THE EFFECT OF NARROW GRASS STRIPS IN CONTROLLING SOIL EROSION AND RUNOFF ON SLOPING LAND

by

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Abstract

The study was carried out on twelve runoff plots installed at Kabete Campus Field Station, University of Nairobi, on a 10% natural slope of eutric Nitisol to assess the effect of grass strips in controlling soil loss and runoff on sloping land. Four treatments, a control plot without grass strip and three different widths (0.5, 1.0 and 1.5 m.) of Nandi setaria (*Setaria anceps*), were tested under natural rainfall during 1982 and 1983, simulated runoff, and simulated rainfall of 80 mm/hr.

Results showed that the treatment effect was highly significant in reducing both soil loss and runoff under natural rainfall. Annual soil loss for the control plot was 97.7 t/ha. while for the 0.5, 1.0 and 1.5 m. wide grass strips annual soil losses were 35.4, 35.6 and 17.8 t/ha. (36, 36 and 18%) respectively. Annual runoff from the control plot was 100 mm. (20%) and percentage runoff for the 0.5, 1.0 and 1.5 m. wide grass strips were 56, 44 and 24% of the control plot, respectively.

The difference between the three different grass strip widths was not statistically significant although annual soil loss from the 0.5 m. wide grass strip was double that from the 1.5 m. wide grass strip.

The simulated runoff test showed that soil losses from the plot with 0.5 m. wide grass strip were only 4.5, 7.8 and 41.1% of the soil losses from the control plot under the three application rates of 1.5×10^{-4}, 2.5×10^{-4} and 3.6×10^{-4} m^3s^{-1} respectively. Runoff from the 0.5 m. wide grass strip were 1.9, 3.5 and 50.2% of the runoff from the control plot for the same application rates.

Under heavy simulated rainfall, soil losses from the plot with 1.5 m. wide grass strip were 17.1, 25.1 and 36.7% of the soil losses from the control plot for dry, wet and very wet antecedent soil moisture conditions, respectively. Runoff from the plot with 1.5 m. wide grass strip were 32.7, 41.0 and 46.0% of the runoff from the control plot for the same three applications. Efficiency of grass strips in controlling soil loss and runoff increased from the 0.5m. wide grass strip to 1.5 m. wide grass strip and decreased from the dry to very wet antecedent soil moisture conditions.

Strip width was exponentially related to soil loss and runoff with coefficient of determination (r^2) of 0.96 for soil loss and 0.88 for runoff under dry antecedent soil moisture condition.

Sediment was deposited on the plots with grass strips, with most of the deposition taking place on the uphill edge of the grass strip, extending two metres in one and half years. There was little deposition in the grass strips. The maximum mean depth of deposition was 7.6 cm. at the 0.5 m. wide grass strip. Much of scour took place on the upper section of the plots. In almost all the plots the ground slope was reduced by about 2%

Two thirds of sediment transported was in sand size aggregates although the soil contained more than 50% clay. Grass strips had no influence in the trapping of different sized aggregates.

Of the six erosivity indices tested, the amount of storm (A), in mm., was highly correlated ($r = 0.88$) with soil loss followed by the EI_{15} ($r=0.86$) and the EI_{30} ($r=0.73$) indices. The $KE > 25$ index gave the least correlation coefficient ($r=0.41$). The annual rainfall erosivity factor (R) for Kabete was estimated to be 246 m-t-cm/ha-hr and the soil erodibility factor (K) was 0.21 t-ha-hr/ha-m-t-cm. which was higher than that from previous findings.

1. INTRODUCTION

Soil erosion and its undesirable effects remain one of the major problems retarding the development of agriculture in Kenya. Tracts of degraded land seen in Baringo, Machakos and Kitui Districts are evidence of the seriousness of soil erosion problems in Kenya. The removal of the top soil reduces soil fertility and water storage capacity of the soil resulting in a decline of crop yield. In the United States of America, damage due to the removal of the soil alone is estimated to cost 250 million dollars per year (Tollner et. al., 1977). The damage may be far worse in the developing countries, where there is little awareness of the erosion problem, low level of know-how and limited resource allocation to combat the problem. Studies by Dunne et. al. (1978) and Ongweny (1979) suggest that soil erosion rates in Kenya are increasing. Government of Kenya (1978) reported a decline in annual food production per mm. of rainfall from 1.09×10^6 kg. per mm. of rain in 1970 to 0.48×10^6 kg. per mm. of rain in 1976, in the predominantly semi-arid cultivated areas of Machakos, Kitui and Embu Districts. Wain (1982) reported a suspended sediment yield of 1,265 t/km^2-yr. in the Thawake river basin and concluded unless erosion is arrested the potential of the river's resources may not be realised.

The high sediment yield of the upper Tana catchment of Sagana area as assessed by Dunne and Ongweny (1976) and Ongweny (1979) has resulted in siltation of water storage reservoirs and has reduced the quality of water resources - streams and lakes. Out of 1139 dams in Machakos and Kitui Districts, besides those washed by high floods, the remaining dams had their capacity reduced by 80% as a result of siltation. The Kalundu Dam, Kitui, was completely silted in 16 years (1958-1974) at a rate of 733 t/km^{2}yr. (Edwards, 1979). Barber (1982) warned that since erosion rates in Kenya are excessive soil depth will be reduced at drastic rates unless conservation measures are improved.

The efforts of the Kenya Government to combat the problems of soil erosion and deforestation are commendable. The amount of material and technical support given to farmers in constructing terraces and cutoff drains, and the campaign to reclaim gullies, reduce down-stream sedimentation and plant trees are encouraging. These efforts should be supported by sound scientific research aimed at assessing the performance of current conservation support practices, testing new measures and finding appropriate and effective means of erosion control.

The present trends of soil and water conservation in Kenya tend to place more emphasis on the physical measures than on cultural ones. Physical measures despite their immediate effectiveness right after installation, are potentially dangerous, for they concentrate surface water into channels which can cause serious damage if they fail and need adequate maintainance and repair at suitable intervals (Hudson, 1971).

Planting grass strips along the contour can be one simple and cheap method of reducing the erosion hazard. Grass strips absorb part of the runoff and trap part of the sediment transported from the upper part of a field and may gradually develop into a series of terraces stabilised by permanent vegetation. Ministry of Agriculture Annual Reports show, in Kiambu District, for the years 1975-1979, 436 km. of grass strips were established while in Machakos District, 950 km. of grass strips were planted in the years 1978-1980. The reports show that grass strips are being used widely in the semi-arid areas as well as the humid, high potential, areas and that they have become a common conservation measure in recent years. There was no report for the years preceeding 1975. In the U.S. the idea of grass filter strips is gaining importance as a means of controlling sediment production from disturbed areas and reducing the load of soil adsorbed pollutants from non-point source erosion, as sediment retention structures were found to be inadequate (Hayes et. al., 1978; Barfieldet. al., 1979).

There is no doubt that planting grass strips will be far cheaper than other structural methods of erosion control and it will be easier to disseminate the idea among traditional peasant farmers especially in areas where fodder is required. The acceptance of grass strips as a conservation measure should be supported by adequate study and evaluation as to the mechanism of sediment movement through grass strips, their performance, spacing, grass type and effective strip width under different conditions of soil type, slope and climatic conditions. In Kenya there has been very little study and there is a need for research on the performance and different characteristics of grass strips, aiming at recommending the minimum effective width in reducing soil loss and runoff; the ecological zones and ground slopes where grass strips perform best and, the type of grass species that can be used.

This paper deals with work carried out for two years (1982 and 1983) under natural rainfall, simulated runoff and simulated rainfall using runoff plots.

The objectives of the research were:

1) To determine the effect of grass strip width in reducing soil loss and runoff.

2) To assess the effect of grass strips in reducing ground slope as a result of sediment deposition.

3) To assess the effect of grass strips on the development of rills.

4) To determine the distribution of soil aggregates trapped by grass strips.

5) To come out with best erosivity indices and identify most erosive storms.

The work was carried out at the Faculty of Agriculture Field Station on the outskirts of Nairobi.

In addition to the experiments, field observations were made on the use of grass strips for erosion control in Nandi and Narok Districts.

2. LITERATURE REVIEW

2.1. Background

The effect of grass cover on runoff and soil loss has been well documented over many years and strip cropping has been in practice in many countries as a means of controlling soil erosion. But the use of narrow grass strips, also known as buffer strips or grass filters, is limited to a few countries, which include Kenya (Wenner, 1977), Tanzania (Rapp et. al., 1973), and South Africa (Ross, 1977). According to Wenner (1977) grass strips of 0.5 m.- 1.5 m. wide were recommended as conservation measures in Narok District, Kenya, and on drier areas of ground slope of less than 6%. Kimutai (1979) observed 0.5 m.-2.0 m. wide grass strips being in use in Tuloi, Kapkangani Location, Nandi District, Kenya, and found the farmers more responsive to grass strips than any alternative measures. Othieno (1978) reported use of narrow strips of oats at Kericho between rows of newly established tea plants 1.22 m. apart and found soil loss values of 34.9 t/ha. for the first year (1971-1972) and 4.3 t/ha for the second year (1972-1973) while soil loss from the plots without strips was 161.3 and 48.3 t/ha. for the same years.

One of the early studies in Tanzania (van Rensburg, 1955) on a 6.6% slope of sandy loam soil over a four year period (1950-1954), showed that the average soil loss and runoff from plots with two grass strips two metres wide each placed one-third from top and bottom were 37.8% and 65.7% respectively of the average soil loss and runoff of the control plot cultivated with sorghum which had no grass strips. This value would have been lower if one of the grass strips had been on the lower part of the plot. Kemboy and Muracia (1981) working on Kabete Field Station on slope of 6% and with one metre wide grass strip, found the amount of sediment and runoff from the plot with a grass strip was much less than from the plot without a grass strip. Neibling and Alberts (1979), working on a 7% slope of eroded Miami silt loam soil and grass strips of 0.6, 1.22, 2.44 and 4.88 m. widths, found all four strip widths reduced total sediment discharge rates by more than a factor of ten.

In U.S.A. much of the study and emphasis has been in developing models to be used in the design of grass filters to control sediment production from disturbed areas and reducing soil adsorbed and water laden pollutants (Doyal and Stanten, 1977;

Hayes et. al., 1978; Venderholm and Dickey, 1978; Barfield et. al., 1979; Oiercash et. al., 1981).

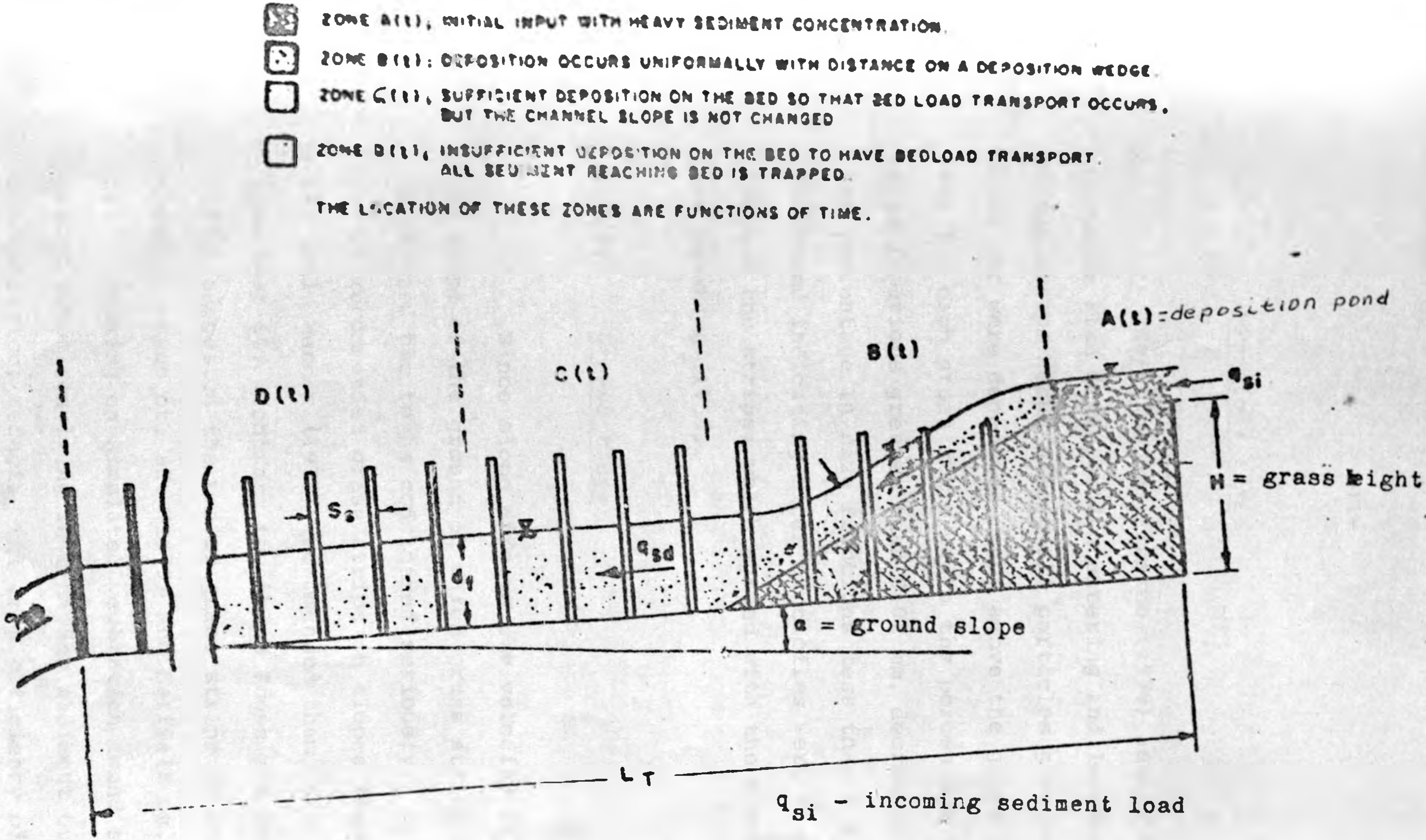
2.2. *Mechanism of sediment flow through grass strips*

To develop a model that can be used in designing grass strips to effectively control sediment and water laden pollutants from agricultural fields to a desirable level, it is necessary to understand the mechanism of sediment movement through a grass filter. Grass strips spread the flow of water, thus reducing the velocity of runoff and causing the sediment to be deposited around and between plants (Wilson, 1967). According to Wilson (1967), deposition is due to mechanical obstruction which retards the flow velocity causing most of the heavier particles to be trapped and due to adsorption whereby positively charged dead plant parts attract negatively charged clay particles. This later concept seems to be ignored by other research workers. Kao and Barfield (1978) consider drag resistance as the dominant force that retards flow and a large portion of the total drag is dissipated on the grass (Barfield et. al., 1979b).

Tollner et. al. (1976) listed flow rate and depth of runoff, particle size of eroded sediment,

sediment load, spacing between grass strips and strip width as the major factors involved in the mechanism of sediment movement in grass filters. Hayes et. al. (1979) included density of grass elements as one of the major factors. Infiltration rate within the grass strip is also considered to be another factor that can affect the sediment transport capacity of flow within a strip (Foster, 1982).

Recent mathematical models developed from laboratory studies of simulated grass and sediment are based on three approaches (Foster, 1982). The first approach neglects the deposition pond (zone A(t) of Figure 1) and assumes a transport capacity beyond which the sediment load within a grass strip will not decrease even if strip width increases to infinity ($q_{so} = q_{sd}$). The second approach considers the deposition pond (zone A(t)) extending in time upwards as concave slope. The third approach assumes a uniform deposition face and gives sediment yield that approaches zero as width approaches infinity ($q_{so} = 0$ if strip is wide enough). Of the three the first seems a bit unrealistic, even though these models have not been fully tested under field conditions, and there is a lot more to be done to determine where and how deposition occurs.



q_{si} – incoming sediment load

q_{so} – outflow sediment load

d_f – depth of flow

Figure 1: Schematic of the Sediment Deposition Process with Homogeneous Sediment in an Artificial Rigid Media. (After Barfield et al, 1977)

2.2.1. *Particle size*

Neibling and Alberts (1979) analysing the particle size distribution entering and leaving the grass strips found almost all particles greater than 0.02 mm. were deposited in or above the grass strips and for each grass strip width the percentage in size fractions greater than 0.02 mm. decreased while the percentage in size fractions less than 0.02 mm. increased indicating finer particiles were transported through the strips; which agreed with the findings of van Rensburg (1955).

2.2.2. *Ground slope*

Since slope affects the velocity of flow, the slope of the ground on which grass strips have to be used has to be considered seriously. Hudson (1971) recommended grass strips on slopes less than 4%, while Wenner (1977) recommended them on slopes less than 6%. Contrary to others Roose and Bertrand (1971) suggested the use of grass strips on steeper slopes. Hayes et. al. (1979) and Barfield et. al. (1979) working on simulated vegetation found steeper ground slope resulting in a higher sediment out-flow concentration, reducing the trap efficiency of strips.

Whether at steeper slopes high rate of erosion accompanied by high sediment inflow result in a higher rate of deposition and bank formation has to be tested.

2.2.3. *Strip width*

Grass strips also should be of minimum width that can effectively control most of the sediment load. This is particularly important if we have to recommend grass strips as conservation support practice to small holder farmers. The area of croplands taken by grass should be acceptable to the farmer. Wilson (1967) suggested that width depends on runoff rate, ground slope and grass characteristics. The desired level of sediment outflow or pollutant level should also be considered. Wenner (1977) gave 0.5 m.-1.5 m. strip widths as the most commonly used in Kenya. Neibling and Alberts (1979) found increasing strip width beyond 0.63 m. gave no significant differences in sediment trapping.

2.2.4. *Grass type*

What grass type to use in strips is another question to be answered. Tufted grasses do not provide a continuous ground cover and may have small gaps whereby runoff can flow without any obstruction. On the other hand stoloniferous and rhizometous grasses grow low and provide less resistance to flow. They also spread to fields, demanding labour to keep them to the desired width. Wilson (1967) gave the following requirements in selecting a grass type:

1) deep root system to resist scouring if swift currents develop,
2) dense, well ramified top growth,
3) resistant to flooding and drought,
4) ability to recover growth subsequent to inundation with sediment,
5) yield economic return.

Wenner (1977) recommended the use of Napier grass (*Pennisetum purpureum*) in grass strips though it may be very competitive with adjucent crops and tends to leave gaps.

Models so far developed to predict the flow of sediment through a grass filter consider only erect grasses (Barfield et. al., 1979 a and b; Hayes et. al., 1979; Tollner et. al., 1976, 1977). Hayes et. al. (1978) in their attempt to evaluate the model developed under natural grass conditions used grain sorghum, tall fescue and perennial rye grass. The reason for taking erect grasses were easy geometry - one of the assumptions being flow through grass strips was taken as aggregation of minute rectangular open channel flow - and maximum flow retardance and minimum sediment transport occur under non-submerged flow conditions (Ree, 1939). Another reason being, both grass strip width and sedimentation pond size directly depend on grass height.

2.3. *Change in ground slope*

Erosion and sediment transport from the uphill part of a field and deposition near and within the grass strip definitely result in a change of field slope. Kimutai (1979) observed banks of 50-100 cm. height developed in three years due to sediment deposition, in Nandi District, Kenya. Roose and Bertrand (1971) in Ivory Coast, found banks of 50 cm. height formed in two years on slopes up to 7%. Barfield et. al. (1979) took the depth of deposition to be equal to grass height. This assumption needs to be evaluated under actual field conditions where the grass keeps on growing.

3. MATERIALS AND METHODS

3.1. *Site*

The study was carried out in Field 14, at Kabete Field Station, Faculty of Agriculture, University of Nairobi, on an area selected for its steepness and which has been under cultivation for more than two years.

Kabete lies 1^{o} 15' S and 36^{o} 44' E at an altitude of 1930 metres above sea level, in an agro-climatic zone referred to as semi-humid (Sombroek et. al., 1982). It has a bimodal distribution of rainfall, with the long rains from early March to late May and the short rains from October to December with three months of dry period between the two rainy seasons (Appendix 8a). Mean annual rainfall of Kabete is 925 mm. based on 27 years period (Taylor and Lawes, 1971).

Soils of Kabete are eutric Nitisols (Sombroek et. al., 1982) or Rhodic Paleudult (U.S. Taxonomic system). The soils are developed on Tertiary trachytic lava, with a dark red clay A horizon overlying a red clay B horizon with a strong subangular blocky structure. Soils are extremely deep and well drained. Soil texture of the top 30 cm. measured at the site was 22% sand, 24% silt and 54% clay with a pH of 5.2 and bulk density of 0.61 g/cc. The bulk density of this soil is low compared to soils derived from the basement complex (1.2-1.4 g/cc) because of the high aggregation of the clay particles into sand size aggregates which gave the soil a good structure with high water retention capacity and porosity. These soils are mostly common on the rolling upland of central Kenya and, west of the rift valley, on the foot of Mt. Elgon and parts of Kericho areas.

Background history of the field used for the experiments is as follows:

1975 - 1976	-	pasture
1977 - 1980	-	crop sequence trial (mainly maize, beans and potatoes)
1980 short rains	-	fallow
1981 long rains	-	potatoes
1981 short rains	-	fallow

3.2. *Plots*

Twelve Djorovic (1977) type simple runoff plots were installed on a natural 10% slope. Each plot was two metres wide and twelve metres long.

The twelve metres plot length was based on the formula for terrace spacing:

$$V.I. = 0.3 (a S + b)$$

at 10% slope, where

V.I. = vertical interval (m.)

S = slope (%)

a = 0.25

b = 2 for Kenyan conditions

(Thomas and Barber, 1979). This will help when comparing the efficiency and performance of grass strips with terraces.

Each plot was bounded by galvanized sheet metal, 20 cm. wide with 10 cm. driven into the ground. A 50 cm. and a 3.0 m. wide space were left between plots and blocks respectively. Main components of each runoff plot are: the collecting trough, end plate, conveyance, storage tank and fifteen iron rods (Figure 2).

3.2.1. *Collecting trough and end plate*

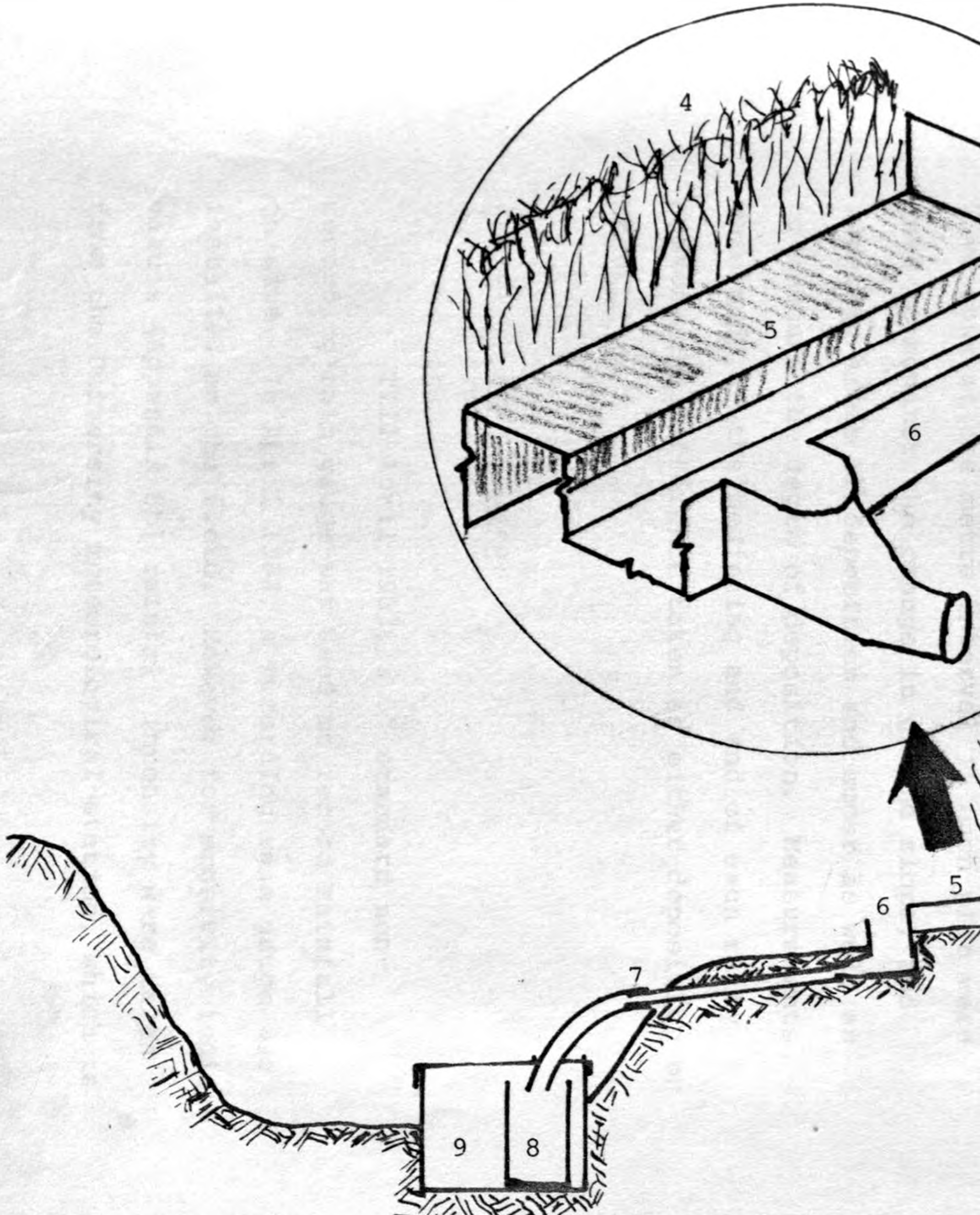
Runoff from a plot is collected in the trough and channelled to the collecting tank. The end plate provides a firm seal and smooth contract between collecting trough and ground surface. Later it was used as bench mark in the profile survey, used to determine the change in ground slope and the depth of deposition.

3.2.2. *Conveyance*

Two and half inches diameter (6.4 cm.) PVC pipes at an average slope of 11.0% were used for conveying runoff to the collecting tanks. These are far higher than the calculated minimum values (6.2 cm. in diameter and 4.5% slope) based on Muchler's (1963) recommendations. These higher values of slope and pipe size have assured a very safe conveyance without a slight sign of siltation in the conduit although deposition has occured in the collecting trough.

3.2.3. *Storage tank*

A 920 liter capacity storage tank was used based on design considerations of a one hour 20 years storm of 60 mm/hr intensity with runoff coefficient of 50% (Barber et. al., 1979) and soil loss values of 0.24 mm. (Thomas et. al., 1981). The tanks were



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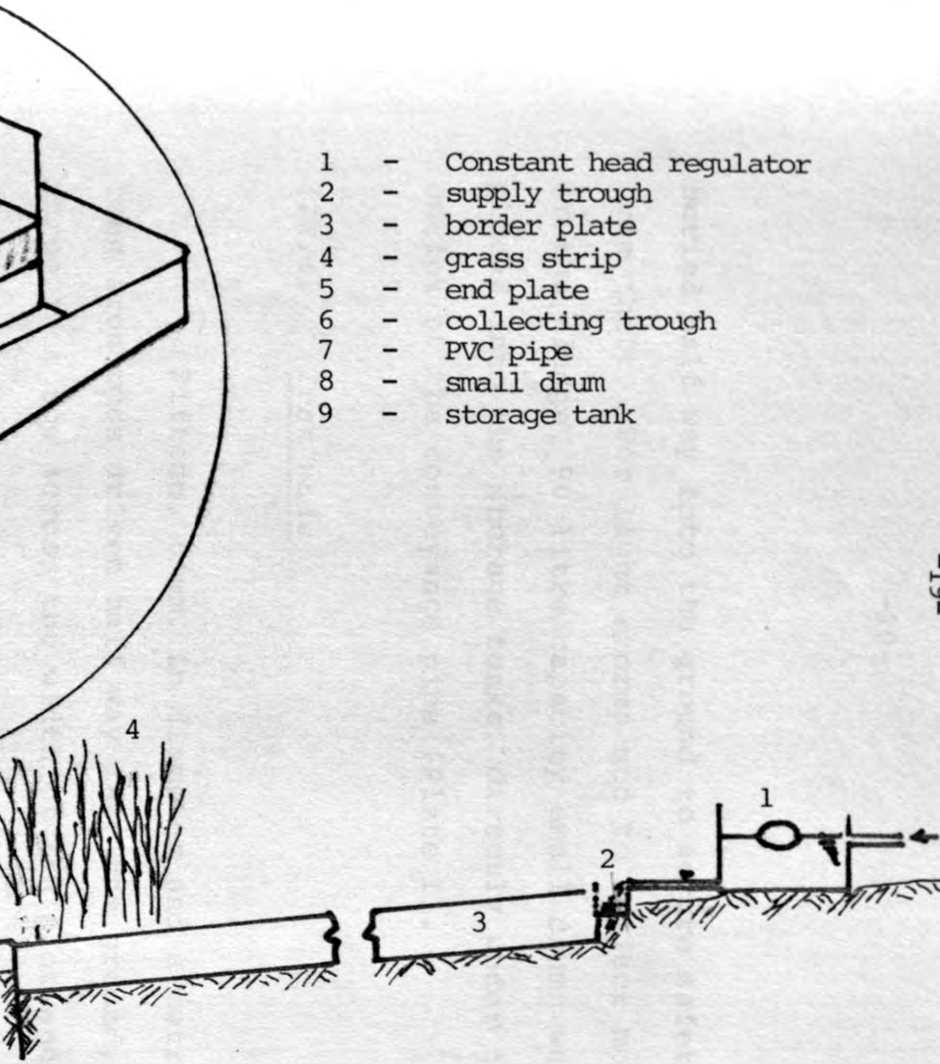


<u>Figure 2</u>. Runoff plot, section view.
1 and 2 are used on simulated runoff trial only.

buried half way into the ground to secure safety from theft. For light storms and to collect most of the sludge, 90 litre capacity small drums were placed into the storage tanks, directly under the outlet of the conveyance pipe (Plate 1).

3.2.4. *Iron rods*

Fifteen, 8 mm. in diameter and a metre long iron rods driven half way into the ground, three in a row across the width of the plot and in five rows at one metre interval in each plot were used to monitor the change in ground slope, and identify areas of deposition and scour as well as to measure the depth of deposition. Measurements were made at the beginning and end of each rainy season, the difference taken as either deposition or scour.

3.2.5. *Rain gauges*

Till April 1983, a 5" standard non-recording rain gauge was used to record rainfall on site. In April 1983, a recording rain gauge was installed on the field. However for erosivity indices values (Appendix 8b) rainfall intensity were taken from the University meteorological station, which is

Plate 1. Storage tanks and conduit pipe used in the runoff plots

Plate 2. Runoff plots showing grass used in the study (*Setaria anceps*)

about half a kilometre from the plots. Paired t-test for daily rainfall records of the two sites showed no significant difference at 0.5% level.

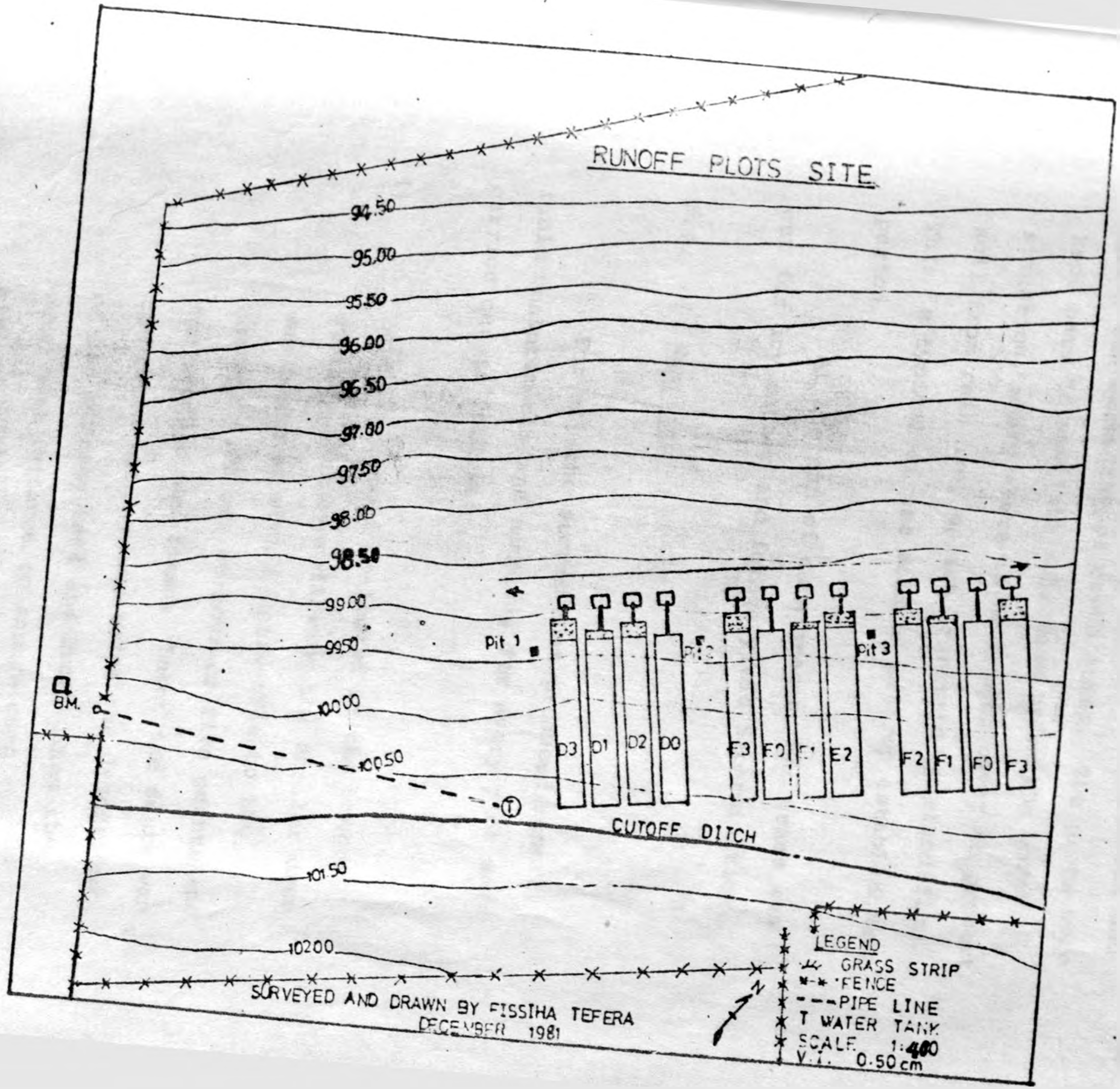
3.3. *Treatments*

The twelve runoff plots were arranged in a completely randomised block design with three blocks labled as D, E and F and four equally spaced grass strip widths taken as treatments (Figure 3). The treatments were:

a control with no grass strip	-	0
0.5 m. wide grass strip	-	1
1.0 m. wide grass strip	-	2
1.5 m. wide grass strip	-	3

Nandi setaria (*Setaria anceps*), a grass with an erect growing characteristics that can reach up to 1.5 m. high was used (Plate 2).

The grass was established from splits three months in advance of the 1982 long rains but plots for treatment 3 were installed after the 1982 long rains, due to shortage of funds. For the two years study period the plots were kept bare by regular hand weeding and hoeing. A herbicide (200 cc. of Roundup)


RUNOFF PLOTS SITE
94.50
95.00
95.50
96.00
96.50
97.00
97.50
98.00
98.50
99.00
99.50
100.00
100.50
101.50
102.00
Pit 1
Pit 2
Pit 3
B.M.
D3 D1 D2 D0
F3 E0 E1 E2
F2 F1 F0 F3
CUTOFF DITCH
N
LEGEND
GRASS STRIP
FENCE
PIPE LINE
T WATER TANK
SCALE 1:400
V.I. 0.50 cm
SURVEYED AND DRAWN BY FISSIHA TEFERA
DECEMBER 1981

was applied once on 11th April 1983 to control and deter the spreading of couch grass. The plots were kept bare to simulate soil loss under the worst situation, where there is no ground cover to protect soil from rain drop splash or retard overland flow. This is typical of the seedbed or crop establishment period.

At the end of each season, the grass was cut for dry matter and forage yield determination.

3.4. *Sampling*

For all the storms that produced runoff, field measurements and sampling for every plot were carried out as follows:

1) Depth of runoff co-lected in the bigger storage tank over-flowing the smaller drum was measured with a metre-rule to the nearest 0.05 cm. at four or five points and the average was taken. Later the depth was converted into volume using the dimensions of the storage tank and drum. Then the water was agitated to ensure complete mixing of all fine sediment and one or more 730 ml. samples were taken with "tree-top"

bottles. Later in 1983, samples were taken with 540 ml. wide-mouthed plastic bottles.

2) For that part of the suspended sediment overlying the sludge in the drum, volume was measured using a calibrated bucket and samples were taken from each bucket, after a thorough agitation.

3) After removing most of the runoff water and suspended sediment about 100 gm. of sediment were taken for aggregate size distribution analysis, before disturbing the sludge. The sample represents settled sediment of larger size, since the interest was to determine the distribution of larger aggregates and the filtering capacity of grass strips. The sludge was then scooped out of the small drum and was placed in a bucket and weighed to the nearest 0.05 kg. using a spring balance. The sludge was thoroughly mixed till it formed a uniform consistency and samples were taken in plastic bottles.

4) Finally the storage tanks were drained and cleaned to be ready for the next storm.

The evaporation method (Dendy et. al., 1979) was followed to determine the water content and sediment concentration of samples. Samples were put into bowls of known weight and weighed. Then 0.6 ml. of 0.2 molar solution of aluminum potassium sulfate ($Al\ K\ (SO_4)_2 \cdot 12H_2O$) flocculant was added to each sample and the samples were allowed to flocculate for over twelve hours. Clear water was then decanted till a third of it remained. Samples were oven dried at 160^{o}C for 24 hours. This temperature was used throughout for it was not possible to lower the temperature of the available oven to 105^{o}C.

3.5. *Simulated runoff*

To assess the effect of rills on the performance of grass strips and to collect more data, simulated runoff was used during the dry months of July and August 1982, on two separate plots. A control plot (with no grass strip) and one-half metre wide grass strip of Kikuyu grass (*Pennisetum clandestinum*) were used in the study. Plot sizes were the same.

Nine furrows, 3.5 cm. wide, 2.0 cm. deep and 20.0 cm. apart were made on each plot running straight down the plots. Prior to the running of the test plots were watered to field capacity.

Water was supplied at required rates from a constant head tank, regulated by means of a float valve to a supply trough. The supply trough was having perforated holes in one side, to uniformly distribute runoff across the width of the plot.

The test was run under three flow rates (1.5, 2.5 and 3.6 x 10^{-4} m^3s^{-1}) each for a duration of three hours which was equivalent to 67.5, 112.5 and 165.0 mm. of rain, and each flow rate was applied four times at 24 hours interval.

To determine the anticedent moisture content of the soil, samples at four different places down the plot at 5 cm below the surface and from all the furrows were taken.

Samples of 730 ml. were taken at every 60 litres of runoff collected. Sediment concentration were determined as described above.

3.6. *Simulated rainfall*

To evaluate the performance of grass strips under heavy storms, simulated rainfall test of one hour storm at 80 mm/hr. intensity, with a return period of more than 100 years (Taylor and Lawes, 1971) were run on plots of Block D on March 1983.

A simulator from Kenya Rangeland Ecological Monitoring Unit (KREMU) (Plate 4) was used to simulate rainfall. The simulator was 5 m. high and covers an area 2 m. by 6 m. It had two 80150 veejet nozzles mounted on trollies running on rails along the plot length. Movement of nozzles was done manually at an average speed of 8 cycles per minute. Rainfall intensity was regulated at a pressure of 0.5 atm. (7 psi) and amount was recorded by means of 6 cans placed on the plots. Three runs, a dry run followed by two wet runs were applied at each plot with 24 hours interval.

Except for plot D3, where samples were taken every 15 minutes, for other plots samples were taken every five minutes.

3.7. *Aggregate size distribution*

Aggregate size distribution was determined by wet sieving through 5 sieves of 4.0, 2.0, 1.0, 0.5 and 0.21 mm. for 10 minutes. Prior to sieving air dry samples were wetted by immersing under atmospheric pressure for 10 minutes (van Bavel, 1953). A portable sieve shaker with 1.0 cm. stroke and 300 cycles per minute was used. Fine drops of water was applied on the top sieve. Samples for 1982 rainfall were not used due to a long period of storage (Neibling et. al., 1981).

Plate 3. Runoff collected on 26/4/83 and the 0.54 l. sampling plastic bottles.

Plate 4. Rainfall simulator used to simulate 80 mm/hr storm

3.8. *Evaluation of methods used*

The runoff plots installed at Kabete are generally adequate enough to provide reliable data on soil erosion. However some modifications are necessary to improve the sensitivity of plots. These are:

1) For future research it will be good to increase spacing between plots to 1.0 or 2.0 m. wide.

2) The slope of the collecting troughs have to be modified to avoid deposition and the size has to be enlarged to make sure runoff from the sides does not enter.

3) The iron rods used to monitor depth of deposition and scour were not very sensitive, as the rods might lie on the centre of a rill or soil might heap around the rods during cultivation. Thus it will be better to change this method by profile surveying, done at regular intervals.

4) The rainfall simulator was an important research tool, but its present timber stands make it practically difficult to move it from plot to plot. It will be advisable to modify the stands, by using steel pipes

even if it is a bit costly. To minimize cost the height can be reduced to three metres.

5) The wet sieving device was not standard and it was used because there was no other alternative method available in the country at the time of carrying the experiment. Results can not be compared to other experiments. Future research workers interested in wet sieving should try to get at least a Yoder type sieving machine on time.

4. RESULTS

The findings of the experiment are divided and presented in seven sub-headings in order to present the data in the most clear and easy way to follow. These are:

1) Soil loss and runoff from natural rainfall.
2) Soil loss and runoff from simulated runoff.
3) Soil loss and runoff from simulated rainfall.
4) Depth of deposition and scour from natural rainfall.
5) Change in ground slope due to natural rainfall.
6) Sediment size distribution.
7) Erosivity indices.

4.1. *Natural rainfall*

Total rainfall in 1982 was 1,136 mm. A small percentage of rainfall (56 mm.) fell in the normally accepted dry months of June, July and August.

Total rainfall for the first six months of 1983 was 555 mm. The 1983 long rains were slightly lower than normal. In the one and half year period only 24 storms produced runoff. The occurence of unusual rainfall in February 1983, led to four rainy periods in 18 months, and the analysis and results are presented per rainy season.

4.1.1. <u>*Soil loss*</u>

Table 1 shows the mean soil loss (t/ha/season) for the four rainy periods of 1982 and 1983 for the four treatments. Analysis of variance (Appendix 5) of the data shows that treatment effects were significant at less than 2% with the exception of the 1982 long rains, where results show significant differences of treatment effect at 7.3%, which can be reasonably acceptable at 4 degrees of freedom for error. Mean Comparison (Tukey's method) shows no significant difference between the grass strips.

Table 3 gives percentage soil loss for the four treatments during the four rainy periods. Annual soil loss was 36% of that of the control plot for the 0.5 and 1.0 m. wide grass strips while it was only 18% for the 1.5 m. wide grass strip. The efficiency of grass strips in reducing soil loss, is defined as follows:

$$\text{Efficiency (\%)} = \frac{Q_{so} - Q_{st}}{Q_{so}} \times 100$$

where Q_{so} is soil loss from the control plot and

Q_{st} is soil loss from plot with grass strip.

This definition also holds for efficiency of grass strips in reducing runoff, whereby soil loss is replaced by runoff values.

Efficiency values are 100 minus the values on Table 3. Generally efficiency of grass strips in reducing soil loss improved in time and were higher for short rains with less intense storms than for long rains.

Combining the 1982 short rains data with the 1983 rainfall data gives a good estimate of annual soil loss and runoff. This was done because plots for 1.5 m. wide grass strips were not installed for the 1982 long rains. The highest annual mean soil loss was 98 t/ha. for the control plot and the lowest was 18 t/ha. on the 1.5 m. wide grass strip. The annual soil loss is exponentially related to strip width with high coefficient of determination (r^2) of 0.88.

4.1.2. *Runoff*

Table 2 shows the mean runoff (mm) for the four rainy periods of 1982 and 1983. Results show a significant difference between the grass strips and the control plot and no significant difference between the grass strips except the 1983 long rains where there was a significant difference between the 0.5 and 1.5 m. wide grass strips.

The highest annual mean runoff was 107 mm. on the control plot and the least was 25 mm. on the 1.5 m. wide grass strip. Runoff from the 0.5 m. and 1.5 m. wide grass strips was 56% and 24% of the control plot respectively, indicating less runoff with the wider grass strips. Again runoff was exponentially related to strip width with a coefficient of determination (r^2) of 0.98.

Table 1. Mean soil loss (t/ha/season) of the four rainy periods of 1982 and 1983 as affected by grass strip width

Season	rainfall (mm)	No. of storms	strip width (m) 0	0.5	1.0	1.5	Standard error
1982 LR[1]	328.3	6	75.32a[2]	61.82a	59.03a	-	3.63
1982 SR[3]	175.3	5	6.96a	2.14b	0.14b	0.0b	1.16
1983 FR[4]	113.3	4	17.52a	5.28b	1.52b	0.45b	2.04
1983 LR	211.7	9	73.25a	27.90b	33.97b	17.33b	5.18
Annual[5]	500.3	18	97.73a	35.36b	35.63b	17.78b	6.54

1. LR = long rains
2. means of a season labled with the same letter are not significant at 5% level.
3. SR = short rains
4. FR = February rains
5. sum of the last three seasons

Table 2. Mean runoff (mm/season) for the four rainy periods of 1982 and 1983 as affected by grass strip width

Season	rainfall (mm)	No. of storms	strip width (m)				Standard error
			0	0.5	1.0	1.5	
1982 LR	328.3	6	75.96a	64.94b	68.75b	-	1.69
1982 SR	175.3	5	8.49a	2.97b	1.25b	0.0b	1.10
1983 FR	113.3	4	19.11a	7.84b	2.91b	1.61b	1.32
1983 LR	211.7	9	79.16a	48.51b	42.53bc	23.62c	4.97
Annual	500.3	18	100.76a	59.31b	46.69bc	25.23c	5.47

Table 3. Percentage soil loss and runoff for the four treatments during the four rainy periods of 1982 and 1983

Season	soil loss				runoff			
	0	0.5	1.0	1.5	0	0.5	1.0	1.5
1982 LR	100	82.08	78.37	-	100	85.49	90.51	-
1982 SR	100	30.75	2.01	0.0	100	34.98	14.72	0.0
1983 FR	100	30.14	8.68	2.5	100	41.03	15.23	8.42
1983 LR	100	38.09	46.38	23.66	100	61.28	53.73	29.84
Annual	100	36.18	36.46	18.19	100	55.55	43.73	23.63

4.2. *Simulated runoff*

Table 4 shows total soil loss and runoff under three different application rates of simulated runoff for a control plot with no grass strip and a plot with 0.5 m. wide grass strip. Soil loss from a plot with the 0.5 m. wide grass strip was only 4% of the control plot under low application rate and the value increases to 41% at the higher application rate. Similarly, runoff from a plot with the 0.5 m. wide grass strip was only 2% under the low application rate and 50% for the higher application rate. Antecedent soil moisture content in all the cases was almost similar, ranging between 0.26 to 0.30 g/g with a maximum standard deviation of 0.017 and a minimum of 0.006 (Appendix 6).

Table 4. Total soil loss (t/ha) and runoff (m^3) of three application rates of simulated runoff for a control and a 0.5 m. wide grass strip. Total of 4 runs.

Application rate ($X10^{-4} m^3/s$)	soil loss				runoff			
	control		0.5m.		control		0.5m.	
	t/ha	%	t/ha	%	m^3	%	m^3	%
1.5	4.70	100	0.21	4.47	0.95	100	0.02	1.89
2.5	119.83	100	9.06	7.76	4.82	100	0.17	3.51
3.6	138.41	100	57.17	41.13	7.46	100	3.74	50.15

4.3. *Simulated rainfall*

4.3.1. *Runoff*

Runoff hydrographs for the three runs and four treatments are shown in figures 4 to 6. In almost all cases the control plot gave the highest runoff. In all the cases the wet runs produced more than twice as much as the dry runs and there was not much difference between the two wet runs (Table 5). During the wet run runoff started after a very short time and reached peak rate rapidly. For the dry run the delay time for runoff was more than 10 minutes and it took much longer to reach peak rate.

4.3.2. *Soil loss*

Cumulative soil loss values for the three runs and four treatments are shown in figures 7 to 9. In all the cases the control plot gave the highest soil loss values and except for plot with 0.5 m. wide grass strip, the wet runs removed more than twice as much soil as the dry runs. Percentage soil loss from the plot with 0.5 m. wide grass strip was 67% of the control plot under dry run and decreased to 18% and 7% for the plots

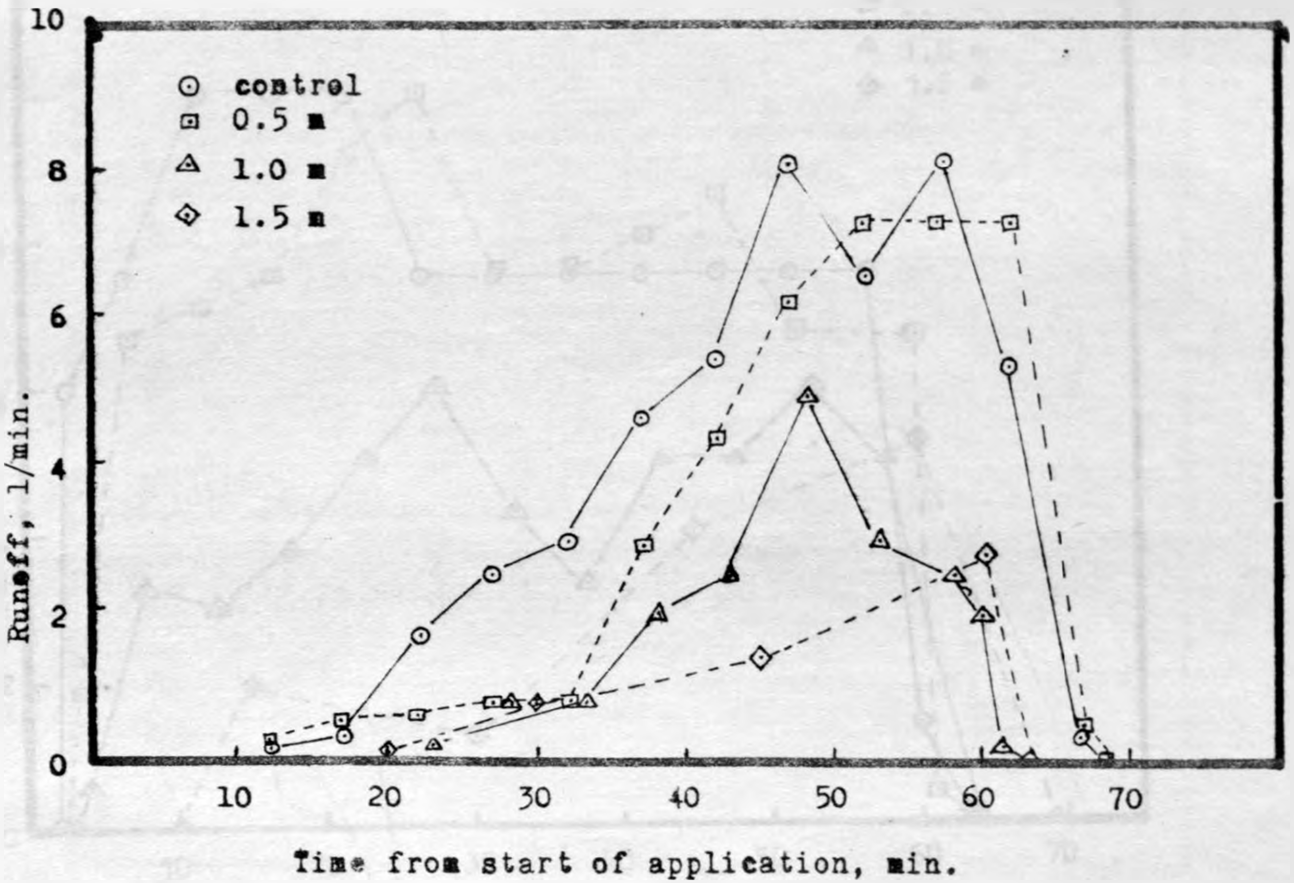


Figure 4. Runoff hydrograph for the four treatments during dry run of simulated rainfall (80 mm/hr).

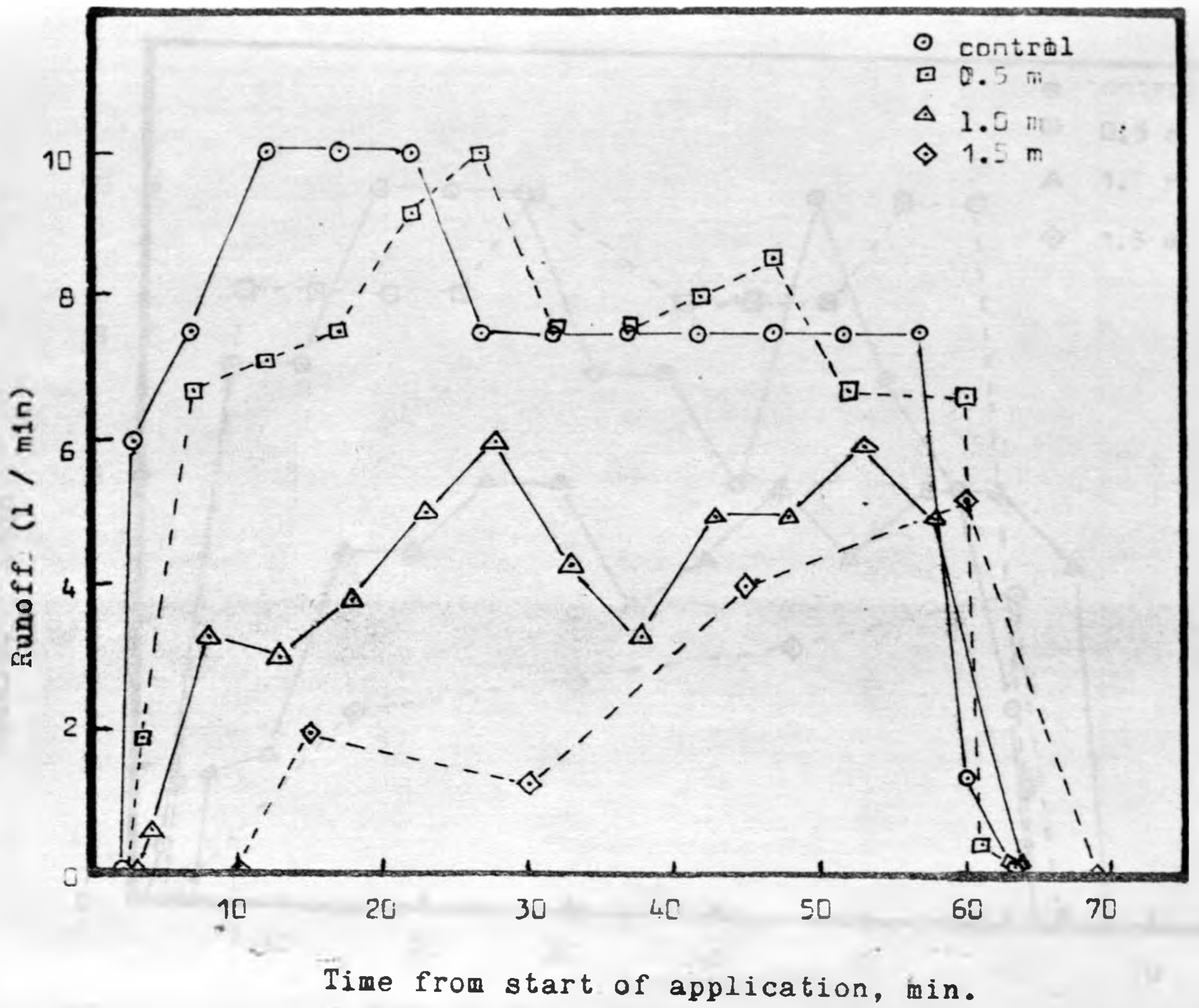


Figure 5. Runoff hydrograph for the four treatments from first wet run of simulated rainfall (80 mm/hr).

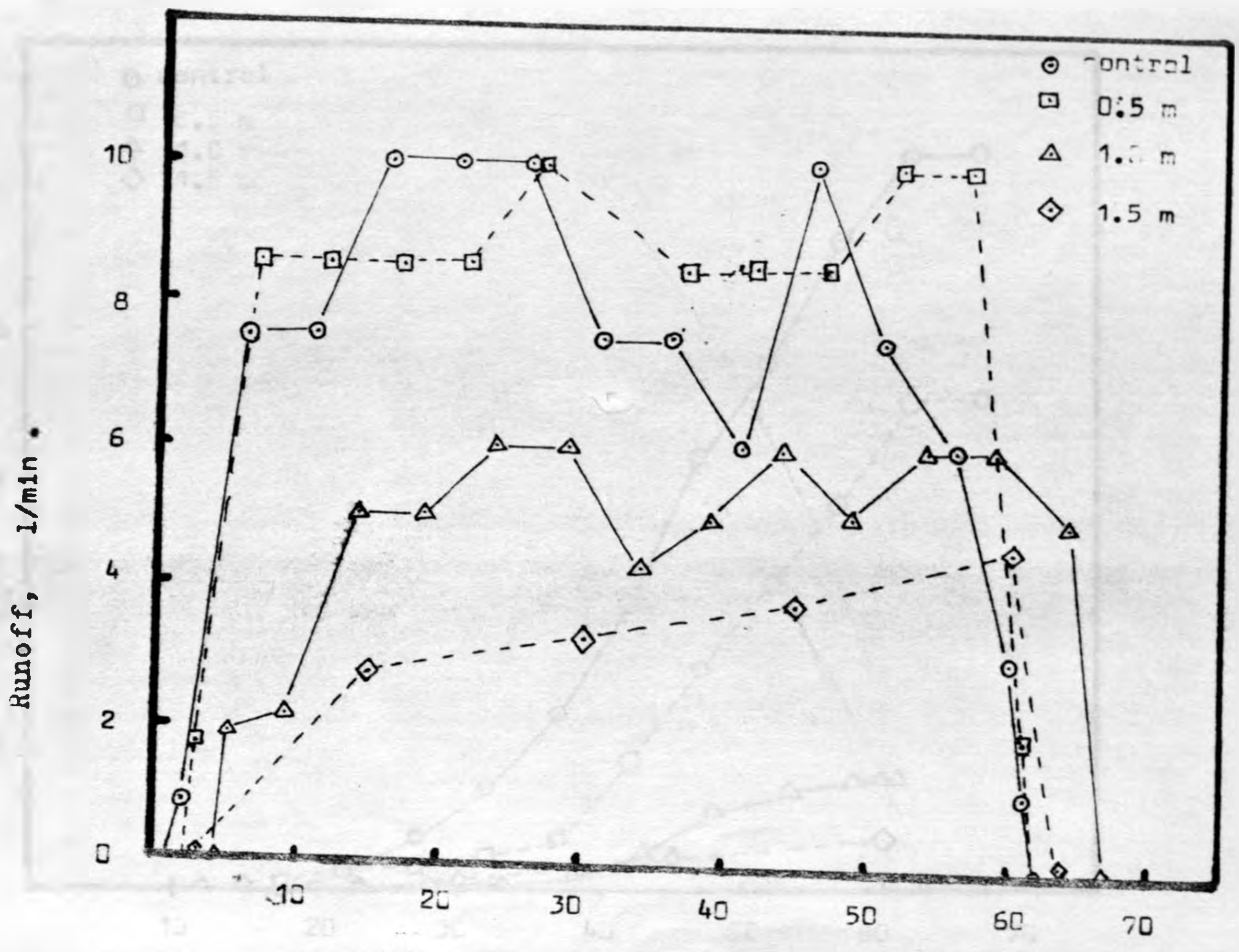
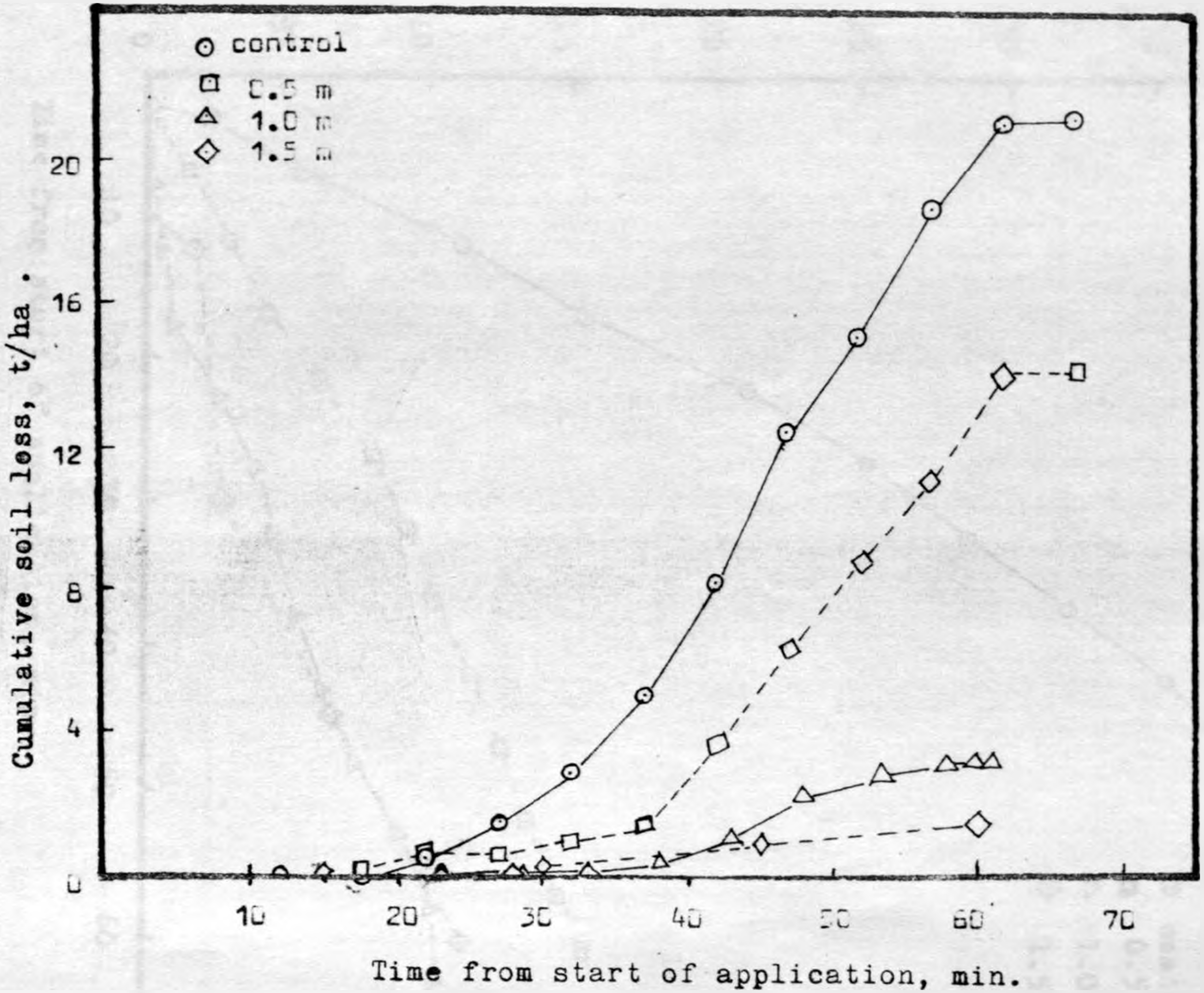


Figure 6. Runoff hydrograph for the four treatments from second wet run of simulated rainfall (80 mm/hr).



<u>Figure 7</u>. Cumulative soil loss (t/ha) for the four treatments from dry run of simulated rainfall (80 mm/hr).

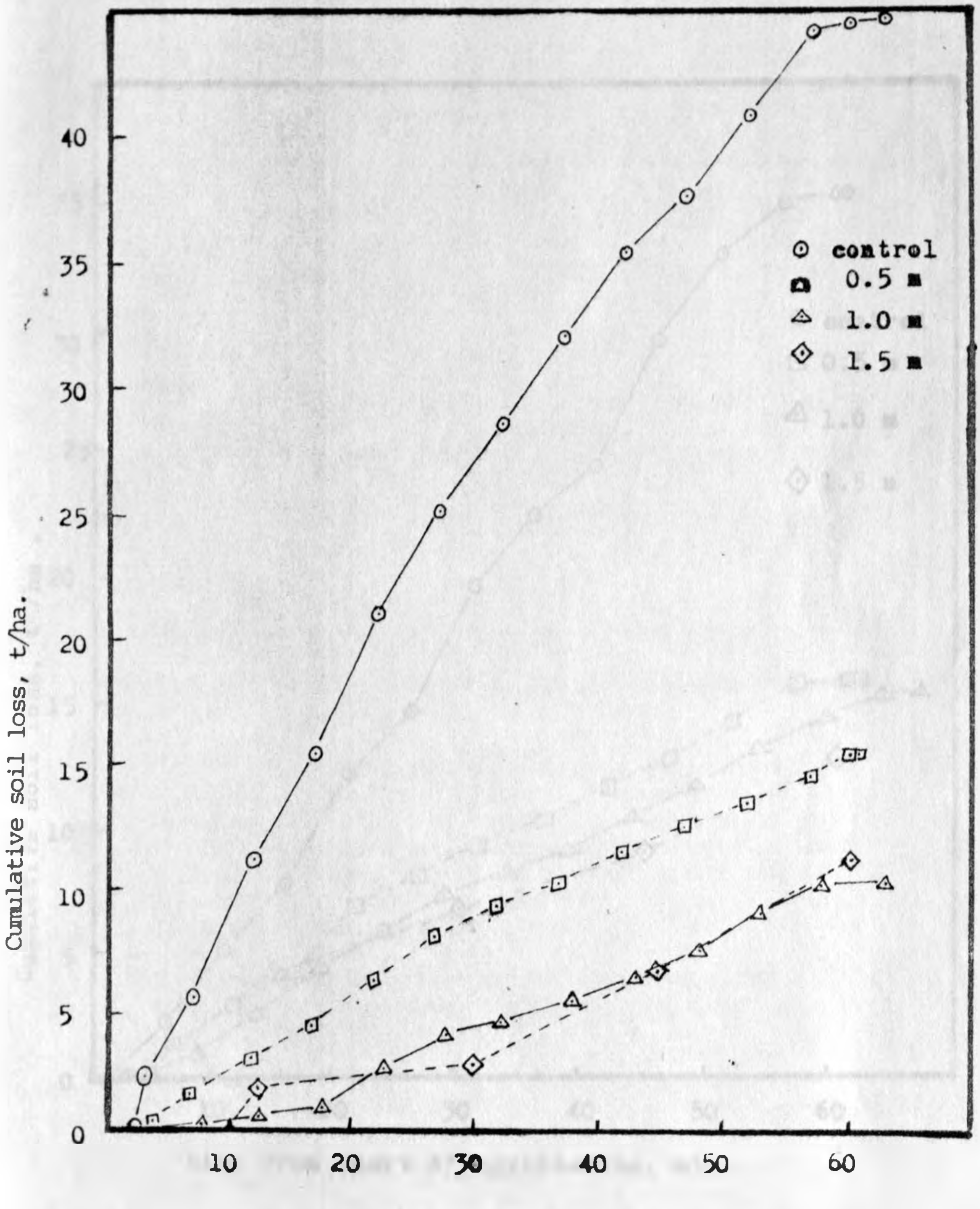


Figure 8. Cumulative soil loss for the four treatments from first wet run of simulated rainfall (80 mm/hr).

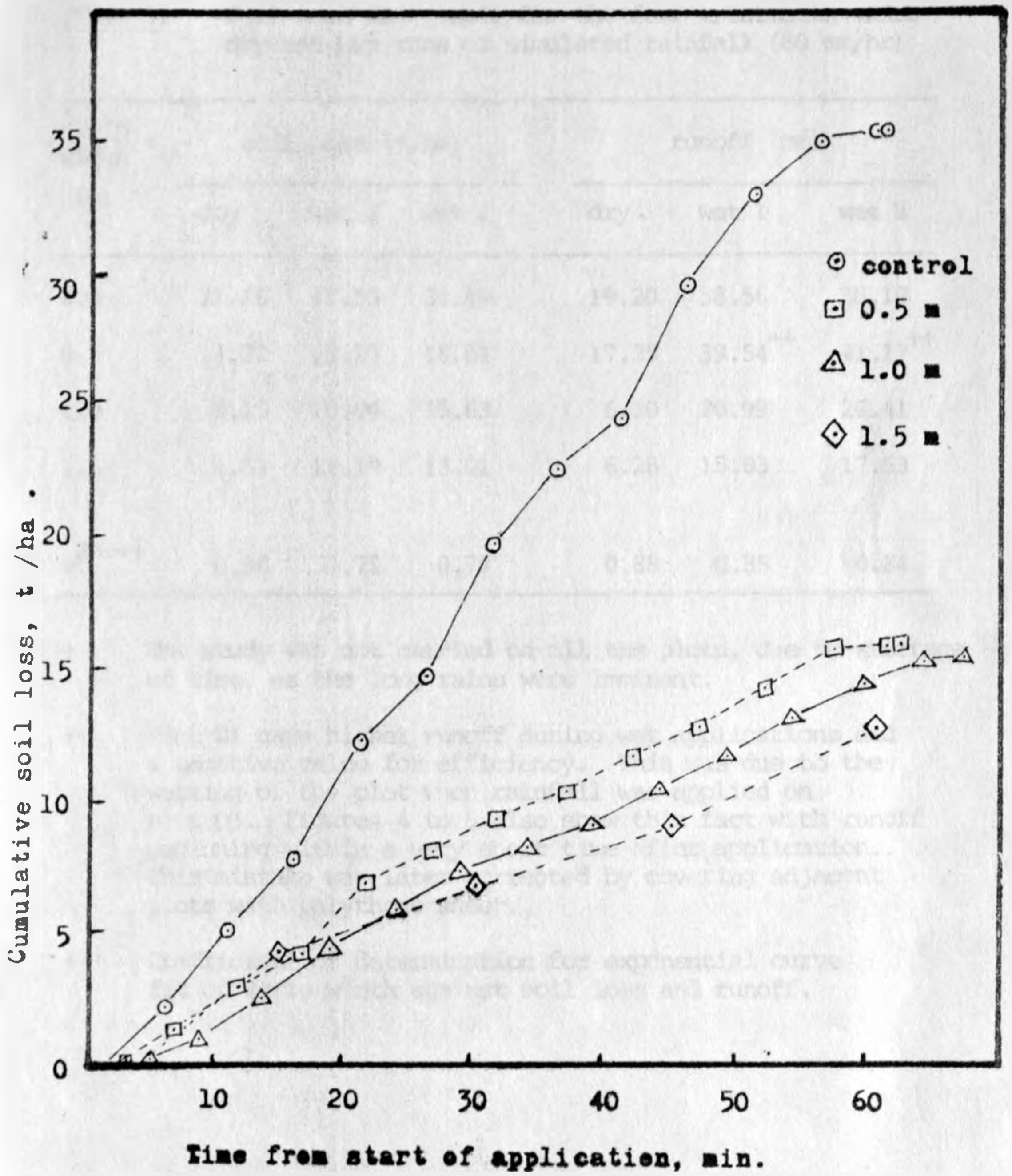


Figure 9. Cumulative soil loss for the four treatments from second wet run of simulated rainfall (80mm/hr).

with 1.0 m. and 1.5 m. wide grass strips. These values slightly increased under wet runs (Table 6).

Table 5. Soil loss and runoff for the four treatments under dry and wet runs of simulated rainfall (80 mm/hr)

Strip width + (m)	soil loss (t/ha)			runoff (mm)		
	dry	wet 1	wet 2	dry	wet 1	wet 2
0.0	21.16	44.53	35.49	19.20	38.56	38.10
0.5	14.22	15.23	16.01	17.25	39.54 ++	41.17 ++
1.0	3.15	10.06	15.63	6.50	20.99	26.41
1.5	1.51	11.19	13.01	6.28	15.83	17.53
r^2 +++	0.96	0.75	0.77	0.88	0.85	0.84

\+ The study was not carried on all the plots, due to shortage of time, as the long rains were imminent.

++ Plot D1 gave higher runoff during wet applications and a negative value for efficiency. This was due to the wetting of the plot when rainfall was applied on plot D3. Figures 4 to 6 also show this fact with runoff beginning within a very short time after application.. This mistake was later corrected by covering adjacent plots with polythene sheet.

+++ Coefficient of determination for exponential curve fit of strip width against soil loss and runoff.

Table 6. Percentage soil loss and runoff for the four grass strip widths under simulated rainfall

Strip width (m)	soil loss			runoff		
	dry	wet 1	wet 2	dry	wet 1	wet 2
0.0	100	100	100	100	100	100
0.5	67.12	34.20	45.11	89.94	102.54	108.06
1.0	17.96	22.59	44.04	33.85	55.43	69.32
1.5	7.14	25.13	36.66	32.71	41.05	46.01

Both soil loss and runoff are exponentially correlated with grass strip widths with high values of coefficient of determination ($r^2 \geqslant 0.75$) (Table 5). The decrease in both soil loss and runoff from the control plot to the 0.5 m. wide grass strip was rapid and became gradual from 0.5 m. wide grass strip to 1.0 m. and then to 1.5 m. wide strip.

4.4. *Depth of deposition and scour*

Iron rod measurements at the beginning and end of each rainy period showed deposition occuring in all the plots with grass strips and a scour in the control plots (Table 7 and Figure 10). Most of the deposition occured on the upper edge of the grass strip (referred to as the deposition pond) which extended up to two metres (Plates 5, 6, 11). Depth of deposition decreased with distance from the edge of strip and a scour occured at three metres distance in almost all the plots. Analysis of variance showed no significant difference between the treatments.

Maximum mean depth of deposition was 7.6 cm. at 0.5 m. wide grass strip. The deposition pond extended from 1.0 m. in 1982 long rains to 2.0 m. in 1983 long rains.

Table 7. Depth of deposition and scour (cm)[+] measured at the upper edge of the grass strips using iron rods

Season	grass strip width (m)			
	0.0	0.5	1.0	1.5
1982 LR	-1.07	2.19	2.34	-
1982 SR	-0.14	2.46	1.89	3.12
1983 LR	-0.17	3.00	2.70	2.57
Total	-1.38	7.65	6.93	5.69

+ mean of nine

4.5. *Change in ground slope*

Differences in profile survey made at the beginning, December 1981 and June 15, 1983, showed an average change in ground slope of 2% and depth of sediment deposition ranging from 7.0 - 14.0 cm. for the grass strips and no deposition for the control plot (Table 8. Difference in ground slope between the first survey and the second survey was uniform in all the plots.

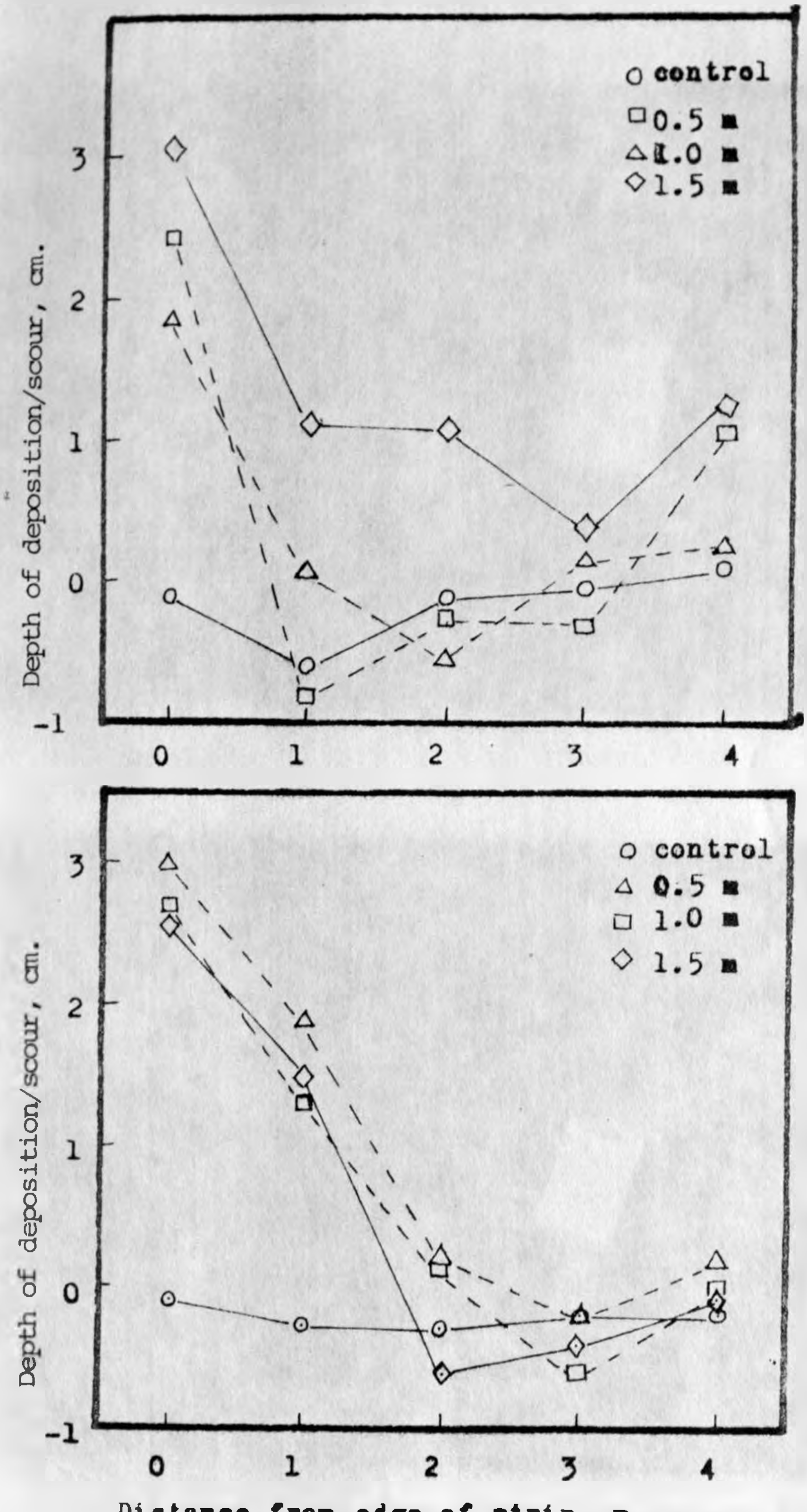


Figure 10. Depth of sediment deposition and scour as affected by grass strip width, for 1982 short rains (top) and 1983 long rains (bottom).

Plate 5(a).

Plate 5(b). Difference in deposition between the control plot (5(a)) and the 0.5 m. (5(b)) wide grass strip where deposition pond has extended up to two metres from the edge of grass strip (26/4/83).

Plate 5(c).

Plate 5(d). Deposition on 1.0 m. (5(c)) and 1.5 m. (5(d)) wide grass strips. Top picture shows rills ending 2 m. before the strip.

Plate 6. Deposition pond on plot F1 with a major rill. The control plot is partly seen (right) where a rill extends up to the end plate.

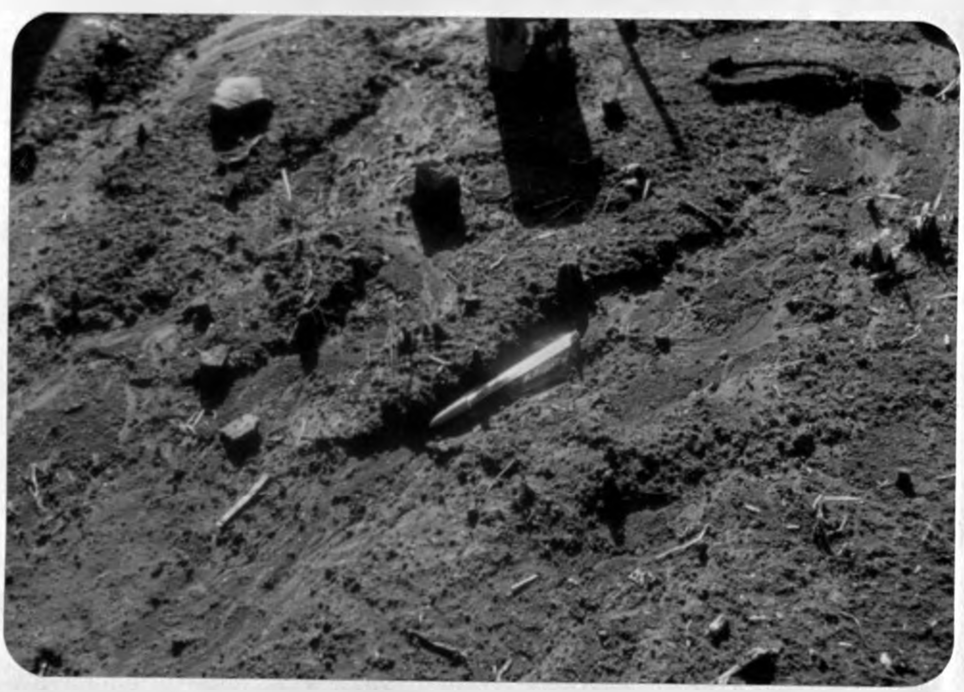


Plate 7. Picture showing surface condition after the wet run of 80 mm/hr simulated storm and effect of trash and gravel in protecting the soil.

Plate 8. Picture showing uniformity of application of simulated storm (80 mm/hr) on plot D3.

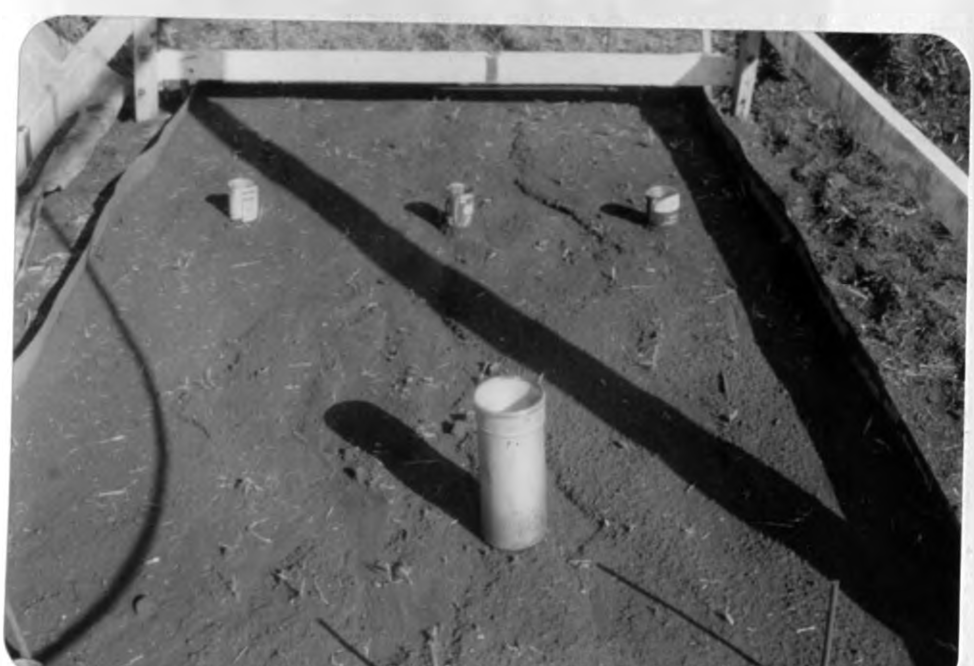


Plate 9. Picture showing rills extending to the end of plot on the control plot, after the wet run.

Plate 10. Rills and deposition pond caused by simulated storm on plot with 0.5 m. wide strip.

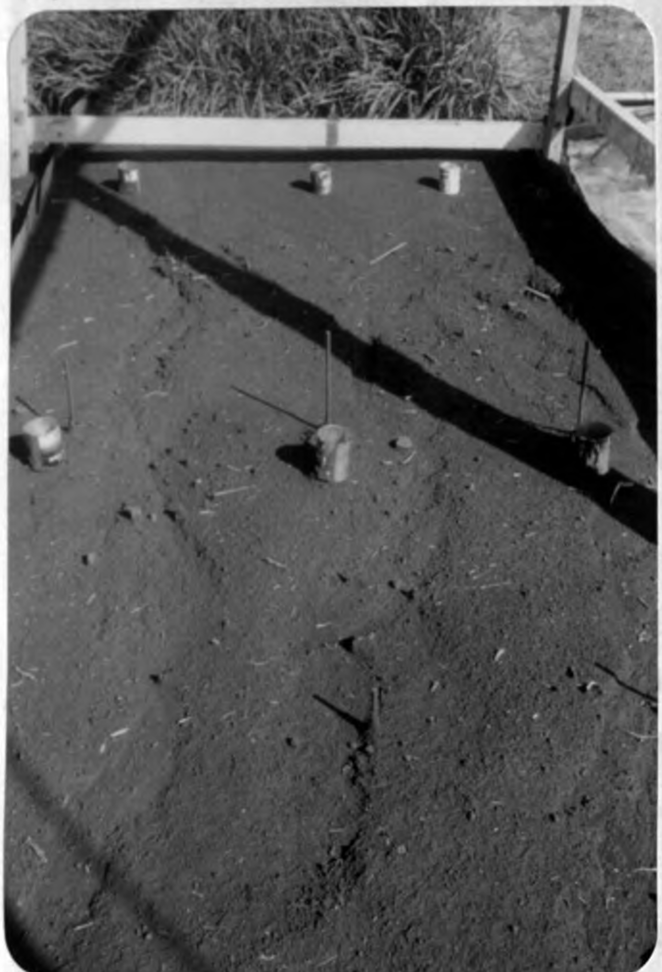


Plate 11.

Rills and deposition pond on plot with 1.0 m. grass strip.

A closer look (below)

Table 8. Depth of sediment deposition (cm) and change in ground slope (%) as determined by profile survey of the runoff plots

Plot	deposition (cm)	original slope (%)	new slope (%)
D0	0.0	11.1	9.8
D1	12.0	11.6	9.8
D2	11.0	11.3	9.8
D3	12.0	12.5	9.5
E0	0.0	10.2	9.4
E1	7.0	10.1	8.9
E2	8.0	10.4	8.9
E3	14.0	10.7	9.3
F0	0.0	10.3	8.9
F1	8.0	10.1	7.6
F2	10.0	10.4	8.4
F3	7.0	10.6	8.1

4.6. *Sediment size distribution*

Tables 9 and 10, Figures 11 and 12 show the distribution of water stable aggregates for the 1983 long rains and simulated rainfall, as affected by grass strip width. In general, two thirds of the sediment was transported in sand size fractions (Tables 9 and 10). Effect of grass strip in trapping different sized aggregates was negligible.

4.7. *Erosivity indices*

Different erosivity indices have been suggested by different workers. Besides the EI_{30} (the product of the kinetic energy of the storm and the 30 minute intensity) (Wischmeier and Smith, 1958), Hudson (1971) suggested the kinetic energy of the storm with intensity greater than 25 mm/hr (KE >25), Lal (1976) recommended the product of the amount of storm (cm) and the maximum 30 minute intensity (AI_m). In this study test of correlation of these indices plus the amount of storm (A). The EI_{15} (the product of KE and the maximum 15 minutes intensities) and the EI_5 (the product of the KE and

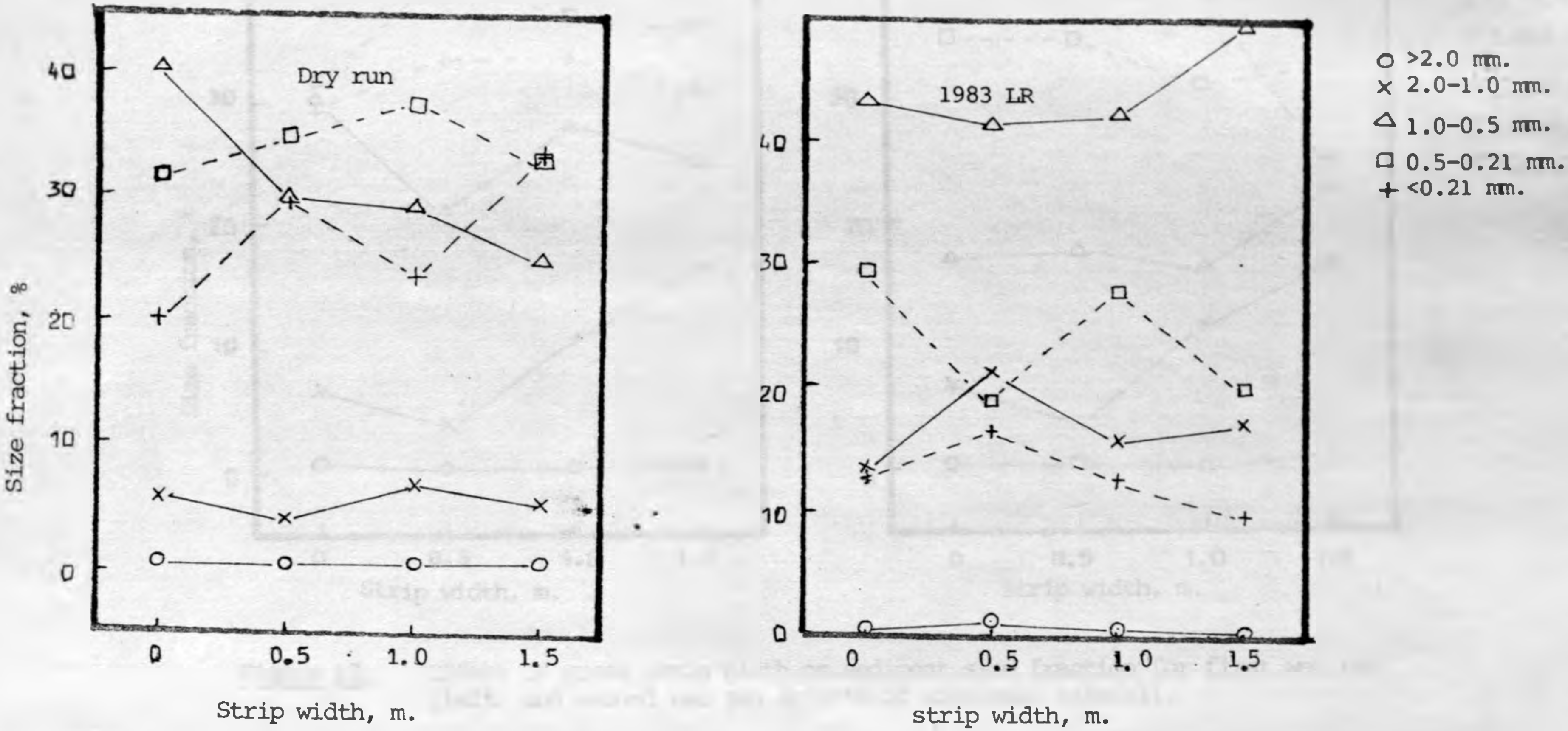


Figure 11. Sediment size distribution (%) as affected by strip width, 1983 long rains (right) and simulated rainfall (left).

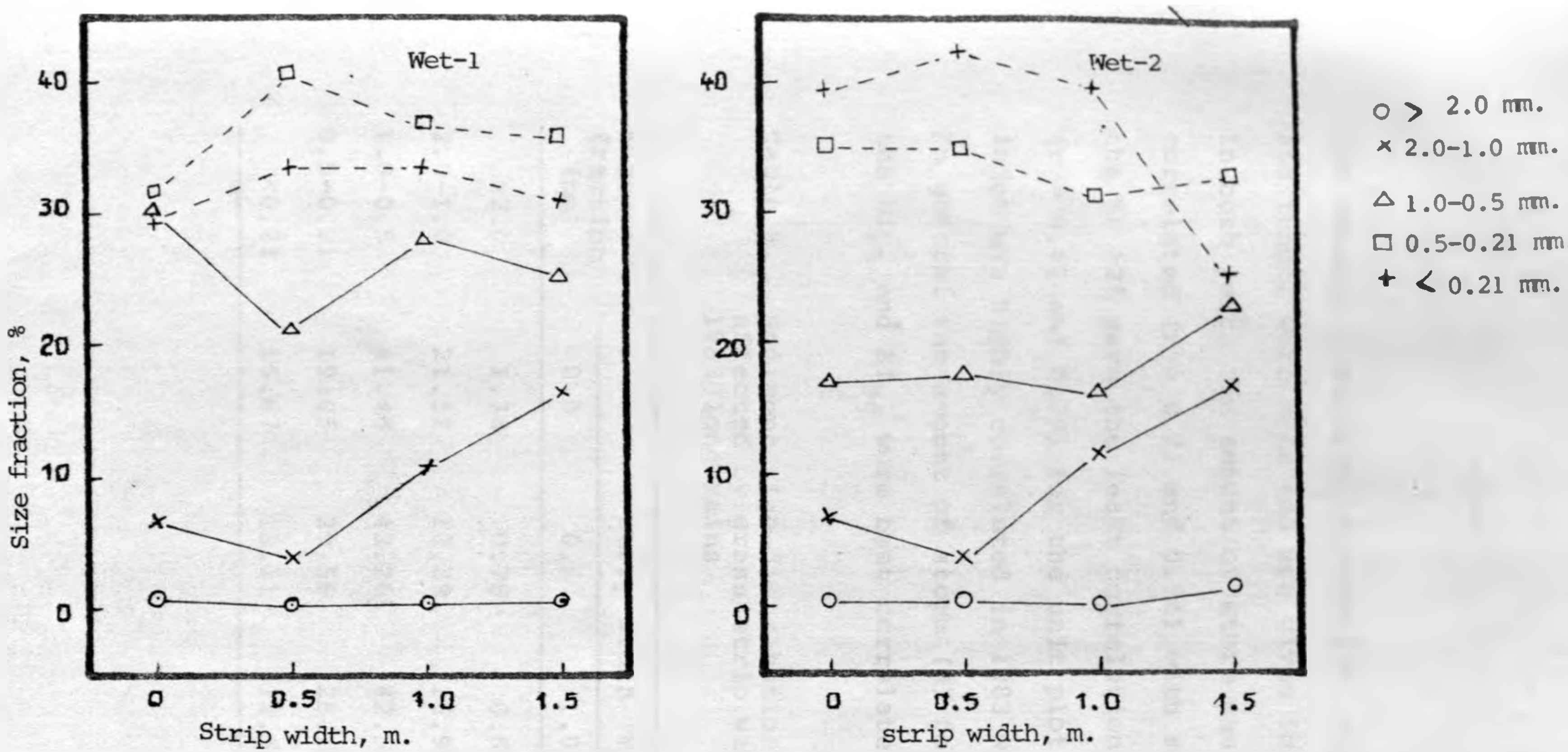


Figure 12. Effect of grass strip width on sediment size fraction for first wet run (left) and second wet run (right) of simulated rainfall.

the maximum 5 minutes intensities) with soil loss and runoff were made and are given in Table 11. In both years the amount of storm was highly correlated (r = 0.91 and 0.84) with soil loss and the KE >25 gave the least correlation coefficient (r = 0.41 and 0.79) for the unit plot. The AI_m index was highly correlated in 1983 with r = 0.82. In general the amount of storm (A) followed by the EI_{15} and EI_{30} were best correlated.

Table 9. Sediment size distribution (%) as affected by grass strip width for 1983 long rains

Size fraction (mm)	strip width (m)			
	0.0	0.5	1.0	1.5
>2.0	1.78	0.78	0.69	0.56
2.0-1.0	21.52	13.29	15.98	17.12
1.0-0.5	41.48	43.26	42.50	50.23
0.5-0.21	19.05	29.56	28.18	20.11
<0.21	16.67	13.11	12.66	9.98

Table 10. Sediment size distribution (%) for the three runs of simulated rainfall as affected by grass strip width

Size fraction (mm)	strip width (m)			
	0.0	0.5	1.0	1.5
		dry		
>2.0	0.84	0.51	0.93	0.97
2.0-1.0	6.16	4.49	7.25	5.83
1.0-0.5	40.73	30.25	29.57	25.26
0.5-0.21	31.91	35.08	38.31	33.84
<0.21	20.35	29.66	23.93	34.09
		wet-1		
>2.0	0.80	0.21	0.42	0.55
2.0-1.0	6.89	3.77	10.70	16.65
1.0-0.5	30.32	21.29	28.08	25.35
0.5-0.21	32.18	40.81	27.02	26.36
<0.21	29.81	33.82	33.78	31.09
		wet-2		
>2.0	0.55	0.51	0.38	1.44
2.0-1.0	6.95	3.77	12.01	17.03
1.0-0.5	17.59	17.97	16.46	23.24
0.5-0.21	35.65	35.14	31.31	33.16
<0.21	39.26	42.60	39.84	25.14

Table 11. Correlation coefficients (r) of various erosivity indices with soil loss and runoff for the four treatments

Year	strip width (m)	A	EI_{30}	EI_{15}	EI_5	AI_m	KE>25
				soil loss			
1982	0.0	0.91	0.69	0.84	0.80	0.61	0.41
	0.5	0.93	0.54	0.73	0.72	0.49	0.23
	1.0	0.94	0.50	0.64	0.59	0.50	0.16
1983	0.0	0.84	0.77	0.88	0.73	0.82	0.79
	0.5	0.78	0.78	0.86	0.69	0.82	0.55
	1.0	0.73	0.67	0.80	0.56	0.74	0.46
	1.5	0.64	0.59	0.74	0.50	0.67	0.39
				runoff			
1982	0.0	0.94	0.44	0.55	0.51	0.47	0.11
	0.5	0.94	0.44	0.54	0.49	0.48	0.10
	1.0	0.92	0.39	0.49	0.43	0.44	0.04
1983	0.0	0.89	0.95	0.95	0.79	0.89	0.80
	0.5	0.78	0.83	0.89	0.67	0.85	0.57
	1.0	0.85	0.80	0.88	0.61	0.83	0.55
	1.5	0.70	0.64	0.75	0.53	0.68	0.41

5. DISCUSSION

This section follows the pattern of the results section. First the effect of grass strips in reducing soil loss and runoff under natural rainfall is discussed. Then follow discussions of the results of the simulated runoff tests, simulated rainfall, erosivity indices and soil erodibility. The last part of this section deals with economic considerations of using grass strips as a conservation support practice.

5.1. *Performance of grass strips in reducing soil loss and runoff under natural rainfall*

5.1.1. *Effect of grass strips in reducing soil loss and runoff*

Results of this experiment show grass strips to be very effective in reducing both soil loss and runoff during the short rain (Appendices 3 and 4). The efficiencies were nearly 70% and above. The efficiencies were lower during the long rains because the storms were heavy and with high intensities. Efficiency for all the strip widths improved with time, as the deposition pond extends upslope, the velocity of overland flow is reduced for a longer period over a wider area inducing more deposition and infiltration. It is interesting to find the efficiency of narrow grass strips similar to the efficiency of a graded terrace with 0.25% channel slope (Foster and Ferreira, 1981). According to Foster and Ferreira (1981) there was no sediment deposition in a uniform grade open end terrace with channel slope of 0.6%. Deposition of sediment in terraces mostly occur in the terrace channel which retain about 80% of the soil moved (Wischmeier and Smith, 1978). The support practice factor (P) value for graded terraces on 9-12% ground slope is 0.30. Later Foster and Highfill (1983) gave sediment yield subfactor (P_y) of 0.4 and 0.15 for the old type terraces of side slopes of 5:1 and the new type terraces of side slopes of 20:1 respectively with channel slope of 0.25%. The P values will be 0.36 for the 0.5 and 1.0 m. wide grass strips and 0.18 for the 1.5 m. wide grass strip. These values suggest that both graded terraces and grass strips have a similar effect in reducing soil loss on a 10% ground slope.

This is encouraging especially to the small holder farmers. The small holder farmers of Central Province, where there are similarities in both soil and climatic conditions to Kabete, are faced with the problem of land scarcity, which will be aggravated in time through subdivision. They therefore want to utilise every square metre of land available. Thomas (1982) mentioned shortage of land and difficulty of finding an acceptable alignment as the main reason why artificial waterways have not always been developed where they were needed. A conservation support practice that takes into consideration this problem will be highly acceptable and beneficial.

Narrow grass strips do not waste land, they provide animal fodder, they eliminate the need for waterways and they do not concentrate runoff into channels which run the risk of bank failure if not properly maintained. Besides they are easy to install and need no skilled knowledge.

The fact there was no significant difference between the three grass strip widths except in one season was found also by Neibling and Alberts (1979) and indicates that the use of narrower strips of 0.5 m. wide can be recommended to farmers, though the annual soil loss from the 0.5 m. wide grass strip was twice the annual soil loss from the 1.5m.

wide grass strip (Table 1). Small land holders cultivating steeper slopes by hand can improve the effectiveness of grass strips by closer spacing.

5.1.2. *Relation of strip width to soil loss and runoff*

An attempt has been made to derive an equation relating strip width with the ratio of out-flowing sediment or runoff to in-flowing sediment or runoff. An exponential relation best fits to describe these relations. Figure 13 shows these relationships for the twelve months period of July 1982 to June 1983. The equations developed are:

$$f_s = \frac{Q_{st}}{Q_{so}} = 0.85e^{-1.03\ sw} \quad \ldots.(1)$$

with $r^2 = 0.88$

and

$$f_r = \frac{R_t}{R_o} = 0.97e^{-0.90\ sw} \quad \ldots.(2)$$

with $r^2 = 0.98$

where f_s = ratio of out-flow sediment load (Q_{st}) in t/ha/yr, to in-flow sediment load (Q_{so}) in t/ha/yr.

f_r = ratio of out-flow runoff (R_t) to inflow runoff (R_o)

sw = grass strip width in m.

Equations 1 and 2 can be used to determine the width of a grass strip required to produce a certain desirable level of soil loss in situations similar to the experimental conditions, where slope is 10%, grass is Nandi setaria, soils are deep, well drained clay Nitisols and rainfall is similar. For example, if soil loss from a 10% slope 12 m. long continuous maize field fertilised with NPK is 29.76 t/ha., taking R=246, K=0.21, LS=0.9, C=0.64 (Wenner, 1977) and P=1; and if it is required to reduce soil loss to 10 t/ha., the ratio (f_s) will be 0.34. From the graph at f_s of 0.34, the strip width required will be 0.88 m.

Survey of the runoff plots on June 15, 1983 showed there was little advance in the deposition wedge (Appendix 9). Deposition wedges had advanced only 10-30 cm. within the strips, while the deposition ponds extended to more than 2.0 m. This suggests

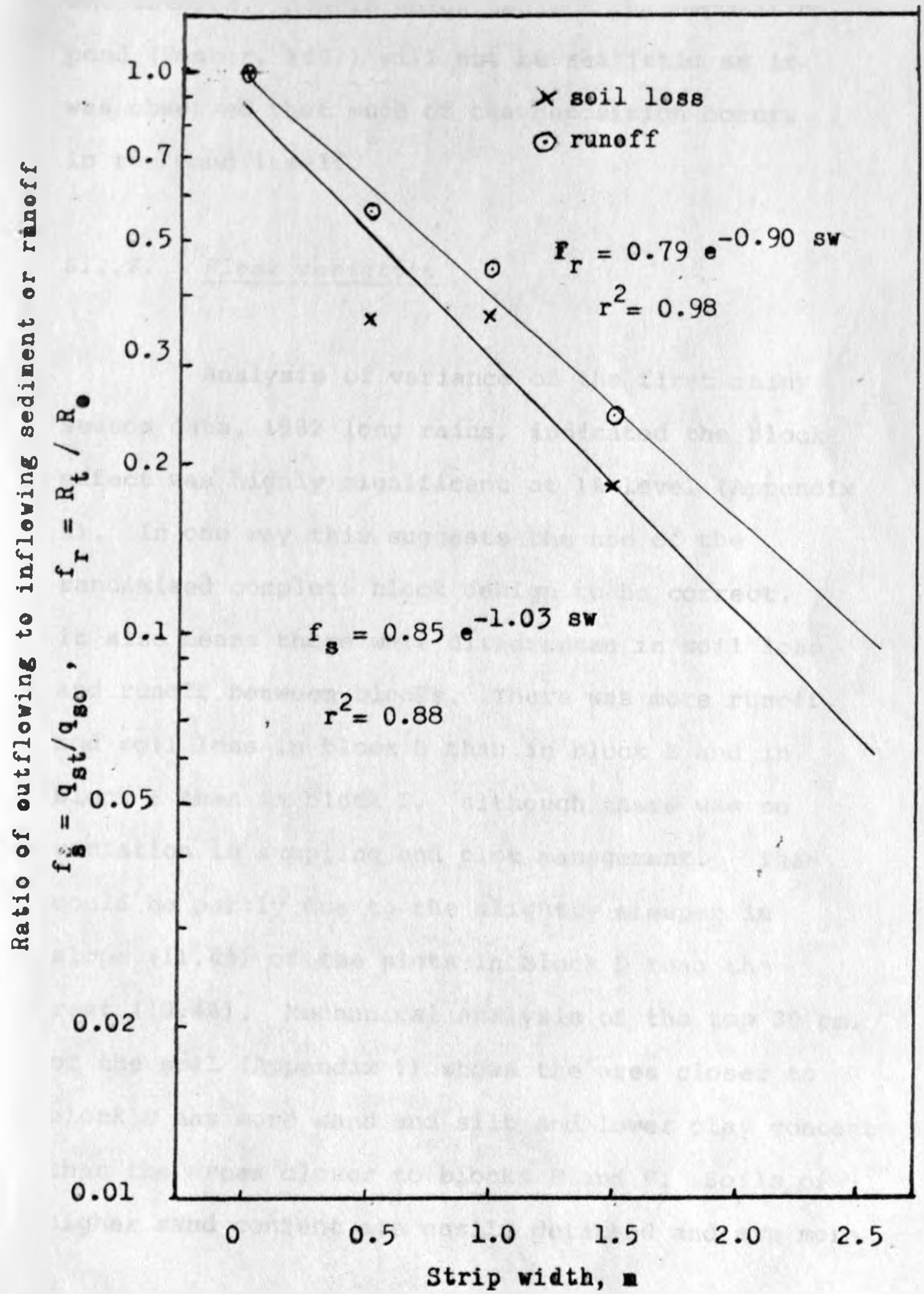


Figure 13. Relation of strip width to the ratio of outflowing and inflowing sediment / runoff.

much of the deposition occurs at the upper front of the grass strip where resistance to flow is encountered. Models which neglect the deposition pond (Foster, 1981) will not be realistic as it was observed that much of the deposition occurs in the pond itself.

5.1.3. *Block variation*

Analysis of variance of the first rainy season data, 1982 long rains, indicated the block effect was highly significant at 1% level (Appendix 5). In one way this suggests the use of the randomised complete block design to be correct, it also means there were differences in soil loss and runoff between blocks. There was more runoff and soil loss in block D than in block E and in block E than in block F, although there was no variation in sampling and plot management. This could be partly due to the slightly steeper in slope (11.4%) of the plots in block D than the rest (10.4%). Mechanical analysis of the top 30 cm. of the soil (Appendix 1) shows the area closer to block D has more sand and silt and lower clay content than the areas closer to blocks E and F. Soils of higher sand content are easily detached and are more susceptible to erosion (Farmer, 1973). Soils high in silt content are the most erodible (Wischmeier and Mannering, 1969) and once detached clay silt size fractions are easily transported (Cooke and Doornkamp, 1974; Neibling and Foster, 1977).

Saturated hydraulic conductivity tests also show soils of block F having a slightly higher infiltration rate than the others (Appendix 2). Soils near block D and E have lower values of hydraulic conductivity in the 30-60 cm. zone. This could affect the overall infiltration rate, acting as a bottle-neck, thus causing more runoff than on block F.

5.1.4. *Influence of grass type on sediment trapping*

The grass used was Nandi setaria (*Setaria anceps*) which is a tufted grass and does not form a continuous ground cover. It would be better to have narrow grass strips with closer growing grass to obtain maximum deposition and higher efficiency. It was observed during the simulated runoff and simulated rainfall that runoff finds the weakest point and flows through it. If there are wider gaps between grasses, runoff finds its way through the gaps drastically affecting the trap efficiency. This could be one of the reasons why there was no difference in the distribution of water stable aggregates between the treatments.

The choice of grass type from this point of view is very important. Nandi setaria is not ideal, though it may provide strong stalk resistance and have a vigorous growth, unless it is planted very close together initially which farmers are unlikely to do. A spreading grass that grows more densely and has the physical strength to resist sub-mergence might be more effective. However, rhizomatous grasses such as Kikuyu grass (*Pennisetum clandestinum*) that spread widely may not be acceptable to farmers, as they extend into the cropped area and create extra problems. Alternative grasses should be found that could be best fitted to this situation. A mixture of a tall, errect, tufted grass with a non-spreading, low and dense grass could be a possibility. Further study in the performance and efficiency of different grasses will be useful in understanding and determining the effect of grass type in the trapping of sediment by grass strips and to recommend the right type of grass for each ecological zone.

5.2. *Simulated runoff*

Data from the simulated runoff trials should be taken only to indicate the relative differences between a plot with a grass strip and a plot without a grass strip, as there was no rain drop splash, which could have played a major role in the detachment of soil and interill erosion. It was observed, that the little furrows made to simulate runoff stopped at about 1.0 m. from the edge of the grass strip as the result of deposition while the furrows were continuous down to the end plate on the control plot. Alberts et. al. (1980) found rill erosion detaches bigger aggregates than under interill erosion and most of the clay was being transported as soil aggregates. Bigger aggregates are easily deposited due to reduction in flow velocity caused by grass strip resistance. Alberts et. al. (1980) also found discharge rate did not significantly affect the size distribution but higher discharge rates produced higher soil loss, which is in agreement with Table 4.

Results of simulated runoff were not statistically analysed, since there were no true replicates, even though each flow rate was carried four times. However, similar to the natural rainfall, the efficiency of grass strips was lower at higher flow rates than at lower flow rates.

5.3. *Simulated rainfall*

Simulation of high intensity rainfall was necessary to observe the performance of grass strips under heavy storms, since such heavy but rare storms could be very disasterous. Results show efficiency of the grass strips during the dry run being very high and similar to the efficiency of grass strips during the long rains. The efficiency decreased from the dry run to the wet run. This suggested grass strips can effectively control soil loss from heavy storms, if the storm is not preceeded by any rain in the previous three days, but the efficiency will be reduced to about 55% of what it would otherwise have been if such a storm is preceeded by rainfall the previous day.

The cumulative soil loss graphs (Figures 7 to 9) show a sharp rise in soil loss from the control plot and a gradual increase in the other plots. Under dry run a short duration (30-40 min.) 80 mm/hr. storm will produce a very low soil loss and a 10 minutes storm will not produce any at all. However such a storm could be hazardous if the soil is wet, where runoff begins almost immediately (within two minutes). The cumulative soil loss graphs also show after a certain period of application soil loss rates achieve a constant value. A close examination of the slopes of the cumulative soil loss graphs suggest two groups of soil loss rates, the control plot with a mean soil loss rate of 0.69 t/ha/min. and standard deviation of 0.07 and the plots with grass strips with mean soil loss rate of 0.25 t/ha/min. and standard deviation of 0.12.

5.4. *Depth of deposition and scour*

Use of the iron rods to monitor depth of deposition and scour was not sensitive enough. Values given in Table 8 are on the average less by 15.3% when compared to the total measured soil loss values, taking the soil bulk density of 0.61 g/cc. Values for the depth of deposition and scour are far less from the values determined by profile survey of the plots. Besides some rods may lie on the centre of rills;others might have a small heap of soil around formed during cultivation (which in most cases gave lower values of scour) and in both cases gave exaggerated values. More rods were not installed for fear of interference with detachment effect of rainfall.

However it was observed a maximum mean deposition of 7.6 cm in one and half years. At the upper end of the plots 15-20 cm. of scour had taken place. Assuming such depth of scour can take place under the actual field conditions, where the end plate and collecting trough do not protect the soil at the lower edge of the grass strip, a bank height of 20-30 cm. should develop in one and half years. This will be a very close figure to the values found by Kimutai (1979) and Roose and Bertrand (1971). What happens after a long period is yet to be answered. Whether after a certain period of deposition, grass strips reach a state of equilibrium, whereby the volume of sediment entering and leaving the grass strips is the same has to be tested. Models developed assumed after bank height reaches grass height flow is inundated and the system reaches equilibrium state. This study however suggests that with the continuous growth of grass above the level of deposition, resistance to flow and deposition continues till ground slope approaches zero and bench type terraces are formed. This is a desirable long term objective however slow the process might be.

Whatever the outcome will be after a long period, it would be a mistake to neglect the immediate role of grass strips in controlling soil loss and water laden pollutants. Although pollution is not yet a very serious problem in Kenya, the increasing use of insecticides and herbicides will lead to greater emphasis on measures such as grass strips which provide some control. In countries like Ethiopia, where there is a lack of trained manpower to carry the urgently needed and immense task of conservation and where there is a lack of awareness by the peasant population of the dangers of erosion, introducing the idea of grass strips can play an important role, as it is simple and cheap to install and compared to structural measures like cutoffs and terraces, there is no risk of damage due to failure. In areas where ultimate conservation practices emphasize terraces, grass strips can be spaced with the same terrace spacing, and it will be easy to shift to terraces at a later stage if the need arises.

The foregoing results were obtained under bare soil conditions with the intentions of simulating the situation at the start of the rains before plant cover has established or when the erosion hazard is high. As mentioned effectiveness of grass strips is greatest during light storms and it will also be greatest when plant cover has established. On an annual basis under normal cropping practice it could therefore be expected that grass strips would be even more effective than the results presented here suggest.

5.5. *Erosivity indices*

Results of correlation test of the different erosivity indices with soil loss and runoff gave the amount of rainfall (A) best correlated followed by the EI_{15}, EI_{30} and AI_m. The amount of rainfall (A) was also best correlated with soil loss at Katumani, Machakos District (Ulsaker, 1983). If further studies prove this is to hold true, this index has got advantage over the other erosivity indices, for it is very simple to measure and soil loss values can easily be calculated from regression equations using simple rain gauge readings. Work in the U.S.A. has shown that rainfall kinetic energy and intensity are the two parameters that are most useful in assessing rainfall erosivity, but in Kenya total rainfall is closely correlated with energy and intensity and is therefore as good an indicator of erosivity.

Only 36% of the total annual rainfall has intensities greater than 25 mm/hr. for 15 minutes duration. But the occurance of such storms at the early period of the rainy season (Appendix 8) when the ground has little or no crop cover makes them dangerous (Fisher, 1977).

Generally, for the Kabete soil it was observed that rainfall below 25 mm. caused little or no danger at all, even when the ground is without any vegetative cover. This is mainly due to the soils high infiltration rate, good structure - stable microaggregation (Ahn, 1979) - and low susceptibility to crusting and sealing.

Annual R values for Kabete for 1982 and 1983 were 246 and 236 m-t-cm/ha-hr-y respectively. The 1983 value does not include the 1983 short rain values, which contribute about 18.2% as estimated from 1982 values (though the 1982 short rains were quite heavy). These values are close enough to 212 (Wenner, 1977) and 225 (Moore, 1979). Calculating annual R value from the EI_{30} index gives 231.3 for 1982 and 189.8 for 1983.

Though the EI_{30} index was not as highly correlated with soil loss as the amount of rainfall and the EI_{15} index, it still gives good results in calculating the R value and can therefore be used. Besides it is the widely supported index which can be used in the Universal Soil Loss Equation.

5.6. *Runoff coefficient*

The maximum runoff coefficient observed was 58% which occured on 28th April and was preceded by seven days of quite heavy storms. This value was close enough to values determined by Barber et. al. (1979) from simulated rainfall studies and the value (50%) used in the design of the runoff plots.

5.7. *Soil erodibility*

K values for the erodibility of Kabete soil were calculated from the Universal Soil Loss Equation (USLE)* where:

$$K = \frac{A}{0.9\ R}$$

Taking LS = 0.9, for 10% and 12 m long plots and a unit value for C and P. The Table below gives these values:

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*The USLE is A = RKLSCP, where:

A = soil loss per unit area (t/ha)
R = rainfall and runoff factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover and management factor
P = support practice factor

		A	R	K
		(t/ha)	(m-t-cm/ ha-hr-y)	{t-ha-hr / ha-m-t-cm}
Natural	1982	46.76	246.15	0.21
rainfall	1983	85.53	236.07	0.40
Simulated	dry	22.16	176.0	0.13
rainfall	wet 1	44.53	176.0	0.28
	wet 2	35.49	176.0	0.22

R-values for the simulated rainfall were calculated from the drop characteristics where the median drop size was 3.8 mm. falling from 5.0 metre height. The drops will have a terminal velocity of 7.6 m/s (Laws, 1941), and the intensity was 80mm/hr. According to Meyer and Harmon (1979) drops from 80150 veejet can achieve terminal velocity at about 3 m. height and at pressure of 41 N/m^2 (6 psi), close to the one used on the plots, and can provide an impact energy of 275 kJ/ha-mm. The energy will be the same as that of natural rainfall at intensities greater than 25 mm/hr.

These K-values are higher than the ones given by Barber et. al. (1979) and Gachene (1982). Barber et. al. (1979) reported maximum K value of 0.15 for wet run from 1.5 m^2 plots of newly ploughed field with a very high percent of clay (79.2%). Gachene (1982) working on disturbed samples under simulated rainfall got K values of 0.077 for tray dry, 0.05 for field wet and 0.076 for nomograph of Wischmeier and Smith. His soils had 64% clay. Higher clay content leads to good aggregate stability reducing the susceptibility of the soil to erosion, and this could be one of the reasons for the difference in K values. Secondly both Barber et. al. (1979) and Gachene (1982) used small plots and simulated rainfall. Basically the USLE is not recommended for prediction of specific soil loss events, rather for long time average soil losses (Wischmeier and Smith, 1978). For small plots the number of replicates and surface microtopography might play an important role. The fact that K values from simulated rainfall came close to the natural rainfall values can indicate the importance of plot size, to some extent. Therefore it will be necessary to monitor both soil loss and rainfall erosivity for more years to come to arrive at a more reliable figure.

5.8. *Economic considerations*

Although the benefits of using grass strips far out-weigh the disadvantages there are two problems for the small farmer which must be recognised.

1. Grass strips take up land, especially for small holder farmers. This loss of land

can be compensated by grass production. In areas of intensive small holder farming such as Central Kenya, stall feeding of cows is widely practised and grass has become a marketable commodity selling at about 7 K.shs. per bag. On this basis, a farmer at Kabete, using Nandi setaria grass, can get 2.25 Kshs. per metre of 0.5 m. wide grass strip per season, and he will be only loosing one row of crop.

2. The grass competes with adjacent crops for moisture and nutrients. This can be minimised by choosing the right grass type - non-competitive perennial grass. Besides this can be balanced by retaining water and nutrient that would otherwise have been lost.

Some farmers may object to the use of grass strips, because they may think grass strips can harbour pests. This could not be different from grasses used on terrace banks, or grassed water ways or from field boundaries which are usually left unploughed.

The economic benefits of using grass strips as a conservation support practice are:

1. They are cheap to install. A farmer may need to spend about 5.8 Kshs. per metre or 6,698 Kshs. per hectare to construct a simple "fanya juu" terrace at Kabete while he may not need to invest on grass strips or waste any man-hour, as grass strips can develop from trash lines left unploughed. Besides terraces involve a considerable amount of labour which is not laways available.

2. Rate of decline of yield can be kept low due to maintained fertility and soil moisture that would otherwise be lost. Lal (1976) reported artificial removal of 7.5 cm. of soil decreased maize yield by 49% and 5.0 cm. by 38%. In Australia, Molnar reported removing 7.6 cm. of the top soil reduced wheat yield by 27% (In: Cooke and Doornkamp, 1974). Soil erosion may not be identical to the artificial removal of soil, and results may not be as serious as reported above, but it can definitely reduce crop yield and result in a lower income to a farmer.
   Ruthenberg (1980) makes a point that conservation will always pay in the long

run because if you place a value on the yield loss you would get without conservation, that sun could theoretically be invested and would go on accumulating interest year by year until the total accumulated could eventually outweigh the cost of conservation. If in fact the conservation uses family labour for which the opportunity cost is zero, then conservation will pay immediately.

On the other hand a farmer at Kabete might save an equivalent of 1055.40 Kshs. worth of nutrient that he will need to replace by using fertiliser if eroded from a maize field. This was calculated from:
taking soil saved = 39.92 t/ha-y and
crop factor of 0.64,
nutrient content of soil :

N = 0.2%
P = 110 ppm
K = 6%,

NPK values were taken from top soil analysis of a near by field which has not been fertilised for more than 2 years. Ignoring K for it is readily available and taking availability of N and P as 60% and 20% respectively, this will amount to available nutrient of 47.90 kg/h-y of N and 0.88 kg/h-y of P. Current price of Di Ammonium phosphate (DAP) is 231.35 Kshs. per 50 kg. The farmer will need 223.1 kg. of DAP, which amounts to 1055.40 K.shs.

3. Terraces disturb the soil profile. If not properly constructed, putting the subsoil on top during construction can result in a drastic yield reduction of two or three rows of crop while this problem does not arise using grass strips.

4. In the less developed countries like Kenya, faced with high rate of population growth, a pressing need for more and more food and fiber, low level of industrial expansion and an increasing level of unemployment, the soil is the most important resource that should be conserved and pass from generation to generation. Thus conservation work has a very valuable moral benefit, which is not often realised.

5. Grass strips, like other conservation measures that reduce sediment delivery into streams, contribute to reduced sediment load of streams and improved quality of water resources.

6. CURRENT PRACTICES OF USING GRASS STRIPS IN NANDI AND NAROK DISTRICTS - FIELD OBSERVATIONS

This section is based on field observations and interviews with farmers and Ministry of Agriculture field staffs involved in the implementation and layout of grass strips. The areas visited were: Kapkangani and Kemeoloi areas of Songhor Division, Nandi Hills of Tinderet Division and Kabyet area of Mosop Division, all in Nandi District. In Narok the areas visited were Eastern and Central Mau.

The areas visited in both districts received annual rainfall over 1000 mm. In both districts land is not scarce and most of the farms are on recently cleared forest lands. Soils are well drained and deep clay soils with high percentage of organic matter. There is no human and cattle population pressure on the land as in Central Kenay, and the native population (the Nandi and Masai) are traditionally pastoralists. The farming population are mainly new comers to the area (the Luhya in Nandi and the Kikuyu in Narok). In Nandi District except for the few tea farms, there are no large scale farms while in Narok the gentle slopes (9-20%) are mainly large scale wheat and the small scale farmers are on the steeper slopes.

In both districts, grass strips are the major conservation practices employed. The 1982 Ministry of Agriculture report shows a total of 76,868 m. and 48,076 m. of grass strips being laid out in Nandi and Narok Districts respectively. Field practices of using grass strips as a conservation support practice vary considerably in the two districts.

The major differences are in strip alignment and spacing. Also grass strips were adopted in Nandi District earlier than in Narok. In the large scale wheat farms of Narok, where the farmers are not the owners of the land, they care less for the land and most of the strips are of grass and bushes left at random and non-continuous; some even running up and down the slope. Strips laid up and down the slope have guided ploughing to be up and down the slope inducing more erosion instead of becoming erosion control practices. In some fields the strips have acted as a sort of channels and where they end in the middle of a field rills have developed. In Nandi, most of the farms are small holdings and grass strips are laid properly along the contour by the agricultural staff, and the problems encountered in Narok are non-existent. In Narok grass strips are spaced 30-100 m. apart on the large scale farms while in Nandi the spacing is 15-40 m. apart, with most farmers prefering wider spacings.

In both districts, a wide variety of indigenous grasses are used, as strips have developed from trash lines left unploughed. The most common grasses observed are *Hypperhenia* sp., star grass (*Cynodon* sp.), couch grass (*Digitaria scalarum*), Kikuyu grass, Nandi grass, Napier grass and a mixture of any of these. Napier grass (*Penni-setum purpureum*) is mostly grown by farmers who practise stall feeding where grass from strips is used as fodder (Plate 12). In most cases, grass strips were not used for fodder and had no value. On the large scale farms of Narok, most strips consist of a mixture of low growing grasses and bushes.

Although the Ministry of Agriculture recommended grass strip width of 1.0 m., strips in Nandi district are mainly of 0.5-1.0 m. and are especially narrow on the steeper slopes. In Narok,

Plate 12. Long narrow grass strips on a 10% slope used in Tuloi, Nandi District (24/8/83)

Plate 13. One of the grass strips seen on 55% ground slope in Meloi, Nandi District. Star grass providing good bank cover (26/8/83).

Plate 14. A narrow (0.5 m. wide) grass strip of Kikuyu grass on a rape seed field trapping sediment from road runoff in Upper Mau, Narok District (17/9/83)

strip width reaches up to 5.0 m. and on the small holder farms are more or less the same as Nandi District.

There is no upper limitation of ground slope where grass strips are not used. Farmers cultivating as steep as 44% in Narok and 55% in Nandi (Plate 13) have used narrow grass strips, though such practices are contrary to some of the recommendations. It was very difficult to assess the effectiveness of grass strips under such steep slopes, but they are still helpful, as deposition and interruption of rill development are observed.

Old grass strips laid in 1977 and 1978 in Nandi district have formed 0.60-1.20 m. bank height. The recently established grass strips of 1982 have formed 0.25 m. bank height. On the steeper slopes, it seems much of the bank height was formed as the result of scour from the lower edge of the grass strip.

So far farmers are not aware of the problems that could arise out of using grass strips. Competition of grass with the adjacent crops (even Napier grass) seems not to bother them. Even the spreading of grass in to the field is not taken as a serious problem. Those farmers using Napier grass are satisfied with the amount of fodder they get and are not keen about the possible disadvantages. In most farms, the first two rows of crops on the lower edge of the grass strips gave poor yield, and one farmer had reduced the bank height by scooping soil downhill to get a better yield. Poor yield on the lower edge of the grass strips is mainly caused by soil erosion accelerated by downhill movement of soil during ploughing and cultivation, especially when done by hand hoeing. All the farmers interviewed complained about this and mentioned the fact that soil beneath the grass strips was hard to dig. Farmers are indifferent to the problems of rats and rodents, as a considerable area is left uncultivated. One farmer has complained that rats like best the grass strip even though he admitted the rats were there before the grass strips were established.

In Nandi district most grass strips are supported by cutoff drains which improve their effectiveness. Grass strips are at present the most widely used conservation measures and will remain popular in the future, with more and more people adopting them. However, in Narok, though grass strips are so far the only conservation support practices under use, their effectiveness is not high due to the poor alignment or excessively wide spacing. Carefully laying out of future strips and realignment of the existing strips is required to rectify the current malpractices.

7. CONCLUSION

1. Grass strips were found to be effective in reducing soil loss and runoff on a 10% ground slope both at low and high intensity storms. Annual soil loss for the control plot was 97.7 t/ha. while for the 0.5, 1.0 and 1.5 m. wide grass strips annual soil losses were 35.4, 35.6 and 17.8 t/ha. (36, 36 and 18%) respectively. Annual runoff from the control plot was 100 mm. (20%) and percentage runoff for the 0.5, 1.0 and 1.5 m. wide grass strips were 56, 44 and 24% of the control plot respectively. The efficiency of grass strips is almost the same as open end graded terraces with 0.25% gradient. The fact that grass strip width was found to be exponentially related to runoff and soil loss suggests that any strip width is better than nothing and the 1.5 m. wide strip was the best in trapping sediment and reducing runoff.

2. Grass strips also play an important role in stopping the formation of rills and reduce the rate of rill formation both above and below the strip.

3. Grass strips can induce the formation of bench terraces on gentle slopes by the action of scour from the upper section and deposition on the lower section of the field, but this action is slow and is a time-taking process.

4. The amount of rainfall (A) was found to be the best erosivity index highly correlated with soil loss and runoff, but for practical reasons the EI_{30} index is safe to use, as it is the only index most widely accepted. For Kabete annual R values between 200 and 250 can provisionally be used in the USLE.

5. For the Kabete soil, a soil erodibility factor value (K) of 0.21 can provisionally be used till future research confirms as this value seems slightly high.

8. RECOMMENDATIONS

1. Grass strips of 1.0-1.5 m. wide can be used in areas where land is not scarce and in areas where land is scarce like Central Kenya, the 0.5 m. wide grass strips of close growing grass types with measures like cutoff drains can be effective. Generally when grass strips are used on slopes steeper than 20% and farms receive outside runoff, additional measures like cutoff drains and waterways are needed to divert the excess runoff, and strip width should be wider and or spacing closer. Attention should be given to current practices of using very narrow grass strips (less than 1.0 m. wide) of tufted grasses like Napier grass on steep slopes, up to 55%, to change the strip width and grass type or convert them to terraces.

2. There is a need for more information on the performance of grass strips on steep slopes, the types of grass that can best be used without causing problems to farmers, performance of grass strips on the different soil

types and in different ecological zones, the various erosivity indices and soil erodibility factors. Future research should be directed on these topics and the work started in this study must continue in order to get more data which can be used in formulating policy for soil conservation.

3. In areas where there are no conservation measures and farmers are unwilling to make terraces, the use of grass strips should be considered an essential practice to reduce erosion.

REFERENCES

Ahn, P. M. 1979. Microaggregation in tropical soils: Its measurement and effect on the maintainance of soil productivity. In Soil Physical Properties and crop production in the Tropics. Lal, R. and D. J. Greenland (eds.) John Wiley and Sons, Chichester. pp. 75-85.

Alberts, E. E., W. C. Moldenhauer and G. R. Foster. 1980. Soil Aggregates and primary particles transported in rill and interill flow. Soil Sc. Soc. Am. J. 44(31)590-595.

Barber, R. G. 1982. The magnitude and sources of soil erosion in some humid and semi-arid parts of Kenya, and the significance of soil loss tolerance values in soil conservation in Kenya. Paper presented at a Soil and Water Conservation Workshop, held at the Faculty of Agriculture, University of Nairobi, March 10-13, 1982.

Barber, R. G., T. R. Moore and D. B. Thomas. 1979. The erodibility of two soils from Kenya. J. Soil Sci. 30:579-591.

Barfield, B. J., E. W. Tollner and J. C. Hayes. 1977. Prediction of sediment transport in a grassed media. A.S.A.E. Paper No. 77-2023, A.S.A.E. St. Joseph, Michigan.

__________. 1979a. Filtration of sediment by simulated vegetation I. Steady-state flow with homogenous sediment. Trans A.S.A.E. 19: 540-545 .

Barfield, B. J., E. W. Tollner and J. C. Hayes. 1979b. Hydraulics of erect vegetal filters used for sediment control. Paper presented at the 1979 Summer Meeting of A.S.A.E. and C.S.A.E. A.S.A.E. Paper No. 79-7059.

Cooke, R. V. and J. C. Doornkamp. 1974. Geomorphology in Environmental Management - An Introduction. Clarendon Press, Oxford.

Dendy, F. E., P. B. Allen and R. F. Piest. 1979. Sedimentation. In: Brakensiek et. al. coordinators. Field Manual for Research in Agricultural Hydrology. U.S. Department of Agriculture, Agriculture Handbook 224, pp. 239-394.

Djorovic, M. 1977. Use of runoff plots to evaluate soil loss. F.A.O. Conservation Guide 1. pp. 53-83.

Doyle, R. C. and G. C. Stanton. 1977. Effectiveness of forest and grass buffer strips in improving the water quality of manure polluted runoff. A.S.A.E. Paper No. 77-2501, A.S.A.E., St. Joseph, Michigan.

Dunne, T., Dietrich, W. E. and M. J. Brunenge. 1978. Recent and past rates of erosion in semi-arid Kenya. Z. Geomorphol. Suppl. 29:91-100.

Edwards, K. A. 1979. Regional contrasts in rates of soil erosion and their significance with respect to agricultural development in Kenya. In: Soil Physical Properties and Crop Production in the Tropics. Lal, R. and D. J. Greenland, (Eds.). John Wiley and Sons, Chichester, pp. 441-454.

Farmer, E. E. 1973. Relative detachability of soil particles by simulated rainfall. Soil Sc. Soc. Am. J. 37:629-633.

Fisher, N. M. 1978. Cropping systems for soil conservation in Kenya. In: Soil and Water conservation in Kenya, Occasional Paper No. 27, Institute of Development Studies, University of Nairobi, pp. 47-55.

Foster, G. R. 1982. Modelling the erosion process. In: Hydrologic modelling of small watersheds. C. T. Haan, P. H. Johnson and D. L. Brakensick (Eds.) A.S.A.E. Monograph No. 5 pp 297-383.

Foster, G. R. and V. A. Ferreira, 1981. Deposition in uniform grade terrace channel. Proceeding of A.S.A.E. Conference on crop production with conservation in the 80. A.S.A.E., St. Joseph, Michigan, pp. 185-197.

Foster, G. R. and R. E. Highfill. 1983. Effect of terraces on soil loss: U.S.L.E. P factor values for terraces. J. Soil and Water Conservation 38(1):48-51.

Gachene, K. K. 1982. The assessment of the relative erodibility of Kenyan soils and erosion susceptibility of a selected area in Kilifi District. M.Sc. Thesis, University of Nairobi.

Government of Kenya. 1978. Marginal and semi-arid lands pre-investiment inventory report No. 1. Analysis and project identification. Nairobi.

Hayes, J. C., B. J. Barfield and R. I. Barnhisel. 1978. Evaluation of grass characteristics related to sediment filtration. A.S.A.E. Paper No. 78-2513, A.S.A.E., St. Joseph, Michigan.

Hayes, J. C., B. J. Barfield and R. I. Barnhisel. 1979. Filtration of sediment by simulated vegetation II. Unsteady flow with non-homogenous sediment. Trans. A.S.A.E, 22(5):1063-1067.

Hudson, N. 1971. Soil Conservation. Batsford, London.

Kao, T. Y. and B. J. Barfield. 1978. Prediction of flow hydraulics for vegetated channels. Trans. A.S.A.E. 21(3):489-494.

Kemboy, B. K. and J. E. K. Muracia. 1981. Investigation into the effectiveness of grass buffer strips in reducing soil erosion. Project Report for B.Sc. in Agr. Eng., University of Nairobi, Nairobi.

Kimutai, J. N. 1979. A survey of effectiveness of cutoff drains and grass strips as soil conservation measure in Tuloi, Kapkangani Location, Nandi District. Project report in partial fultilment of the requireements for Postgraduate Diploma in Soil Conservation, University of Nairobi.

Lal, R. 1976. Soil erosion problems on an alfisol in Western Nigeria and their control. IITA Monograph No. 1.

Laws, J. O. 1941. Measurements of the fall velocity of water drops and rain drops. Trans. Am. Geophys. Union 22:709-721.

Meyer, L. D., G. R. Foster and S. Nikolove. 1975. Effect of flow rate and canopy on rill erosion. Trans. A.S.A.E. 18(5):905-911.

Meyer, L. D. and W. C. Harnon. 1979. Multiple intensity rainfall simulator for erosion research on row side slopes. Trans. A.S.A.E. 22(1):100-103.

Ministry of Agriculture Annual Reports. Central and Eastern Provinces. 1975 to 1980. Nairobi, Kenya.

Moore, T. R. 1979. Rainfall erosivity in East Africa. Geogr. Ann. 61A(3-4):137-156.

Mutchler, C. K. 1963 . Runoff plots design and installation for soil erosion studies. U.S.D.A., A.R.S. 41-79.

Neibling, W. H. and E. E. Alberts. 1979. Composition and yield of soil particles transported through sod strips. Paper for presentation at the 1979 summer meeting of A.S.A.E. and C.S.A.E.

Neibling, W. H. and G. R. Foster. 1977. Estimating deposition and sediment yield from overland flow process. International symposium on urban hydrology hydraulics and sediment control. University of Kentucky, Lexington, Kentucky , July 18-21.

Neibling, W. H., W. C. Moldenhauer and B.M. Holmes. 1981. Aggregate size analysis for naturally eroded sediment. Presented at the 1981 A.S.A.E. Summer Meeting, Sheraton - Twin Towers, Orlando, Florida, A.S.A.E. Paper No. 81 - 2043.

Oiercash, M. R., S. C. Bingham and P.I.O. Westernman. 1981. Predicting runoff pollutant reduction in buffer zones adjacent to land treatment sites. Trans. of A.S.A.E. 24(2):430-435.

Ongweny, G. S. 1979. The hydrology of sediment production within the upper Tana Basin in Eastern Kenya. Proceedings of the Canberra Symposium, December 1979. IHHS-AISH Publication No. 128, pp. 447-457.

Othieno, C. O. 1978. Effects of mulching on soils and growth of the tea plant. PhD. Thesis, University of Nairobi.

Rapp, A. L., L. B. Berry and P. Temple. 1973. Studies of soil erosion and sedimentation in Tanzania. Bureau of Research Assessment and Land Use Planning (of the) University of Dar es Salaam.

Ree, W. O. 1939. Some experiments on shallow flows over a grassed slope. Am. Geophy. Union Trans. 20:653-656.

Roose, E. J., R. Bertrand. 1971. Contribution to the study of the method of buffer strips for controlling water erosion in West Africa - experimental results and observations on the ground. L. Agronomic Tropicale 26:1270-1283.

Ross, J. C. 1965. Soil conservation in South Africa, with special reference to the control of erosion by water. In: F.A.O. Agricultural Development Paper No. 81, pp. 226-237.

Ruthenberg, H. and U. C. Lohmann. 1980. The economic loss through soil erosion - an example. University of Hohenheim, Stuttgart, Germany.

Sombroek, W. G., H. M.H. Braun and B. J. A. van der Pouw. 1982. Exploratory soil survey report No. El. Republic of Kenya, Ministry of Agriculture-N.A.L., Nairobi.

Taylor, C. M. and E. F. Lawes. 1971. Rainfall intensity duration frequency data for stations in East Africa. E.A.M.D. Technical Memorandum No. 17.

Thomas, D. B. and R. G. Barber. 1979. A proposed new design procedure for steep backslope terraces in semi-arid areas of Machakos District. Paper presented at the third annual general meeting of the Soil Science Society of East Africa. July 25-27.

Thomas, D. B. and R. G. Barber. 1982. The management of erodible soils in East Africa, a conservation planning model for support practices. Paper prepared for the third F.A.O./S.I.D.A. Seminar of Field Food Crops in Africa and the Near East. June 6-24.

Thomas, D. B., K. A. Edwards, R. G. Barber and I. G. G. Hogg. 1981. Runoff, erosion and conservation in a representative catchment in Machakos District, Kenya, In: Tropical Agricultural Hydrology. Wiley. pp. 395-417.

Thomas, D. B. 1982. The design of artificial waterways for densely settled areas of steep land. Paper presented at the Soil and Water Conservation Workshop, Faculty of Agriculture, University of Nairobi, March 10-13.

Tollner, E. W., Barfield, B. J., E. T. Haan and T. Y. Kao. 1976. Suspended sediment filtration capacity of simulated vegetation. Trans. A.S.A.E. 19:(11): 678-682.

Tollner, E. W., B. J. Barfield, C. Vachirakorn-watama and C. T. Haan. 1977. Sediment deposition pattern in simulated grass filter. Trans. A.S.A.E. 20(5):940-944.

Ulsaker. L. G. 1983. Relating rainfall erosivity factors to soil loss from an Alfisol in Kenya. Agronomy Abstracts. In press.

Van Bavel, L. H. M. 1953. Report on the Committee on Physical analysis 1951-1953. Proc. Soil Sc. Soc. Am. 17(4):416-418.

Vanderholm, D. H. and E. C. Dickey. 1978. Design of vegetative filters for feedlot runoff treatment in humid areas. A.S.A.E. Paper No. 78-2570, A.S.A.E., St. Joseph, Michigan.

Van Rensburg, H. J. 1955. Runoff and soil erosion tests, Mpwapwa, Central Tanganyika. E. Afr. Agric. J. 20:228-231.

Wain, A. S. 1982. Athi river sediment yields and significance for water resources developments. Paper presented at the Soil & Water Conservation Workshop, 10-13 March, Fac. Agric., University of Nairobi, Nairobi.

Wenner, C. G. 1977. Soil Conservation in Kenya. Land and Management division, Ministry of Agriculture, Nairobi.

Wilson, L. G. 1967. Sediment removed from flood water by grass filtration. Trans. A.S.A.E. 10(1):35-37.

Wischmeier, W. H. and D. D. Smith. 1958. Rainfall energy and its relationship to soil loss. Trans. Am. Geophys. Union. 39:285-291.

Wischmeier, W. H. and J. V. Mannering. 1969. Relation of soil properties to its erodibility. Proc. Soil Sc. Soc. Am. 31(1): 131-137.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses, a guide to conservation planning. U.S.D.A., Agriculture Handbook No. 537.

APPENDIX 1. Mechanical analysis of the field as determined by the hydrometer method

Pit No.	Depth	% sand	% silt	% clay
1	0.0-0.30	24.76	25.64	49.60
	0.30-0.60	19.40	28.64	51.96
	0.60-0.90	17.12	17.64	65.60
	0.90-1.20	14.40	13.28	72.56
	1.20-1.50	10.40	11.64	77.96
	1.50-1.80	14.76	5.64	79.60
2	0.00-0.30	20.40	25.64	53.96
	0.30-0.60	16.24	19.44	64.32
	0.60-0.90	19.12	16.64	64.24
	0.90-1.20	16.24	11.44	72.32
	1.20-1.50	13.12	6.64	80.24
	1.50-1.80	11.88	7.44	80.68
3	0.00-0.30	20.40	19.64	59.96
	0.30-0.60	19.12	19.28	61.60
	0.60-0.90	19.12	11.28	69.60
	0.90-1.20	18.40	10.00	71.60
	1.20-1.50	19.76	11.36	68.88
	1.50 -1.80	17.12	9.00	73.88
	1.80-2.10	17.48	4.92	77.60

Pit 1 - near block D
Pit 2 - between blocks D and E
Pit 3 - between blocks E and F

Appendix 2. Saturated hydraulic conductivity (cm/hr) for Kabete soil, determined by constant head method

Pit No.	Depth (cm)	samples		
		1	2	3
1	0-30	11.44	20.35	16.42
	30-60	4.46	3.46	4.83
	60-90	3.10	12.52+	6.82
	90-120	10.97	9.30	10.42
	120.150	3.37	5.71	4.23
	150-180	1.16	2.31	1.63
2	0-30	16.54	-	9.33
	30-60	3.84	4.99	6.81
	60-90	6.63	6.25	2.97
	90-120	7.37	3.11	3.49
	120-150	7.36	3.50	6.21
	150-180	5.17	5.76	3.44
3	0-30	24.88	22.31	6.57+
	30-60	19.11+	8.44	8.54
	60-90	2.33	4.09	4.36
	90-120	3.93	4.42	-
	120-150	1.96	2.85	1.27
	150-180	1.23	1.31	4.54
	180-210	0.33	0.31	-

+exceptional values

0.50-2.00	moderately slow
2.00-6.25	moderate
6.25-12.50	moderately rapid
12.50-25.00	rapid

Appendix 3. Soil loss (t/ha) from the twelve runoff plots under natural rainfall

Date	rain-fall (mm)	D0	D1	D2	D3	E0	E1	E2	E3	F0	F1	F2	F3
24/4/82	56.2	17.01	13.82	8.73	-	13.35	12.03	7.42	-	-	7.53	7.63	-
26/4/82	73.6	16.88	18.46	17.63	-	15.20	12.65	13.51	-	9.95	8.45	12.20	-
28/4/82	71.3	30.85	32.77	31.02	-	30.29	22.29	22.90	-	28.10	17.33	20.95	-
4/5/82	51.6	8.91	9.89	9.06	-	6.94	6.57	5.10	-	5.90	4.15	4.09	-
11/5/82	23.4	0.08	0.04	0.08	-	0.07	0.04	0.03	-	0.03	0.01	0.01	-
26/5/82	52.2	14.33	11.85	10.48	-	10.28	4.62	3.48	-	6.89	3.02	2.75	-
18/10/82	3.7	0.56	0.06	0.06	0.0	0.06	0.07	0.01	0.0	0.15	0.001	0.001	0.0
31/10/82	22.0	0.02	0.0	0.0	0.0	0.004	0.0	0.0	0.0	0.02	0.0	0.0	0.0
1/11/82	30.5	1.99	0.0	0.28	0.0	0.06	0.03	0.0	0.0	0.65	0.0	0.0	0.0
8/11/82	19.3	0.05	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.02	0.0	0.0	0.0
3/12/82	63.8	7.74	6.37	0.08	0.0	3.69	0.14	0.0	0.0	5.85	0.001	0.0	0.0
Total	503.6	98.42	93.26	77.42	0.0	79.95	58.44	52.45	0.0	57.56	37.47	47.63	0.0

Appendix 3 cont.

Date	rain-fall (mm)	D0	D1	D2	D3	E0	E1	E2	E3	F0	F1	F2	F3
13/2/83	32.0	8.03	0.94	0.0	0.0	2.63	0.07	0.0	0.0	3.42	0.0	0.0	0.0
14/2/83	29.2	7.41	1.50	0.02	0.0	1.56	2.71	0.02	0.01	4.41	0.02	0.01	0.0
18/2/83	16.6	1.04	0.20	0.0	0.0	0.04	0.0	0.0	0.0	0.04	0.0	0.0	0.0
19/2/83	35.5	9.91	7.83	3.42	1.14	7.76	2.54	1.05	0.21	6.31	0.08	0.04	0.0
26/3/83	17.9	1.46	0.07	0.02	0.01	0.16	0.01	0.0	0.0	0.01	0.0	0.0	0.0
22/4/83	17.0	3.58	0.05	0.0	0.0	1.37	0.0	0.0	0.0	0.04	0.0	0.0	0.0
23/4/83	16.5	0.02	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.003	0.0	0.0	0.0
24/4/83	23.8	8.80	0.28	0.06	0.02	7.53	0.25	0.47	0.0	10.84	0.52	0.01	0.0
25/4/83	23.4	8.22	0.41	0.44	0.73	3.33	2.72	0.56	0.01	8.12	0.35	0.27	0.0
26/4/83	46.0	16.64	10.80	10.48	9.11	13.25	12.14	12.34	6.39	15.84	7.61	9.56	0.03
27/4/83	38.6	18.78	8.91	10.77	10.05	16.84	9.08	11.86	5.68	17.69	3.72	11.59	4.70
28/4/83	28.5	15.98	5.38	12.39	8.55	12.63	11.41	6.84	5.85	13.71	6.85	10.92	0.86
4/6/83	35.0	9.86	0.07	2.04	0.0	6.20	2.29	0.16	0.0	8.85	0.78	1.12	0.0
Total	360.0	109.73	36.44	39.64	29.61	73.31	43.22	33.30	18.15	89.28	19.93	33.52	5.59

Appendix 4. Runoff (mm) from the twelve plots under natural rainfall

Date	rain-fall (mm)	D0	D1	D2	D3	E0	E1	E2	E3	F0	F1	F2	F3
24/4/82	56.2	11.20	9.40	7.64	-	11.42	7.99	9.25	-	-	6.72	6.88	-
26/4/82	73.6	19.22	17.38	17.50	-	20.15	15.92	17.95	-	13.21	15.28	16.53	-
28/4/82	71.3	25.92	24.56	28.15	-	25.60	23.80	24.37	-	28.27	23.49	25.74	-
4/5/82	51.6	13.19	13.03	14.35	-	12.41	9.42	9.82	-	12.30	7.17	8.67	-
11/5/82	23.4	0.57	0.66	0.61	-	0.56	0.08	0.23	-	0.52	0.12	0.16	-
26/5/82	52.2	9.77	9.74	8.98	-	8.79	6.17	5.37	-	5.57	4.03	4.05	-
18/10/82	39.7	1.24	1.45	0.63	0.0	0.84	0.39	1.03	0.0	0.94	0.25	0.16	0.0
31/10/82	22.0	0.28	0.0	0.0	0.0	0.18	0.0	0.0	0.0	0.24	0.0	0.0	0.0
1/11/82	30.5	1.57	0.0	0.63	0.0	1.01	0.20	0.0	0.0	1.13	0.0	0.0	0.0
8/11/82	19.3	0.55	0.0	0.0	0.0	0.30	0.0	0.0	0.0	0.45	0.0	0.0	0.0
3/12/82	63.8	6.99	4.22	1.29	0.0	5.39	2.04	0.0	0.0	4.37	0.34	0.0	0.0
Total	503.6	90.50	80.44	79.78	0.0	86.65	65.93	68.02	0.0	66.90	57.40	62.19	0.0

Appendix 4. (cont.). Runoff (mm) from the twelve runoff plots under natural rainfall

Date	rain-fall (mm)	D0	D1	D2	D3	E0	E1	E2	E3	F0	F1	F2	F3
13/2/83	32.0	4.76	1.59	0.0	0.0	2.87	1.44	0.0	0.0	2.18	0.0	0.0	0.0
14/2/83	29.2	4.96	1.61	0.46	0.0	4.06	2.16	0.97	0.29	3.18	0.56	0.33	0.0
18/2/83	16.6	0.85	0.48	0.0	0.44	0.0	0.0	0.0	0.0	0.93	0.0	0.0	0.0
19/2/83	35.5	13.22	9.20	3.59	1.84	10.69	4.75	2.69	2.70	9.18	1.71	0.69	0.0
26/3/83	17.9	1.56	0.87	0.19	0.20	0.41	0.06	0.0	0.0	0.40	0.0	0.0	0.0
22/4/83	17.0	2.28	0.78	0.0	0.0	1.37	0.0	0.0	0.0	0.97	0.0	0.0	0.0
23/4/83	16.5	0.25	0.0	0.0	0.0	0.19	0.0	0.0	0.0	0.22	0.0	0.0	0.0
24/4/83	23.8	6.62	3.06	0.78	0.24	6.52	2.16	1.40	0.0	6.28	1.56	0.16	0.0
25/4/83	23.4	8.17	3.84	1.41	2.26	7.56	4.14	2.36	0.72	7.03	1.22	0.77	0.12
26/4/83	46.0	25.96	22.99	17.42	16.93	25.35	20.99	17.78	5.34	26.72	9.54	11.30	0.90
27/4/83	38.6	17.92	11.44	9.44	10.05	11.30	10.04	7.64	6.54	11.79	6.22	11.11	1.69
28/4/83	25.5	15.57	14.03	12.29	13.21	11.07	13.88	13.26	9.54	16.34	10.12	10.79	3.11
4/6/83	35.0	9.86	0.07	2.04	0.0	6.20	2.29	0.16	0.0	8.85	0.78	1.12	0.0
Total	360.0	111.98	69.96	47.62	45.17	87.59	61.91	46.26	25.13	94.07	31.71	36.27	5.82

Appendix 5.

5(a). ANOVA - soil loss for 1982 long rains

Source	df	SS	F
'total'	8	2393.27	
Block	2	1779.85	22.48^{++}
St. width	2	455.06	5.75 N/S
Error	4	158.36	

5(b). ANOVA - runoff for 1982 long rains

Source	df	SS	F
'total'	8	542.30	
block	2	319.95	18.68^{++}
St. width	2	188.08	10.98^{+}
Error	4	34.26	

\+ significant at 5%
++ significant at 1%
N/S not significant

5(c). ANOVA - soil loss for 1982 short rains

Source	df	SS	F
'total'	11	143.67	
Block	2	24.54	3.04
St. width	3	94.95	7.85^{+}
Error	6	24.17	

<u>Further test</u> (Tukey's test)

St. width	0.0	0.5	1.0	1.5
Mean	6.96	2.18	0.14	0.0
1.5	6.96^{+}	2.18	0.14	-
1.0	6.82^{+}	2.04	-	
0.5	4.78	-		

TLSD = 5.68 at 5%

= 8.15 at 1%

5(d). ANOVA - runoff for 1982 short rains

Source	df	SS	F
'total'	11	149.40	
block	2	15.70	6.44+
St. width	3	126.38	34.54++
Error	6	7.32	

Tukey's test

St. width	0.0	0.5	1.0	1.5
Mean	8.49	2.97	1.25	0.0
1.5	8.49++	2.97	1.25	-
1.0	5.52++	1.72	-	
0.5	7.24++	-		

TLSD = 3.12 at 5%
= 4.48 at 1%

5(e). ANOVA - soil loss for February 1983 rains

Source	df	SS	F
'total'	11	732.98	
Block	2	106.50	4.26
St. width	3	551.50	14.72^{++}
Error	6	74.95	

Tukey's test

St. width	0	0.5	1.0	1.5
Mean	17.52	5.28	1.52	0.45
1.5	17.05^{++}	4.83	1.07	-
1.0	16.00^{++}	3.76	-	TLSD = 9.99 at 5%
0.5	12.24^{+}	-		= 14.34 at 1%

5(f). ANOVA - runoff for February 1983 rains

Source	df	SS	F
'total'	11	673.18	
block	2	71.82	6.9^{+}
St. width	3	570.16	36.5^{++}
Error	6	31.20	

Tukey's test

St. width	0	0.5	1.0	1.5
mean runoff	19.11	7.84	2.91	1.64
1.5	17.47^{++}	6.20	1.27	-
1.0	16.20^{++}	4.93	-	
0.5	11.27^{++}	-		

TLSD = 6.47 at 5%
= 9.28 at 1%

5(g). ANOVA - soil loss for 1983 long rains

Source	df	SS	F
'total'	11	6051.76	
block	2	203.43	1.26
St. width	3	5364.82	22.19^{++}
Error	6	483.51	

<u>Tukey's test</u>

St. width	0	1.0	0.5	1.5
Mean soil loss	73.25	33.97	27.90	17.33
1.5	55.92^{++}	16.64	10.57	-
0.5	45.35^{++}	16.07	-	
1.0	39.28^{++}	-		

TLSD = 36.44 at 1%

= 25.40 at 5%

5(h). ANOVA - runoff for 1983 long rains

Source	df	SS	F
'total	11	6308	
block	2	1078.53	7.26^{+}
St. width	3	4784.43	21.49^{++}
Error	6	445.32	

Tukey's test

St. width	0	0.5	1.0	1.5
Mean runoff	79.16	48.51	42.53	23.62
1.5	55.54^{++}	24.89^{+}	18.91	-
1.0	36.63^{++}	5.98	-	
0.5	30.65+	-		

TLSD = 24.37 at 5%

= 34.97 at 1%

Appendix 6.

6(a). Soil loss (t/ha) from simulated runoff on two plots under three application rates

Appl. rate (l/min)	Soil moisture+ (g/g)	Control	0.5 m. wide grass strip
9.0	0.28	1.30	0.0
	0.28	0.82	0.0
	0.30	1.38	0.0
	0.27	1.20	0.21
15.0	0.26	30.14	0.29
	0.28	29.32	1.44
	0.30	31.58	4.56
	0.29	28.79	2.77
22.0	0.27	33.35	14.55
	0.29	39.61	13.34
	0.28	30.03	18.22
	0.29	35.42	11.06

+ soil moisture at 5.0 cm. from surface.
duration of application - 3 hours.

6(b). Runoff (%) from simulated runoff on two plots under three application rates

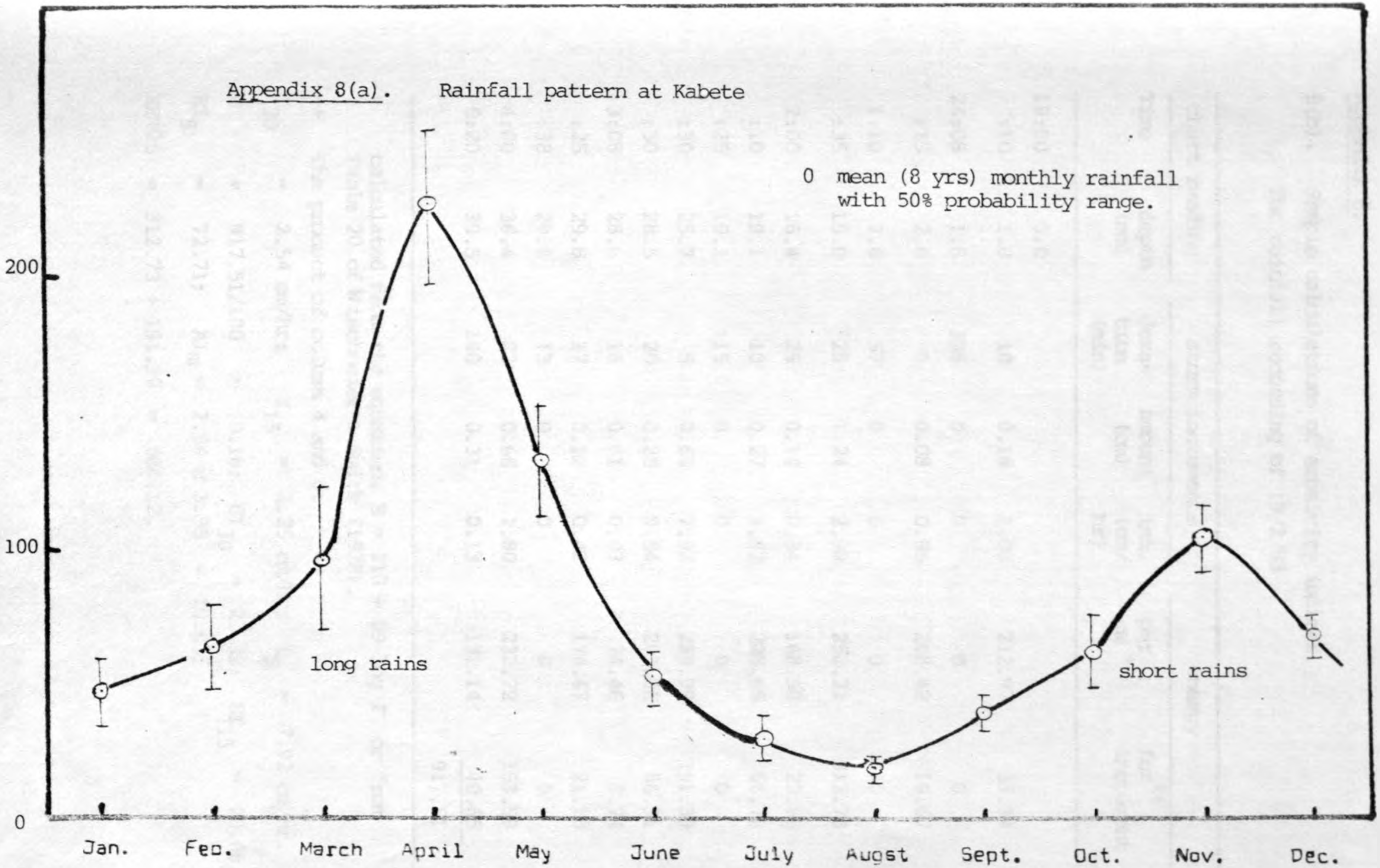
Appl. rate (1/min)	Soil moisture[+] (g/g)	Control	0.5 m. wide grass strip
9.0	0.28	9.78	0.0
	0.28	8.76	0.0
	0.30	21.97	0.0
	0.27	18.30	1.15
15.0	0.26	49.13	1.25
	0.28	42.36	1.54
	0.30	40.72	2.39
	0.29	46.18	1.08
22.0	0.27	44.53	23.36
	0.29	49.91	22.15
	0.28	46.21	28.37
	0.29	47.86	20.67

\+ soil moisture at 5 cm. from surface.
Duration of application = 3 hours.

Appendix 7. Depth of deposition/scour, as measured by iron rods, mean of three (cm)

Season	dist-ance* (m)	D0	D1	D2	D3	E0	E1	E2	E3	F0	F1	F2	F3
1982	0	-0.13	2.37	1.57	-	-0.30	2.17	0.93	-	-2.77	2.03	4.53	-
long	1	-0.50	1.17	0.00	-	0.57	0.43	0.60	-	2.50	1.00	-2.10	-
rains	2	0.67	1.80	1.00	-	0.60	0.63	-0.27	-	-0.50	0.37	-2.47	-
1982	0	0.03	1.67	3.73	3.20	0.07	2.00	0.47	2.53	-0.53	3.70	1.47	3.63
short	1	-1.53	-0.97	-1.07	-0.17	-0.70	0.20	0.0	1.47	0.43	-1.67	1.23	1.77
rains	2	0.47	-0.70	-1.50	1.10	-0.10	0.23	0.27	1.13	-0.70	-0.13	-0.30	1.10
	3	0.20	-0.07	0.13	-0.83	0.03	0.43	0.37	0.67	-0.40	-1.10	-0.03	1.29
	4	0.03	0.47	-0.70	0.80	0.13	0.90	1.00	1.30	0.20	1.90	0.47	1.83
1983	0	0.1	3.3	1.8	1.1	-1.1	1.2	4.0	4.1	0.5	4.5	2.3	2.5
long	1	0.3	3.5	1.9	1.3	-0.7	0.5	0.7	1.2	-0.5	1.8	1.3	2.0
rains	2	0.1	1.1	1.3	-0.3	-0.6	-0.9	-1.2	-1.1	-0.5	0.3	0.3	-0.4
	3	-0.8	-0.7	-0.8	-0.6	0.4	-0.1	-1.3	-0.4	-0.2	0.1	0.2	-0.4
	4	-0.8	-0.4	-1.0	-0.2	-0.3	0.3	0.3	0.0	0.5	0.8	0.8	-0.1

* measured from edge of grass strip.
Negative values show scour.



Appendix 8(a). Rainfall pattern at Kabete

Appendix 8.

8(b). Sample calculations of erosivity indices.

For rainfall recording of 19/2/83

chart reading		storm increments			energy	
Time	depth (mm)	duration (min)	amount (cm)	int. (cm/hr)	per cm +	for increment ++
19:00	0.0					
:10	1.8	10	0.18	1.08	212.97	38.34
24:08	1.8	398	0	0	0	0
:13	2.6	5	0.08	0.96	208.42	16.67
1:10	2.6	57	0	0	0	0
:35	15.0	25	1.24	2.98	252.21	312.73
2:00	16.4	25	0.14	0.34	168.30	23.56
:10	19.1	10	0.27	1.62	228.65	61.73
:25	19.1	15	0	0	0	0
:30	25.7	5	0.66	7.92	289.99	191.39
:50	28.5	20	0.28	0.84	203.26	56.91
3:08	28.6	18	0.01	0.03	74.46	0.74
:25	29.8	17	0.12	0.42	176.47	21.18
:38	29.8	13	0	0	0	0
4:00	36.4	22	0.66	1.80	232.72	153.59
6:20	39.5	140	0.31	0.13	131.14	40.65
						917.51

\+ calculated from the equation: $E = 210 + 89 \log I$ or from Table 20 of Wischmeier & Smith (1978).

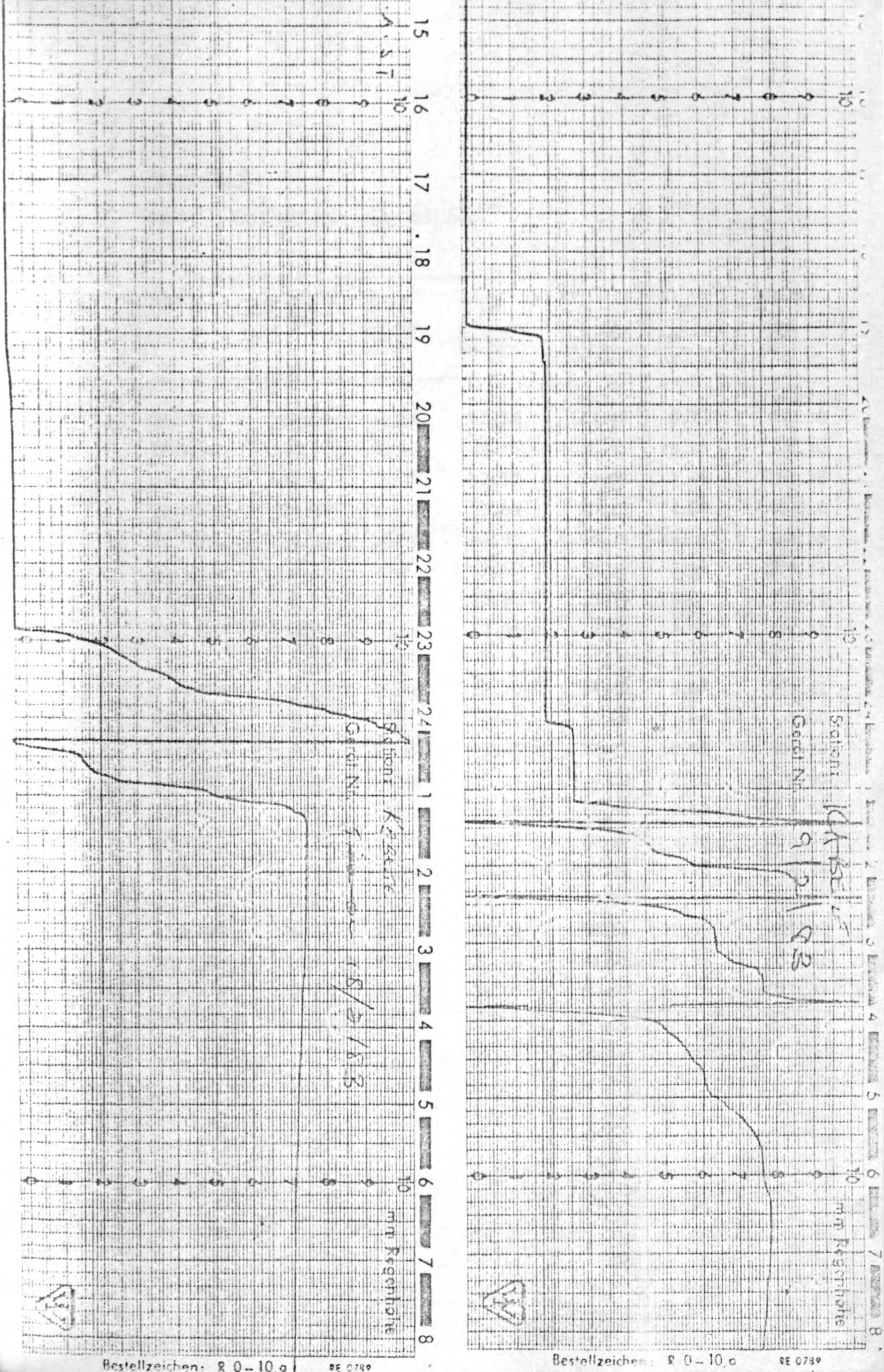
++ The product of column 4 and 6.

I_{30} = 2.54 cm/hr; I_{15} = 2.25 cm/hr; I_5 = 7.92 cm/hr.

E = 917.51/100 = 9.18; EI_{30} = 23.32; EI_{15} = 20.66.

EI_5 = 72.71; AI_m = 2.54 x 3.95 = 10.03;

KE>25 = 312.73 + 191.39 = 504.12.


Station:
Gerät Nr.
mm Regenhöhe
Bestellzeichen: R 0-10,a
RE 0789
Station:
Gerät Nr.
mm Regenhöhe
Bestellzeichen: R 0-10,a
RE 0789

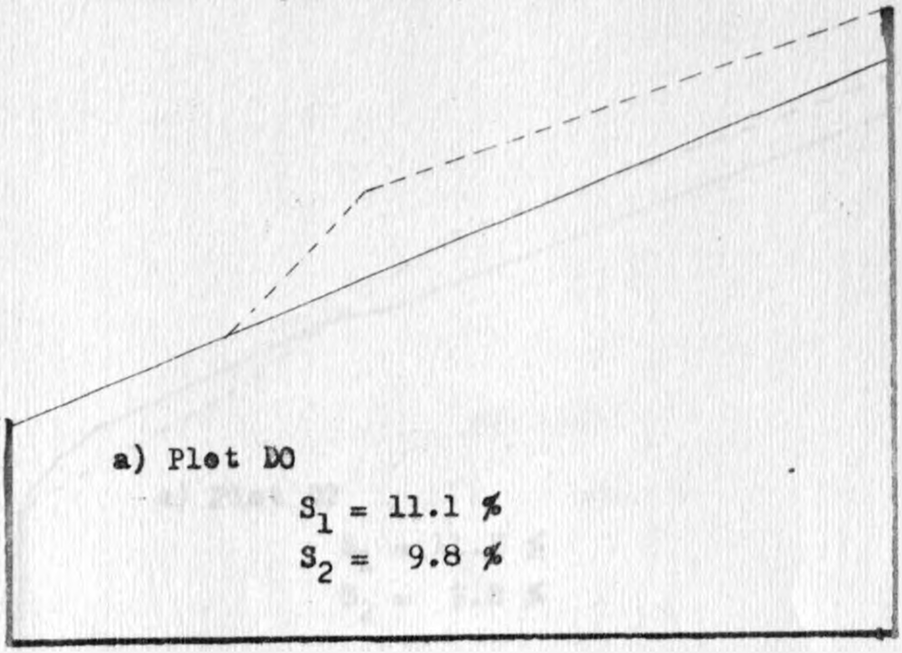
Appendix 8

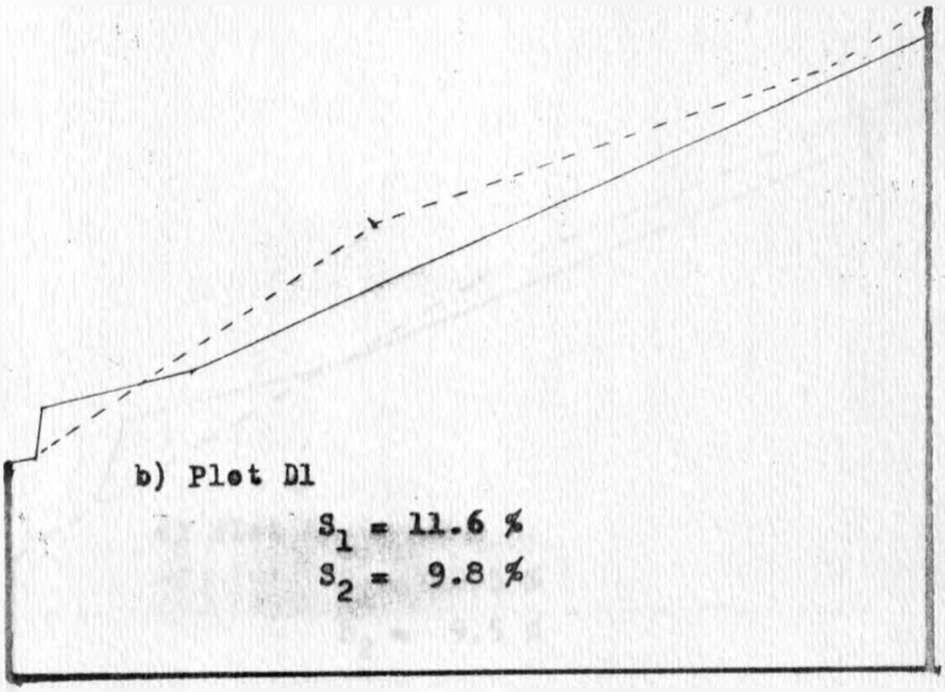
8(c). Various erosivity indices

Date	Rainfall (mm)	EI_{30} $\frac{m\text{-}t\text{-}cm}{ha\text{-}hr}$	EI_{15} $\frac{m\text{-}t\text{-}cm}{ha\text{-}hr}$	EI_5 $\frac{m\text{-}t\text{-}cm}{ha\text{-}hr}$	AI_m $\frac{cm^2}{hr}$	KE>25 $\frac{t\text{-}m}{ha}$
24/4/82	56.2	41.86	62.52	167.46	8.79	681.30
26/4/82	73.6	43.48	44.38	86.95	18.36	378.70
4/5/82	51.6	9.37	12.17	24.09	7.95	161.28
11/5/82	23.4	11.20	15.69	20.17	4.86	447.10
26/5/82	52.2	90.34	64.53	96.79	33.82	1560.58
18/10/82	39.7	6.87	9.62	59.36	3.16	274.33
1/11/82	30.5	19.73	22.88	25.74	8.64	459.50
8/11/82	19.3	8.44	12.36	17.56	3.60	252.46
14/2/83	29.2	10.68	17.70	36.62	5.04	397.42
18/2/83	16.6	4.07	4.80	8.88	1.83	0.00
19/2/83	35.5	23.22	20.66	72.71	10.03	504.12
22/4/83	17.0	4.56	5.18	6.22	2.13	0.00
23/4/83	16.5	5.33	6.10	6.86	2.60	0.00
24/4/83	23.8	13.99	18.72	22.60	6.19	315.58
25/4/83	23.4	9.04	10.47	17.14	4.98	54.46
26/4/83	46.0	46.77	55.28	63.78	20.24	591.99
27/4/83	38.6	22.50	35.71	50.62	12.35	421.49
28/4/83	28.5	20.11	29.28	41.04	8.38	383.41
4/6/83	35.0	29.56	32.09	50.67	11.76	717.31

APPENDIX - 9

Change in ground profile between
December 1981 and June 1983.



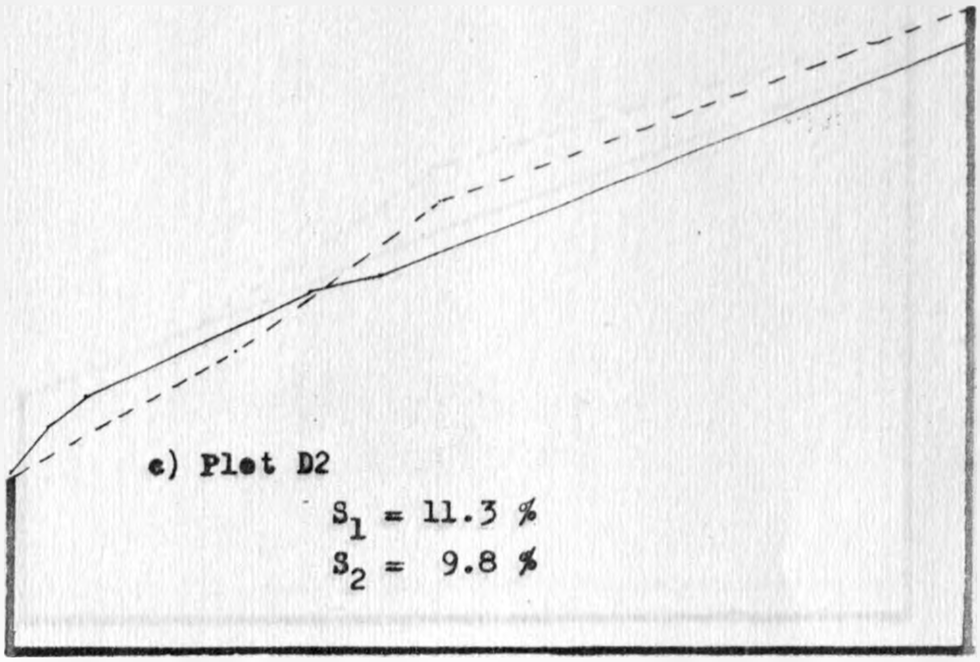


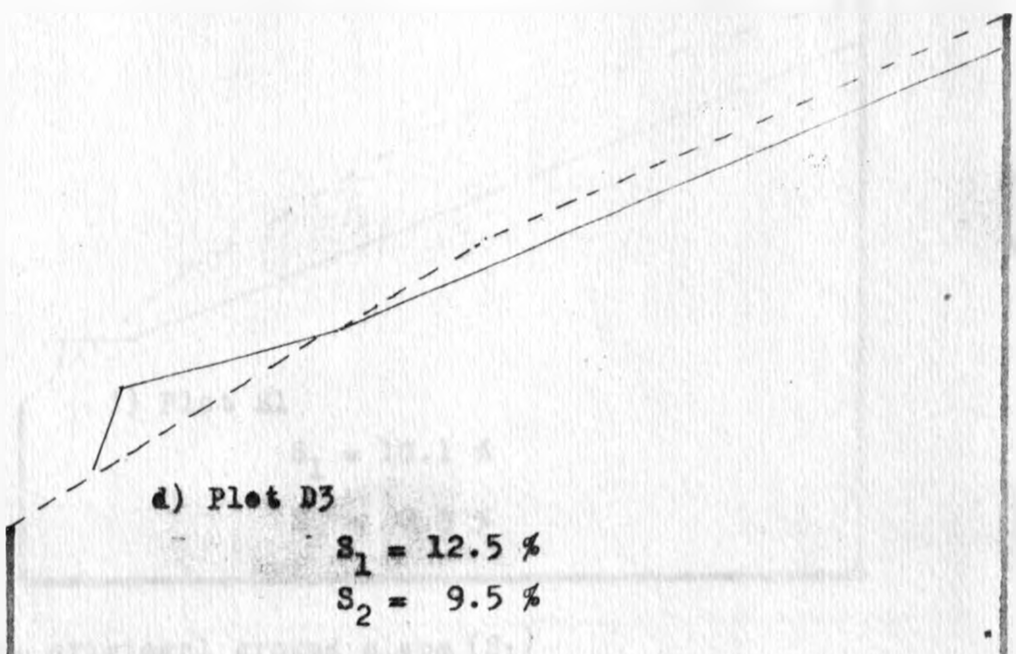
- - - - - origional ground slope (S_1)

———————— final ground slope (S_2)

horizontal scale:- 1:100

APPENDIX - 9 contd.

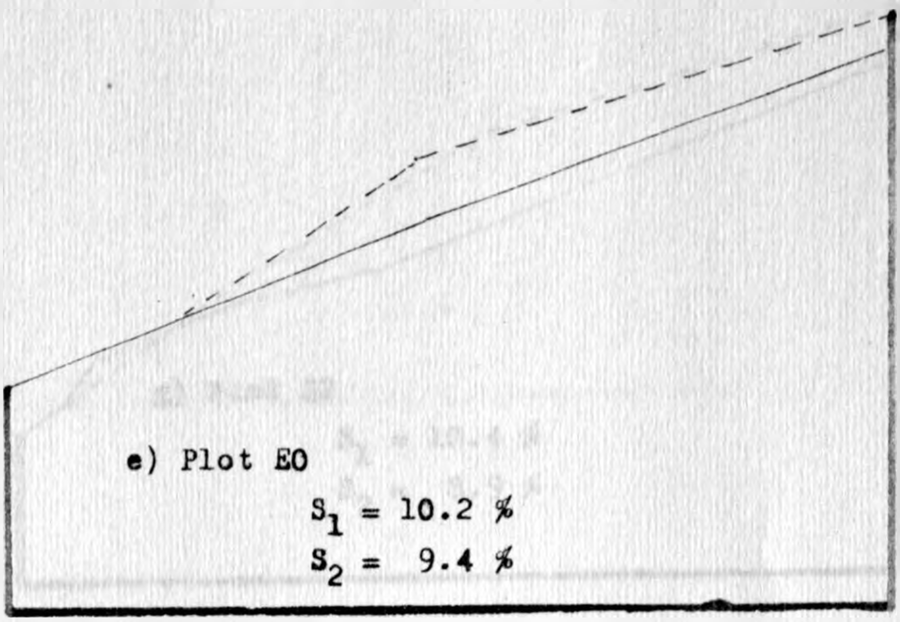




- - - - origional ground slope (S_1)
______ final ground slope (S_2)

horizontal scale:- 1:100

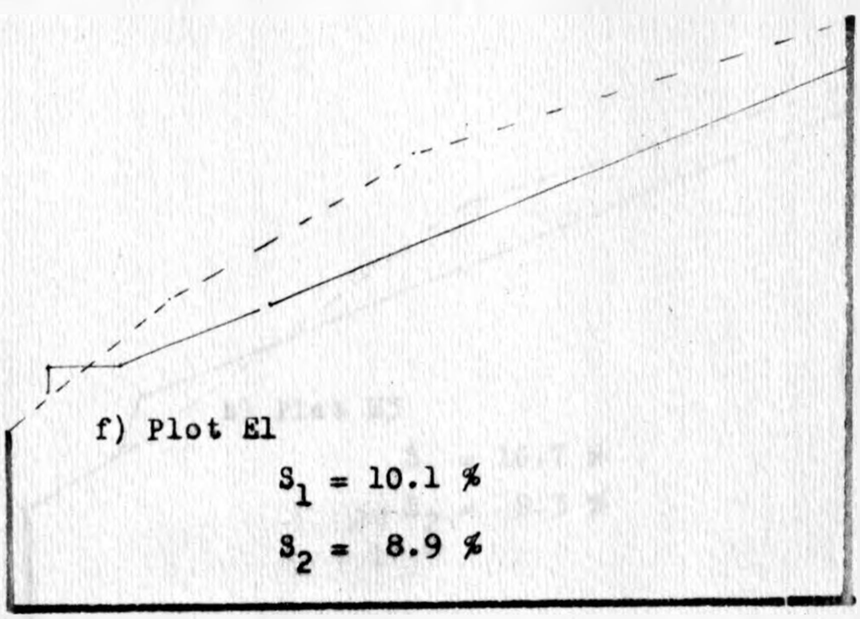
AP PENDIX - 9 contd.



e) Plot E0

S_1 = 10.2 %

S_2 = 9.4 %



f) Plot E1

S_1 = 10.1 %

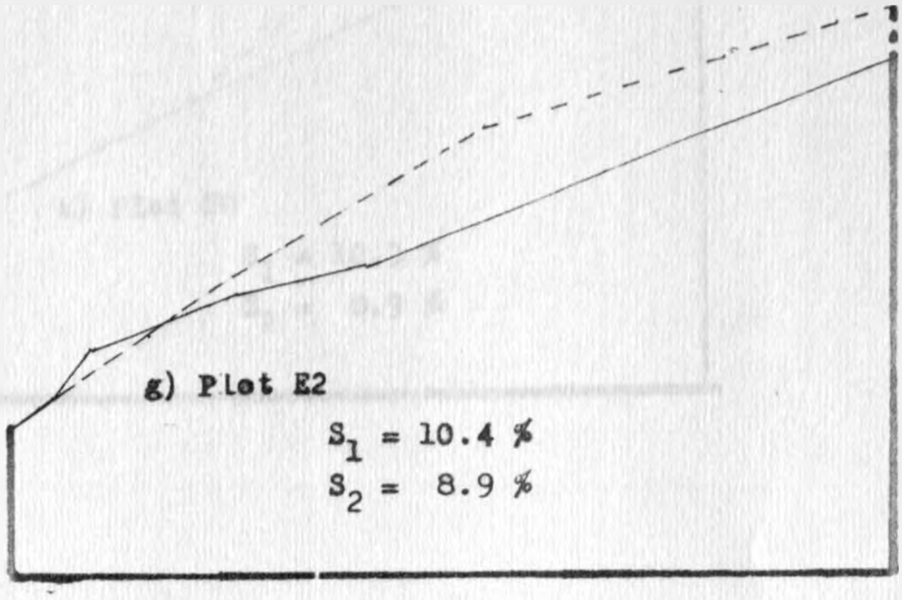
S_2 = 8.9 %

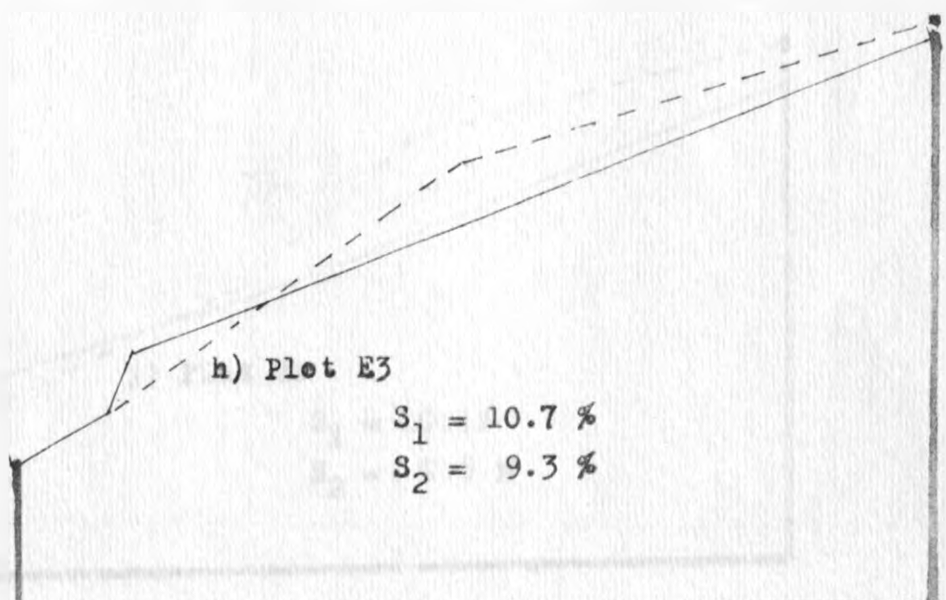
- - - - origional ground slope (S_1)

——— final ground slope (S_2)

horizontal scale :- 1: 100

APPENDIX - 9. contd.



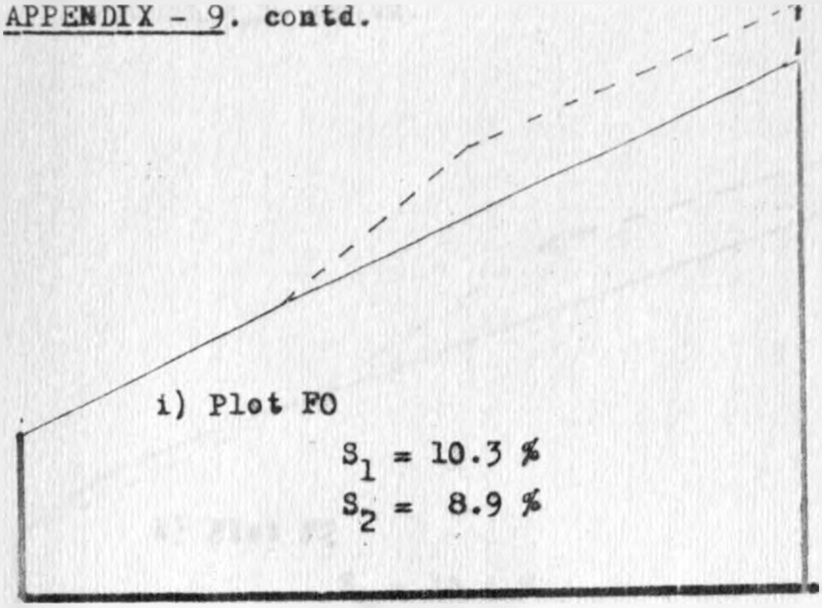


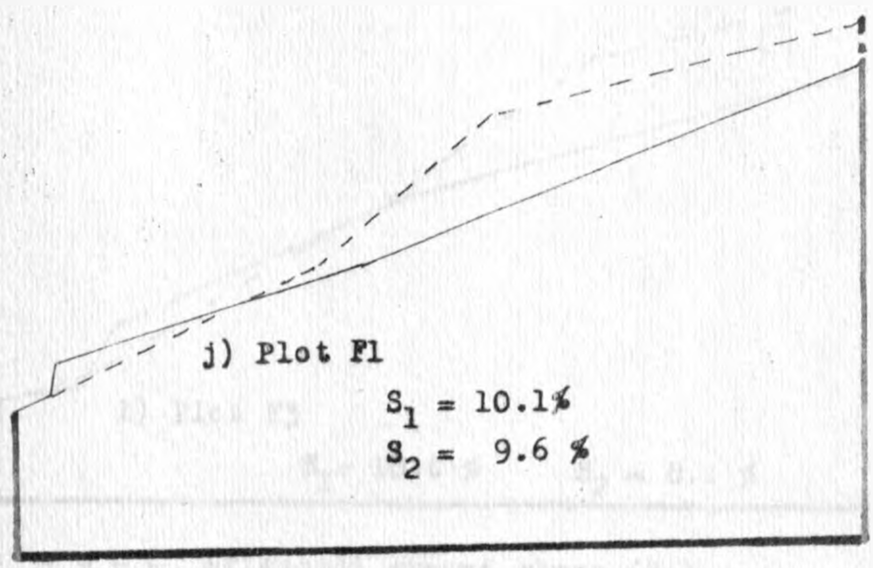
- - - - origional ground slope (S_1)

———— final ground slope (S_2)

horizontal scale :- 1:100

APPENDIX - 9. contd.



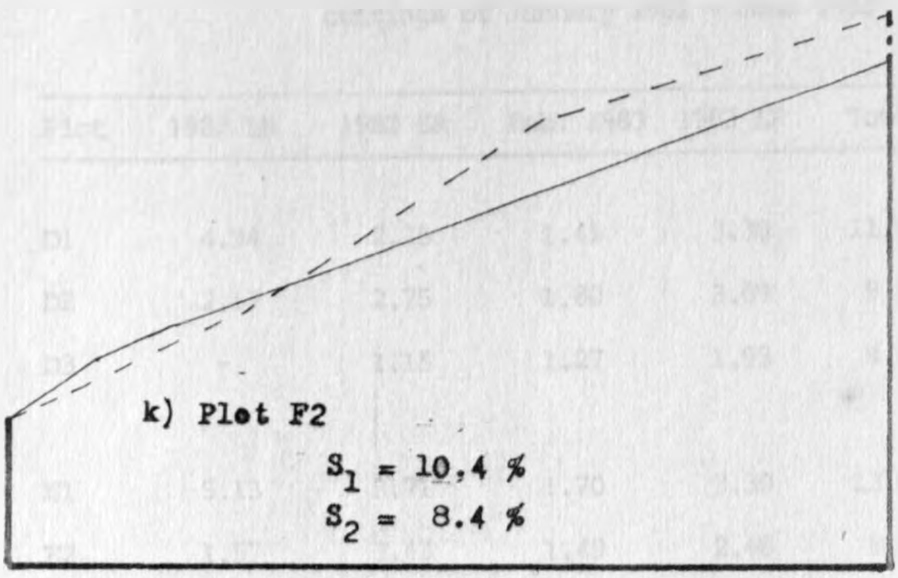


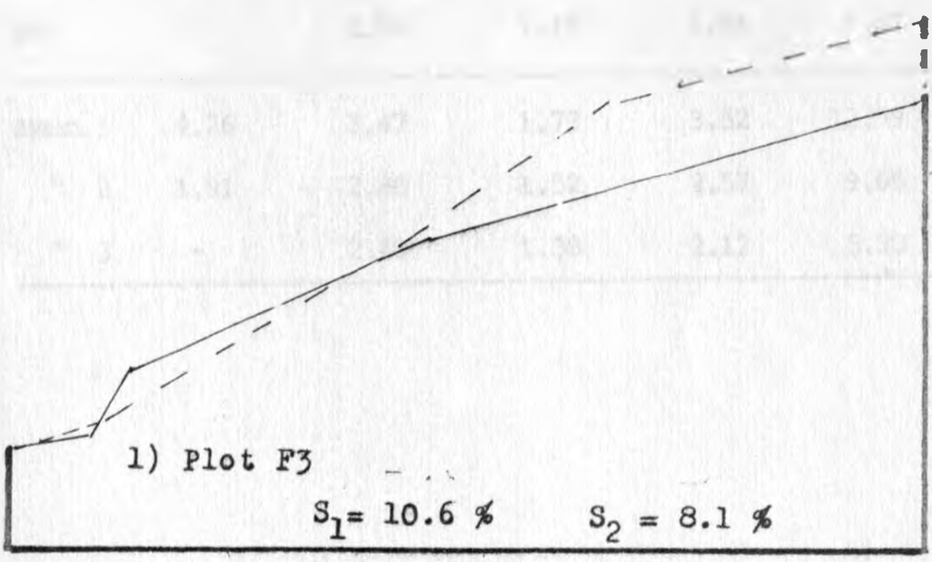
--- - - - origional ground slope (S_1)

——— final ground slope (S_2)

horizontal scale :- 1:100

APPENDIX - 9. contd.





- - - - origional ground slope (S_1)

———— final ground slope (S_2)

horizontal scale :- 1:100

Appendix 10. Dry matter yield of Nandi setaria (kg/m^2) used in runoff plots for four cuttings of January 1982 - June 1983

Plot	1982 LR	1982 SR	Feb. 1983	1983 LR	Total
D1	4.94	2.28	1.41	3.30	11.93
D2	2.17	2.75	1.80	3.09	9.81
D3	-	1.15	1.27	1.93	4.35
E1	5.13	3.71	1.70	3.30	13.84
E2	1.57	3.43	1.49	2.48	8.97
E3	-	3.50	1.67	2.50	7.67
F1	2.70	4.43	2.09	3.97	13.19
F2	2.00	2.96	1.27	2.13	8.30
F3	-	2.54	1.19	1.94	5.67
Mean 1	4.26	3.47	1.73	3.52	12.99
" 2	1.91	2.88	1.52	2.57	9.05
" 3	-	2.40	1.38	2.12	5.90