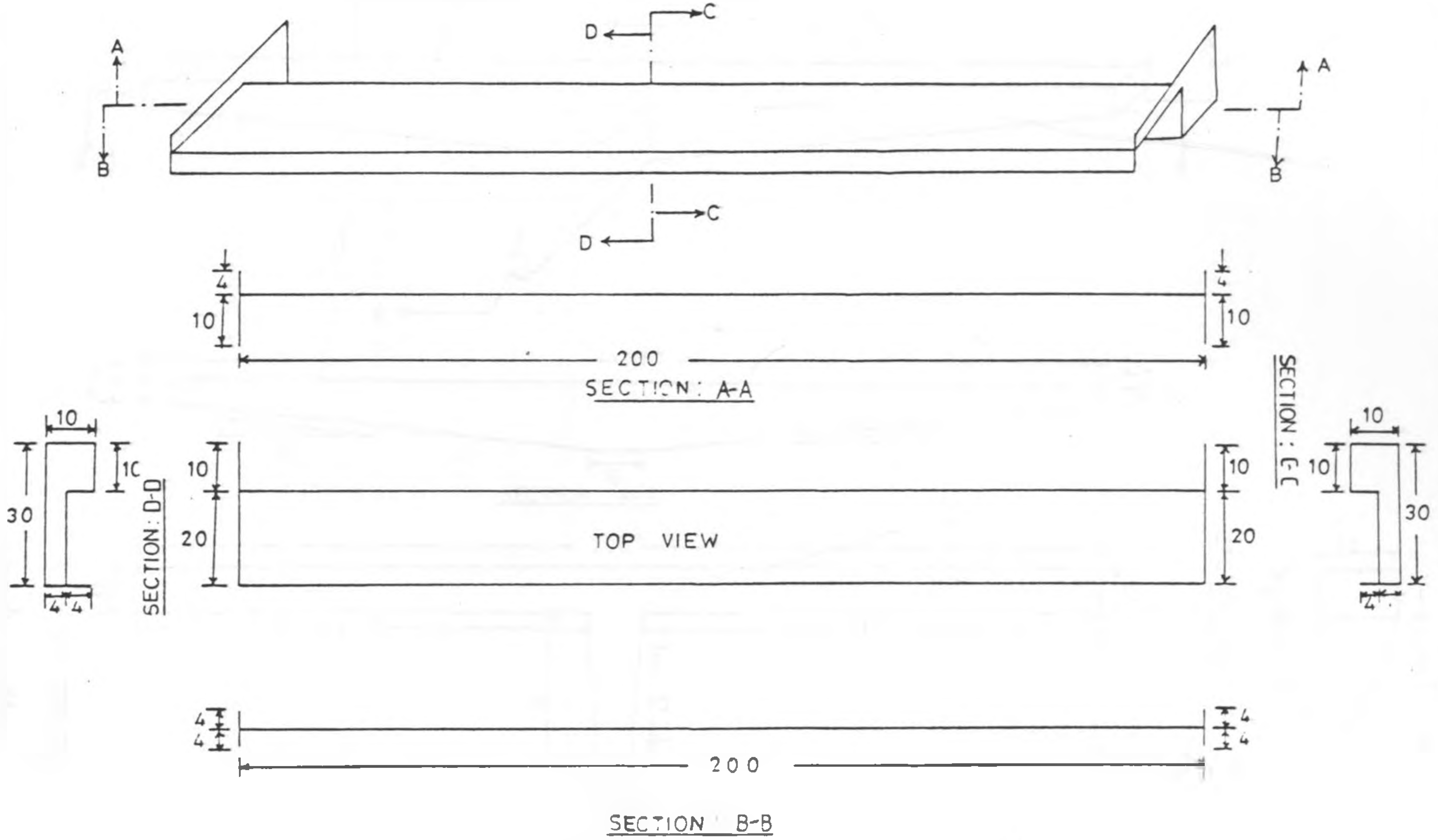
c) Runoff as percent of rainfall from individual storms that caused runoff (figures are means of 3 replications).

Date	Rainfall	Erosivity	RUNOFF	RATIO		
	(mm)	(MJ.mm/ha/h)	0%	10%	20%	40%
21/11/88	30.6	54	1.3	1.0	0.6	0.5
21/12/88	23.5	32	0.6	0.7	0.6	0.8
25/12/88	36.5	83	11.4	11.2	7.6	6.8
06/01/89	48.0	699	44.3	43.4	40.6	33.8
06/04/89	45.1	138	8.0	5.3	5.1	3.1
24/04/89	35.4	470	26.6	22.6	19.2	16.1
25/04/89	36.7	289	19.9	19.6	17.7	19.1
27/04/89	22.9	107	22.7	24.9	22.7	25.3
07/05/89	112.4	1240	-	-	-	-
08/05/89	18.2	6	10.4	11.0	18.1	12.6
09/05/89	50.0	298	31.8	34.8	32.6	33.0
11/05/89	49.7	438	25.8	26.6	28.2	24.9
12/05/89	56.0	584	48.9	48.4	63.6	50.4
13/05/89	19.4	33	18.0	18.6	19.1	18.0
15/05/89	8.1	19	46.9	50.6	53.1	59.3
17/05/89	17.7	132	28.8	32.8	31.6	37.9
18/05/89	182.5	3394	-	-	-	-
03/06/89	26.7	-	68.2	65.2	47.2	63.7

Appendix - 10 Detailed views and Dimensions of the runoff collecting equipment

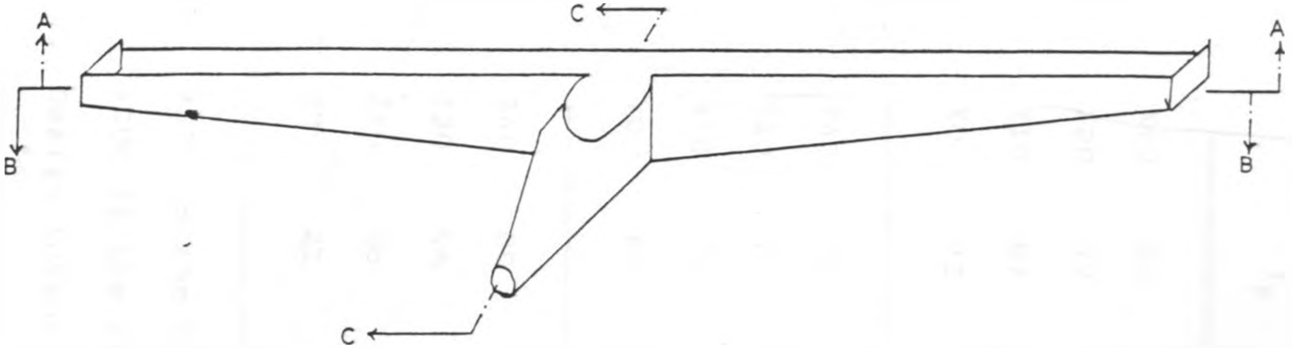
a) The End-plate

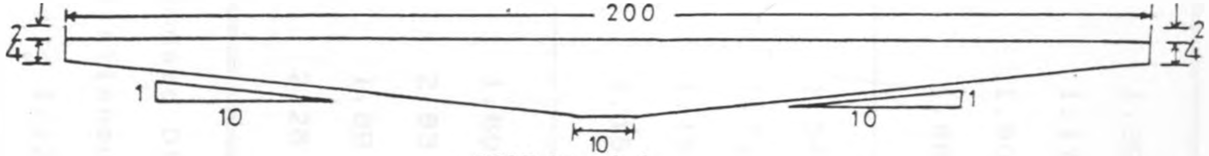
a) THE END PLATE



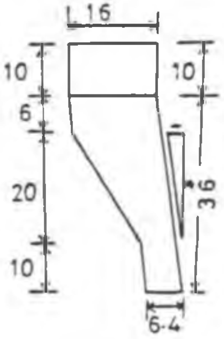
DESIGNED BY	NURZEFA SHAFO		
DRAWN BY	NURZEFA SHAFO		
SCALE	1:15	DATE	1988
DIMENTIONS	IN CM		
PROJECT			
CHECKED BY	PROF. Uo THOMAS		

b) RUNOFF COLLECTING TROUGH

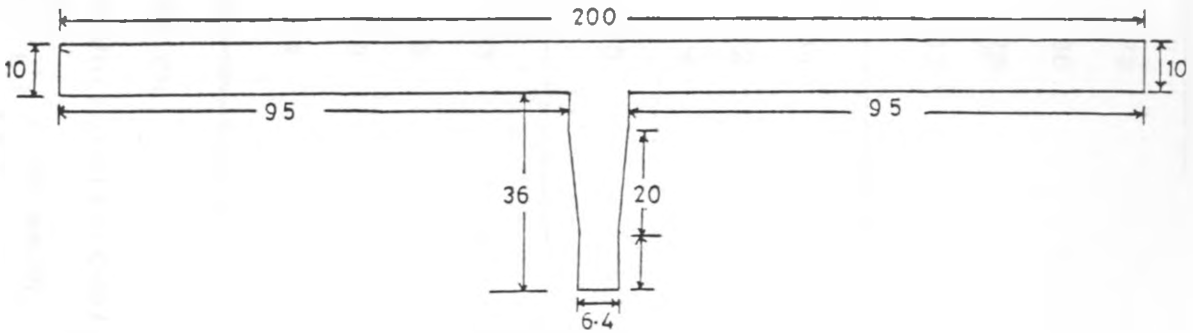




SECTION : A-A

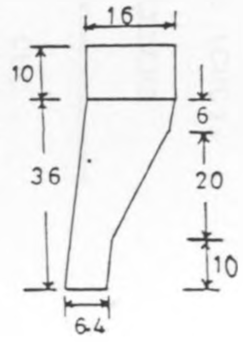


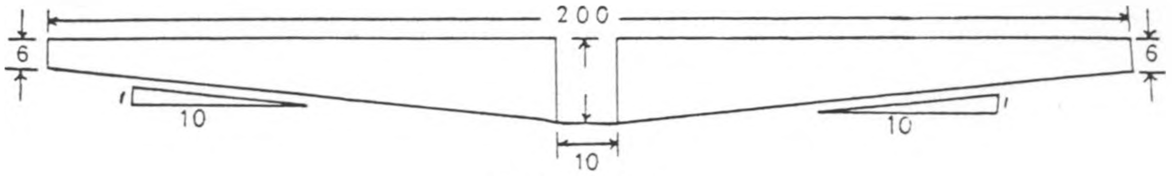
SECTION C-C



TOP VIEW

SECTION : D-D





SECTION: B-B

DESIGNED BY	NURZEFA SHAFO		
DRAWN BY	NURZEFA SHAFO		
SCALE	1:15	DATE	1988
DIMENTIONS	IN CM		
PROJECT			
CHECKED BY	PROF. D.B. THOMAS		

Appendix 11. Average rainfall intensities, standard deviations and Christianson's uniformity coefficient (CUC).

a) During 60 minutes Dry-run

Plot	Intensity I_p	STD*	CUC+
X40	80	1.99	78
X20	72	1.17	86
X10	67	1.90	78
X0	72	1.66	82
Y40	81	1.54	84
Y20	77	1.74	82
Y10	74	1.19	87
Y0	82	2.15	75
Z40	80	1.80	83
Z20	96	2.83	75
Z10	86	1.89	79
Z0	77	2.26	74

*STD is the Standard Diviation

+CUC is the Christianson's Uniformity Coefficient

Design intensity = $1/12 \sum_{j=1}^{12} (I_p)_j$ = 79 mm/h.

Where I_p is the rainfall intensity (mm/h) from a plot in the dry-run.

b) <u>During 20 minutes wet-run</u>

Plot	Intensity I_p	STD*	CUC+
X40	94	2.16	81
X20	71	1.60	82
X10	87	2.43	77
X0	77	1.65	79
Y40	87	1.89	82
Y20	70	1.73	80
Y10	85	1.68	84
Y0	91	2.28	79
Z40	95	2.71	75
Z20	82	1.97	80
Z10	91	2.25	81
Z0	78	2.15	78

*STD is the Standard Diviation

+CUC is the Christianson's Uniformity Coefficient

Design intensity = $1/12 \sum_{j=1}^{12} (I_p)_j$ = 84 mm/h.

Where I_p is the rainfall intensity (mm/h) from a plot in the wet-run.

c) <u>During 20 minutes 1st very wet-run</u>.

Plot	Intensity I_p	STD*	CUC+
X40	83	2.19	79
X20	67	1.46	83
X10	85	1.79	83
X0	70	1.46	82
Y40	89	1.82	83
Y20	68	1.85	78
Y10	92	3.76	68
Y0	77	1.91	79
Z40	91	2.26	79
Z20	88	2.76	75
Z10	84	1.99	80
Z0	91	2.07	80

*STD is the Standard Diviation

+CUC is the Christianson's Uniformity Coefficient

Design intensity = $1/12 \sum_{j=1}^{12} (I_p)_j$ = 82 mm/h.

Where I_p is the rainfall intensity (mm/h) from a plot in the first very wet-run.

d) <u>During 50 minutes 2nd very wet-run</u> .

Plot	Intensity I_p	STD*	CUC+
Y40	89	2.21	77
Y20	87	2.7	72
Y10	82	1.91	80
Y0	91	1.74	79
Z40	89	2.35	77
Z20	66	2.39	76
Z10	72	2.03	80
Z0	71	2.75	74

*STD is the Standard Diviation

+CUC is the Christianson's Uniformity Coefficient

Design intensity = $1/8 \sum_{j=1}^{8} (I_p)_j$ = 81 mm/h.

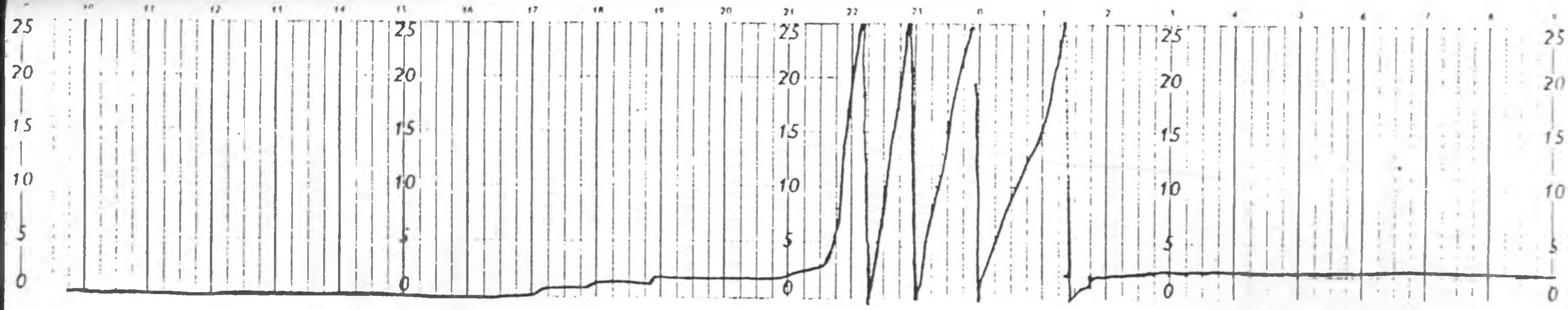
Where I_p is the rainfall intensity (mm/h) from a plot in the second very wet-run.

APPENDIX - 12

Sample calculations of the rainfall erosivity using EI30 method of Foster et al. (1981)

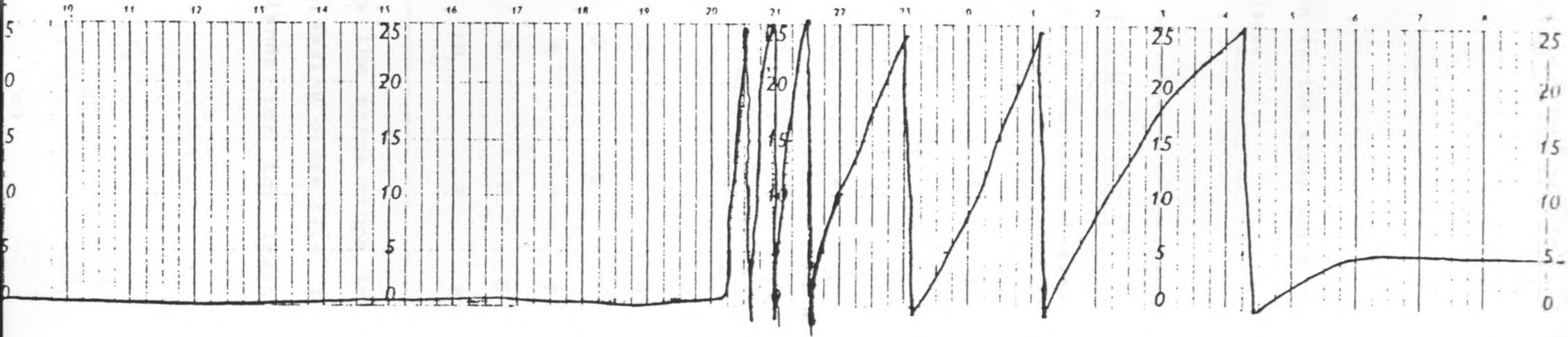
For the rainfall on 07/05/89

Time	Depth (mm)	Duration (min)	Intensity (mm/h)	em (MJ/ha/mm)	E (MJ/ha)	R = EI30 (MJ.mm/ha/h)
17:00	0.00					
17:05	0.75	5.00	9.00	0.20	0.15	
17:50	0.75	45.00	0.00			
17:55	1.00	5.00	3.00	0.16	0.04	
18:55	1.00	60.00	0.00			
19:05	2.00	10.00	6.00	0.19	0.19	
21:20	2.00	15.00	0.00			
21:37	3.00	17.00	3.53	0.17	0.17	
21:45	5.00	8.00	15.00	0.22	0.44	
22:15	27.50	30.00	45.00	0.26	5.92	
23:00	55.00	45.00	36.67	0.26	7.03	
0:00	82.00	60.00	27.00	0.24	6.59	
0:55	95.75	53.00	15.57	0.22	3.07	
1:00	96.00	7.00	2.14	0.15	0.04	
1:25	110.50	25.00	34.80	0.25	3.68	
1:40	110.70	15.00	0.80	0.11	0.02	
1:45	111.70	5.00	12.00	0.21	0.21	
			I30 = 45		27.55	1239.53



5 mm 10 mm on chart Station Kabete Total 9h to 9h Recorder 102 mm Check gauge 112·4 mm 571

Year [illegible] 1989 Month [illegible] 18-19 May, 1989 Time on ... d ... hrs. Time off ... d ... hrs. Duration of Rainfall ... h ... m.



5 mm 10 mm on chart Station Kabete 155 mm 182.5 571

Appendix 13

The type and abundance of crops grown in the stony soils of Baringo as estimated from the visited farms.

CROP TYPE	ORDER OF ABUNDANCE*				
	Marigat	Chap-Chap	Kamnarok	Kabasis	Ewalel
Maize	2	1	1	1	1
Sorghum	2	4	5	-	-
Finger millet	1	2	3	2	4
Sweet potatoes	4	7	5	5	4
Beans	5	5	4	2	2
Pigeon pea	7	-	7	-	-
Ground nut	7	10	-	-	-
Citrus	9	7	9	-	6
Banana	-	6	9	9	7
Coffee	-	7	8	7	7
Cassava	7	5	4	9	6
Fodder grass	-	9	10	8	6

* The figures in the table show the major crops in their order of abundance in a decreasing order (i.e. 1 stands for the most and 10 stands for the least abundant crops).

Appendix 14

Summary of field observation.

A) DIVISION - Kabartanjo

LOCATION - Kamnarok

1. Site Description

Farm No.	Altitude	Average Slope (%)	Surface Stone cover (%)	Mean Stone size (cm)
1	1880	20	80	15
2	1520	35	80	15
3	1340	38	80	20

2. Soil and Water Conservation

Farm No.	Terraced? Yes/No	Terrace Type	Average Spacing (m)	Average Height (cm)	Average Width (cm)
1	Y	stone	5	40	100
2	Y	brush-wood	10	-	-
3	Y	stone	10	60	70

B) DIVISION - Kabarnet

LOCATION - Kabasis

1. Site Description

Farm No.	Altitude	Average Slope (%)	Surface Stone cover (%)	Mean Stone size (cm)
4	2120	35	20	6
5	2200	20	15	10
6	2050	55	50	30
7	2020	45	40	10

2. Soil and Water Conservation

Farm No.	Terraced? Yes/No	Terrace Type	Average Spacing (m)	Average Height (cm)	Average Width (cm)
4	Y	stone + trash	8	75	100
5	Y	stone + soil	9	150	150
6	Y	stone	3	150	150
7	Y	stone + trash	7	150	150

C) DIVISION - Kabarnet

LOCATION - Ewalel

1. Site Description

Farm No.	Altitude	Average Slope (%)	Surface Stone cover (%)	Mean Stone size (cm)
8	2080	36	70	7
9	2250	20	40	10
18	1920	28	80	10
19	1900	40	40	10
20	1900	35	50	10

2. Soil and Water Conservation

Farm No.	Terraced? Yes/No	Terrace Type	Average Spacing (m)	Average Height (cm)	Average Width (cm)
8	Y	stone + trash	5	60	80
9	Y	stone + soil	8	60	66
18	Y	stone	-	-	-
19	Y	stone	6	130	170
20	Y	stone + trash	5	90	140

D) DIVISION - Kabarnet

LOCATION - Chap Chap

1. Site Description

Farm No.	Altitude	Average Slope (%)	Surface Stone cover (%)	Mean Stone size (cm)
11	1870	32	80	15
14	1885	24	40	10
15	1860	38	60	15
16	1850	35	40	15
17	1865	15	60	40

2. Soil and Water Conservation

Farm No.	Terraced? Yes/No	Terrace Type	Average Spacing (m)	Average Height (cm)	Average Width (cm)
11	Y	stone	4	50	65
14	Y	stone	10	90	100
15	Y	stone	9	80	90
16	Y	stone	3	100	100
17	Y	stone	10	100	60

E) DIVISION - Marigat

LOCATION - Marigat

1. Site Description

Farm No.	Altitude	Average Slope (%)	Surface Stone cover (%)	Mean Stone size (cm)
10	1150	22	80	20
12	1480	18	80	10
13	1510	19	50	7

2. Soil and Water Conservation

Farm No.	Terraced? Yes/No	Terrace Type	Average Spacing (m)	Average Height (cm)	Average Width (cm)
10	Y	stone	5	50	75
12	Y	stone	8	50	75
13	Y	stone	7	60	100